Intergovernmental Oceanographic Commission

Workshop Report No. 105 Supplement

Conference on Coastal Change

**Jointly Organized by
the Intergovernmental Oceanographic
Commission of UNESCO
and BORDOMER Organization (France)**

Bordeaux, France
10-16 February 1995

Proceedings

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Edited by Prof. E. Duursma

UNESCO

COASTAL CHANGE '95

BORDOMER-95

A conference organized by the
BORDOMER Organization
and the
Intergovernmental Oceanographic Commission of UNESCO

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CPPS, Comision Permanente del Pacifico Sur
FAO, Food and Agriculture Organization of the United Nations
ICES, International Council for the Exploration of the Sea
IGBP/LOICZ, Land Ocean Interactions in the Coastal Zone
GLOSS, Global Sea Level Observing System
IUGS, International Union of Geological Sciences
SCOR, Scientific Committee on Oceanic Research(*)
UNEP, United Nations Environment Programme, Regional Seas Programmes

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Préface

Comme prolongement de la Conférence des Nations Unies sur l'Environnement et le Développement - CNUED - (Rio de Janeiro, 1992), la Conférence était consacrée aux aspects scientifiques de l'évolution côtière en tant que fondement pour l'évaluation des atteintes et la prévision des changements futurs. Les résultats attendus de la Conférence seront utiles non seulement aux gestionnaires, aux experts techniques et aux décideurs mais aussi à la Communauté scientifique en raison de la prise de conscience des implications socio-économiques de l'environnement marin côtier (Agenda 21, chapitre 17). Dans ce cadre, les espaces côtiers des pays en développement seront étudiés avec un soin particulier.

As a follow-up to UNCED - United Nations Conference on Environment and Development, the Conference has addressed the aspects of coastal change leading to impact assessment and the prediction of future changes. Specific outputs for the Conference are useful to managers, technical experts and decision-makers, as well as to the scientific community, owing to the increased awareness of the importance of the coastal marine environment and its socio-economic implications (Agenda 21, Chapter 17). In that framework, the coastal spaces of developing countries will be studied with particular care.

Jacques Valade
Président du Conseil Régional d'Aquitaine

Gunnar Kullenberg
Secretary of the Intergovernmental Oceanographic Commission, UNESCO

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1. SKS = Super Keynote Speaker
2. KS = Keynote Speaker

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SESSION I

Introduction

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OPENING SPEECH, BORDEAUX COASTAL CHANGE CONFERENCE

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Mr. President, Ladies and Gentlemen

I am pleased and honoured to participate in the opening of the International Conference on Coastal Change here in Bordeaux and to make a few opening remarks. Mr. Badran, The Assistant Director-General for Science, has asked me to express his regrets that he is unable to be present. First of all, I would like to thank the Region d'Aquitaine for its support to the Conference. I know that for a very long time Bordeaux has been oriented towards the sea and coastal problems. Indeed, it is a coastal town. The Aquitaine coast represents a particularly interesting model of a coastal zone, offering a lot of diversified and changing littoral systems. This is probably one excellent reason to explain the specific efforts which have been carried out during the last twenty years to provide support to oceanographic research and to initiate and develop BORDOMER meetings. BORDOMER is now a very well known event within the oceanographic community and I know that the last meeting - BORDOMER 92 - was very successful. I am sure that BORDOMER 95 will be equally successful. We have here an example of co-operation between a national, regional body (Aquitaine) and an intergovernmental, global body (IOC), sharing experiences. Two years ago, taking advantage of this interesting background, The City of Bordeaux proposed to IOC of UNESCO to support and to co-organize the International Conference on Coastal Change that the IOC Assembly decided to organize as a follow-up to UNCED, within the framework of the IOC programme on OSNLR. Information about OSNLR and other IOC programmes/projects is provided in the poster exhibition organized here.

Why then do we have this Conference? An improved knowledge of coastal/ocean ecosystems is a pre-requisite for more effective decision-making and sustainable development of coastal zones. This was clearly stated in the UNCED proceedings, the Integrated Coastal Area Management Programme (ICAM) needs to be based on a more complete understanding of how the marine systems function, an ability to predict how the systems will respond to various activities and some idea of the probable effectiveness of alternative management techniques. This need for action in the face of an inadequate information base is an increasing source of conflict between scientists and managers. Coastal systems are highly variable, evolutive and complex including from the scientific point of view. It would be unsatisfactory to over-simplify them. The manager, for his part, needs straightforward advice on how to improve fisheries stocks, where to construct a port facility, on efforts of pollution control or how to reduce pollution, which should be given on a scientific basis. Oceanography can now provide management tools in the form of systematic observations, data assimilation and modelling for analyses of management options. The coastal module of GOOS is aiming at this.

If the scientific input is to become an integral component of ICAM, a compromise is in order. Managers must clearly state their needs and objectives, define funding and time limitation. Scientists, on their part, must recognize that detailed scientific studies will not always be practicable as a precursor to most coastal management decisions. Thus we need to increase and strengthen the dialogue between science (natural and social), management and decision-making. Also, coastal zones, rich in natural and cultural resources play an important role in the lives of the people. Nowadays, over 60 percent of the world's population live on the coasts, and the natural habitat of these zones have been under stress due to human activities. The resulting environmental detriment is becoming obvious to the flora and fauna of this narrow band of land where the ocean meets the continent. The damage taking place in the shallow waters and on the shore is in some instances irreversible. It is here

where the ocean meets the continent. The damage taking place in the shallow waters and on the shore is in some instances irreversible. It is here on the coastal zone that we need the inputs of social scientists and natural scientists to address the interaction of man with nature and develop a management model to overcome the pressure and the stress caused by the various users of the coastal zones.

One obvious result of the UNCED Conference (Rio de Janeiro 1992) has been an increased awareness of the importance of the coastal marine environment and its socio-economic significance. In this context, it has been recognized that international organizations, and particularly UNESCO and the Intergovernmental Oceanographic Commission, play a critical role in the development of scientific knowledge concerning the coastal zone and its resources. Furthermore, UNCED underlined that coastal erosion and siltation are of particular concern for coastal states. In this context I wish to refer to GLOSS - Global Sea Level Observing System - providing sea level observations and interpretations for applications.

Therefore, as part of the follow-up to UNCED, UNESCO has decided to launch in the next biennium, 1996-1997, a new Interdisciplinary Project which has been included in the Medium Term Strategy for 1996-2001. This Interdisciplinary Project on Coastal Regions and Small Islands will provide a framework for co-operative activities on coastal zones and small islands between the International Geological Correlation Programme (IGCP), the International Hydrological Programme (IHP), the Intergovernmental Oceanographic Commission (IOC), and the Man and the Biosphere Programme (MAB) as recommended in the Joint Statement of the Chairpersons of these four intergovernmental undertakings to the 27th session of the General Conference. The social sciences will be integrated in the Project through the Programme on Management of Social Transformations (MOST). Moreover, the Project will take into account the experience obtained during the last decade of the Coastal Marine Project and associated activities. In addition, the Project will take advantage in its activities of UNESCO's specific position at the interface of education, natural and social sciences, culture and communication, using a holistic approach to address sustainable development of coastal regions, as recommended in Chapter 17 of Agenda 21 (UNCED 1992) and in the Programme of Action of Sustainable Development of Small Island Developing States (Barbados 1994). Another important development of IOC, WMO, UNEP and ICSU concerns the establishment of the Global Observing System, also as a response to UNCED.

The Project aims at enabling Member States of UNESCO and IOC to introduce integrated coastal zone planning and management as a means towards sustainable development. To this end, the Project will collaborate with relevant organizations of the United Nations system, governmental agencies, competent non-governmental organizations, municipalities, local authorities, and will follow a participatory approach that will also involve concerned local populations. In the UN system there is a special body on oceans and coastal areas involving all relevant UN-related bodies UNCED invited coastal states to co-operate in the preparation of international guidelines for integrated coastal zone management and development and, moreover, recommended that a global conference to exchange experience in this field could be held before 1994. The IOC Assembly decided to organize this Conference in co-operation with BORDOMER as a response to UNCED, and the activity is seen as one of a series of actions of IOC in a follow-up to UNCED.

The present Conference will provide a valuable opportunity for scientists and managers to exchange information and experience and to offer advice on how the assessment and control of the evolution of the coastal zone might be improved and made more easily available. As the action plan to organize the Conference was formulated at the request of the IOC Assembly, I am pleased to see that this plan was successful. I invite you all, during the coming week, to ensure the final success of this plan.

Thank you for your attention.

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GEOPOLITIQUE DU LITTORAL FRANCAIS

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Voici 15 ans maintenant que l'Association Nationale des Elus du littoral a vu le jour en France avec le soutien de deux personnalités éminentes, Olivier Guichard et Michel d'Ornano, tous deux élus d'une commune littorale et spécialistes reconnus de l'Aménagement du Territoire dont ils furent les initiateurs dans les différents postes ministériels qu'ils occupèrent.

Nous étions partis d'un constat qui demeure d'actualité; le littoral, territoire à la fois géographiquement étroit, écologiquement fragile et économiquement convoité avait besoin d'une politique globale et adaptée à sa spécificité.

Parallèlement la France, comme toutes les autres nations maritimes, développait des politiques en direction de l'Océan en encourageant, avec des succès divers, des activités marines et en tentant de maintenir à un niveau acceptable une flotte de combat sans pour autant parvenir à enrayer un certain déclin de notre marine marchande.

Depuis lors, la crise économique aidant, la montée en puissance de nouveaux Etats en voie d'industrialisation a relativisé nos prétentions à tenir notre rang dans le concert des nations. C'est regrettable mais pas inéluctable.

Parallèlement, des organismes internationaux comme l'UNESCO ou l'OCDE se sont penchés sur la problématique du développement économique durable de la zone littorale, conscients de l'étroite corrélation entre la situation des zones riveraines et l'essor de l'exploitation des océans, véritables poumons économiques et écologiques de la planète.

Si l'on revient brièvement en arrière, on constate que cette imbrication de l'économie maritime avec son hinterland côtier a eu des conséquences déterminantes sur le destin des nations.

A la fin du XVIe siècle, le célèbre navigateur anglais Sir Walter Raleigh déclara à la reine Elisabeth: *"Celui qui commande la mer, commande le commerce et qui commande le commerce commande la richesse du monde et par là même le monde lui-même".*

Depuis l'aube des temps historiques, les thalassocraties crétoises et athéniennes, l'empire de Charles Quint et plus près de nous l'empire britannique ont démontré le rôle déterminant des Etats qui, par une politique maritime vigoureuse, ont imprimé leur marque au reste du monde.

Aujourd'hui deux chiffres illustrent, me semble-t-il, le poids singulier de l'élément marin dans la vie des nations:

- au plan géographique, les océans couvrent 70 % de la surface du globe et bordent les trois quarts des Etats membres de l'ONU.
- au plan économique, 80 % du commerce mondial emprunte la voie maritime.

Corrélativement, les zones côtières connaissent une pression démographique croissante. Selon certains spécialistes, sur une profondeur de 60 kilomètres du bord de la mer vit 40 % de la population mondiale. Cet espace rare et limité englobe les deux tiers des villes de plus de 2,5 millions d'habitants.

La France n'échappe pas à ce constat même si la pression démographique y est moindre que chez la plupart de nos voisins européens.

Pour une population de 57 millions d'habitants, notre littoral abrite de façon permanente près de 6 millions de sédentaires et accueille annuellement 23 millions de touristes dans 894 communes représentant 4 % de la superficie du territoire.

Outre la suroccupation de l'espace qui en résulte, ces communes ont une densité 2,5 fois supérieure à la moyenne nationale, soit 257 habitants au km² contre 105 habitants au km². Signalons également de fortes disparités régionales puisque la côte

méditerranéenne abrite 47 % de l'ensemble de la population résidente dans les communes littorales contre 17 % du Cotentin aux Flandres.

UNE ECONOMIE EN MUTATION

Depuis toujours le littoral français a vécu principalement des activités liées à la mer, que ce soit bien évidemment la pêche sous toutes ses formes, la construction navale civile et militaire ou les transports maritimes autour desquels sont venues progressivement s'agréger des entreprises de service et de transformation.

Dans les années 60, la révolution des loisirs a permis l'émergence d'une économie touristique qui produit aujourd'hui un chiffre d'affaires de plus de 140 milliards de francs.

Les 154 000 emplois qui en dépendent ont pu masquer les difficultés rencontrées par les autres secteurs traditionnels liés à la proximité du rivage. Des statistiques récentes font état de 670 000 emplois générés directement par des activités marines et maritimes.

Cependant les problèmes économiques et sociaux que connaît le littoral sont perçus de manière ponctuelle et sectorielle par l'opinion publique, voire par les pouvoirs publics.

Les mutations de la pêche, la réforme des ports de commerce, la diminution sensible de nos parts de marché en matière de transport maritime ou la situation de la construction navale ont entraîné des mouvements sociaux d'intensité diverse liés à des diminutions d'emplois parfois dramatiques.

Ce déclin auquel s'ajoute une pression démographique forte a des conséquences préoccupantes pour les collectivités du littoral qui subissent un taux de chômage supérieur à la moyenne nationale.

Il me semble utile à travers l'examen des quelques secteurs économiques significatifs de l'économie littorale de mesurer les difficultés d'adaptation que doivent affronter les zones côtières:

- Un enjeu économique majeur: les ports français

La France est en valeur le quatrième exportateur et importateur mondial et le deuxième exportateur par tête d'habitant. Les ports français traitent 50 % de ce commerce extérieur exprimé en tonnage.

Certains secteurs d'activité y ont une part prépondérante que ce soit le pétrole brut ou raffiné, les minerais, les combustibles solides ou l'exportation des produits agricoles.

Il en a résulté l'implantation d'industries de transformation, des aires de stockage et de multiples services liés à la distribution de marchandises. Une étude de la Délégation à l'Aménagement du Territoire et à l'Action Régionale estime à 250 000 les emplois directs, indirects et induits qui sont générés par les places portuaires et les bassins d'emplois locaux.

Des difficultés d'adaptation liées au statut des dockers mais aussi à l'éloignement de nos ports par rapport aux principaux centres industriels de l'Union européenne ont entraîné une régression qu'il convenait d'endiguer.

La réforme de l'organisation de l'emploi permet progressivement de réintroduire une compétitivité accrue de l'outil portuaire.

Parallèlement, la notion d'hinterland a été intégrée par les pouvoirs locaux et nationaux afin de répondre à la demande de transports combinés. Que ce soit le rail, la route ou le transport fluvial, des investissements importants sont réalisés pour raccorder les ports aux grandes voies de communication qui relient entre elles les connurbations industrielles du continent européen. La dernière réalisation en date a été inaugurée le 20 janvier dans ma ville du Havre où le plus grand pont à haubans du monde franchit l'estuaire de la Seine, redéployant ainsi le deuxième port français vers le sud.

- L'évolution inquiétante du transport maritime

Les échanges maritimes ont augmenté de 60 % ces dix dernières années alors que le tonnage de la flotte sous pavillon français a été divisé par trois. Il en résulte que le nombre de marins français a diminué de moitié, passant de 20 00 à 10 000 salariés.

La flotte française qui représentait 2,4 % de la flotte mondiale en 1984 n'en représente plus que 0,9 % en fin 1993.

Cette évolution préoccupante est due notamment au transfert de nombreux navires sous pavillon économique de pays du tiers monde et par l'arrivée sur le marché de transporteurs d'Asie du Sud-Est.

Nous subissons ainsi des prix de dumping et un développement des sinistres maritimes générateurs de pollutions parfois dramatiques.
Corrélativement la construction navale, si l'on excepte les arsenaux militaires liés à la Défense nationale, vit une crise profonde. Malgré un niveau technologique de premier ordre, les quelques chantiers subsistant ne survivent que sur des segments très particuliers durement concurrencés par les pays de l'Europe de l'Est et surtout du Sud-Est asiatique à bas niveau de salaires.

- Une pêche marginalisée

Le secteur des pêches maritimes subit lui aussi un déclin qui provoque des mouvements sociaux parfois violents comme l'an dernier en Bretagne. En 1986, les effectifs des marins embarqués dépassaient les 18 000, aujourd'hui nous maintenons péniblement 14 000 marins dans des conditions économiques souvent précaires. Les plans de réductions successifs décidés à Bruxelles dans le cadre de la politique communautaire de gestion de la ressource halieutique ne font qu'accompagner, sans tracer de perspectives claires, une profession qui a parfois l'impression d'être littéralement abandonnée.
Ces quelques exemples montrent à l'évidence que l'économie littorale souffre d'un manque de politique volontaire et surtout que les effets négatifs s'étendent à l'ensemble du tissu économique qui innerve les communautés des zones côtières.
Le développement d'une économie touristique vigoureuse a certes permis de compenser en partie cette perte de substance, mais le tourisme de masse que nous avons connu évolue lui aussi. Une segmentation plus prononcée des séjours touristiques, une fréquentation plus courte de nos plages, une exigence de qualité accrue entraînent des dépenses publiques et privées de plus en plus lourdes pour un retour sur investissement parfois aléatoire.
Conscients de la dimension de la tâche que devraient accomplir les acteurs du littoral, les pouvoirs publics et les collectivités territoriales se sont mobilisés afin d'imaginer des politiques adaptées à la variété des problèmes et surtout à l'enjeu géopolitique qu'il fallait relever.

UNE POLITIQUE D'AMENAGEMENT QUI SE CHERCHE

Olivier Guichard dans la préface du rapport Piquard, premier document de synthèse concernant le littoral dans son intégralité, paru en 1973, faisait l'observation suivante *"Dans une France paysanne adossée à la mer, l'homme n'accomplissait le mariage de la terre et de l'eau que dans les bourgs ou les villes de quelques ports. Les hommes des villes ont domestiqué le littoral parfois avec brutalité, souvent avec amour, pas toujours avec talent. Il reste à l'aménager".*

- Une politique ambiguë

La suite de ce rapport Piquard donna lieu à une succession de Comités Interministériels à l'Aménagement du Territoire qui préconisèrent, sans vraiment prévoir les moyens financiers adaptés, un aménagement en profondeur et une coopération intercommunale. Ce furent les Schémas d'Aménagement du Littoral et les Schémas d'Aptitude et d'Utilisation de la Mer et aujourd'hui la loi prévoit des Schémas de Mise en Valeur de la Mer (SMVM). L'idée maîtresse était de définir un territoire littoral géographiquement pertinent pour y pratiquer une étude approfondie des activités devant se répartir dans l'espace considéré. L'objectif à atteindre était d'éviter les conflits dans l'utilisation de l'interface terre/mer partagé entre différentes activités parfois antagonistes.
Objectivement, si ces diverses formules connurent des succès d'estime on ne peut pas affirmer qu'elles bouleversèrent l'aménagement du littoral. Je pense personnellement que la formule des S M V M répond à une procédure lourde, complexe et coûteuse. Les territoires choisis ne sont pas toujours pertinents. Enfin, ils ne préparent pas à une vision d'aménagement d'ensemble à l'échelle d'une façade maritime.
Conscient de ces difficultés, le législateur adopta en janvier 1986, à l'unanimité du Parlement, une loi cadre dite Loi LITTORAL qui devait être complétée par 14 décrets d'application.

- Les effets pervers d'une loi

Schématiquement on peut soutenir l'idée que la philosophie de cette loi était d'affirmer un

nécessaire équilibre entre les impératifs d'un développement économique souhaitable pour l'homme et une protection efficace des écosystèmes littoraux.
Cet équilibre souhaitable et souhaité par le législateur a été rompu par la jurisprudence des tribunaux administratifs qui ont presque systématiquement privilégié l'aspect protection au détriment du développement économique. Mieux, les incertitudes introduites par les tribunaux quant à l'interprétation de la loi ont créé une insécurité juridique préoccupante puisque de nombreuses autorisations régulièrement accordées par les autorités administratives compétentes sont annulées.
Que l'on me comprenne bien, je suis personnellement partisan d'un développement économique maîtrisé et compatible avec la sauvegarde des milieux naturels. Cependant il n'est pas sain que, dans un Etat de droit, la loi manque de lisibilité au point de paralyser toute initiative.

- Des acteurs qui se mobilisent

Depuis quelques années, des collectivités locales de dimension régionale allant du Nord de l'Angleterre jusqu'au Sud du Portugal ont constitué l'Arc Atlantique. Il s'agissait pour ses promoteurs de mobiliser les énergies de cette façade maritime, afin de contrebalancer le poids quelque peu écrasant de l'Axe Lotharingien. Celui-ci part de Londres se prolonge vers la Ruhr puis descend jusqu'en Lombardie. Il fallait éviter que la logique d'un développement essentiellement orienté vers le centre de l'Union européenne ne marginalise complètement les pourtours marins.
En France, ce regroupement fit des émules puisque les régions maritimes travaillent à constituer des synergies à un échelon de façade plus modeste mais significatif : il s'agit après l'Arc Atlantique, de l'Arc Manche et de l'Arc Méditerranéen.
La loi d'aménagement du territoire votée en janvier 1995 par le Parlement incite les régions maritimes à collaborer entre elles sans préciser toutefois le cadre institutionnel que pourrait revêtir cette collaboration.
Une réelle prise de conscience de l'opinion et des pouvoirs publics est en train de se cristalliser et devrait permettre à moyen terme l'émergence d'une véritable politique de développement et d'aménagement du littoral où l'Etat et les collectivités locales seraient des partenaires égaux.

PROMOUVOIR UN DEVELOPPEMENT DURABLE

Chacun d'entre nous est aujourd'hui persuadé que tout développement passe par la préservation de l'environnement. L'un permettant l'entretien de l'autre et l'autre autorisant la pérennité du premier.
Cette protection revêt des aspects variés qu'ils soient juridiques, techniques ou institutionnels.

- Des outils au service de la protection

La politique de l'environnement littoral a consisté à cerner une notion de patrimoine naturel à préserver. De 1985 à 1995, des équipes de scientifiques ont identifié des milliers de Zones Naturelles d'Intérêt Ecologique Faunistique et Floristique (ZNIEFF) ayant un intérêt particulier pour la conservation de la diversité biologique notamment des zones côtières.
Il en a résulté des dispositions réglementaires selon le degré de protection que le ministère désirait accorder à l'espace considéré. Ceci a débouché sur diverses formules: le parc naturel, la réserve naturelle, le site classé, les arrêtés de biotopes auxquels s'ajoute la directive européenne concernant les oiseaux.
La protection par maîtrise foncière a permis au Conservatoire National du Littoral et des Espaces Lacustres, créé en juillet 1975, de voir le jour. Il acquiert et remet en état des terrains qui représentent aujourd'hui 41 000 hectares, soit 543 terrains de 5 500 km de linéaires côtiers, l'objectif étant d'atteindre la maîtrise de 30 % de littoral.
Enfin des protections conventionnelles et contractuelles concernent plus particulièrement l'agriculture qui couvre 40 % de l'espace littoral.
Aujourd'hui la politique du Ministère français de l'Environnement se concentre sur la protection des paysages et des zones humides dont chacun sait la grande utilité écologique, notamment comme frayères pour la faune marine.
Afin de ne pas trop abuser de votre attention, je ne parlerais pas de la politique des Agences de l'Eau et de l'Institut Français de Recherche pour

l'Exploitation de la Mer (IFREMER) qui poursuivent avec une grande compétence un travail remarquable de lutte contre les pollutions marines et le traitement des eaux usées ou pluviales. Certains de leurs représentants éminents sont ici présents et sauront mieux, qu'un élu généraliste par fonction, parler de recherches scientifiques.

Pour conclure qu'il me soit permis de rappeler cette prophétie de Paul Valery, natif de la ville portuaire de Sète en Languedoc-Roussillon: *"Le monde fini commence"*.

Sachons réconcilier l'homme prédateur par destination avec son milieu naturel. Il en va de son bien être voire de sa survie.

Je vous remercie.

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GLOBAL OVERVIEW OF ENVIRONMENTAL CHANGE IN COASTAL ZONES[1]

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NATURE OF ENVIRONMENTAL CHANGE IN COASTAL ZONES

Coastal zones extending from coastal plains across the continental shelves are regions where the land masses, oceans and atmosphere interact. They are characterised by strong gradients in environmental and ecological properties, and provide valuable living and non-living resources which are presently being exploited by humans on a non-sustainable basis. Environmental change is being driven indirectly and directly by human activities. Climate modification, sea level change and changes in land use affect coastal zones globally, whereas the impacts of direct use of coastal resources are usually local or regional. The latter, however, tend to be cumulative and will become increasingly significant at a global scale as the human population continues to grow. The present rates of environmental change in coastal zones are extremely rapid compared to those during recent geological time, and appear to result in a loss of functional integrity and a reduced capacity to retain materials such water, sediment and organic matter at the land-ocean interface.

UNCERTAINTIES IN DIRECTION, RATE AND CAUSES OF CHANGE

Accurate assessment and prediction of changes in coastal zones are limited by a lack of knowledge about the scales and nature of interactions between land, ocean and atmosphere, about the dynamic and complex properties of coastal systems themselves, and about the potential for significant feedback processes which determine large scale biogeochemical and biophysical properties. Examples of such problems which are now being actively investigated are the effects of fresh water use on global sea level, of the modification or destruction of ecosystems on coastal geomorphology, and of the loss of biodiversity and the introduction of non-indigenous species on the functioning of coastal ecosystems. In general, better information is needed on global fluxes of water, sediment, organic matter, nutrients and pollutants between land and ocean, on how such fluxes are varying in time and space, and on the long-term impacts on coastal environments of the exploitation of nearshore physical and biological resources in order to develop scenarios of future conditions in coastal zones.

RESEARCH NEEDED TO REDUCE UNCERTAINTIES

The capacity to predict environmental change in the coastal zone over decadal periods requires new research that adopts an integrated, long-term view of the dynamic functioning of coastal systems. Observational studies must take account of episodic events at a range of scales, and provide data that allow variability and trends to be distinguished and that enable models to be validated. Different types of models - budget, process, system - are needed to define the complex physical, chemical and biological interactions at the land-sea interface and, in particular, to explore the consequences of continuing exploitation of coastal resources by humans. Such work will only be feasible if adequate technological resources are made available for environmental monitoring (including remote sensing), for data archiving and analysis, and for the development of a global typology or classification of coastal systems as the basis for extrapolation in time and space.

[1] Extended abstract.

TRANSFER OF SCIENTIFIC INFORMATION TO THE SOCIO-ECONOMIC SECTOR. Conservation and sustainable use of coastal resources can only be achieved through appropriate management of human activities. Thus, all new research initiatives on the coastal zone should include elements on related socio-economic topics that help define scientific objectives and information needs as well as demonstrate social and economic benefits. The planning and execution of such collaborative research requires new linkages between these two research communities and common methodologies to be established.

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**The IGBP and LOICZ reports can be requested from the LOICZ Core Project Office, NIOZ, P.O.Box 59, 1790 AB, Den Burg, Texel, The Netherlands.*

SESSION II

Mechanisms and Processes

Session II-a
Sea level variability and coastal impact

Chairmen: D. Pugh & A. Selivanov
Rapporteur: A. Tolkachev
Commentator: L. de VREES

Proc. Int. Conf. 'Coastal Change 95' Bordomer-IOC, Bordeaux, 1995, p. 15

MONITORING AND PREDICTING LONG TERM SEA LEVEL CHANGES[1]

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In the last decade, great efforts have been made to put in place a strategic system for monitoring global sea level changes. This system, called GLOSS (Global Sea Level Observing System), is coordinated by the Intergovernmental Oceanographic Commission (IOC) and its development has been aided by great improvements in tide gauge techniques, in satellite radar altimetry and in measuring vertical land movements by means of advanced geodetic methods. Some of these recent developments will be reviewed in this presentation.

In parallel, over the last decade it has been realised that there is a need to understand as far as possible the observed rise of global sea level of order 1-2 mm/year during the past century, and to be able to make meaningful predictions about global sea level for the next century. A large part of this study is coordinated by the Intergovernmental Panel on Climate Change (IPCC) which is at present conducting a updated review for publication in 1995. Recent findings from the IPCC study, so far as they are available by the time of the meeting, will be discussed.

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[1] Abstract. See selected references for broader information.

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A PREVIEW OF THE IPCC 1995 ASSESSMENT FOR COASTAL ZONES AND SMALL ISLANDS[1]

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In December 1995 the United Nations Intergovernmental Panel on Climate Change (IPCC) will publish its Second Assessment Report, which will consist of three volumes, prepared by the three Working Groups that form the IPCC. One of the main goals of this report is to assess and present to policy makers any relevant new information that may either support or challenge the conclusions from the 1990 First Assessment Report and the 1992 Update. The 1995 Second Assessment Report will address: (i) the mechanisms and uncertainties of climate change, (ii) impacts of climate change and options to adapt to or mitigate climate change, and (iii) the macro-economic implications of climate change and implementation of adaptation or mitigation options. The assessment of impacts and response strategies is done in parallel for a large number of socio-economic sectors (e.g., agriculture, fisheries, and industry) and physiographic systems (e.g., mountain regions, rangelands, oceans and large lakes, and coastal zones and small islands). The Executive Summary of the second-order draft of the chapter "Coastal Zones and Small Islands: Impacts and Adaptation" is given below. This draft will be sent out for Government review in March 1995, and may *not be cited or quoted* before final publication in December 1995.

EXECUTIVE SUMMARY

Coastal zones and small islands represent the narrow transition zone between the world's land and oceans, and are characterized by highly diverse ecosystems. These ecosystems are important as a source of food and as habitat for many species. They also support a variety of economic activities, which, in many places, has led to a higher rate of population growth and economic development than elsewhere. As demands on coastal resources continue to increase with growing population and economic activity, multiple-use conflicts also continue to increase. Many examples have been identified of uncontrolled and unrestricted coastal development and single-sector oriented decision making, which

[1] [DRAFT: Not to be cited or quoted without permissions of the authors]

have often resulted in the degradation of natural coastal systems. For example, coastal wetlands are presently disappearing at a rate of 0.5-1.5% per year.

In the IPCC First Assessment Report (1990) and its Supplement (1992) the interrelationships between impacts of climate change and human activities were not yet clearly established. At present, however, many studies indicate that over exploitation of resources, pollution, sediment starvation and urbanization have:

- led to a decrease of the resilience of natural coastal systems to cope with natural hazards that could result from natural climate variability; and,
- adversely affected the natural capability of these systems to adapt to changes, including climate change and sea-level rise.

Hence, although potential impacts of climate change by itself may not always be the largest threat to *natural coastal systems*, in conjunction with other stresses they can become a serious issue for *coastal societies* in those places where the resilience of natural coastal systems has been reduced. By acting now, future development may be designed to be sustainable and to accommodate potential impacts of climate change and associated sea-level rise. Taking a pro-active approach to enhance resilience and reduce vulnerability could be beneficial not only from an environmental but also from an economic perspective, and is in line with the recommendations of UNCED's Agenda 21 with regard to sustainable development. Failure to act expeditiously could reduce the mitigative effect of an otherwise appropriate strategy.

Important findings by Working Group I which are of relevance to this chapter include the following:

- Present preliminary estimates of sea-level rise (including the unexplained global mean sea-level rise observed over the last century) range from 25 to 80 cm for the year 2100, with a best estimate of 50 cm. This is ± 25% lower than the best estimate presented in the IPCC 1990 Assessment, which was 66 cm by 2100. However, it is important to note that even these lower estimates of sea-level rise represent a rate that is two to four times the rate experienced during the last 100 years.
- Climate change may cause regional oceanic changes which will alter the dynamic effects of sea-surface "topography". This would lead to large regional differences in sea-level change by a factor of two or more. Further regional differences will be caused by vertical movements of the land relative to the sea. Because of the dynamic ocean and atmosphere effects, the local and regional sea-level rise will probably not be identical to the global-mean value, although for any given location it is currently not known whether it will be higher or lower.
- At this stage, it is not possible to say if the intensity or frequency of cyclones would increase or change location in a warmer world. If such changes did occur, however, this would have serious implications for safety management as existing statistics on these events will become less reliable.

Since 1990 there has been a great increase of research effort directed at understanding the biogeophysical effects of climate change and particularly sea-level rise on coastal zones and small islands. Studies have shown, *inter alia*, that:

- the coast is not a passive surface over which the sea may rise; instead, the coast is a dynamic system;
- coastal geomorphic and ecologic systems can undergo a number of different responses to sea-level rise depending on local conditions; and,
- variations between and within coastal types suggest that conclusions obtained in one location cannot be automatically extrapolated to another.
- While some *marshes and mangroves* may be under threat from sea-level rise over the next century, human development is the major threat at present. In addition, short-term (decades) fluctuations in the rate of sea level may contribute to wetland loss;
- Projected increases in seawater temperature are a major threat to *coral reefs*. Estimates of global sea-level rise are within the range of reef accretion rates, which may, however, decrease due to warming of seawater;
- *Coral atolls and reef islands* appear especially susceptible to climate change and sea-level rise, although responses are difficult to predict; and,

- *Delta coasts* are particularly susceptible to any acceleration in the rate of sea-level rise. Sea-level rise is likely to cause extensive submergence, and progradation of most deltaic coastlines could be curbed with erosion becoming more extensive and more rapid. Problems will be enhanced if sediment availability is reduced by upstream dams and other human activities.

The assessment of the latest scientific information on socio-economic impacts of climate change on coastal zones and small islands has led to the following main findings:

- Sea-level rise can have negative effects on tourism, ports and harbours, coastal ecosystems, natural freshwater systems, fisheries, agriculture, human settlements, insurance, and human health. Many of these impacts will be reflected as financial losses through market pricing. Some of the most important impacts, such as loss of coastal ecosystems and health impacts, will have additional non-market effects;
- Given the above considerations on sea-level rise, the rather arbitrary values of 30 cm and 1 metre used in the IPCC Common Methodology for assessing vulnerability to sea-level rise are not unreasonable. Vulnerability case studies that have been carried out using a scenario of 1 metre sea-level rise by 2100, the high estimate of the IPCC 1990 Assessment, can still be considered to be useful, especially because sea-level rise is expected to continue beyond 2100;
- These studies show that small islands and deltaic settings are particularly vulnerable. For 26 studies, estimated land losses range from 0.05% in Uruguay to over 80% of the national land area of the Marshall Islands, with average losses of 1%; and,
- On average, some 46 million people are estimated to experience flooding due to storm surge every year under present conditions. A 50 cm and 1 metre rise in sea level would increase this number to almost 92 million and more than 118 million people, respectively.

A major task confronting coastal zones and small islands is the planning and implementation of appropriate response strategies. Studies have shown that:

- The total protection costs for OECD countries facing a sea-level rise of 50 cm by 2100 have been estimated to amount to US$ 521 million per year, based on the assumption that sea walls and protective infrastructure will need to be fortified by 0.5 cm each year. In this analysis, future costs are discounted by 2% per year. The overall conclusion is that it is cost-effective to protect most of their coasts, but this could be at the expense of coastal wetlands and sandy beaches;
- The situation facing developing countries is, however, substantially different. In general the risk they face from sea-level rise is higher because their existing sea and coastal defence systems are relatively less well established;
- Adaptive response strategies for the threatened low-lying island states (e.g., Tuvalu, Tokelau, Kiribati, Marshall Islands, Maldives) and deltaic nations (e.g., Bangladesh, Nigeria, Egypt, China) that have been identified as especially vulnerable are problematic, as the options are limited and likely to be very costly. As all of these nations will continue to experience rapidly increasing vulnerability to natural coastal hazards, due to increasing human activity, strategies must be devised to ameliorate the economic damages and social hazards *well before* climate change and associated sea-level rise becomes a significant factor;
- Integrated coastal zone management (ICZM) could provide both developing and industrialized countries with an effective framework for the achievement of the twin objectives of finding solutions to short-term problems while at the same time developing responses to longer-term events, such as the effects of climate change;
- ICZM is a useful process for identifying future sustainable opportunities in coastal zones and small islands. It should be noted, however, that there is not a single recipe for, but that there are many approaches to ICZM and diverse institutional arrangements that can be tailored to the particular culture and style of governance;
- Even though, in many cases, long lead times are required to begin the process of ICZM, few countries have begun any planning or taken any measures as might be necessary. Yet, many options are available and include, *inter alia*, the

adoption of structural, legal, financial, economic and institutional measures. Attention might also need to be focused on capacity building, as part of a comprehensive response strategy. Countries may also wish to consider, as part of their overall response strategy, the application of indigenous technologies, if appropriate, flexible and cost-effective; and,

- Constraints which could hinder the successful implementation of ICZM include, but are not limited to:

(i) technology and human resources capability;
(ii) financial limitations;
(iii) cultural and social acceptability; and,
(iv) political and legal framework.

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COASTAL CLIMATOLOGY OF CURRENTS, TEMPERATURE, AND DISPERSION OF NORTH AMERICAN GREAT LAKES

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The Laurentian Great Lakes lie between 41 and 49 degrees north and between 76 and 92 degrees west. They contain a fifth of the earth's fresh water, sufficient to locally moderate the cool continental climate to a semi- maritime climate. Only the relatively shallow Lake Erie and the very small Lake St. Clair freeze over completely in winter.

Forests, small lakes, and rugged rock formations of the Canadian Shield border much of lakes Superior and Huron, while predominantly fertile farmland surrounds much lakes Ontario, Erie, and Michigan. Small areas near lakes Erie and Ontario support specialized crops such as orchards, typical of regions much further south. These areas are being rapidly overrun by urban and industrial development, particularly near major cities.

Transportation has been a key factor in the development of the Great Lakes Basin as far back as early native settlements. The first Welland Canal opened in 1829, allowing ship traffic to climb the hundred meters from the level of Lake Ontario to that of Lake Erie through a series of locks. The modern St. Lawrence Seaway links all the Great Lakes with each other and with the Atlantic Ocean. Ships up to three hundred meters long move iron ore from mining areas near Lake Superior to steel mills on the lower lakes.

Once a major hydro-electric power development, Niagara Falls is now a relatively small part of a power network which includes several large fossil-fuel and thermo-nuclear power plants located on the lakes for easy access to cooling water. Human activities affect even very large lakes, but by far the greatest impact occurs in the so-called coastal-zone; an area of substantially different characteristics from the open lake. Currents here are typically stronger, and predominantly shore-parallel, reversing in direction every five to ten days, while offshore currents undergo gradual, but almost continuous, change in direction. Although not rigorously defined, the coastal zone is generally considered to extend about 10-15 kilometres offshore. The biology, and chemistry of this region are complex, highly variable, and strongly influenced by physical processes, which are, in turn, largely driven by weather.

With growing population, suitable placement of drinking water intakes and wastewater outfalls in the coastal zone of the Great Lakes becomes more and more difficult, while declining overall water quality narrows the margin of error in determining the risk of serious water supply contamination. Adding to this the increased danger of accidental toxic spills from transportation or industrial accidents, the importance of understanding physical processes of transport and dispersal of pollutants is easily recognized.

At Canada Centre for Inland Waters we have conducted intensive coastal experiments at several locations in the Great Lakes over the past three decades. While instrumentation has improved, the design of the basic coastal experiment has remained unchanged. A series of current meter moorings are installed in a line perpendicular to the local shoreline, at intervals ranging from 500 m to 1 km apart near shore to 2-4 km apart at the offshore end of the line. The first mooring is set at the minimum practical water depth for one instrument (at least 8 m depth to avoid being struck by ships, and to minimize data contamination by surface wave influences). In deeper water instruments are placed at minimum depth, bottom, and appropriate regular intervals between (eg. 8 m, 12 m, 20 m, 50 m, bottom). Each current meter measures current velocity and water temperature. The system is activated at

some preset sampling interval (10 min, 20 min, 30 min, etc.); readings are taken; and data is recorded on tape or in memory to be downloaded when the instrument is recovered - usually after several months of operation.

Along with current meters, two meteorological buoys are moored near the offshore end of the chain to record wind velocity, air temperature, relative humidity, surface (1 m) water temperature, and solar radiation. FTP (fixed temperature profiler) moorings with many regularly spaced thermistors distributed along a vertical cable suspended below a surface buoy containing a battery powered data logger, are placed at intervals along the mooring chain to provide detailed vertical temperature data. Sample times of all instruments are synchronized so the whole data set can be treated as a regular time-series with horizontal and vertical dimensions.

The basic coastal chain is often operated concurrently with other experimental programs, such as ongoing water quality monitoring programs conducted by regional and/or provincial agencies. The combined spatial coverage achieved by such co-operative instrumentation schemes yields a far more comprehensive data base than could ever be achieved individually.

Coastal chain time series data provide the basis for a climatological description of the site as a function of weather - most notably winds (Murthy and Blanton, 1975). Initially, statistical-climatological summaries are prepared, usually with reference coordinates aligned shore-parallel and shore-perpendicular instead of east and north. An example is the vector "rose plot" and summary: velocity data for a selected period is separated into three speed ranges for each of a chosen number of direction sectors, and the results are tabulated and plotted as in Fig. 1.

Individual recorded velocities are the resultant of motions of many types and spatial scales - seiches, many kinds of waves, inertial oscillations, turbulence etc. (Murthy and Dunbar, 1981). Spectral analysis, a mathematical process developed to analyze complex electrical signals, looks at time series data and determines the proportion of the energy (kinetic energy for current or wind data; heat flux for temperature data) attributable to phenomena of different frequencies. For instance, near-shore current data yields high energy values for shore-parallel velocity at frequencies below .02 cycles per hour, compared with the shore-perpendicular component, and with concurrent values for offshore sites. The offshore sites show a peak of energy in a narrow band at the inertial frequency (about 17 hours for the latitude of the Great Lakes) that often fails to show up at all on near-shore data. Plotting total kinetic energy, and component energies, for comparable periods and depths at all mooring sites as a function of offshore distance yields a distribution like Fig. 2. The Coastal Boundary Layer consists of two zones: the Frictional Boundary Layer lies inshore of the peak energy and is dominated by shore and bottom friction; the Inertial Boundary Layer responds to lake-wide circulation phenomena.

Temperature affects coastal zone dynamics and has a major influence on biological and chemical processes. The interplay between natural thermal events and thermal plumes from power plants is of major concern for coastal zone water users. During summer months the thermocline, a relatively thin layer with a sharp vertical temperature gradient, creates density stratification strong enough to prevent bottom water from mixing with warmer surface water - a situation which, in seriously polluted waters, can lead to anoxic conditions at depth. Strong winds across a lake tilt the thermocline, causing a thickening of the warm layer downwind and a thinning of it along the upwind shore, often creating outbreaks of relatively cold water - called upwelling - at the surface. In autumn, when surface temperatures drop to 4 °C - the temperature of maximum density for water - the whole water mass mixes vertically until limited by weak stratification with lighter, colder water at the surface. In spring, warming in shallow coastal waters can occur rapidly enough to create a thermal bar which is a narrow shore-parallel band of 4 degree water separating warm inshore water from cold offshore water. As warming continues the thermal bar moves offshore with stratification developing in the near-shore water mass behind it.

Coastal experiments are usually enhanced by the inclusion of intensive measurements of related physical parameters using a variety of other equipment. Ship-tracked or satellite-tracked drifting buoys are used to track near-surface (3 to 4 metres) currents. High sample-rate current and temperature platforms are installed near a standard current meter mooring to define small-scale motions and temperature structure close to the bottom in order to study boundary-friction and sediment resuspension. Fluorescent tracer injection moorings are installed to generate tracer plumes to study coastal dispersion processes. Concentration profiles are measured and analyzed to determine dispersion parameters governing the mixing process.

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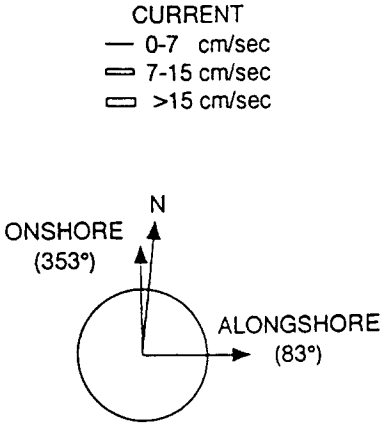
Fig. 1. Summary of currents in Lake Ontarion off Darlington NGS 1989.



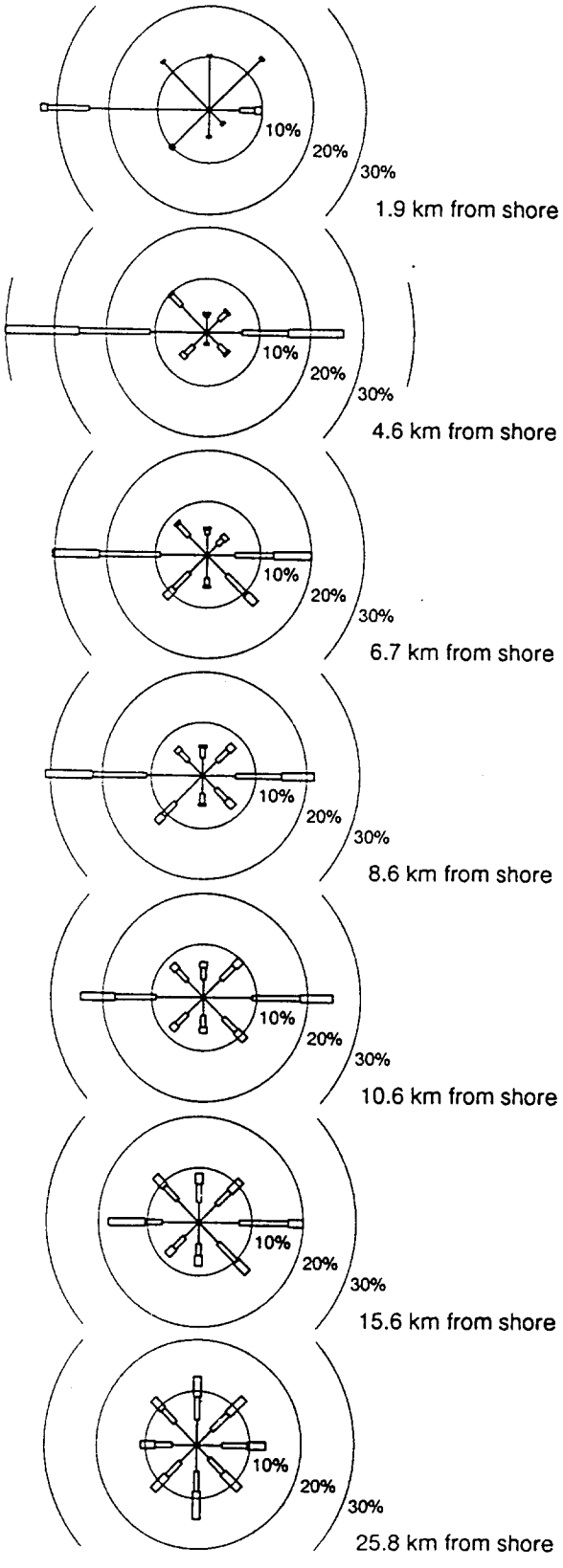
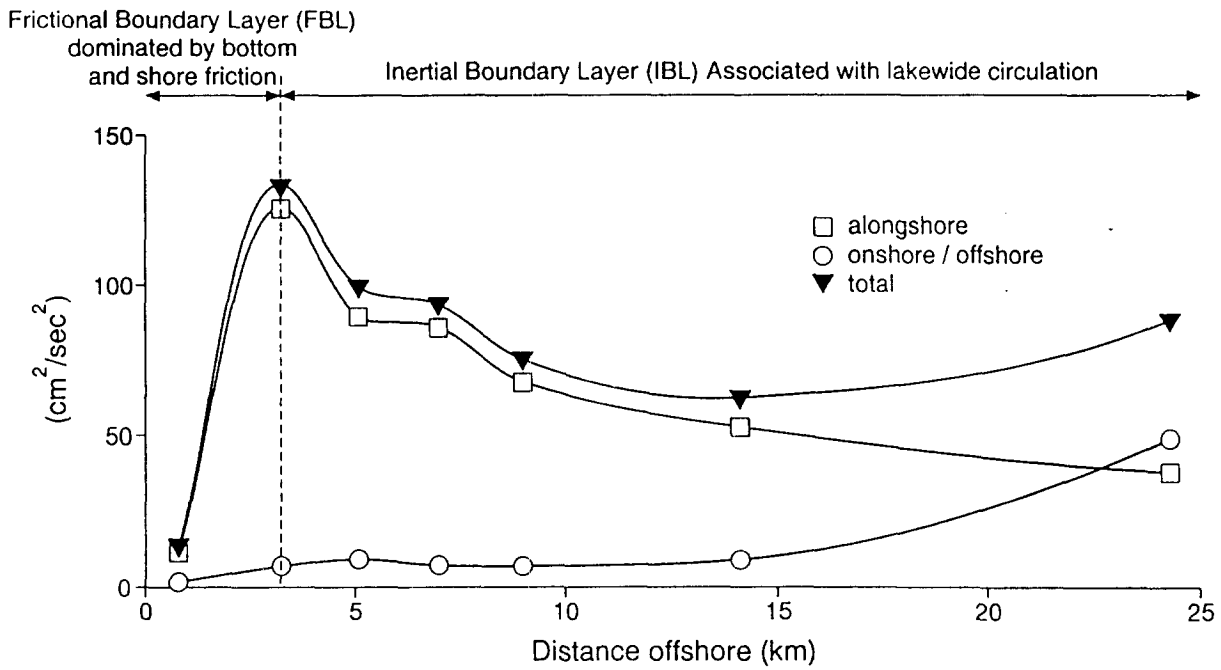


Fig. 2. Total kinetic energy, and component energies, for comparable periods and depths at all mooring sites as a function of offshore distance.



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MONITORING GLOBAL SEA LEVEL RISE/RELATIVE SEA LEVEL RISE IN A DEVELOPING COUNTRY - THE NIGERIAN EXPERIENCE

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KEY WORDS: Developing nations, monitoring, tidal data, sea level rise, subsidence, and coastal zone management.

ABSTRACT

Developing nations such as Nigeria with a low lying coastal topography will be adversely affected by the global rise in sea level. Nigeria has only one functioning tide gauge manned by a government establishment. Long term and good quality tidal data are virtually non existent except for the 19 years that was recently collated from one of the oil companies in Nigeria. This was based on local datum. Therefore, indications of subsidence and relative sea level rise could not be obtained but a sea level rise of 1 mm per year was observed from the data.

Efforts should be made to establish more tide gauges especially on the Niger Delta. Provision of topographic maps and the setting up of a coastal zone management are very vital in addressing the problems of sea level rise and the impacts on the Nigerian Coast.

United Nations agencies should help Nigeria and other developing countries in manpower training, attendance at international conferences, and supply of equipment for coastal studies.

INTRODUCTION

Historically, the seas and oceans were used for navigation, fishing, and a sink for all forms of wastes. The coastal environment is a very important resource base and generally fertile. For these reasons, agriculture, fishing, logging, and different types of industries have been attracted to this zone. These activities encouraged concentration of population. Most important cities of the world such as Paris, Bordeaux, Lagos, London, Rotterdam, Cairo, and Tokyo are located along the coast. It is estimated that at present about 66% of the world population live within 60 km from the coast (Hanson and Lindh, 1993). This number is expected to increase to about 75% by the year 2020 (UNEP, 1992). Apart from population concentration, there are several infrastructural and economic developments that are located here.

The sea is known to vary over different geological time scales, some are inter annual, decadal, and so on. Some years ago, the sea level was 100 m below the present level while at another time, it was about 6 m above the present level. Most of these changes have been natural and humanity has been able to adapt to the changes.

Recently, however, there is evidence to show that sea level is once more rising. The rise is associated with human action, due mainly to increased emission of green house gases and the resultant global warming. Increased temperature leads to expansion of the volume of the ocean/sea and melting of mountain glaciers. In addition, the icecaps in Greenland and the Antarctic may melt over time; these will ultimately increase the volume of Ocean water which is translated into rise in sea level.

So far, there has been a steady rise in sea level at the rate of 1-2 mm per annum globally. No acceleration has been noticed (Woodworth, 1993) but it is projected that by the turn of the century there may be an acceleration. On a local scale, coastal subsidence could lead to a much higher relative sea level rise than the global average. Subsidence could be natural or human induced due to fluid withdrawal.

Rise in sea level will lead to destruction of properties, flooding, erosion, salinity intrusion, deforestation, destruction of settlement and more frequent storm surges, and changes in ocean

dynamics (IPCC, 1990 & 1992; and Ibe 1988 & 1990). Some of these factors including erosion, flooding, inundation and destruction of coastal vegetation, and more frequent storm surges, are already very evident on the Nigerian Coast (Nwilo, 1995; Ibe, 1990).

Due to a global concern on the impact of sea level rise, the United Nations Environment Programme and the World Meterological Organisation set up the Intergovernmental Panel on Climate Change (IPCC) to provide the basis for an internationally acceptable strategy to address climate change. This Panel has come up with a number of reports and updates on the issue of climate change.

THE NIGERIAN COAST

Nigeria has a population of 88.9 million (Onuoha, 1993) of which about 20 million are located within the coastal areas. Although this 20 million represents only about 22% of the population and less than the global average, it is still large when viewed from the point of view of Nigeria's population density. Also, the difficult nature of the Nigerian Coastal environment especially in the Niger Delta has led to concentration of population mainly in Lagos, Port Harcourt, Warri and the historical towns of Bonny, Forcados, Brass, Badagry, Escravos, and Calabar. Fig. 1 shows the coastal areas of Nigeria.

Nigeria has a coastline of about 850 km (Ibe, 1988; 1990; Awosika, 1992; 1993). The Coast is generally sandy and of low lying topography. It is divided into four main geomorphological units namely: the Barrier Lagoon Coast, the Mud Coast, the Niger Delta, and the Strand Coast. These morphological units have been described in literature (Ibe, 1988; Pugh, 1953a & 1953b; Allen, 1965a & 1965b; Awosika, 1992 & 1993; Nedeco, 1959; Nwilo & Onuoha, 1993). The Nigerian Coastal area is dominated by the Niger Delta which occupies a total area of about 20,000 square kilometres. Although some literature exists about the Nigerian Coast, most were studies done for oil prospecting or for solving some problems such as coastal erosion at Victoria Island, or harbour construction and were generally done on a short time basis. One major exception is the Coastal Erosion study by the Nigerian Institute for Oceanography and Marine Research, Lagos.

The vegetation along the Nigerian Coast varies from palm trees, coconut trees, and shrubs on the Lagoon Barrier Coast to Mangrove, grasses, ferns at the Mud Coast, the Niger Delta and the Strand Coast. Destruction of coastal vegetation due to flooding, inundation, salinity intrusion and human activities is increasingly evident. Ibe (1988) and Ebisemiju (1985) have all reported cases of dead or dying vegetation along the Nigerian Coast especially along the Mud Coast. The destruction of coastal vegetation has created a conducive environment for increased coastal erosion.

The climatic regime along the Nigerian Coast comprises of rainy and dry seasons with temperatures in the range of 26-34 °C. The rainy season could last for up to nine months.

The coastal region of Nigeria is highly developed with about $^3/_4$ of all the industries located here. The oil industries which are the mainstay of the Nigerian economy are located in the area in addition to airports, sea ports, rail terminals and several road networks. This level of development shows the importance of the Coastal zone to the Nigerian economy.

MONITORING SEA LEVEL IN NIGERIA

Most of the available information globally on the rate of global sea level rise has been from long term tidal data from tide gauges mainly located in the Northern hemisphere. Most developing countries do not have long term tidal data with which to monitor sea level rise. Developed countries have the technology and the resources with which to monitor sea level rise and defend their coasts against the impacts of the rise. IPCC (1990 & 1992) warned that developing countries, such as Nigeria, with low lying topography are likely to be more susceptible to the impacts of sea level rise.

Tidal Data

Tidal data have in the past been collected for a few days to months and up to one year at different parts along the Nigerian Coast. These tidal data were collected for dredging, navigation, and port development purposes. In 1961, the

Nigerian Ports Authority (NPA) installed a stilling well tide gauge at the East Mole. This gauge functioned intermittently until 1985 when it was damaged by a ship. Due to fund constraints and possibly commercialisation of the NPA, the NPA was not able to install another gauge at the location. Some years later, the Shell Petroleum Development Company installed another stilling well tide gauge at the same location. The gauge stopped functioning in 1992 when the Department responsible for collecting the data was reorganised. Shell also manned another tide gauge at Morocco, Lagos along the Five Cowrie Creek for about two years. Outside Lagos, Shell also has tide gauges at Bonny, Forcados and along some of the Creeks on the Niger Delta. The Shell tide gauges outside Lagos are based tide poles or staffs.

Around 1991, a stilling well tide gauge was established within the premises of the Institute of Oceanography and Marine Research as part of the Global Sea Level Observing System (GLOSS) programme and in 1992, a more modern tide gauge was also added to the existing one under the same programme.

Among all the sets of data available, it is only the data from Bonny that are generally of good quality and long enough for any meaningful scientific investigation. So far, up to 19 years' of data have been collated from the originators. About the same number of years data are available from Forcados. Quality checks were applied to these two sets of data. The data from Forcados failed the tests as the data seemed to be from different locations. More clarifications are needed from the originators. Although the Nigerian Ports Authority had gathered tidal data from 1961-1985, there were several gaps in the data. In many cases, several months of data were missing. For this reason, the data could not provide any meaningful information relating to global or relative sea level change. The data from the GLOSS sponsored tide gauge at the Institute for Oceanography, Lagos is of short duration but could provide some information. However, the data are not yet available for public use as they are still undergoing some quality controls.

From the analysis of the Bonny tidal data, a sea level rise of about 1 mm per year was observed. This rate of sea level rise falls within the global average of 1 - 2 mm per annum. Fig. 2 shows a graph of annual mean sea level against time for Bonny. It must be borne in mind that this rate of sea level change for Bonny does not take into consideration the subsidence phenomenon which is believed to taking place on the Nigerian Coast especially on the Niger Delta. Some authorities such as Pugh (1987) suggest that for a meaningful trend to be determined, about 30 years of good quality data is needed. In The Nigerian case, however, only 19 years of data have been used and more importantly the data were collected using tide poles. This method of data collection may seem absurd at this time but this portrays the appalling situation in Nigeria as in most developing countries. To collate and edit this amount of data involved so much personal effort and cooperation with others working in this area. This data set will obviously form a basis for further research on sea level rise and other related problems along the Nigerian Coast.

Annual mean sea level for Takoradi, Ghana was also studied, using over 40 years of data. A sea level rise of 3.9 mm per annum was observed for that Port. This rate of sea level rise may give a more regional picture of the situation on the West African Coast than the information from Bonny. Unfortunately, apart from the Takoradi and Bonny data, there does not seem to be any other port with a long set of tidal data along the West and Central African Coasts.

Further Research Needs

Although the data from Lagos are based on the Lagos datum which is the Nigerian height datum, those from Bonny and Forcados, both on the Niger Delta, are based on the chart datums of the respective ports. The reason for this situation is that there are no National primary or secondary vertical controls in these areas (Fajemirokun **et al.**, 1991). It has been difficult to establish primary and secondary geodetic networks in the Delta due to the difficult nature of the terrain and lack of funds. The Delta is made up of several creeks cris-crossing one another, generally swampy and

heavily forested. Most of the controls in the Niger Delta were established by the oil companies, strictly for oil prospecting and exploitation. Efforts have not been made to connect them to the National Geodetic Network. There is, therefore, a need for the harmonisation of the various origins to enable the nation tp address the issue of sea level rise along the Nigerian Coast from a "global perspective". This harmonisation can be achieved through a satellite technique such as the global position system (GPS). A recent joint campaign by most of the oil companies in Nigeria to establish primary controls along the Nigerian Coast by GPS techniques was a step in the right direction. Unfortunately, however, the height component of the results of that campaign was doubtful.

The 1 mm sea level rise per annum obtained at Bonny does not, as earlier stated, take into account subsidence believed to be taking place along the Nigerian Coast. Ibe (1988), Ebisemiju (1985), and Nwilo & Onuoha (1993) have all reported that the Nigerian Coast is believed to be subsiding due to natural and human induced actions. Although, there is no reliable quantitative value for the rate of subsidence on the Nigerian Coast, indications from flooding and inundation and their pattern seem to suggest that they are exacerbated by subsidence, especially the human induced subsidence. This human induced subsidence is caused by fluid withdrawal in form of gas, oil, and water; and canalization. The natural subsidence is due to the compaction of the thick sediments with their high water contents. This type of subsidence is peculiar to the Niger Delta but is typical of most large deltas such as the Nile and the Mississippi.

The need to monitor subsidence on the Nigerian Coast cannot, therefore, be overemphasised. No meaningful response measure on the impact of sea level rise on the Nigerian Coast can be successfully implemented without a clear understanding of the contribution of the subsidence phenomenon. Geodetic levelling techniques will not be a feasible approach in determining rates of subsidence on the Nigerian Coast. A combination of geodetic levelling and GPS techniques is advocated. The process involves the establishment and monitoring on regular basis of benchmarks established on the coastal areas. The monitoring must include tide gauge benchmarks. In addition, the benchmarks should be connected to other benchmarks on stable areas.

Contoured topographic maps of most parts of the coastal areas of Nigeria are not available. These maps are very essential in the study of the impacts of sea level rise along the Coast. Shell Petroleum Development Company of Nigeria recently produced a topographic map of the Niger Delta and other parts of the Nigerian Coast but this map has no height information. It was difficult to produce contoured maps because as earlier stated, there are no national primary and secondary geodetic controls and the existing controls are on local datums. The Federal Government of Nigeria must make a conscious effort to establish controls and produce contoured topographic maps. Current aerial photographs can also be useful in the study of the impacts of sea level rise. In the past, the aerial photographs were taken at an interval of about 10 years. With the economy of Nigeria in serious crisis, it now takes a much longer time. If funds are available coupled with careful planning, aerial photographs could be supplemented with satellite images in the study of the impacts of sea level rise.

Effective monitoring of sea level rise cannot be realised along the Nigerian Coast without adequate coverage of the coastline with tide gauges. As earlier mentioned, it is only the tide gauge located at the NIOMR compound that is manned by a government agency and functions regularly. The major reason for the shortfall is lack of funds for the equipment, maintenance, and manpower training. The United Nations agencies such as UNESCO and UNEP should give additional assistance to Nigeria and other developing countries in areas of manpower training, attendance at conferences, and provision of equipment for coastal studies. Developed nations can also offer help in the form of sponsoring research in developing countries. This could be done through research cooperation between institutions in developed and developing countries. Furthermore, The United Nations

agencies can sponsor international conferences in developing countries. This will offer many scientists, researchers, managers, and administrators from the developing countries the opportunity to attend.

To effectively cover the entire coastline of about 850 km, it is estimated that about six tide gauges will be required. The Niger Delta alone requires three, one on each of the flanks and one at the tip. The other three will be located at each of the remaining three main geomorphological units. The present situation where tidal data available in the country is dependent on oil companies operations is not ideal. Apart from the fact that the quality may not reach the generally accepted standards either due to instrumentation or other reasons, it is possible that for operational reasons some of the stations could be closed down over time. That has actually happened with the Shell tide gauges at East Mole and Morocco in Lagos. Some human activities on the Nigerian coastal areas will exacerbate the impact of sea level rise on the Nigerian Coast. Such activities as mineral exploration and exploitation, dredging, deforestation, pollution, fishing, and construction works, have been going on without integrated coordination and management. This form of coordination and management will ensure that the consequences of these activities on the coastal environment are given due consideration at various stages of the developments. It is for this reason that we call for an integrated management of the Nigerian coastal areas. This can be achieved through the establishment of a Nigerian Coastal Management Commission. The proposed Commission should aim at developing and implementing a dynamic strategy for the allocation of environmental, socio-cultural, and institutional resources to achieve the conservation and sustainable multiple use of the coastal area (Coastal Area Management and Planning Network, 1989). The Setting up of a Coastal Management Commission will be in line with Agenda 21 of UNCED.

CONCLUSIONS

The coastal areas of most developing countries will be adversely affected by a global and relative rise in sea level. These nations lack the technology and resources for the monitoring of sea level rise and the implementation of effective strategy to defend their coasts against the impacts of sea level rise.

Nigeria is among the nations facing the adverse consequences of a global sea level rise. An annual sea level rise of 1 mm per annum observed so far at the Bonny Port, is believed to be much less than the actual situation on the Nigerian Coast. Coastal subsidence which is believed to be occurring on this coast has not been accounted for as information on this is not yet available. More tide gauges need to be installed along the coastline. Presently, only one tide gauge is manned by a government agency. The other ones which are mainly from tide poles, are manned by the oil companies and are set up for their activities. There is, therefore, a need for the setting up of more tide gauges. United Nations agencies and developed countries can help Nigeria and other developing countries in setting up new tide gauges and in manpower development on coastal management.

Up to date topographic maps and survey controls based on national origin are in most cases not available. The Federal Government of Nigeria is called upon to allocate funds for mapping and control extension in the coastal areas. The setting up of a coastal management commission is also a very important step in addressing the issue of sea level rise and its impact.

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Fig. 1: Map Coastal areas of Nigeria.

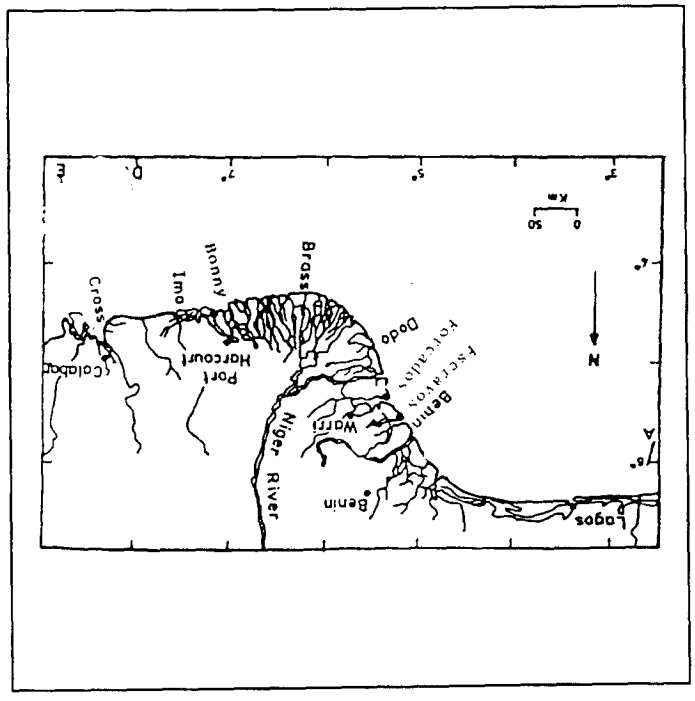


Fig. 2 : Graph of annual mean sea level against time for Bonny.

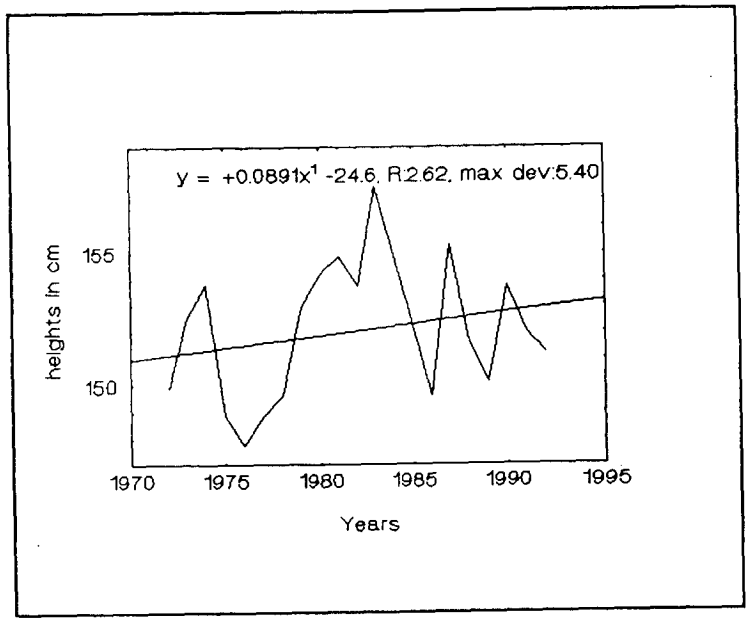
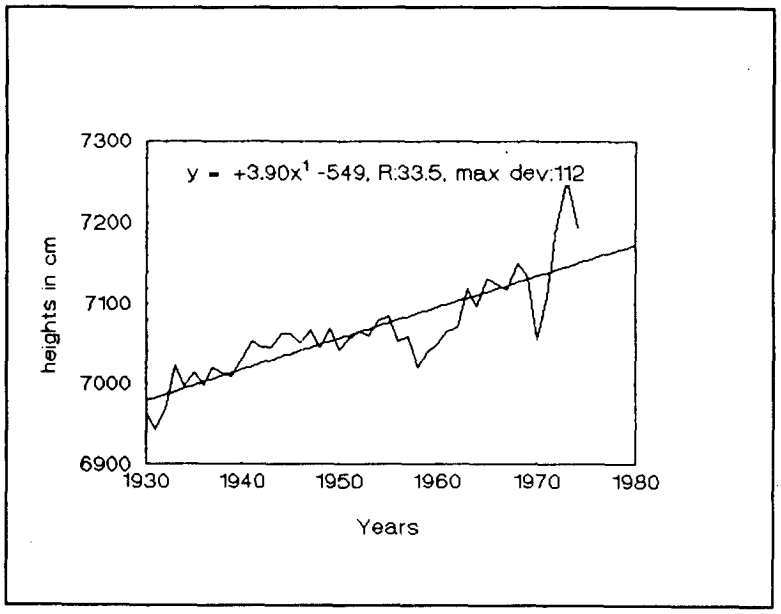


Fig. 3: Graph of annual mean sea level against time for Takoradi, Ghana



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THE CASPIAN SEA LEVEL FLUCTUATIONS AND THE FEATURES OF THE VOLGA DELTA WATER REGIME

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The river mouths have been of great importance in human development since ancient times: favourable climate, fertile soils, abundance of the fish and wildfowl, easy transport and roads served as a reason for these regions high population and development. The greatest European seaports are located at river mouths of Hamburg, Rotterdam, London, Riga etc.

Economic development causes serious changes of the river mouth's ecological balance. The negative consequences of the anthropogenic influence - the runoff value decrease and regulation, industrial and domestic pollution, reconstruction of delta's streams network with the dams and channel building - take place in the river mouths. There is destruction of the unique natural complex in some coastal regions. Therefore, investigations of the river mouths as a zone of active marine and river factors interaction, occurring with intensive economic development, is of special importance.

River mouths are located at the boundary between sea and river. The marine and riverine interaction defines the specific hydrological regime and a unique environment. This interaction causes an unsteady-state regime, which is characterized by the movement of forward and reverse long waves of different origins. The investigation of this regime's features have great scientific and applied interest. In consequence of the interaction of these factors, the Caspian Sea and the Volga delta are a unique natural laboratory for investigations of the influence of sea level fluctuations on the delta and shallow offshore zone. These investigations are very important for the evaluation of possible impacts of World Ocean level rise for European coastal zones.

The Caspian Sea level has varied significantly during all its history. Several factors caused these fluctuations: the global climate, the river flow from Caspian drainage basin (mainly the Volga river water flow) and economic activity (Fig. 1).

The global climate had changed during the last 1000 years from the warmest to the coldest not only for this period, but for the Holocene (Rodionov, 1989). The fact of the Caspian Sea level declined to -31 m - -32 m (Baltic system of measurement - BS) during the XI-XIII centuries is well-known. For Europe this period is known as the Epoch of medieval rise in temperature. The new great Caspian Sea level rise began at the beginning of the XIV century. This rise might been caused both by the restoration of Amu-Daria flow to the Caspian Sea and the rapid fall of temperature at the beginning of the XIV century. The next Caspian Sea level decline continued more than 60 years in the XVI century, till the level mark -29.0 m. One of the reasons of this regression can also be the termination of Amu-Daria flow to Caspian Sea.

The level began to rise at the end of the XVI century and at the beginning of the XVIII century, it was 4 m higher than now. This high level period is characterized by the widest short-time fluctuations. The cold period of the XVII-XIX centuries is known as the Small Ice Age. The development of blocking anticyclones took place during the Small Ice Age, and caused the prevalence of North winds. All atmospheric circulation was anomalous. The vast region of low pressure with great precipitation over the Volga river drainage basin was the result of these processes. The whole of this period was characterized by high humidity (Fig. 1).

The beginning of the XX century is known as the period of Arctic warming. The temperature in the Northern Hemisphere had increased and reached the maximum temperatures since the XVI century

by 1920-1930. The sea level fell by 2 m from -26.6 m BS during the 1930s, and the average rate of decline reached 16 cm per year (Fig. 2). The decline slowed in 1940-1950 and stabilized at -28.5 m in the 1960s. The next rather dramatic drop followed in the 1970s - down to -29 m BS. This was the lowest level for the last 400-500 years. After 1978 the level rose rapidly, and this process has continued into the present and the Caspian Sea level has already increased to -26.7 m BS in 1994. Two factors have a major effect on the level of Caspian in this century: climate and economic activity.

The drop in the Caspian level in the 1930s has to do with large-scale climatic anomalies in the Northern Hemisphere: an increase in air temperature and decrease in precipitation over a large part of Europe, including the Volga drainage basin. The Volga water volume entering the Caspian during the 1930s declined by 50 km^3 per year in comparison with the preceding period, when it reached 270 km^3 per year. Roughly 395 km^3 of water evaporated from the surface of the Caspian - much more, than flowed into it. The water balance deficit over the period 1930-1941 comprised approximately 62 km^3 per year (Table 1).

Conditions for the formation of surface water flow are first of all determined by the area of the drainage basin. The area of the Volga basin takes more than 40% of whole Caspian Sea drainage basin area. The Volga water flow depends directly on the character of atmospheric processes in its basin, especially during the winter, when a large part of its annual water volume is formed.

Multibranched system of the Volga delta of fan type (the area of more than 10,000 km^2) has a number of connected alluvial fans of large systems of deltaic branches. The main are the Buzan system (the east part of the delta), fed by the Volga River at the delta head, and Akhtuba River, and the system of the west delta: Bakhtemir, Old Volga, Kamyzyak, Bolda. From the delta head (where first main branch Buzan separates) to the delta coastal line, the river flow considerably dissipates and redistributes between the main deltaic branches (Fig. 3).

The modern Volga delta was formed during last century in conditions of fluctuation of the Caspian Sea level; and in periods of relative stabilization of the sea level intensive development of the delta in different lithological-morphological directions dominated (growing forward of alluvial fans and fragmentation of the hydrographic net). That caused formation of a number of deltaic terraces within terrestrial and aquatic parts of the alluvial fan of the Volga delta. During the period of rather rapid changes of sea level, passive development or regression of the delta caused by relict morphology of terrestrial (while sea levels rise) and submerged (while sea levels drop) parts of the alluvial fan dominated (Polonsky & others, 1992).

Water river flow coming into the Volga delta top has 3 components: channel flow of the Volga River, flow of the Akhtuba River and flow of the Volga-Akhtuba flood plain. Observation data on the Volga flow covers the period since 1881 (Fig. 2).

Analysis of long-term alterations of the total Volga flow in the delta top allowed identification of its regime in several specific periods. The period 1881-1955 is called the period of natural conditions of flow.

The period 1956-1993 is called the period of altered regime of flow. In this period all large reservoirs of the Volga-Kama cascade began to operate. By 1961 the main volume of reservoirs had filled up, and the period of river flow regulation began.

Through the whole period of observation, the climate conditions were favourable for high water in the first decade and in the last 15 years. In 1881-1890 the mean annual volume of flow reached 273 km^3/yr, and in 1978-1993 - 270 km^3/yr. The lowest water years for the whole period of observations were 1930-1940 and 1971-1977, when mean annual discharge was 195 km^3/yr (Q = 6190 m^3/s) and 198 km^3/yr (Q = 6290 m^3/s) respectively. During 1971-1977, in spite of rather low levels of water withdrawal in the Volga basin, in comparison with previous decade, mean annual discharge was very low. Based on these data we can conclude that the Caspian Sea level decrease to -29.0 m BS by 1977 was

evidently caused by a strongly pronounced climatic low water period of the Volga river that coincided with essential irretrievable economic withdrawal of flow in the two previous decades.

The water regime of the delta (space and time distribution of discharges and water levels, regime of inundation) depends on river flow, morphology and the flow capacities of some elements of the hydrographic net of delta, hydrotechnical measures in the delta. Distribution and redistribution of flow in the systems of delta branches was studied using hydrometric data by physical-statistical analysis of the changeability of relations Qi = f(Q total) (Polonsky & other, 1992).

Long-term changes reflect in sum changes of the ratio of passing capacities of different elements of the hydrographic net of the delta. In periods of relatively small variability, relations reflect changeability of flow distribution in delta branches (Qi) due to river discharge (Q total).

The most considerable distribution of the river flow in the delta in the XX century took place while sea-level fell by 1.8 m during 1930-1940. Intensive dredging works in the Volga-Caspian Canal (VCC) implemented at that time caused strong differences between passing capacities of the VCC and the natural shallow offshore zone. While sea level dropped, along with natural and human induced increase of the Bakhtemir flow, there was a natural increase of percent of flow of branches ending at relatively short and deep sites of avandelta. Branches ending at vast shallows of the delta offshore decreased the percent of their flow.

Further redistribution of flow during relative stabilization of sea level went on in different ways. Systems of branches that were active before sea level dropped, for example Kamyzyak, gradually increased the percent of their flow. The systems, which were dying before the sea level dropped, such as the Old Volga, Rychan, experienced a decreasing trend of the flow percentage. And systems that were most closely connected hydraulically with the artificially supported navigable Bakhtemir branch, died faster or slowed down their activity. Dying systems without direct connection with the sea quickly decreased the percent of their flow and branches coming to the relatively short, deep parts of the avandelta became more stable.

Using relations Qi = f(Q total), we determined the modern trends of redistribution of flow in the Volga delta. Immediately after river regulation in the Low Volga (1956-1960), the percent of flow in almost all main deltaic branches strongly increased. It is accounted for by the dying of small side branches in the main branch of the Volga River from the delta top to the Bakhtemir head as a result of the decreasing of channel forming discharges of water. In high degree in this period, the increased percent of Bakhtemir flow was because of the reconstruction and considerable dredging of the VCC.

Starting from the middle of the 1960s, engineering works of water distribution in the main Volga channel below the head of Buzan branch caused additional flow in this place, reaching at high water 20 cm. Since 1956-1960 to 1983-1993, the percent of Buzan flow coming to the east part of the delta increased by 10% on average, because of reduction of flow into the west part of the delta. In large measure, the increase of percent of Buzan flow manifested itself as big discharges of the Volga River (Q total > 14000 m^3/s. As reasons for Buzan's activity, one can suggest construction of the Belinski (1961) and Igolkinski (1965) canal water distributor in the main Volga branch (1973). The dam of the water distributor created obstacles to streams in the direction of the main Volga channel. In operable state during flood, when sluices are closed, the water distributor can create afflux in the head race up to 50 cm in comparison with inoperable conditions.

Assessment of the intensity of redistribution of flow in local subsystems and branches showed that the overall relatively slow redistribution of flow in the water heads of large branches does not reflect properly the processes of redistribution at the side of the delta and at the delta coastal line (Polonsky & others, 1992). It was found that having rather stable main branches, processes in local subsystems have different trends and sometimes are one order of magnitude more than the intensity of relative changes of flow of main branches.

Essentially in all subsystems of the main deltaic branches - Bakhtemir, Old Volga, Kamyzyak, Bolda, Buzan - for the last period around 30 years there is a clear trend of concentration of flow in the main directions, leading to natural collectors (banks), incised into relict terraces correlated with delta coastal line of period of sharp drop of the Caspian Sea level at the beginning of the XIX century and in the 1930s. Concentration of flow in banks is artificially intensified when they connected with fish pass canals cutting the shallow delta offshore. Interdeltaic side branches linking main systems of branches die, as a rule. Branches, coming to the most shallow zones or sites blocked by islands die too. The highest concentration of flow is in the Bakhtemir system to the delta coastal line, where up to 95% of Bakhtemir flow goes into VCC in low water and 85% in flood.

The hydrological regime of the Volga delta is strongly influenced by intensive use of water resources in the lower part of the Volga river. The main components of the hydrological regime most affected by the anthropogenic action are water river flow and inundation during the spring-summer flood period. The main anthropogenic actions are the following:

- the regime of water flow regulation by the Volgogradskaya hydroelectric power station;
- the construction of artificial levees along the delta branches and flood plain massif;
- water draw off and diversion;
- construction of large fish pass canals in the lower part of the delta and at the offshore;
- operation of the water distributor at the delta top.

Table 2 gives the changes in volume and duration of the water flow in the flood period at the Volga delta top (gauge station - g/s N 1, Fig. 3) during the period from 1942 to 1993. Water flow regulation by cascade of large reservoirs led to strong redistribution of the water flow through the year and primarily to changes in flood parameters. During natural regime conditions the mean volume of the water flow in the flood period (W flood) was equal to 150 km and the mean duration of the flood period (T flood) was 116 days. But after regulation of the water flow these values became 1.5 times less. We did not take into account the period from 1956 to 1961, as this was a period of intensive storage of the reservoirs of the Volga cascade.

The mean date of the flood start was displaced from April 11 in natural conditions, to April 19 in altered conditions. The date of the flood peak and flood ending was displaced from June 4 to May 21 and from July 29 to July 3 respectively. At the Volga delta head the duration of the flood rise decreased from 59 days in natural conditions to 39 days in altered conditions, and the duration of the flood fall decreased from 57 to 40 days respectively. The period with high water flow (from 1978 to 1990) was examined separately. In this period the mean annual volume of the water flow was 269 km^3 /yr. In this period the duration of the flood fall strongly exceeded the duration of the flood rise (48 and 28 days correspondingly) and the shape of the flood wave at the delta top became sharply asymmetric (Gorelits, 1994).

The shallow offshore zone blocked the delta from the sea during the 50 years after the sea level drop in the 1930s (Fig. 4). The terrace of the relict delta coastal line exists near the modern delta sea coast. Its elevations vary from -27 m BS to -28 m BS. The sea level stood on the marine slope of this terrace after the sea level drop in the 1930s to 1990. So this relief feature provided the hydraulic gap between river and the sea. Volga river water flows through this so called "broadcrested submerged weir" into the sea in a thin layer, ranged from 50 m during low flow period to 1.5-2.5 m during flood period with mean velocity 0.2-0.3 m/s (in spite of fish pass canals - the velocity in the canals can reach 1.5-2.0 m/s in flood period). Short-term fluctuations of the sea level (storm surges and wind effected long waves) practically did not penetrate into the delta.

During 50 years the shallow offshore was overgrown by swamp vegetation and converted into the stagnant water body, blocked by the delta. Fish pass canals were constructed through shallow offshore regions for normal generation of valuable fish species in the 1940-1950s. As a water flow began to concentrate in the channels, linked with the fish pass canals at the offshore, other delta channels became degraded. The delta has not been influenced by the 2 m sea water level

increase during the last 15 years. Only in 1991 the water level reached the top elevation of the relict terrace, and backwater penetrated into the delta coastal line.

Since 1991 at the sea level elevation of -27.3 m BS, storm surges with a range more than 1 m at the delta coastal line became to display in the delta. In 1992 at the sea level elevation of -27.0 m BS storm surges above the mentioned range penetrated up to the delta top in spite of the presence of the water distribution dyke. For the present, the sea level rise has its main influence on storm surges and the decrease of distribution of the water flow in the canals.

To draw the surface of water levels under different water discharge in the Volga Delta in modern conditions, without consideration of wind-induced surges, we used data of diurnal level observations of 16 gauge stations (g/s) in the Volga Delta located along branches (Fig. 3) and data on measured and diurnal water discharge in the delta top (Q total) for the period 1978-1993.

To understand quantitative patterns of water level fluctuations in the Volga Delta due to sea level fluctuations, we used similar observed data on river discharge and water level in the Volga Delta since 1942, and during 1881-1941 data on average monthly water discharge in the delta top extrapolated from discharge near Dubovka gauge station (Baidin, 1962) and data on average monthly water discharge in gauge stations operational during that time.

For analysis of patterns of transformation of level surfaces in the delta we used surfaces according to representative total water discharges coming into the delta: maximum flood discharge Q total = 32000 m^3/s (about 1% probability); maximum flood discharge with 50% probability - Q total = 22000 m^3/s and mean annual water discharge with 90% probability Q total = 6000 m^3/s.

Analysis of data of gauge stations in the Volga Delta made by the State Oceanographic Institute showed that during the period of the Caspian Sea level rise from 1978 to 1993 (from -29.0 m to -26.9 m BS) with stable water discharge in the delta top = 18000 m^3/s, water level rise was not recorded even at the delta coastal line. Hence it is possible to use modern equations, Hi = f(Q total), selected for the flush-analog, to calculate maximum levels for the near future.

Nevertheless at the distance of about 30 km from the delta coastal line on the shallow delta offshore (data of MGP the Iskusstvenny island g/s N 16 (Fig. 3), the backwater began to manifest in 1985, and by 1993 it reached about 1 m in each stage of the hydrological regime of the Volga River. Since 1990, the intensity of increase of mean annual level near the g/s N 16 reached about 0.8 of intensity of mean annual sea level rise. The difference of levels between the delta coastal line and the marine slope of the shallow delta offshore in low-water decreased from 1978 to 1993 from 2.5 m to 0.5 m.

In drought period (Q total = 6000 m^3/s) the sea level rise began to manifest itself near the delta coastal line after 1990 and in 1991 reached about 0.2 m. The backwater event is not recorded in other gauge stations. The average sea level rise during the period was 0.35 m.

In order to calculate water levels during the flood peak while sea level is -27.0 m and less, we can use relations between levels in the Volga delta and water river discharge at its head drawn on the base of data of the 1979 (maximum water flow) and of the 1992 (average water flow) (Fig. 5).

With these relations we calculated maximum water levels in the Volga delta. These data were used to draw profiles of water surface for three representative directions of flow in the Volga delta. To draw the same curves for the drought period we used curves Hi=f(Q total) for the period 1991-1992.

Levels and slopes of the water surface in the delta are essentially changing from the flood to draught period. The range of water level fluctuations in years with extremely high flood discharge reaches 5 m in the delta top (0 km), and o.5 m near the delta coastal line (130-160 km). Declivity in low-water period is around 0.01%. in the top and middle part of the delta and 0.015%. in the west and 0.02 %. in the east parts of the low delta. During the flood peak in the top and middle parts of the delta declivity is around 0.03%, in the low delta 0.04%, and in the west and east parts 0.05%-0.06%, respectively.

To make an assessment of possible water level rise in the delta due to sea level rise we used data of gauge stations, based on these data curves Hi = (Q total) for the period 1881-1954 while sea level was between -25.5 - (-28.0) m in g/s N 3 and g/s N 13 (Fig. 3) and for the period 1931-1954 while sea level was between -26.0 - (-28.0) m in g/s NN 2, 9, 10, 11 (Fig. 3).

We found approximate relations of water level rise Hi in g/s N 3 and g/s N 13 with variable value of average sea level H in accordance with the state of the sea level H = -28 m. These relations were obtained from the data during period of unregulated Volga flow, because this period encompasses large ranges of sea level fluctuations and includes years of its higher position. At the same time the curves Hi = f(Q total) for different years are similar in shape due to the relatively stable water regime. During the period of river regulation and intensification of hydrotechnical construction in the Volga delta these curves changed this shape so that identification of the role of the Caspian Sea level fluctuations in their shift up or down was not feasible.

Taking into account future sea level rise we found using these relations that water level rise can reach in high flood about 0.1-0.3 m (sea level H = -26.0 m), 0.5-0.8 m (sea level H = -25.0 m) near the delta coastal line and about 0.1 m (sea level H = -26.0 m), 0.3-0.5 m (sea level H = -25.0 m) near g/s N 3. Water level rise in draught period can reach about 0.7 m (sea level H = -26.0 m), 1.5 m (sea level H = -25.0 m) near the delta coastal line and about 0.2 m (H = -26.0 m), 0.8 m (H = -25.0 m) near g/s N 3. Water level rise near g/s N 2 is adapted as similar to water level rise near g/s N 3.

With account of possible water level rise near g/s N 16 (following relation Hi = f(Hm)) on the delta coastal line, g/s N 13 , g/s N 2 and g/s N 3 by linear extrapolation along profiles of the water level's surfaces of 1991, we made profiles of forecasted level surfaces and, by their extrapolation, also water surfaces of the delta in isolines.

Thus it was found that water level rise in the Volga delta will increase while sea level rise. This increase is highest and most pronounced now in the low zone of the Volga River. With maximum discharges considerable water level rise in the delta manifest itself only under sea level rises above -26.0 m. Water slopes will change strongly in the low delta zone.

Comparison of forecast profiles of water surface with the delta morphology shows that under sea level -26.0 m strips of the coastal zone of the delta will be inundated (even in draught period) up to 5 km in the west and up to 10 km in the east. Under sea level -25.0 m inundation of the coastal zone of the delta will reach 15-20 km in the west and up to 20-25 km in the east.

Characteristics of inundation of the delta in modern conditions may be evaluated using space images. At the flood peak in 1991 when duration of maximum discharges in the delta top Q total >29000 m^3/s reached 25-30 days, actual inundation of the delta was greatest for the last years and was equal to 97% of the east part of the delta and 85% of the west part. The area of inundation of west sub-steppe Ilmeni was 47% of this territory. The difference in percent distribution of inundated areas between 3 parts of the delta at the flood peak reflect their morphology and the structure of their hydrographic net. The low-lying and relatively low-populated east part of the delta is inundated more intensively and evenly than the middle part of the delta, where large settlements, industrial and agricultural enterprises are located. In this zone many land areas are surrounded by levees.

These data were obtained by interpretation of space images made during fall of the flood, when water levels in the delta remained still rather high the flood peak passed, only agricultural lands and settlements surrounded by levees and Bar's hills (natural elongated hills) remained above water. Retreat of waters from flood plain continued during 30-40 days, and near the delta coastal line higher water levels were recorded till late August. The space images show very well the role of levees in the west part of the delta.

It was first attempted to make assessment of the impact of the Caspian Sea level on inundation of the delta. In this purpose we used relations of areas of inundation of different part of the delta

with water level in Astrakhan that were found by Baidin, (1962), based on aerial observations during floods in 1959 and 1961.

The following method was used:

-1. The Volga delta was divided into 7 different zones.

-2. The ratio was found of water level in g/s N 3 Ha (g/s indicates inundation in the upper zone of the delta I and in the west sub-steppe Ilmeni V) to water levels Hi in g/s N 9 (g/s indicates inundation in the west part of the middle zone of the delta II), g/s N 7 (g/s indicates inundation in the east part of the middle zone of the delta III), g/s N 14 (g/s indicates inundation in the low zone IV), g/s N 12 (g/s indicates inundation in the middle zone of the west sub-steppe Ilmeni VI), g/s N 13 (g/s indicates inundation in the low zone of the west sub-steppe Ilmeni VII) (Fig. 3).

-3. For each identified zone of the delta (I-VIII) with ratios Hi = f(Ha) we obtained relations of the inundated areas (% from the area of each considered zone) with water levels at the same g/s - Fi,% = (Hi).

-4. Under different discharges and sea levels we rebuilt the level's surfaces in different part of the delta, including levels Hi in points according to the g/s used for assessment of inundation.

-5. For these levels Hi using relations Fi,% = f(Hi) areas of inundation in the Volga delta Fi,% were calculated.

Analysis showed that under water discharges in summer-fall season Q total = 6000 m^3/s and sea levels from -27.0 - (-25.0) m only the low part of the delta is inundated (5% under sea level Hm = -27.0 m and 20% Hm = -25.0 m). Inundation of the low part of west sub-steppe Ilmeni increases very little: under sea level rise from -27.0 m to -26.0 m from 0 to 14% and strongly increases till 100% under sea level -25.0 m. At this sea level partial inundation of the middle part of the west sub-steppe Ilmeni starts (up to 70%).

Under maximum flood water discharges, Q total = 22000 m^3/s (50% probability) and sea level -27.0 m all zones of the delta are inundated from 30% to 73%, and the upper zone of the delta is inundated in highest degree; in the middle zone the east part is mostly inundated (Table 3). While sea level rises to -26.0 m inundation of the low zone and the east part of the middle zone and of the west sub-steppe ilmeni increases up to 100%, inundation of other part of the delta is not inevitable. Under sea level -25.0 m the whole territory of the delta will be inundated excluding the specially dammed areas in the regions of large settlements and economic enterprises, and the west sub-steppe ilmeni with 50% inundation of the upper and middle parts.

Under maximum flood discharges, Q total = 32000 m^3/s (1% of probability) practically the whole delta, except specially protected territories and Bar's hills, is inundated by any level of the Caspian Sea.

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Table 1. Multi-year changes in caspian water balance components (by R.E. Nikonova, SOI, Moscow)

Years	River discharge km^3	Ground water km^3	Precipi-tation km^3	Evapo-ration km^3	Flow into Kara-Bogaz km^3	Reulting balance cm/km^3
1990-1929	332.4	5.5	69.8	389.4	21.8	-1.0/-3.5
1930-1941	268.6	5.5	72.9	394.8	12.4	-15.4/-60.2
1942-1969	285.4	4.0	74.1	356.3	10.6	-0.9/-3.4
1970-1977	240.5	4.0	87.6	374.9	7.1	-13.8/-49.9
1978-1933	308.6	4.0	84.8	348.0	2.4	13.6/51.2

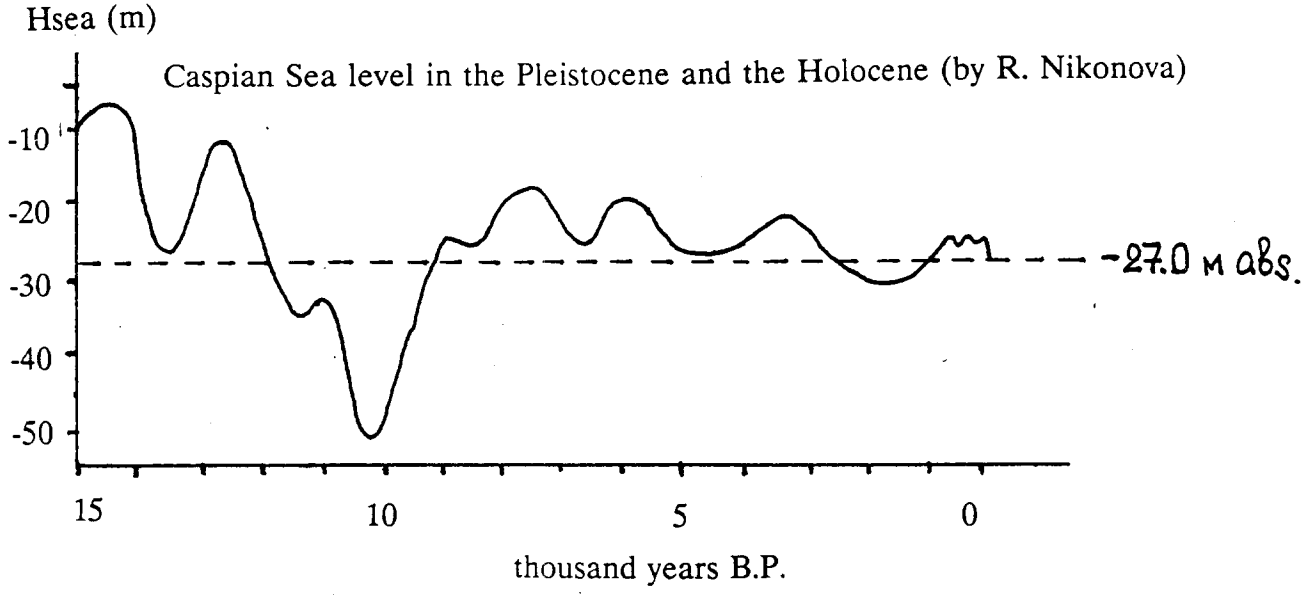
Table. 2. Volume and duration of the water flow in the flood period in the Volga delta head.

Periods	Annual volume of the water flow	Volume of the flood water flow	Duration of the food period, T days	Duration of the food period, T days	Duration of the food period, T days
	km^3	W flood, km^3	rise	fall	whole period
1942-1955	252	150	60	56	116
1962-1970	235	98	40	40	80
1971-1977	198	68	31	31	62
1978-1993	270	99	28	49	77

Table 3. Different Caspian sea levels (Hsea) and the areas of inundation of the Volga delta (Fi) (% of the area of each considered zone)

Qtotal (delta head)	Delta zones	Caspian sea levels (Hsea, m abs.)	Caspian sea levels (Hsea, m abs.)	Caspian sea levels (Hsea, m abs.)
Q = 6000 m^3/s		%	%	%
	I Upper zone	0.0	0.0	0.0
	II Middle west	0.0	0.0	0.0
	III Middle east	0.0	0.0	0.0
	IV Low zone	5.0	10.0	20.0
	V Upper Ilmeni	0.0	0.0	0.0
	VI Middle Ilmeni	0.0	0.0	7.0
	VII Low Ilmeni	0.0	15.0	100.0
Q = 22000 m^3/s				
	I Upper zone	73.0	80.0	100.0
	II Middle west	32.0	40.0	100.0
	III Middle east	50.0	100.0	100.0
	IV Low zone	50.0	100.0	100.0
	V Upper Ilmeni	42.0	47.0	65.0
	VI Middle Ilmeni	45.0	57.0	80.0
	VII Low Ilmeni	30.0	100.0	100.0
Q = 32000 m^3/s				
	I Upper zone	100.0	100.0	100.0
	II Middle west	100.0	100.0	100.0
	III Middle east	100.0	100.0	100.0
	IV Low zone	100.0	100.0	100.0
	V Upper Ilmeni	100.0	100.0	100.0
	VI Middle Ilmeni	100.0	100.0	100.0
	VII Low Ilmeni	100.0	100.0	100.0

Fig. 1. Above: Caspian Sea level in the Pleistocene and the Holocene (by R. Nikonova); Below: Caspian Sea level in the X-XX centuries.



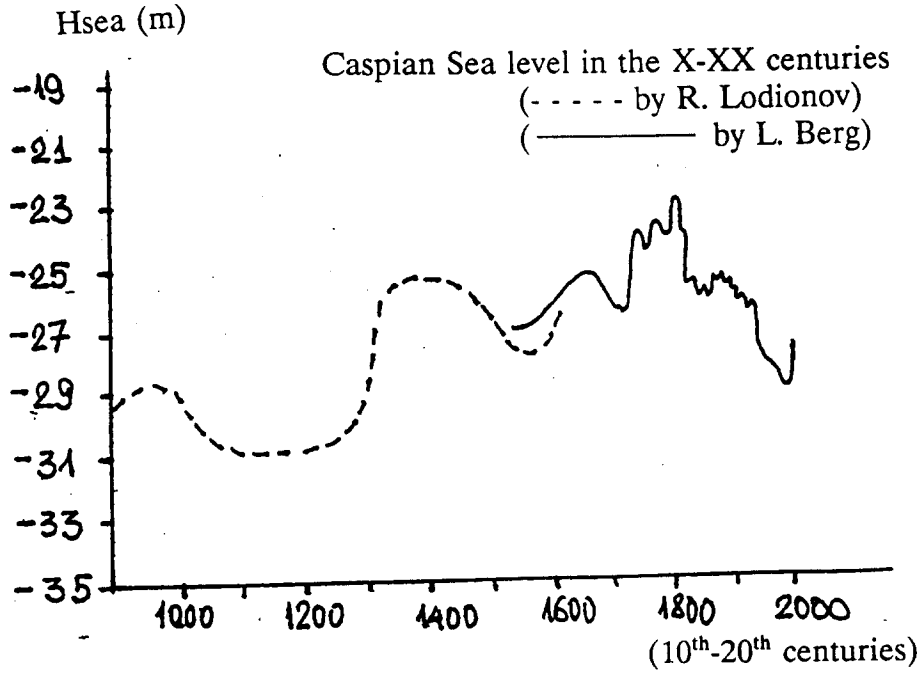
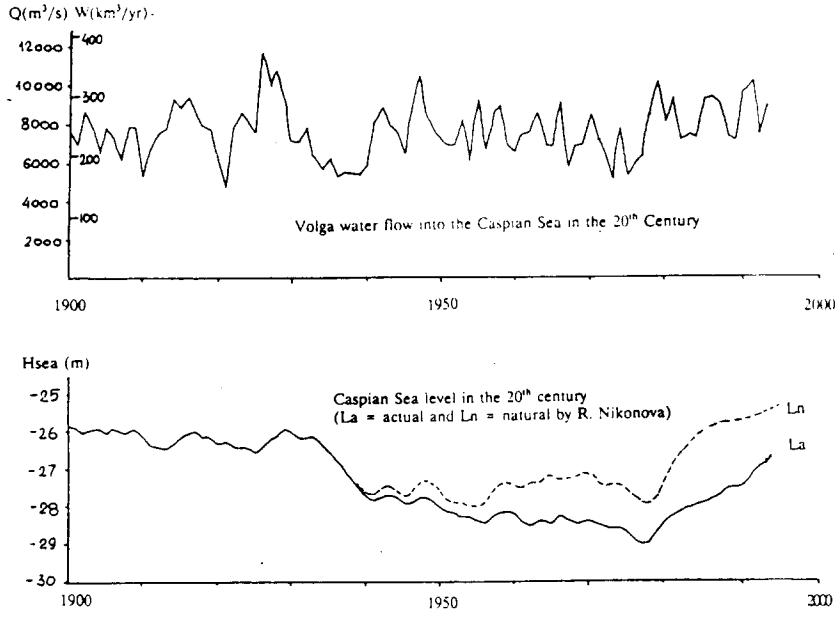


Fig. 2. Above: Volga water flow into the Caspian Sea in the 20th Century; Below: Caspian Sea level in the 20th century (La = actual and Ln = natural by R. Nikonova).



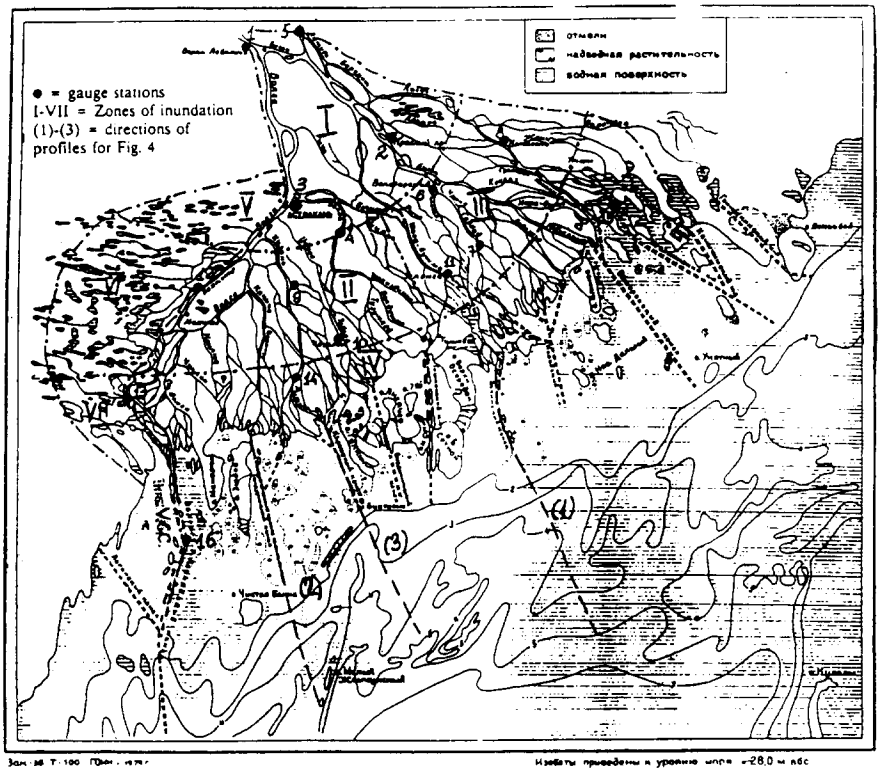
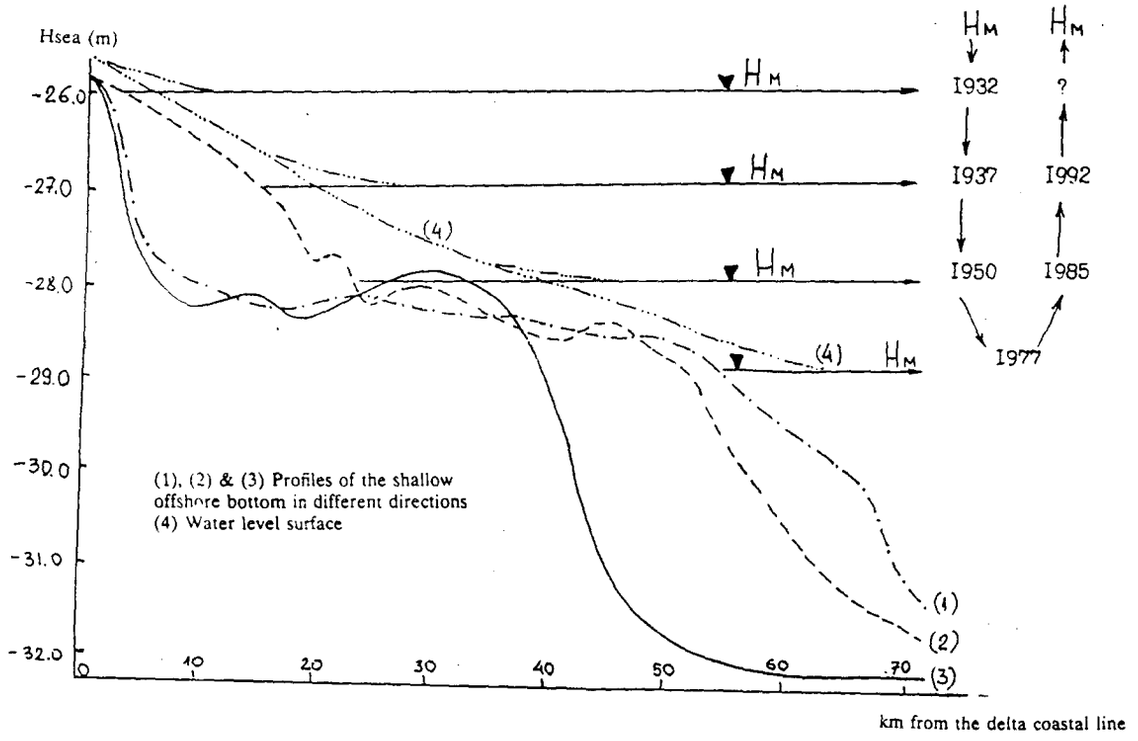


Fig. 3. Map with gauge stations. • = gauge stations; I-VII = Zones of inundation; (1)-(3) = directions of profiles for Fig. 4.

Fig. 4. Profiles of the shallow offshore bottom in different directions and the water level surface.



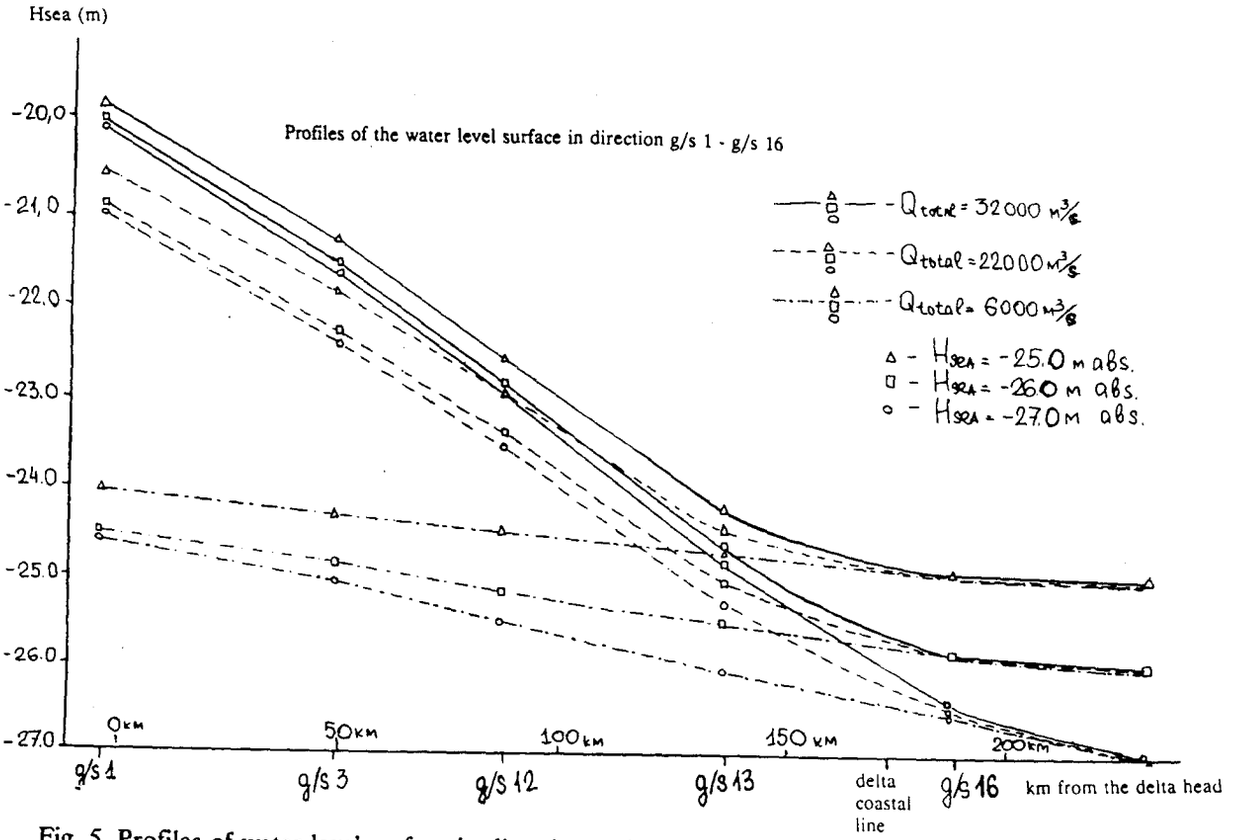


Fig. 5. Profiles of water level surface in directions g/s 1 - g/s 16.

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POSSIBLE FUTURE COASTAL EVOLUTION OF THE NORTH BLACK SEA AND THE SEA OF AZOV COASTS UNDER GREENHOUSE-INDUCED SEA-LEVEL RISE: QUANTITATIVE ESTIMATES OF SHORELINE RETREAT AND RISK ASSESSMENT ANALYSIS

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KEYWORDS: Sea-level rise; coastal modifications; shoreline retreat; natural vulnerability; economic losses; response strategies.

ABSTRACT

A comprehensive methodology for the prediction of shoreline retreat under the sea-level rise, according to different scenarios is proposed. The methodology combines the Bruun approach, an inclination-dependent and a rate-dependent model of coastal responses to sea-level changes. An economic risk estimate is expressed as a sum of property value and values of natural and cultural resources, in the zone subject to danger due to shoreline retreat or temporary flooding. An assessment of anticipated losses of natural resources includes estimation of natural vulnerability to sea-level rise and value of resources on a per unit area basis. A medium-scaled map for the eastern Sea of Azov, in the borders of Russia, exemplifies the above approach.

INTRODUCTION

Accumulation of carbon dioxide, methane, chloro-fluorocarbons, and some other "greenhouse gases" in the Earth's atmosphere is amongst the most important, inevitable, consequences of man's activities. It results in an increase of air temperatures, melting of continental glaciers, thermal expansion of ocean water, changes in precipitation and water supplies in continental areas. All of these processes tend to replenish the ocean and to raise global sea level.

Estimates of global sea-level rise in the next century range from 0.1-0.2 meters to about 4.0 meters and there is no reliable corroboration to favour one estimate over another. The Intergovernmental Panel on Climate Change agreed unanimously on the 0.31-1.10 m rise in global sea level between 1990 and 2100; the best estimate is thought to be 0.66 m (Houghton et al., 1990). Global sea-level rise over one meter during the next century is, therefore, not likely, but cannot be totally excluded as yet. In any case, a strong possibility exists for the significant acceleration of sea-level rise in the near future in comparison with the 0.10-0.15 m rise in global mean sea level during the last century (Klige, 1990; Emery and Aubrey, 1991; Gornitz, 1993).

Moreover, even a rise in a global sea level of 0.1-0.5 m would have substantial negative impacts on a worldwide scale. Storm surges would increase in their frequency above critical inundation levels and saltwater intrusions to estuaries and coastal aquifers would cause problems in water supply and coastal ecosystem survival. Passive inundation would occur only at a few low-lying coastal segments, e.g. in small semi-enclosed bays and along very gentle-sloping coasts where wave and tidal energy is much reduced at the coastline. Modification, landward retreat, and general erosion of coastal morphological features (cliffs, barriers, bars, lagoons, marshes, mangroves, coral reefs, etc.) would become the most expressive and significant impact of sea-level rise.

Coastal zones will exert the substantial economic and environmental damage due to shoreline retreat and changes in the environmental conditions at the preserved part of land areas due to underground flooding and other related processes. In addition to the direct loss of property, many agricultural areas and industrial

facilities will need reconstruction or change of their specialization.

PREDICTION OF COASTAL MORPHOLOGICAL RESPONSES

Mapping of coastal inundation for different sea-level rise scenarios remains the most popular activity in this field. There is a positive experience of such a kind for the United States (Barth and Titus, 1984; Giese and Aubrey, 1987; Pilkey and Davis, 1987; Titus, 1988), Canada (Eddington and Andrews, 1985) and certain areas in Western Europe (Tooley, 1989; Tooley and Jelgersma, 1992). Some of these studies include corrections for tectonic deformations and estimates of increase in storm surge elevations due to sea-level rise.

Nevertheless, passive coastal inundation will occur only on few coasts: in small semi-enclosed bays and on very gentle-sloping coasts, i.e. where wave energy does not reach the shoreline. In most cases an active reformation of "land edge" will be inevitable. During water level rise, shoreward slopes of coastal accumulative features, usually steeper than nearshore bottom surface, come into the wave-active zone. The steeper the surface, the higher is the wave energy to erode a shoreface. Sediments from the shoreface are cast to the nearshore bottom slope thus causing a shoreline and an accumulative feature as a whole to move inland, onto the shoreface or the lagoon behind it. The above model, put forward by Vsevolod Zenkovich and his successors, was applied to different coastal areas (Zenkovich, 1958, 1967; Leontyev, 1960; Kaplin, 1973; etc.). American and European scholars involved into related problems denominate the similar model as the Bruun Rule (Schwartz, 1967) after the pioneering studies of Per Bruun (1962). The Bruun Rule postulates the equality of sediments eroded on a coast during sea-level rise to their deposition in the nearshore, as well as preservation of the transverse profile shape. According to this rule, a shoreline retreat R is proportional to the change U of relative sea level and width, B, of wave-induced bottom zone, and inversely proportional to its depth, D:

$$R = U*B/D = U*\tan A \quad (1)$$

where R = surface inclination of an underwater coastal slope.

However, this simple model adequately describes coastal evolution only for the narrow boundary conditions:

(a) slow sea-level rise in comparison with shoreline retreat, i.e. R >> U;

(b) general availability of sediments to maintain an equilibrium profile;

(c) exclusively shoreline-transverse sediment movement by waves in a seaward direction;

(d) existence of a seaward limit of sediment movement by waves or any other factor ("lower limit of an underwater coastal slope", or "wave base"). Therefore, determination of the "wave base" becomes an important problem and depends upon wave parameters. According to different authors, the "wave base" varies from 1.5 to 3.5 times the height of 5% of the waves beyond the breaking zone (Zenkovich and Popov, 1980; Bruun, 1988). Generally, over 90% of longshore sediment transport occurs above this "wave base" (Bruun, 1988).

To account for the possible variety of parameters mentioned in (b)-(d), as well as for other processes involved in reformation of the coastal zone, different modifications of the BR were developed (see Selivanov, 1993 for a review).

Field studies reveal that under special conditions coastal evolution pattern can differ significantly from the above model. The Caspian Sea serves as an excellent "natural laboratory" for study of sea-level rise impacts: the water level raised at a rate over 10 cm year during the last two decades (Kaplin, 1989).

Investigations in this region show that during sea-level rise a significant portion of sediments can be cast ashore and overwashed inland to the landward slope of an accumulative feature. Other portions can be drawn into a longshore current or moved down the bottom slope to the depths where waves do not act. Field observations demonstrate not only strong dependence of shoreline retreat values on nearshore slope, as was postulated by the Bruun Rule, but differences in the very patterns of coastal evolution according to the nearshore surface slope (Kaplin, 1989; Kaplin and Selivanov, in press) (Fig. 1). It is

possibly the case because nearshore slope values determine not only the position of the wave-breaking zone, but also the character of the breaking process.

Moreover, an assumption of equilibrium pattern for all coastal modifications limits an application of the Bruun Rule most severely. Possible sea-level rise in the next century can reach significant rates and turn coastal evolution to essentially disequilibrium patterns. Shoreline migration would lag behind sea-level rise. SCOR Working Group members (1991) believe the time lag to be the primary reason for the fact that single storm-induced shoreline migration values are usually 3 to 6 times lower than those predicted by the Bruun Rule.

Essential problems arise if one tries to predict shoreline migrations for erosional coasts with cliffs. Extrapolation of historical trends usually involved into the studies in this field (Barth and Titus, 1984; Leatherman, 1989; etc.) does not meet possible shift in patterns of future coastal evolution due to the acceleration of sea-level rise. Our predictive methodology of sea coasts under the accelerated sea-level rise allows for the morphology of backshore and nearshore zones, their slopes, supplies of beach-forming material in the coastal zone itself and from neighbouring rivers, lithology of sea cliffs, etc. (Kaplin et al., 1993; Selivanov, 1993). As a first step, we attribute future evolution of each coastal segment to one (or more) "primary" coastal process: passive inundation, reformation of accumulative coastal features, and retreat of erosional scarps (sea cliffs). Deltaic, meso- and macrotidal, glacial and some other coastal types were attributed to the special evolutionary types.

Further separation of depositional coasts into different future evolutionary patterns was based upon the natural analog method primarily derived from the Caspian Sea coastal response to the recent transgression.

In order to estimate relative sea-level change U where intensive tectonic movements occur, a recent vertical deformation trend p obtained from tide-gauge records should be incorporated into the global sea-level rise value A:

$$U = A + p*Dt \quad (2),$$

where Dt is a prediction time interval in years. In the vast majority of the studied coasts, the tectonic correction is less than 15-20 percent of global sea-level change, but in the areas of intensive subsidence, e.g. in the south-eastern corner of the Sea of Azov, p exceeds 1 cm/year, thus doubling U.

QUANTIFICATION OF SHORELINE MOVEMENT MODELS

A complex methodology has been proposed to estimate shoreline migration induced by sea-level rise in case of depositional coasts. The empirical "Caspian-based" slope-dependent model (Fig. 1) can be used as a first approximation.

The very gentle coasts (tan a = 0.0005 or lower) will possibly exert passive inundation (Fig. 1a). To evaluate an intensity of this process one can take necessary data on coastal morphology from topographic maps, coastal inventories and sailing directions. Mean annual position of shoreline should be used as a primary parameter. Lacking reliable predictions of storm surge elevations under rising sea level, we could not take their changes into account.

Shoreline retreat on relatively gentle sloping coasts (tan a approx. 0.001) with submerged coastal ridges (Fig. 1b) may be evaluated using the Bruun rule if one includes parameters of a seaward slope of the ridge into the equation (Dubois, 1977). It is worth noting, however, that in several cases of excessive sedimentary supply, submerged ridges may emerge above the water surface and behave further as typical coastal ridges (Kaplin and Selivanov, in press). Steeper coasts (tan a approx. 0.005-0.01) are usually characterized by coastal dunes (Fig. 1c) or barrier depositional features that separate lagoons (Fig. 1d). Sedimentary exchange between shoreface and backshore can be indirectly taken into account if a height e of coastal dunes is included into the traditional Bruun equation (Weggel, 1979):

$$R = U*B/(e+D) \quad (3).$$

The so-called "generalized" Bruun Rule (Dean and Maurmeyer, 1983) allows us to account for sediment washover to the lagoon:

$$R = U*(B+W+Bl)/[(D+h)-(Dl+hl) \quad (4),$$

where h - height of a beach berm, Bl, Dl, and hl - parameters of the landward (lagoon) slope of the barrier island, and W - its width.

In the case of relatively steep nearshore (tan a more than 0.01), and an absence of emerged and submerged barrier coastal features (Fig. 1e), the Bruun Rule itself can be used. But in every case, from b to e, the principal limitations of the Bruun Rule and all its modifications should be borne in mind. Where appropriate information is available, a portion S of suspended material (less than 0.005 mm) usually carried out to an open sea (Hands, 1983) and a quantity L of material brought/carried away by longshore currents shoals should also be evaluated. Then a tentative equation for the retreat of accumulative shoreline comes to the following shape:

$$R = U*B/D*(1-S) +/-L \quad (5).$$

The most natural way to predictive estimates of shoreline migration on erosional coasts is to use one or another empirical equation. It becomes commonplace to analyze shoreline retreat on erosional coasts as a function of the rate of sea-level rise. Linear character of this function is a usual assumption in prediction surveys (Barth and Titus, 1984; Kay, 1990 etc.). However, the statistical analysis proved this assumption only for erosional coasts composed of loose sediments and unconsolidated rocks, where only poor beaches exist at the foot (Shuisky and Vykhovanetz, 1989). A more adequate model of sea cliff retreat and bench lowering based on hydrodynamic analysis of unconsolidated rock destruction was put forward by Nicolay Yesin and his colleagues (Yesin et al., 1980; Yesin and Kuklev, 1992). The model allows for wave parameters and directions, the morphology of the nearshore, rock strength, cliff height, bottom sediment erosion strength, and sedimentary budget. The model is represented by a system of second-order differential equations. It is assumed that the shallow nearshore maintains its straight-line profile, whereas its slope changes. If sea level rises at a constant rate u, after an unlimited long time, a model has an asymptotic simplification for cliff retreat rate v(x):

$$v(x) = u*(\tan a) \quad (6),$$

where a is a slope of the nearshore breaking zone. One can easily see that Eq. 6 is similar to the Bruun Rule, thus confirming its reliability for equilibrium processes. Eq. 6 meets well the instrumental time series on erosional coast retreat for the Sea of Azov eastern coast. Moreover, the rate of cliff retreat, both for condensed and weak rocks, depends upon the volume of sediments to be eroded from each meter of the cliff width, i.e on its elevation H (Yesin, 1980).

The simple model (6) remains valid only for the conditions of slow uniform sea-level rise when the equilibrium cliff retreat process can be maintained. One of the necessary, but not sufficient, premises for this being, the relative weakness of sediments composing the cliff. The last value should be sufficient to allow the bench to reform, adapting the sea-level rise. It depends upon the rate of rise u and the rate of bench lowering v(y) that can be obtained from instrumental data, where available, or from theoretical estimate of erosional strength for certain rock types.

Bearing in mind the above-mentioned regularities, we have put forward the step-by-step scheme for evaluation of shoreline retreat on erosional coasts. Where u exceeds v(y), shoreline retreat will maintain the present rate, or even decelerate, because erosional processes will not keep pace with the sea-level rise. During the possible future sea-level rise at a rate up to 1-2 cm per year this evolutionary pattern will become widespread on erosional coasts composed of crystalline and metamorphic rocks, conglomerates, schists, etc. Where u is lower than v, retreat of erosional shoreline can be calculated according to Eq. 6 with maximal observed rate of this process for certain type of rocks used as an upper limit.

The empirical coefficient K1 should be also included in several cases to allow for slope processes. The value of the coefficient K2 depends upon morphology, lithology and position of the cliff to dominant waves. Moreover, one can consider also for the longshore sedimentary movement L. The final equation for the horizontal retreat C of sea cliff in equilibrium conditions becomes the following:

$$C = K1*K2*u*dt/H*(\tan a) +/- L \quad (7).$$

A variety of factors that interact in coastal response to sea-level rise makes us calculate a

shoreline retreat as in any given coastal segment as a probabilistic value. It can be expressed in the following form:

$$S = [s + k(s)]^*t, \quad (8)$$

where s - mean predictive rate of shoreline retreat, (s) - its standard deviation, K - reliability coefficient of the forecast, which is a function of reliability of prediction in percents.

GENETIC SERIES OF COASTAL RESPONSES UNDER VARIOUS RATES OF SEA-LEVEL RISE AND DIFFERING SEDIMENTARY SUPPLY

A rate of shoreline movement depends strongly upon a pattern of shoreline response. In several cases, a sea-level rise may result in a seaward shoreline movement and vice versa. The sedimentary budget of a coastal segment and a rate of sea-level change serve as primary factors influencing the patterns of coastal response.

In general, the faster the sea-level rise, the higher the possibility of drowning or destruction of the coastal depositional body. The faster the sea-level fall, the more probable is the preservation of depositional bodies above the retreating sea, e.g. in the form of beach ridges and coastal dunes. The sediment budget of a coastal zone serves as another primary factor governing coastal responses. Under an excessive sediment supply, a shoreline may advance to sea even during the sea-level rise. This phenomenon called depositional regression is common on many sea coasts (Dolotov, 1992). In the conditions of intensive lateral sediment movement a coast may react differently to the successive periods of sea-level rise (Selivanov, in press).

The present author analyzed sedimentary sequences on several sea coasts of Russia as well as data of direct observations of coastal changes under the fast water-level changes on the Caspian Sea. These studies resulted in the construction of two genetic series of coastal evolutionary patterns under the accelerating sea-level rise for the conditions of substantially excessive and insufficient sedimentary supply, respectively (Selivanov, in press) (Fig. 2). Under excessive sedimentary supply on a primary graded coastal profile (Fig. 2A), slow sea-level rise causes formation of a beach ridge and, in extreme cases, depositional regression. A moderately accelerating sea-level rise usually results in a landward translation of a coastal depositional body by overwash processes. No significant transformation of coastal morphology occurs. Faster sea-level rise results in a transformation of a depositional body, namely increase of its elevation, steepening of a landward slope, etc. An extreme acceleration causes drowning of a coastal depositional body by the rising sea level and formation of an overlapping sedimentary sequence.

Under insufficient sedimentary supply (Fig. 2B), mobilization of existing scarce sediments on a primary graded coastal slope results in formation of a poorly expressed depositional body. With an accelerating sea-level rise, this body moves landward in a translational manner and undergoes erosion of its seaward slope. The last process causes partial or total destruction of a coastal body under the very rapid sea-level rise. The extreme acceleration may bring in-place drowning of a depositional body and overstepping of a shoreline. Grading of the coastal profile is also possible.

The patterns distinguished by conditions of excessive sedimentary supply (Fig. 2A) may be interpreted in the terms of quasi-equilibrium evolution under the relatively slow sea-level rise (2). With the accelerating sea-level rise, possible intensity of coastal reformation becomes insufficient to keep pace with the rising sea level (3). Disequilibrium evolution becomes total under extremely fast sea-level rise (4). Following the terminology proposed for evolution of coral reefs under the sea-level rise at various rates (Neumann and Macintyre, 1985, Spencer, 1993), the response patterns (2-4) for the conditions of excessive sedimentary supply (Fig. 2A) can be termed as keep-up, catch-up and give-up respectively.

PRINCIPLES OF THE RISK ASSESSMENT ANALYSIS

During the last decade, a number of large-scale studies directed at the risk and damage assessments for sea coasts was undertaken. The methodology of comprehensive assessment of coastal hazards from sea-level rise elaborated by

the United States Geological Survey, is based upon the five-graded scale for a number of parameters that may characterize coastal vulnerability to sea-level rise (Gornitz, 1991). Parameters considered include observed coastal recession rates, morphology and geological structure of the backshore and nearshore zones, intensities of waves and tides, etc.

The UN Food Organization put forward the methodology for classification of coastal lowlands in the developing world according to their vulnerability to the possible sea-level rise (Jelgersma et al., 1993). This methodology is also based on a sequence of environmental parameters expressed in a graded scale.

Coastal Zone Management Subgroup of the Intergovernmental Panel on Climate Change (IPCC) implemented the global assessment of vulnerability to the possible sea-level rise on a country-to-country basis (IPCC Coastal Zone Management Subgroup, 1992). They were the first to consistently assess the physical changes imposed by sea-level rise and the related socio-economic and ecological impacts. IPCC distinguished the socio-economic values at loss, at risk, and at change, and used the per unit area capital values and population numbers as socio-economic parameters. Areas of environmentally valuable lands characterized direct ecological losses and the numbers of cultural and historical sites represented the respective losses.

Anticipating damage in the specific coastal segments depends not only upon the value of property, both economic and cultural, in the zones subject to erosion, shoreline retreat, or underground flooding, but also upon the natural peculiarities of the environment. Other conditions being equal, the more sensitive landscapes will exert the greater damage. All these facts make the risk assessment from sea-level rise at a specific coastal segment an extremely complicated but important objective. The present author, in collaboration with Professor Pavel Kaplin, has concentrated on the assessment of environmental vulnerability to the sea-level rise, as well as on the estimation of indirect economic losses. The concept of various types of resources (environmental, economic, cultural) has been applied for these studies.

Direct consequences of shoreline retreat owing to sea-level rise include the loss of existing property and the damage to natural and cultural resources. Under these assumptions, an economic risk estimate, R, for any coastal segment can be expressed as a sum of property value, P, and value of natural, N, and cultural, C, resources in the zone subject to danger due to shoreline retreat, temporary inundation, or underground flooding. According to the IPCC Coastal Zone Management Subgroup (1992), values at risk can be expressed as the product of the specific value in a certain risk zone and a probability of a flooding event, the values at risk being summed up over the risk zone.

However, this approach requires the data on various parameters of property, natural and cultural resources. In carrying out the preliminary small- and medium-scale studies, especially in developing or undeveloped coastal areas, we encountered a dramatic lack of knowledge of these parameters. Moreover, even if these parameters are available, a routine summing up of property values and resource cost estimates becomes necessary. Therefore, another approach based on existing and easily obtained integrated characteristics of economy and the environment is an urgent need.

The promising methodology should allow for resource values and for natural vulnerability of coastal segments. Therefore, a general expression for the integrated risk value, A, in the specific coastal segment under the possible accelerated sea-level rise takes the following form:

$$A = V*\mathrm{sum}(Rn), \quad (9)$$

where V - natural vulnerability index; sum(Rn) - sum of all resource values Rn, including various kinds of natural, economic, and cultural resources.

To estimate the natural vulnerability index, V, for any coastal segment, it is necessary to explicitly define morphological vulnerability, V1, and ecosystem vulnerability, V2. Therefore, a natural vulnerability index may be presented as following:

$$V = V1*V2 \quad (10).$$

Morphology and surface sediments or rocks form the necessary basis of every natural complex,

including coastal one. Therefore, vulnerability index for the "lithogenic basement" of the specific coastal segment may, as a first approximation, serve as an integrated parameter for estimation of risk vulnerability index of this coastal segment.

Most of sea coasts have exerted a series of evolutionary stages since the postglacial transgression and, in recent times, come to the stage of maturity, which is characterized by the general dynamic equilibrium of the coastal morphology and its maintenance during the slow landward translation of coastal profiles (Zenkovich and Popov, 1980; Carter, 1988). Under these conditions, morphological vulnerability of a coastal segment may be assumed to be proportional to the predicted value of shoreline retreat until the specific time in the future due to sea-level rise and self-development processes of this segment.

In order to come to the integrated index of morphological vulnerability, we have constructed the graded scale of shoreline retreat values for each principal type of coastal evolution. According to the predicted values of shoreline retreat, extremely vulnerable, vulnerable, relatively stable, and stable coasts may be distinguished.

Meanwhile, natural vulnerability of a coastal segment depends also upon the vulnerability of the ecosystems that exist in this segment. Owing to the primary attention to sea-level rise and coastal retreat processes, I refer here only to land ecosystems. Based on the analysis of existing field data and on our own observations, we came to the four graded scale of vulnerability of ecosystems that exist on sea coasts of Russia to various kinds of external forcing, presumably to sea-level and climate changes:

(1) Extremely vulnerable ecosystems;
(2) Vulnerable ecosystems;
(3) Relatively stable ecosystems;
(4) Stable ecosystems.

For example, ecosystems of north forest-tundra and tundra zones developed on cryogenic grounds at the coasts of the Barents, Kara, Laptev, East Siberian and Chuckchi seas and semi-arid ecosystems of the Russian coast of the Caspian Sea have been regarded as extremely vulnerable, whereas ecosystems of boreal coniferous forests developed on hard rocks at the White Sea may be regarded as stable or relatively stable.

Resources at risk in the specific coastal segment are equal to the gross resource value in the coastal strip of width S in Eq. 8. Estimation of the per unit area resource parameters is preferable in our studies. Two principal types of resources are considered by our methodology (natural and economic):

$$R = Re + Rn \quad (11).$$

The problem of evaluation of cultural resources still awaits a solution.

Natural resources, Rn, include land, water, and biological resources, mineral wealth, etc. For a number of coastal segments in Russia, natural resources may be evaluated by the National Codification of Natural Resources, which is in preparation at the Ministry for Environmental Management of Russia and other governmental departments. The graded scale seems to be convenient for our reconnaissance surveys. The problem is that natural resources at risk include not only their possible loss under the shoreline retreat but also the decrease in quality of the coastal environment due to underground flooding, salinization etc. These processes should also be quantified in terms of the possible loss of natural resources.

The problem of estimation of economic resources in absolute values meets substantial difficulties owing to the absence of general methodologies for regional economic analysis in current Russia. However, some preliminary steps can be formulated as following.

Gross value of economic resources at risk, Re, may be presented as a sum of several components:

$$Re = W + G + C, \quad (12)$$

where W - national wealth, G - national income , and C - compensation costs.

National wealth, W, is the material and pecuniary values of residents of any territory produced by the labour activity of residents. National wealth is concentrated in populated areas and in infrastructural objects, and consists of industrial and non-industrial funds and private property of residents.

Industrial component of the national wealth, as well as labour activity of residents, gives rise to the national income, G. The loss of some part of the national income due to termination of any industrial activity results in the decrease of the gross national product. Therefore, an estimation of the national income at risk may be proceeded by the comparison of the gross national product before and after the sea-level rise and resulting shoreline retreat, underground flooding, salinization, etc. However, this approach cannot account for the inevitable decrease in consumption of energy and raw materials and, therefore, usually overestimates the possible losses.

The preferable approach to the estimation of national income at risk allows its separation into two main components by their use in investments and in consumption (presumably private consumption) respectively. Loss of job, which needs to be compensated either by creation of new working places or by payment of unemployment benefits, should be added to the value of national income at risk.

Compensation costs, C, mean investments in the restoration after the sea-level rise of the social and economic territorial system, which would be able to supply the living standards not lower than before the event. In other words, compensation costs are the cost of dismantling, transportation, and repetitive mounting of the national wealth, presumably of industrial funds and private property. These costs, especially in case of huge industrial objects, may exceed the national wealth itself manifold.

In the small-scale surveys, a per unit area population number and value of economic production may be used as integrated indices of economic resources.

RISK ASSESSMENT ANALYSIS FOR THE NORTH BLACK SEA AND THE SEA OF AZOV

Our methodology served as a basis in compiling of the first small-scale (1: 4,000,000) map of future coastal evolution and risk assessment for the former USSR (Kaplin et al., 1993). Coasts of the north Black Sea and the Sea of Azov have been selected as case study areas. Being one of the most densely populated and high developed coastal areas in the former USSR, the north Black Sea and the Sea of Azov coasts would be significantly damaged by sea-level rise. Patterns and intensities of possible future changes on these coasts gain primary attention of scholars, decision-makers, and lay public. Medium (1 m) and extreme (2 m) scenarios of the global sea-level rise until 2100 were selected (Fig. 3).

Erosion and destruction of coastal depositional bodies, namely liman barriers on the north-western Black Sea coast, tombolos and spits on the Sea of Azov, should be anticipated as major processes under the future sea-level rise. Under the medium scenario one can expect partial destruction of most of these accumulative bodies, whereas the high scenario anticipates their total disappearance. Exceptions would be scanty. The Kuban River delta, Perekop Isthmus and some other regions would exert catastrophic inundation potentiated by intensive tectonic subsidence. General acceleration in recession of coastal erosional scarps composed of losses and sands could possibly become disastrous near the cities of Odessa, Mariupol, and Primorsko-Akhtarsk, where shoreline recession would be aggravated by landsliding and rockfalling. The least pronounced changes are anticipated for the south Crimean coasts.

Coastal evolution under the possible sea-level rise would have unfavourable impacts on the economy of coastal communities. The effects would be the worst for urban, recreational and infrastructural development on erosional and landsliding coasts, as well as accumulative barriers and spits. Railways, highways, seaports, and fish-processing facilities on liman barriers, fish breeding and freshwater storage in limans, rice cultivation in deltas would be the primary items to suffer sea-level rise.

Existing coastal protective structures, represented primarily by sea-walls, revetments, groynes, and rarely by boulder levees, would become ineffective under either scenario of sea-level rise. If the medium scenario is implemented, artificial beaches would become cost-effective for many valuable coastal segments. Under the high

scenario, most of the coasts should be "given up" to sea, new construction of long-term structures being prohibited and maintenance of existing ones abandoned.

The coastline of the Sea of Azov in the borders of Russia, 560 km in length, represents one of the areas most vulnerable to the possible rise in the global mean sea level. Major premises for the dramatic impact of sea-level rise on these coasts include:

(1) The prevalence of land subsidence and, therefore, higher regional estimates of the relative sea-level rise in comparison to the globally averaged values;

(2) an intensive retreat of the prevailing loess coastal scarps, substantially aggravated by landsliding processes, and degradation of depositional coastal bodies composed presumably of detrital sands;

(3) high economic development of coastal zones with intensive crop- and fruit-growing on rich black earth soils, as well as cultivation of white beet, corn, and sunflower, and food industry, including fish processing, and light industry as a principal economic strategies; and

(4) relatively high sensitivity of natural steppe and meadow ecosystems and even higher sensitivity of anthropogenic ecosystems to soil moisture content and, therefore, to the possible underground flooding. Sand extraction from beaches and other depositional coastal bodies contribute much to the increase of coastal vulnerability.

Fig. 4 demonstrates clearly that high losses are anticipated in the studied region in the case of the accelerated sea-level rise. Mean per unit population number in the coastal zone is 64 persons per sq. km, whereas the highest value is over 150. Shoreline retreat during the next 100 years may be as high as 50-100 m in some segments of erosional coasts, over 300 m on depositional coasts, and up to 1.5 km on low-lying inundated coasts. Therefore, 50 to 200 inhabitants should be resettled from each kilometre of the shoreline length in the countryside and over 1000 - in towns and large villages, such as Eisk, Azov, Novomargaritovo, Staroshcherbinovskaya, etc. At least threefold numbers characterize those of inhabitants whose quality of life would be decreased by the secondary impacts of sea-level rise (underground flooding, higher sick and unemployment rates, etc.). Direct loss of economic production is estimated at US$ 180,000 per km^2 on a yearly basis, whereas total losses that include industrial funds, private property, and compensation costs are over US$ 10,000,000 per km^2 in several segments of the coastal zone.

The main components of losses are arable and pasturable lands, allowing for 60-75 percent of the total area of the countryside, industrial structures in towns (fish, light, and construction industry in smaller towns and heavy engineering industry in Taganrog and Azov), and private property in inhabitants. Natural resources of the risky coasts in this region are represented by the relatively homogeneous ecosystems of black-earth grass and wormwood steppes and meadows with the unique bird fauna. Their bonification may be regarded as high and extremely high. Even of higher importance are marsh ecosystems of fluvial and deltaic plains and insular communities of deciduous forests in river valleys and other kinds of morphological depressions.

In general, anticipated losses on one third of the total shoreline length in this area may be regarded as extremely high, and on 50% - as high. Only coasts of Miuss Liman, comprising 5 to 7% of the total shoreline length, were attributed to the group of relatively low losses.

DISCUSSION

Three main categories of adaptive response strategies to the possible future sea-level rise have been distinguished by the IPCC Coastal Zone Management subgroup (1992):

(1) retreat, i.e. abandonment of structures in currently developed risky areas, resettling of the inhabitants, and resumption of new development father inland;

(2) accommodation, i.e. continuation of development in the risky areas with inevitable shift in economic strategies;

(3) protection, i.e. defense of risky areas, especially population centres, economic structures, and natural resources, either by "hard" engineering structures or by beach nourishment and other "soft" measures. Accommodation and

protection strategies may be further separated according to their anticipate (preventive) and urgent character (Barth and Titus, 1984).

Our integrated approach to the risk assessment estimation for coastal zones under the possible future sea- level rise, is promising in the site-specific economic comparison of various response strategies. The consistent retreat strategy results in the loss of the most part of the national wealth and the derivative national income. Compensation costs and costs of cultivation of newly developed lands are also high. The last value may be comparable to the value of industrial funds and private property of residents. However, this strategy is characterized by the cessation of compensation losses since the moment of termination of the respective economic activity in the new place. Therefore, if the national wealth in the area at risk is quite low and the lands of new development may be cultivated at quite low costs, then the cost-effective strategy of economic retreat may, in principle, be developed. The accommodation strategy in its "pure" form minimizes costs of retreat of the national wealth. However, if the future sea-level rise really occurs, these costs will inevitably arise owing to the necessity of resettling of the inhabitants. Moreover, implementation of this strategy increases significantly other components of the possible losses: industrial and non-industrial funds of an area at risk will be lost in case of sea-level rise; economy will suffer the decrease of the national income for much longer period than under the previous strategy; an urgent resettling of the inhabitants and the private property will cost much more than the anticipate measures of that kind. According to our estimates for the developed coastal segments of the Sea of Azov (near the towns of Eisk and Primorsko-Akhtarsk) the total losses may be 80-140% as much in comparison to the retreat strategy.

The protection strategy requires significant expenses on protection measures, whereas other components of economic losses minimize. In many developed areas this strategy is the most cost-effective one. However, the delicate site-specific design of protective measures is an urgent need. An example of this approach for the coast of the Sea of Azov in the borders of the Krasnodar Region was published recently (Kirillov and Peshkov, 1993). Moreover, the reliable prediction of sea-level rise and its coastal consequences comprise a necessary premise for the cost-effective implementation of the protection strategy.

CONCLUSIONS

Possible global greenhouse-induced sea-level rise would inevitably bring substantial losses from shoreline retreat, underground flooding, and other consequent processes. Indirect consequences of sea-level rise may bring greater damage than direct ones. The anticipating damage in the specific coastal segments depends not only upon the value of property, both economic and cultural, in the zones subject to shoreline retreat, or underground flooding, but also upon the natural peculiarities of the environment. Other conditions being equal, the more sensitive landscapes will suffer the greater damage. All these facts make the risk assessment from sea-level rise at a specific coastal segment an extremely complicated but important objective. Our integrated methodology of risk assessment of sea coasts of Russia is based on the concept of various types of resources (environmental, economic, cultural) and probabilistic predictions of shoreline retreat for different morphological types of sea coasts.

The methodology allows for per unit area resource values and for natural vulnerability of coastal segments. Value of economic resources at risk consists of national wealth, national income, and compensation costs. Graded scale is usually constructed for each type of resources and for natural vulnerability. In the small-scale surveys, a per unit area population number and value of economic production may be used as integrated indices of economic resources.

The example of risk assessment case studies for the Russian coasts of the Sea of Azov demonstrates their high and extremely high vulnerability to the possible rise in the global mean sea level by 1 m until 2100. Major premises for the dramatic impact of sea-level rise on these coasts include:

(1) The prevalence of land subsidence and, therefore, higher regional estimates of the relative sea-level rise in comparison to the globally averaged values;
(2) an intensive retreat of the prevailing loess coastal scarps substantially aggravated by landsliding processes and degradation of depositional coastal bodies composed presumably of detrital sands;
(3) high economic development of coastal zones with intensive crop- and fruit-growing on rich black earth soils, as well as cultivation of white beet, corn, and sunflower, and food industry, including fish processing, and light industry as a principal economic strategies; and
(4) relatively high sensitivity of natural steppe and meadow ecosystems and even higher sensitivity of anthropogenic ecosystems to soil moisture content and, therefore, to possible underground flooding.
Our integrated approach to the risk assessment estimation for coastal zones under the possible future sea- level rise is promising in the site-specific economic comparison of various response strategies, i.e. retreat, accommodation, and protection.

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Fig. 1. Different patterns of coastal morphological evolution during the sea-level rise depending upon an underwater coastal slope (Kaplin and Selivanov, in press). Dotted lines show profiles before the sea-level rise; solid lines - profiles after the sea-level rise. (1) eroded part of the profile; (2) deposited part of the profile; (3) dominant direction of transverse sediment movement; (4) ground water table rise and marsh formation. see text for further explanations.

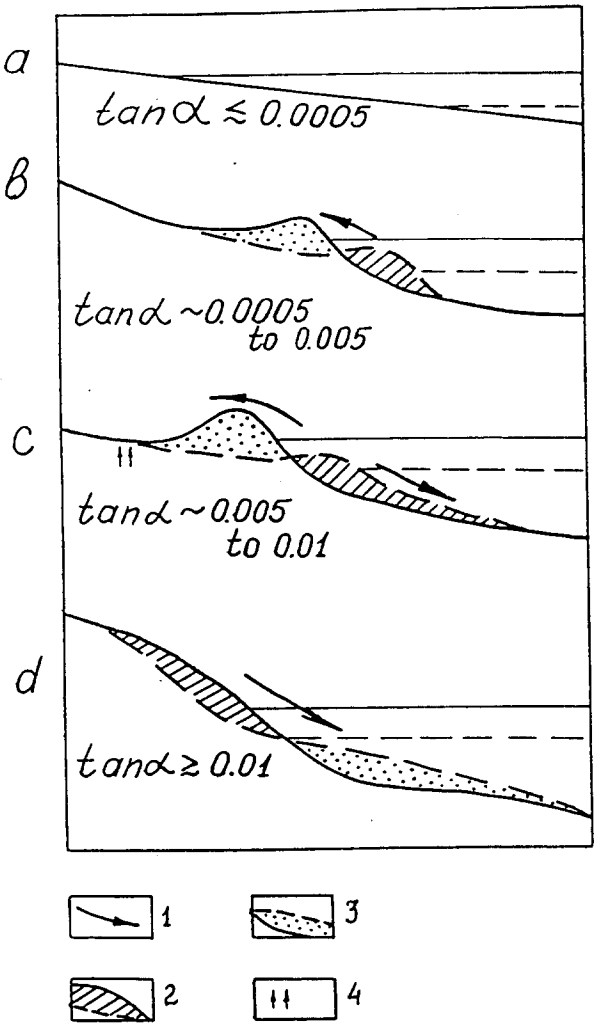


Fig. 2. Patterns of coastal response to sea-level rise depending upon the rate of this process (1-4) and the supplies of sediments in the coastal zone: (A) excessive; (B) insufficient.

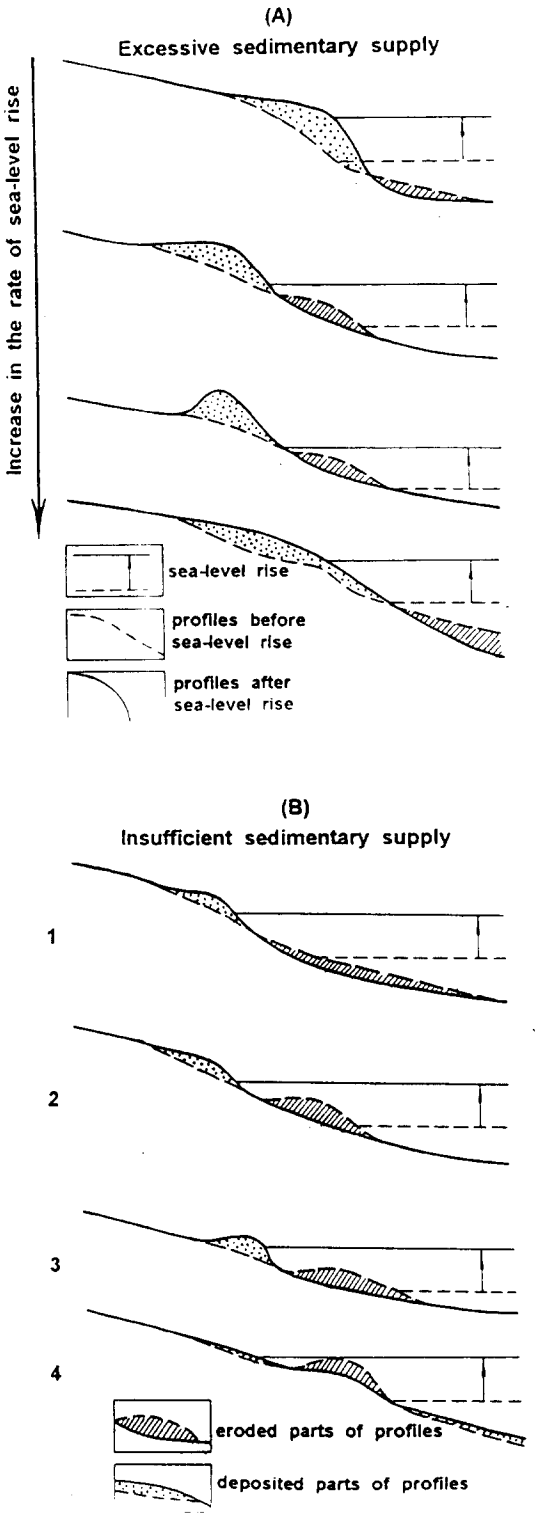
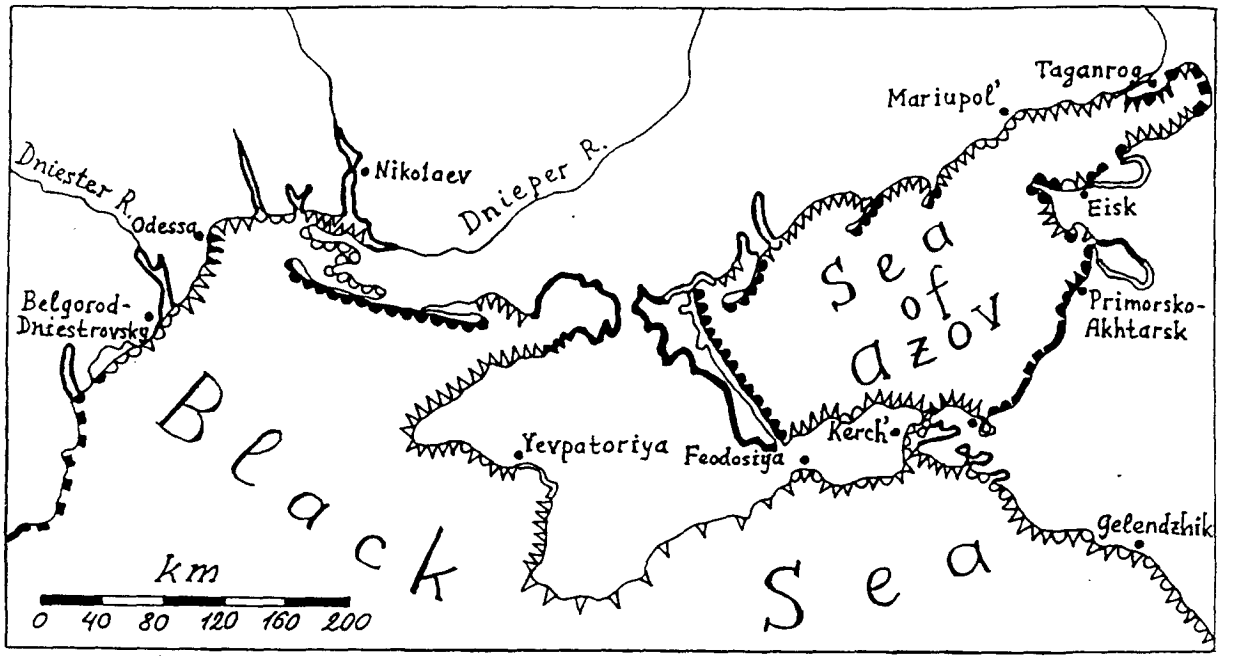


Fig. 3. Anticipated morphological changes on the North Black Sea and the Sea of Azov coasts under the possible 1-meter rise in the global sea level by 2100.



Passive inundation of low-lying coasts without significant morphological reformation:

- low intensity, less than 300 m,
- medium intensity, 300-1000 m,
- extreme intensity, over 1000 m;

Erosion of a seaward slope of depositional bodies and their general destruction:

- low intensity, less than 50 m,
- medium intensity, 50-200 m,
- extreme intensity, over 200 m;

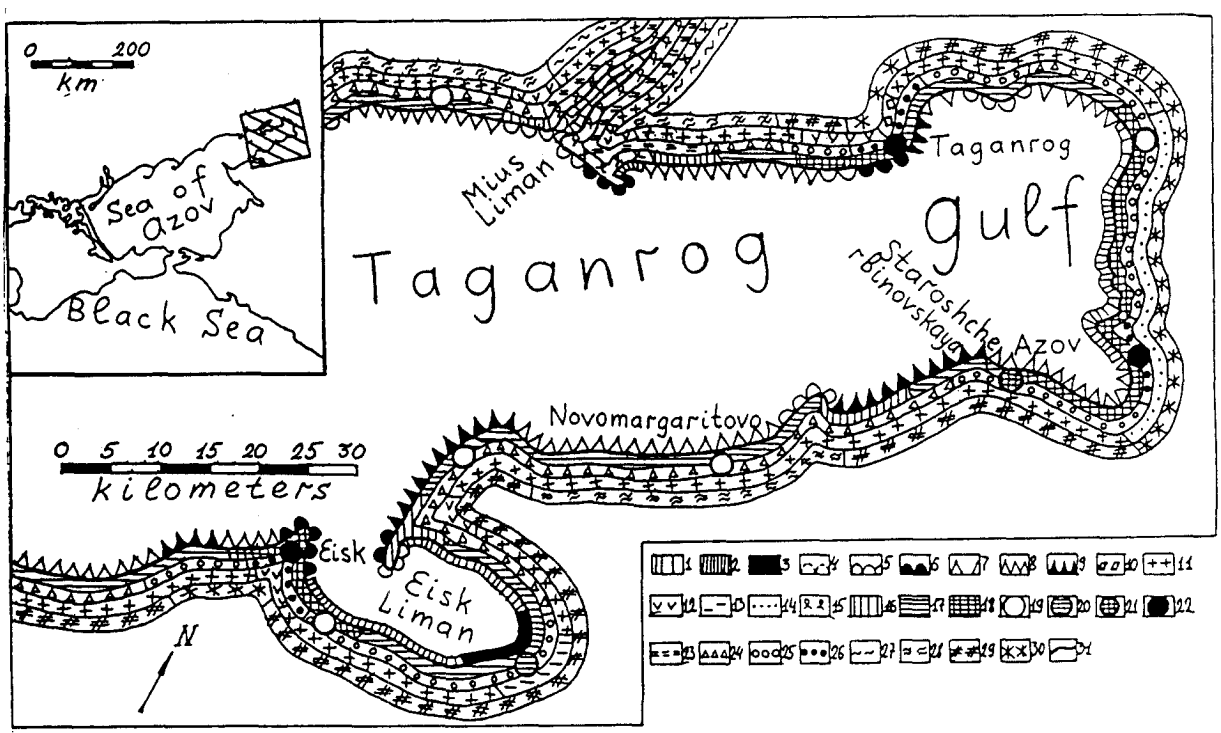
Retreat of erosional and landsliding coastal scarps:

- low intensity, less than 20 m,
- medium intensity, 20-50 m,
- extreme intensity, over 50 m.

Degradation of deltaic coasts

Eisk **Cities and towns under heavy danger of inundation, erosion and other adverse effects of sea-level rise**

Fig. 4. Risk assessment map of the Sea of Azov coasts under the possible 1-meter rise in the global mean sea level until 2100.
(1-9) Morphological vulnerability of sea coasts: (1-3) passive inundation of low-lying coasts without significant morphological reformations - (1) of relatively low intensity, less than 300 m, (2) intensive, 300-1000 m, (3) extremely intensive, over 1000 m; (4-6) retreat and general destruction of coastal depositional bodies - (4) of relatively low intensity, less than 100 m, (5) intensive, 100-300 m, (6) extremely intensive, over 300 m; (7-9) retreat of erosional and landsliding coastal scarps - (7) of relatively low intensity, less than 30 m, (8) intensive, 30-100 m, (9) extremely intensive, over 100 m.
(10-14) Natural resources and ecosystem vulnerability: (10) relatively low vulnerable denudation plains with grass, cereal, and wormwood steppe vegetation; (11) vulnerable loess plains with grass and cereal steppe vegetation and insular deciduous forests in depressions; (12) extremely vulnerable marine depositional plains with solonchak and ravine meadow vegetation; (13) extremely vulnerable fluvial plains with grass and cereal steppe and marsh vegetation; (14) extremely vulnerable deltaic plains with meadow, grass steppe, and marsh vegetation.
(15-26) Economic resources: (15-18) Population number, persons per sq. km: (15) less than 50, (16) 50-75, (17) 75-100, (18) over 100; (19-22) Towns and large villages, the number of inhabitants, thousands: (19) 5-10, (20) 10-30, (21) 30-100, (22) over 100; (23-26) Economic production, thousand US per sq. km on a yearly basis: (23) less than 100, (24) 100-250, (25) 250-500, (26) over 500.
(27-30) Integrated index of risk from the possible future rise in the global mean sea level by 1 m until 2100: (27) relatively low, (28) medium, (29) high, (30) extremely high.
(31) Present shoreline position.



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SOUTH PACIFIC SEA LEVEL AND CLIMATE MONITORING PROJECT

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ABSTRACT

The South Pacific Sea level and Climate monitoring project is a joint initiative of South Pacific Forum member countries. Drawing on Australian scientific and financial resources, the project will accurately record variation in long-term sea levels in the South West Pacific, making these data available for Pacific Islands countries.

The project aims to help Pacific Islands countries and their governments understand the scale and implications of changing sea level and climate. Probable global warming calls for a precise monitoring of the secular sea level change, particularly for low-level atolls. The South Pacific Sea level and Climate monitoring project was established to give an assessment of the secular sea level rise in the area of the Pacific Forum countries. To reach this ultimate goal, the National Tidal Facility:

- Has set up a network of high resolution monitoring stations in eleven island countries to measure the relative sea level motions at each station.
- Has recently acquired the expertise in Spatial Altimetry, to be able to analyze fluctuations in sea level on both small and large scales.
- Carries out a geodetic programme to measure movement of the crust with respect with the reference station to identify absolute changes in sea levels with reference to the Australian Baseline Sea level Monitoring programme.
- Collaborates with on-going international programmes, which may be incorporating satellite altimetry, GPS (global Positioning System) and radio astronomy to provide measure of regional vertical land movement.
- Exchanges information and data with international Sea level and Climate organisations.

1. INTRODUCTION

Historical evidence indicates that, in stable tectonic areas, sea level has been rising during the past century at a mean rate of 1 to 3 mm per year, with no evidence for any acceleration as a result of recent global warming (Woodworth, 1990). In the Pacific, the task of estimating the secular sea level rise is very difficult since climate is only one part of the problem of changing sea levels. Other include the movements of continental plates, active volcanoes and earthquakes which are all present in the region.

The variability of the oceanic heat storage has received considerable attention in recent years because it is a major component of the Earth's climate system, mainly in the tropical and equatorial regions. Actual climatic programmes observe sea level variations because sea level will have to provide much of the necessary empirical guidance to understand the importance of the heat storage transfer and variability in the oceans on basin-wide scales and for periods from several days to years. Generally, on a seasonal time scale, sea level records in open areas not contaminated by rivers discharges, are known to be negligibly contaminated by local effects and are representative of the open ocean fluctuations. In the open ocean, the seasonal variations in sea level are representative of the steric level, which is the effect of expansion and contraction of the water column (Patullo et al., 1955; Wunsch, 1972, Verstraete, 1987).

The present study investigates the seasonal variations of sea level, heat content, steric height and dynamic height in different areas of the

western tropical Pacific within the framework of the South Pacific project.

2. MONITORING STATIONS

It took nearly two years to progressively implement the network of eleven sea level stations of the South Pacific project. The monitoring sites (Fig. 1) have been implemented, on behalf of the Forum countries, by the National Tidal Facility (NTF) at Flinders University, from October 1992 (Fiji, Kiribati) to September 1994 (Solomon Islands, Papua New Guinea). The same equipment has also been installed around Australia.

The gauges are acoustic tide gauges using the SEAFRAME (Sea level Fine Resolution Acoustic Measuring Equipment, Fig.2) system. SEAFRAME measures sea level at six minutes intervals (from 181 one second samples over a period of 3 minutes) and meteorological data every hour : barometric pressure, wind speed, wind direction, maximum gust, sea surface and air temperature, together with the near surface vertical temperature profile. The equipment has the capacity to measure sea level changes with a few millimetres accuracy.

The data are transmitted to Japan via the Japanese Geostationary Meteorological Satellite GMS, and to the NTF in Adelaide by modem from the Melbourne Meteorological Headquarters. The transmission interval from each station is 3 hours. At the NTF, the data are downloaded, subjected to quality control, and archived in a secure data bank. Further processing and later refined analysis of the data will produce scientific results, available for use by governments and general public.

3. PRODUCTS FROM THE PROJECT

Considering that the heat capacity of the upper 3 metres of the ocean is equivalent to that of the entire atmosphere, sea level is obviously related with climate. Sea level contains significant information about integrated quantities such as heat content, dynamic height and steric changes within the water column.

The primary aim of the project is to give an assessment of the secular sea level rise. This is a long-term objective, that may require twenty years of continuous sea level observations to be meaningful. However, information of more immediate relevance to the interests of Pacific Islands countries will be produced. This information includes: local tidal characteristics, local tidal predictions, local meteorological data, contributions to the local meteorological service and the setting up of a regional data base, navigational aids, assistance for port operations, advance warning of anomalies in sea levels, investigations into storm surges, tropical cyclones and tsunamis, regional sea level topography and features of large-scale water density indicating yearly climate variability.

4. BRIEF REVIEW OF THE SEASONAL AND INTERANNUAL VARIABILITY IN THE WESTERN TROPICAL PACIFIC

Basic knowledge of the western tropical Pacific circulation is essential to the South Pacific project. Heat stored in the warm water pool west of 170 °E may be the main energy source for the Southern Oscillation (Gill and Rasmusson, 1983), and perturbations of the annual northwest monsoon in the western Pacific may be related to the onset of El Niño / Southern Oscillation (ENSO) events.

4.1 Seasonal Variability

The western equatorial Pacific is a region of strong atmospheric forcing on annual and interannual time scales, and the mean wind stress is relatively small compared to the seasonal variation. The main feature in the western Pacific is the monsoon influence clearly seen in the reversal, twice a year, of the wind stress. The period June through September is characterized by southeast trade winds while the period from December to April is typically one of relatively strong northwesterly winds. In the early stages of the canonical ENSO event (Rasmusson and Carpenter, 1982), the southeast trade winds weaken dramatically and westerly winds may appear to the west of the date line.

4.2 Interannual Variability

The equatorial Pacific ocean is known to have not only a strong seasonal signal but also an important interannual variability. The dominant mode of interannual variability is the Southern Oscillation at time scale of about three years, but the oscillation is so irregular than El Niño episodes may occur within a broad range of time scales, from two to ten years (Philander, 1990). The interannual variations of the ENSO phenomenon cannot be understood and monitored without a general picture of the mean circulation and seasonal cycle. During an El Niño, there is a massive shift of warm upper ocean water from west to east, accompanied with a large-scale depression of sea level in the western Pacific and a corresponding sea level rise in the eastern equatorial Pacific. Recently, one exceptionally strong ENSO has been observed in 1982-83, followed by the 1986-87 and the 1991-92 events. Examination of sea level deviations relative to the 1975-1986 mean sea level (Fig. 3), computed from the tide gauge sea level records at Honiara Island (9° 26'S, 159° 57'E), shows strong negative deviations during the last El Niño events: nearly -40 cm in July 1983, -25 cm in June 1987, -30 cm in July-August 1992, surprisingly followed by a -20 cm deviation in September 1993.

It is interesting to note that some ENSO in the Pacific are followed by a "replica" in the equatorial Atlantic ocean, as it was the case in 1984 and in 1987-88, suggesting that there is an equivalence of the Pacific events in the Atlantic interannual warm events. Philander (1990) believes that upper-atmospheric changes associated with the increased convection in the eastern equatorial Pacific affects the trade winds over the Atlantic.

The Change in sea level observed at Honiara during an El Niño is the signature of a large space scale phenomenon. In the warm pool area as well as in the region of the South Pacific subtropical gyre, ENSO-related sea level changes may easily obscure any secular sea level rise, with sea level anomalies up to ±40 cm. Satellite altimetry provides the only way of obtaining basin-wide sea level observations over a long time period. New analysis in the Atlantic and Indian oceans confirm the capability of the Topex-Poseidon altimetry in detecting, within 2 cm rms uncertainty, the low frequency sea level variations with periods greater than 60 days.

5. SEA LEVEL VARIATIONS IN THE WESTERN TROPICAL PACIFIC

5.1 The seasonal cycle from historical data

The sea level and meteorological time series produced by the new network are far too short to be used to establish the seasonal cycle, particularly in 1992-94, in a full scale El Niño situation. We are therefore obliged to rely upon historical data to study the basic climatic parameters. The data used for this study are:

(1) The historical sea level data assembled at the University of Hawaii Sea level centre. The ISLPP deviations (IGOSS Sea Level Program in the Pacific), were provided by the International TOGA Sea Level Centre / Joint Archive for Sea Level (TSLC/JASL). The TSLPP deviations are computed from the 1975 to 1986 mean sea level value, including two El Niño events in 76-77 and 82-83, and

(2) The monthly in-situ temperature and salinity at standard levels, 0-1000 m, on a one degree latitude-longitude grid (NOAA Atlas NESDIS 3 and 4, World Ocean Atlas 1994, Washington, D.C., Levitus and col., 1994). We have extracted from the World Ocean Atlas the monthly T(z) and S(z) profiles in the vicinity of the islands where sea level is measured.

The NTF is presently studying the seasonal variations of sea level, heat content, steric height and dynamic height, in the oceanic areas close of each Island station as well as along the East Australian coast. Changes in the steric sea level represent the effect of expansion and contraction of the water column due to changes in density profiles, consequences of variations in temperature and salinity. Steric changes in sea level are the result of large-scale heat exchange processes in the ocean, not necessary well represented by the local sea surface temperature. Monthly steric sea level anomalies were computed in various layers of the upper ocean, up to a depth of 1000 m. As for the upper 500 m of the ocean, the steric level is given by:

$$\xi_{steric} = -\frac{1}{\rho_0}\left(\int_{-500}^{0} \frac{d\rho}{dT} T' dz + \int_{-500}^{0} \frac{d\rho}{dS} S' dz \right) \quad (1)$$

where T' and S' are the monthly temperature and salinity anomalies in reference to their climatic annual mean values, $\rho_$ is the density and $\rho_$ the sea surface density.

We define the heat content H_c (in J / m ^{2}) of a water column H as:

$$H_c = \sum_{0}^{H} \rho . C_p . T . \Delta z \quad (2)$$

where ρ is the density, C_p the specific heat in $J.kg^{-1}K^{-1}$ and T the temperature in °C. In (2), C_p is computed at each level (formula in Siedlers Peters, Landolt-Bornstein New Series, V3, 247-248). In both formula (1) and (2), the in situ density is computed using the most recent equation of state $\rho = \rho(S,T,p)$. Changes in the heat content are only due to changes in the temperature profiles, whereas the steric changes ζ_{steric} raise from temperature (ζ_T) and salinity (ζ_S) variations. The seasonal variations of the steric sea level computed for the upper 300 m of the ocean in the area of the Cook Islands (Fig. 4) have an amplitude of about 3 cm, with maxima in April-May and minima in October-November.

5.2 The Interannual signal in the tropical Pacific as observed by TOPEX / POSEIDON altimetry.

The Southern Oscillation Index (SOI, usually the Tahiti-Darwin normalized sea level pressure) is negative for the fourth consecutive year, since 1991. If the 1982-83 El Niño was the strongest in intensity, the 1991-94 El Niño will certainly be the most persistent in this century. By May 1992, the sea level in the eastern Pacific was near to normal. However, the El Niño was not over.and in October 1994, the SOI was still strongly negative. The TOPEX /POSEIDON satellite altimetry data show a strong interannual signal. We have used the two first year of data from cycle 2 to cycle 72 to build the mean sea surface topography for the period 3 October 1992 through 27 September 1994. The reference of this surface is the Ohio State University OSU91A geoid (Rapp et al., 1991).The processing of the T/P data is given in detail in Verstraete and Park (1993).

The mean T/P sea surface topography for two years shows the two large subtropical gyres of the Pacific, rotating in an anticyclonic direction (Fig. 5). The northern gyre (Maximum Height, MH=120 cm) is stronger than the southern one (MH=110 cm) by about 10 cm, in agreement with Levitus (1982) or Wyrtki (1979) hydrography-derived mean sea surface dynamic topography. But we observe a large change in the T/P-derived equatorial zonal slope from the Levitus-Wyrtki climatic sea surface dynamic height along the equator. The maximum heights, which are usually between 140°E and 180°W, are shifted of about 40° eastward. The eastward equatorial zonal pressure gradient is now situated between 160°W (110 cm) and the Galapagos (35 cm), whereas the sea surface topography is essentially flat along the equator between Papua New-Guinea (PNG) and 160°W. This is related with a large eastward displacement of the warm water pool, of more than 40° in longitude.

Taking the two year T/P mean sea surface topography as a reference, we have computed the yearly residuals in 1993 (RESI 1= year I - year I+II) for the period 3 October 1992 through 24 October 1993. Note that the residuals are free of geoid errors. On the RESI 1 map (Fig. 5), we observe an El Niño situation, with negative anomalies in the western equatorial Pacific, up to -4 cm east of PNG. A large scale V-shaped pattern delineates a yearly negative anomaly in a very large area, extending from the Philippines to 40°N and from PNG to Tahiti. The eastern equatorial Pacific yearly sea surface topography anomaly is positive, with anomalies of +2 cm off the Galapagos. At the time of writing this paper, our time series were too short to establish the yearly anomalies in 1994. However, we must stress here that the T/P - derived sea surface

topography reference is probably biased, due to the fact that both 1993 and 1994 are El Niño years. As a matter of fact, we did not observe in 1994 any retreat of the maximum sea surface heights in the central equatorial Pacific (at 150°-180°W) towards PNG and the western equatorial Pacific. In December 1994, the SOI is still strongly negative (-1.5), and El Niño conditions prevail in the western tropical Pacific.

The RESI 2 map (Fig. 6), for the period 25 September 1993 through 27 September 1994, we observe positive anomalies off PNG (+2 cm) and negative anomalies off the Galapagos (-2 cm). This reversal of the yearly anomalies in 1994 does not mean that the El Niño situation is over, because the reference T/P - derived sea surface sea surface topography is strongly biased, due to the fact that both 1993 and 1994 are El Niño years. The positive anomalies in the western Pacific come from a strong increase of the two anticyclonic gyres, but we do not observe any retreat of the maximum sea surface heights in the central equatorial Pacific (at 150°-180°W) towards PNG and the western equatorial Pacific. In December 1994, the SOI is still strongly negative (-1, 5), and El Niño conditions prevail in the western tropical Pacific.

It is possible to distinguish these relative contributions by using a coefficient r defined as

$$r = \frac{\xi_T}{\xi_T + \xi_S} \quad (3)$$

CONCLUSIONS

This note presents the actual approach at the National Tidal Facility, for observing and understanding sea level changes in the Western Tropical Pacific. This relies on a network of eleven SEAFRAME (SEA level Fine Resolution Acoustic Measuring Equipment) tide gauge stations and the TOPEX-POSEIDON satellite altimetry data. The seasonal sea level variations at the eleven tide gauge stations for monitoring sea level and climate, as well as the T/P derived sea surface heights, could be used to build maps of surface currents, as well as predictors to deduce the seasonal ocean heat content variations. Satellite altimetry is the indispensable and complementary tool to continuously monitor the oceanic heat content and sea surface current variations over large areas surrounding the sites, and at basin wide space scales. The TOPEX / POSEIDON mission is scheduled to proceed until 1998, beyond its three year nominal duration.

The South Pacific Sea level and Climate monitoring project is a long-term project for a precise monitoring of the secular sea level change at each Island station. The project is coordinated with the Australian Baseline Sea level programme, which operates 15 stations around Australia. In the future, the Australian baseline TGBMs (Tide Gauge Bench Mark) will be placed in the absolute ITRF system (IERS Terrestrial Reference Frame). The NTF is planning a geodetic programme to monitor the TGBMs in a GPS programme (Global Positioning System). This effort aims to separate the Ocean secular signal from the vertical crustal motions. However, at the seasonal or at the ENSO time scales, the ocean variability and the tectonics processes are totally decoupled, and it is more important at these scales to study the low frequency relative sea level variability than studying the absolute sea level variability.

At very short time scales, the South Pacific network has the capability to observe high frequency waves (Murty, 1977) and could be incorporated into the Pacific Tsunami warning centre in Hawaii, for the benefit of the tsunami-prone Pacific nations.

By combining the sea level data with the altimetry data, the project has the capability to study ENSO-related sea level changes in a vast area including the warm pool region as well as the Pacific subtropical gyres. Baroclinic Rossby waves with period of years have been documented and the merged data open the possibility to study these low frequency / large scale sea level variations.

In the perspective of monitoring permanently the Ocean at the horizon of year 2000, this project will contribute to the development of a Global Ocean Observing System (GOOS) for Climate

studies and predictions. GOOS is being planned as a comprehensive system to provide the information needed for oceanic and atmospheric forecasting, for ocean management by coastal nations, and for the needs of global environmental change research, with education and training programmes and technical assistance essential to ensure that all countries can participate and benefit.

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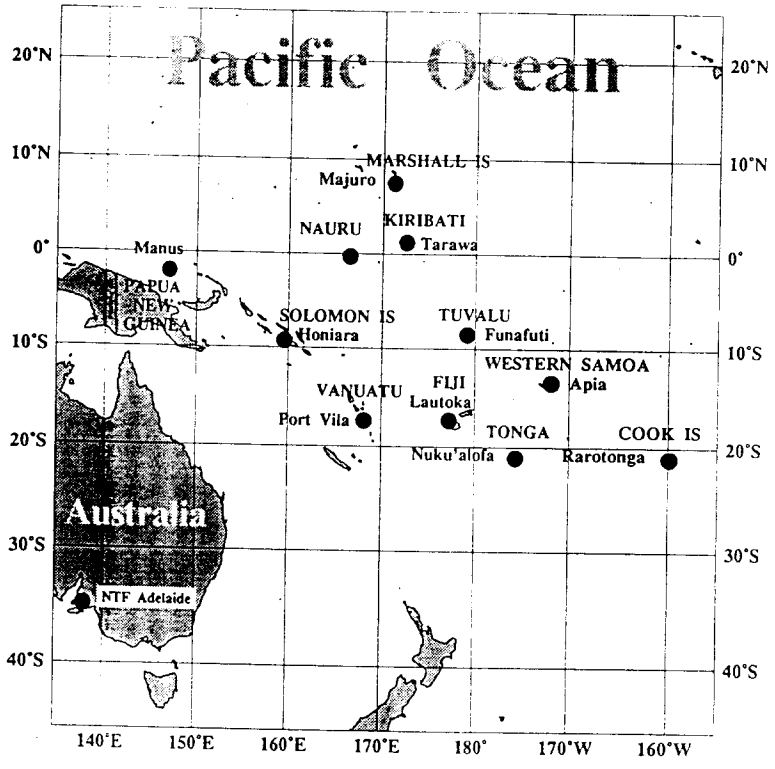
Fig. 1. Monitoring sites of the South Pacific Sea level and Climate project



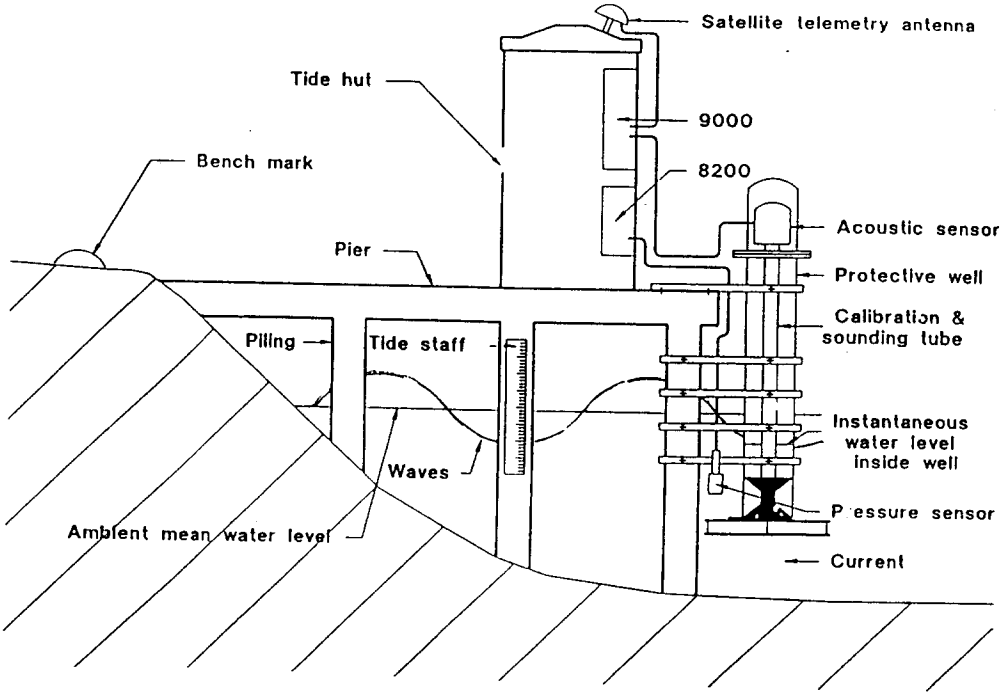
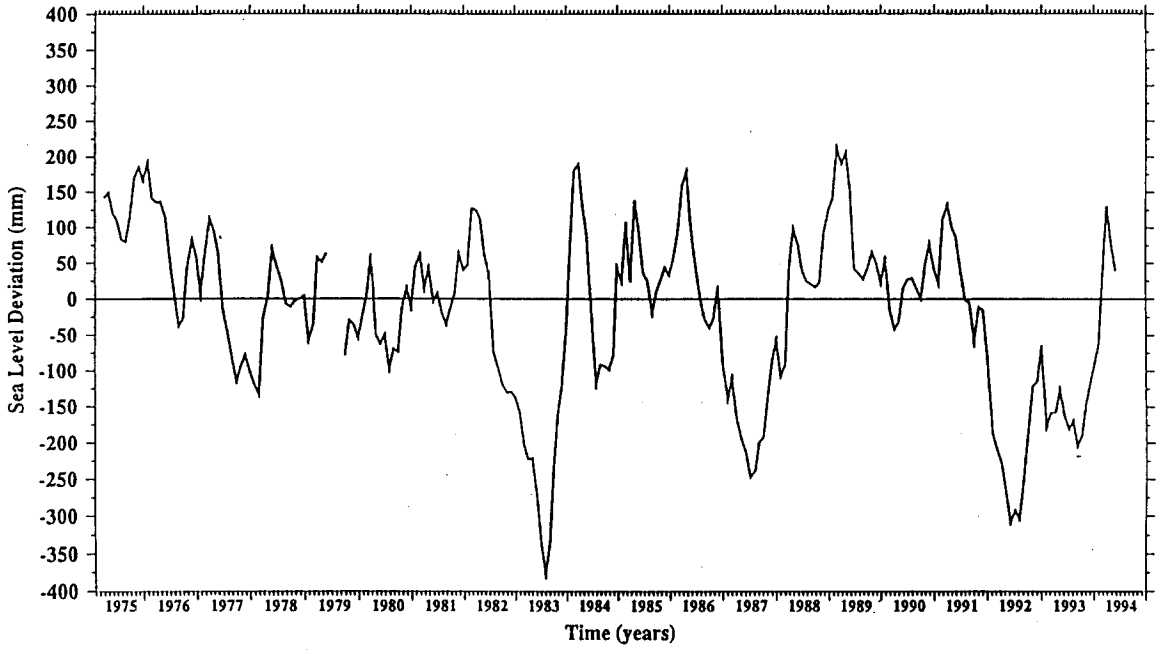


Fig. 2. Diagram of a SEAFRAME tide gauge station. The master acoustic tide gauge (Aquatrak unit) is the new generation of water level measurement system used by NOAA. Note the pressure sensor unit used as backup. The ancillary sensors are not shown on this diagram.

Fig. 3. Mean sea level deviations at Honiara (9° 26'S , 160° E), Solomon Islands, during the last twenty years (1975-1994). The reference is the mean sea level for the period 1975-1986. Origin of data : TOGA Sea Level Centre, Hawaii.



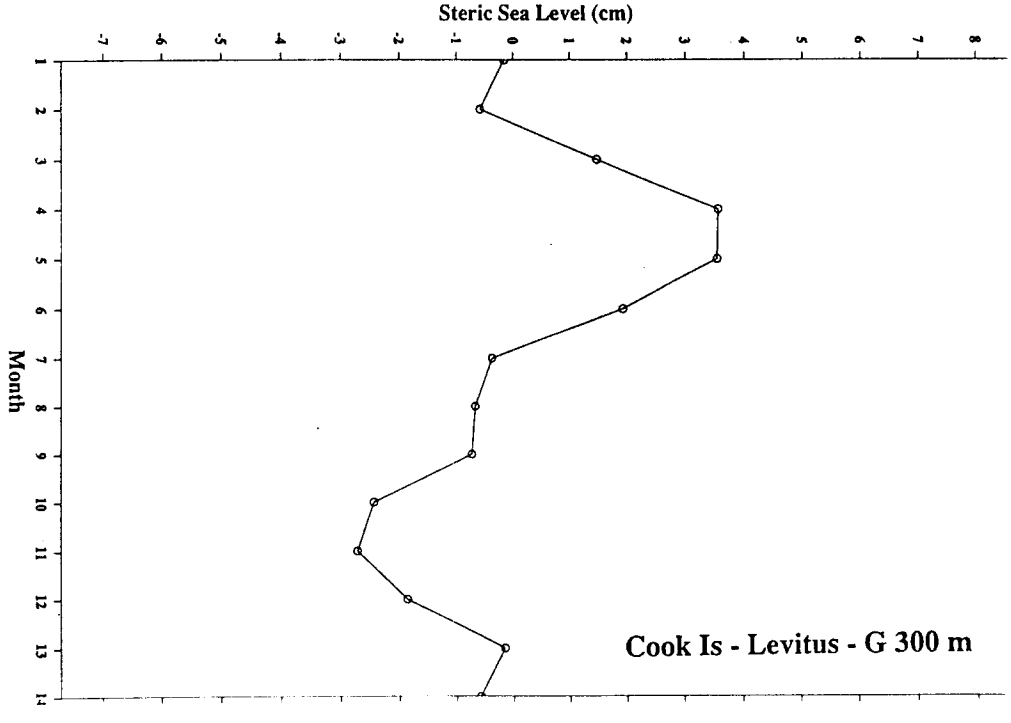
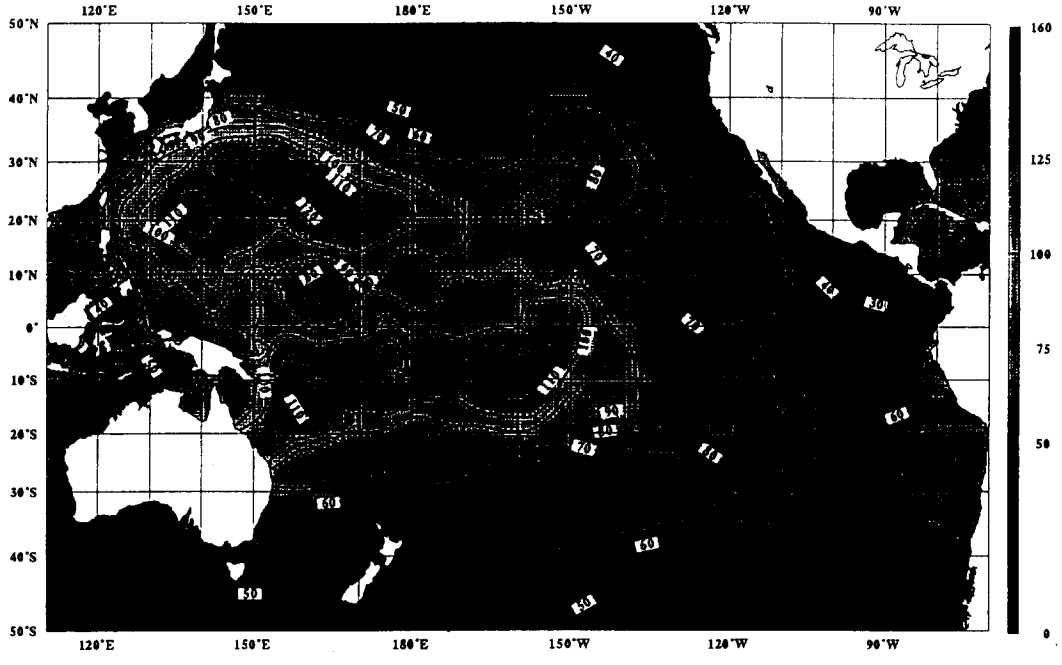


Fig. 4. Seasonal steric sea level variations (cm) in the area of the Cook Islands, computed from the Levitus atlas temperature and salinity data.

Fig. 5. The mean sea surface topography (cm) from October 1992 to September 1994, as observed by the TOPEX / POSEIDON altimeters. The small scale geoid errors are filtered out by a Gaussian-shape window of 2000 km radius.



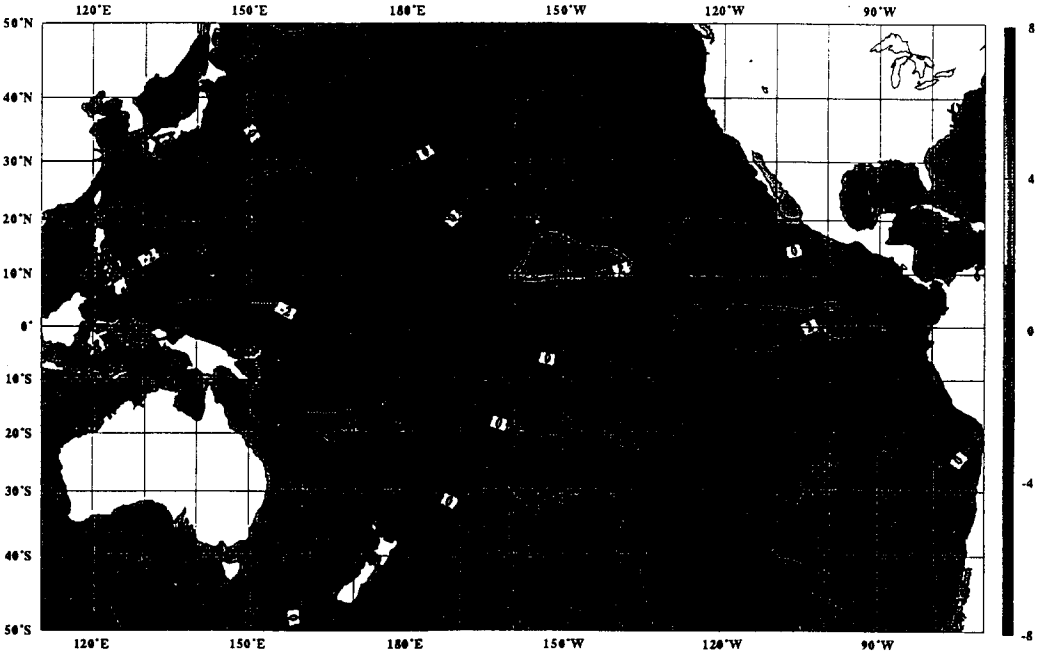


Fig. 6. TOPEX / POSEIDON - derived map of the yearly residuals (cm) of the sea surface height for the period 3 October 1992 - 24 October 1993. Reference : T/P mean sea surface topography during the period 3 October 1992 - 7 September 1994, as given in Fig. 5.

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METHODS FOR THE ESTIMATION OF MARINE PARAMETERS IN COASTAL ZONES

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KEYWORDS: storm surge, tidal wave, coastal zone, shelf, hydrodynamic modelling, sea level, total current, extremal characteristic long return period.

ABSTRACT

In the State Oceanographic Institute a complex of models is developed for the estimation of marine environment characteristics of hydrometeorological phenomena including long return period values. Hydrodynamic models and stochastic models are used as core components of the system. The complex is based upon threshold value method along with the binary exponential law and Langbein's relationships. Extremal characteristics of surge level and currents, as well as total sea level and currents within coastal regions where observations are scarce or lacking completely, are calculated by hydrodynamic models for the most extreme storms recorded during the period of observations.

The method was applied for some platform feasibility studies on the Sakhalin shelf, and in the south-eastern part of the Barents Sea for design of an underwater gas pipeline crossing of the Baydaratskaya Guba Bay in the Kara Sea.

The shelf zone of the Russian Federation coasts (in the Arctic seas in particular) has not been adequately studied. This is quite explicable considering its vast expanse, which makes it difficult to establish regular long-term observations of the main elements of hydrodynamic, hydrochemical and ice regimes over the area. At the same time, work on the open shelves (primarily, oil and gas resources prospecting and exploitation) required the development of new automated techniques for long return period characteristics calculation of the main elements of hydrometeorological regime (wind, waves, sea level, currents).

Promising fields of hydrocarbons are located on open shelves of Arctic seas where observations are scarce or lacking completely. Search for oil and gas fields, construction and exploitation of hydrotechnical complexes for the hydrocarbons exploitation, production and transportation require specialized information corresponding to various stages of design, construction, and exploitation of the offshore oil- and gasproduction installations.

It does not seem likely that field observations alone will provide, in the near future, all of the data necessary for hydrometeorological support of work on the search for oil- and gas-bearing areas on the shelf and their development.

Accordingly, the most urgent issue is to develop an integrated approach to evaluation of all essential parameters of the marine environment by the use of observational data at hand along with thermodynamic and probabilistic models. In such case, special field works (optimized with a view to minimize expenses) are carried out in order to collect information needed to set the boundary conditions in the thermodynamic models and to verify the latter.

Recently in the State Oceanographic Institute a new technology aimed at estimation of the primary marine elements (wind, waves, currents, sea level), including low-frequency characteristics, was developed (see Fig. 1). It includes two components: first, hydrodynamic models and computational techniques applied to estimate the above-mentioned hydrometeorological elements within meso scale and synoptical variability ranges; second, stochastic models of hydrometeorological phenomena, including those of rare occurrence. The approach is similar to those developed in the United Kingdom with reference to the North Sea and in the USA for the Atlantic shore (Davies & Flather, 1987).

An important component of the technology is the hydrodynamic models of tides and storm surges. The model is based upon shallow water equations (Flather & Heaps, 1975). Numerical solution uses Arakawa "C" (see Mesinger and Arakawa, 1976) and a Richardson grid is obtained with an explicit finite difference method.

To approximate the non-linear advective terms a new difference method was constructed by means of the special hybrid procedure (Safronov et al., 1986). If the gradients of the velocity fields are not significant, and depth gradients are not great the numerical scheme is of the second order of accuracy in space and of the first order in time (Safronov, 1987). In this case, centered space difference was used as in the Lax-Wendroff scheme. In the regions where the current or depth gradients are considerable, we obtain the first order of accuracy in space and time. In this case we have the upstream scheme (Roache, 1972).

Without the advective terms, a scheme has the second order of accuracy in space and time (Safronov, 1987; Zilberstein et al., 1990). The influence of advection on tidal climate was found to be quite small. Nevertheless, in the coastal zone the contribution of advective acceleration to such a phenomenon as the residual tidal circulation and the non-linear interaction between the tide and storm surge may be 50% as compared with other non-linear terms.

RESULTS OF SIMULATIONS

Forcing for the simulations of storm surges is determined by atmospheric pressure gradients and wind stress. They are calculated using a computerized data base on storm cases, which has been specially prepared for each sea. Usually two numerical model of different spatial resolution are in use. Results obtained by the coarse resolution model represent boundary conditions for modelling storm surges in the coastal zone. At the open boundary of the coarse model the surge component is obtained through the "inverse barometer" relation, while the tidal component may be represented by a sum of harmonic constants, which are derived from observational data series with a desirable duration at least of one month.

Being intended to serve as a part of an automated forecasting technology, which should be used for all seas of the Russian Federation, the model has been tested with respect of many seas namely Sea of Okhotsk, Azov, Barents Seas, Baydaratskaya Bay of Kara Sea.

The model was tested in the course of simulations of tides and storm surges in the Okhotsk Sea and the Azov Sea, respectively. A grid network used for the simulation of tides in the Okhotsk Sea is shown in Fig. 2. The step of the grid is 18.52 km. At the boundary of this grid sea level variations were obtained using harmonic analysis prediction for 9 principal tidal waves. The coefficient of quadratic bottom friction k is equal to 0.0026. Fig. 3 shows the temporal variation of tidal sea level at point Tavvatamsky at Shelikhov's Bay, simulated using hydrodynamic model and predicted by harmonic constants for 9 principal waves of tide for moments of spring tide and neap tide. Good coincidence between modelling and predicted sea level values is noteworthy.

The model was also used for the simulation of the catastrophic event during the night from 28th till 29th October 1969, when sea level in Temruk was 2.5 m higher than its normal value. The surge was observed on a coastal line 150 km wide with flooding up to 8-10 km inland. Many lives were lost and the economic loss was great. The surge was caused by fast propagation of a deep cyclone. Grid networks used for the simulation of storm surge in the Azov Sea and in Taganrog Bay are shown in Fig. 4. Step of the coarse grid is equal 9.26 km, step of the fine grid used for storm surges simulation at Taganrog Bay is equal 1.852 km. The coefficient of quadratic bottom friction is equal to 0.0025. For winds and atmospheric pressure information was taken using data of regular meteorological observations performed by coastal meteorological stations Mysovoe, Primorsko Akhtarsk, Mariupol, Taganrog, Ejsk and was interpolated to the nodes of 9.26 km and 1.852 km resolution grids.

Figure 5 represent the temporal variations of surge sea level at Taganrog simulated by hydrodynamic model with a coarse spatial resolution (9.26 km grid) and with fine spatial resolution (1.852 km grid). It should be noted that

simulated values of sea level correspond well to observation series in the latter case. Figure 6 shows temporal variation of sea level at Temruk, Azov Sea during the catastrophic storm of 1969. It is seen that simulated values of sea level correspond fairly well to observations. Thus the tested and verified hydrodynamic model of tides and storm surges constitutes a good foundation of computerized technology of evaluation of essential parameters of the marine environment. However, exploitation of sea shelf mineral resources, oil and gas being the most important ones, requires specific knowledge of primary hydrodynamic parameters such as sea level, waves, currents including their extremal (rare occurrence) values. The methods for the estimation of rare occurrence values of random functions are sufficiently well developed for cases in which long series of discrete measurements are available (Pugh & Vassie, 1979; Pugh, 1982; German & Levikov, 1988). It is known, however, that sufficiently long series that could lead to statistically significant estimates for open shelf waters constructions usually do no exist.

Extremal characteristics long return periods necessary for pilot projects on oil rig construction are calculated by the method of extremal storms and are based on the joint use of hydrodynamic and statistical models. A similar approach is used in the Britain for the shelf zone of the North Sea. The difference is that it is based on the long series of observations.

Extremal characteristics of surge level and currents as well as total sea level and currents within regions where observations are scarce or lacking completely are calculated for most extreme storms recorded during the period of observations by the hydrodynamic modelling. For example, for the eastern Sakhalin coast 28 storms were selected for the 37 years long interval. Their duration varied from 2 to 6 days. For Barents Sea 24 storm cases were selected for 40 years period. Then sea level and current variations were calculated for the each of selected storms. After that, hourly values of sea level and vertically averaged current components were analysed and extreme values obtained. For currents, maximal speeds were estimated for each angular 15° interval. The mean direction of the first interval was taken equal to 0°.

The series of extreme sea level and current components values obtained by hydrodynamic modelling were then analysed by a stochastic model. It was based on threshold value method along with the binary exponential law and Langbein's relationships.

Description of sea level and current regime must include estimations of values of long return period. A threshold value method may be recommended for that with the assumption that probability distribution for such rare values obeys binary exponential law and Langbein's relationships (Gumbel, 1962; Langbein, 1949; German & Levikov, 1988). Threshold values are taken equal to calculated values of minimal probability.

As result of statistical processing of series of extreme sea level and current components values obtained by hydrodynamic modelling, probability curves for sea level and current are calculated. Long return period values are interpolated and extrapolated by Student's distribution or on the basis of X^2 criterion (see Fig. 7).

An example of calculated probability curves for sea level and currents is shown in Figs. 7 and 8 for a point located near Cape Varandey in the south-eastern part of the Barents Sea. Such estimations are used to assess values possible once in n years.

Such a method was applied by the State Oceanographic Institute for the designed platform feasibility studies on the Sakhalin shelf and in the south-eastern part of the Barents Sea, as well as for design of underwater pipeline crossing for the Baydaratskaya Guba Bay in the Kara Sea.

In Fig. 9 a chart of south-eastern part of the Kara Sea and Baydaratskaya Guba Bay is given. A gas pipeline is being designed to be buried across the bay. To conduct feasibility studies and design of this construction, distributions of extremal characteristics of basic parameters (current, wind wave, sea level variations for 11 points along the crossing area) were obtained using the above described technology. It may be seen from Fig. 10, that sophisticated processes in the coastal zone have many feedbacks, and that long return period

values of currents and wind wave may vary considerably over a small distance. Strongest near shore currents and highest waves cause sea bed erosion and shore destruction leading to bottom sediment transport and bottom topography changes. If hummocks (i.e. ice ridges) are large enough bottom scouring may happen, which potentially causes pipeline damage. The works were executed jointly by the State Oceanographic Institute and research company ECO-SYSTEM Ltd.

CONCLUSIONS

Hydrodynamic modelling of storm surges is a core component of their prediction. Along with experimental studies and field data analysis, it has lead to considerable progress in sea level regime research, particularly as applied to evaluation of its long period values for open areas of shelf waters.

Further achievements with 2-D model may be expected from the development of data assimilation methods for shallow water models. In some areas where mean sea level is unstable, such as Caspian Sea with rapidly rising level, use of historic data for evaluation makes no sense. For such cases some components of specially designed regional systems for analyses and prediction of the principal marine elements will be applied to calculate regime characteristics of the Caspian Sea for different scenarios of mean sea level change.

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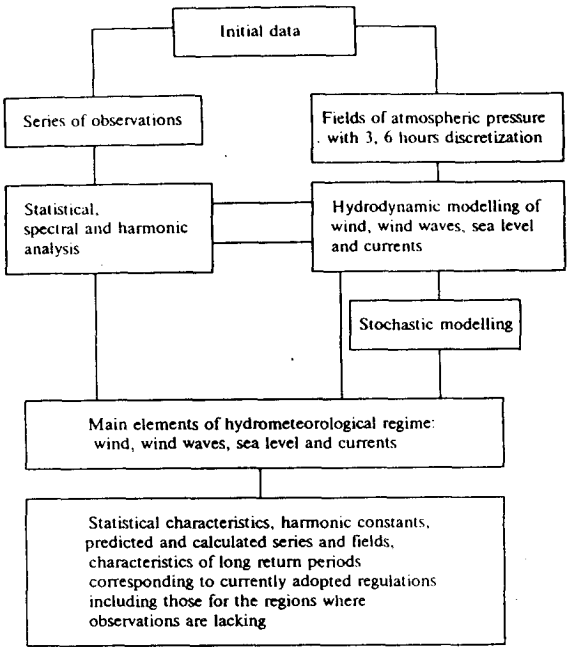


Fig. 1. Technology of regime characteristics calculation of main elements of marine environment for the hydrometeorological support of surveys on shelf zone.

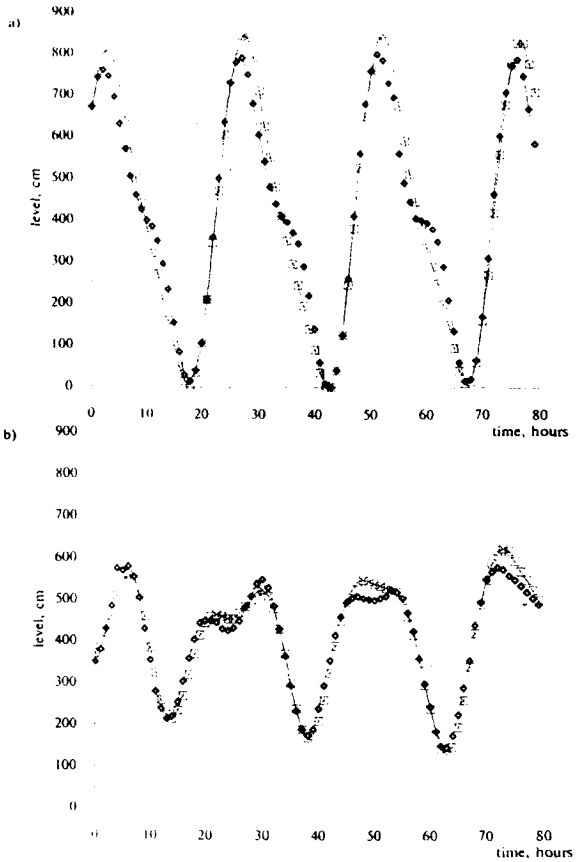


Fig.3 Temporal variation of tidal level at cape Tavvatamsky at Shelichov's Bay, Sea of Okhotsk, simulated using hydrodynamic model (o) and predicted by harmonic constants (⁻)
a) spring tide, b) neap tide.

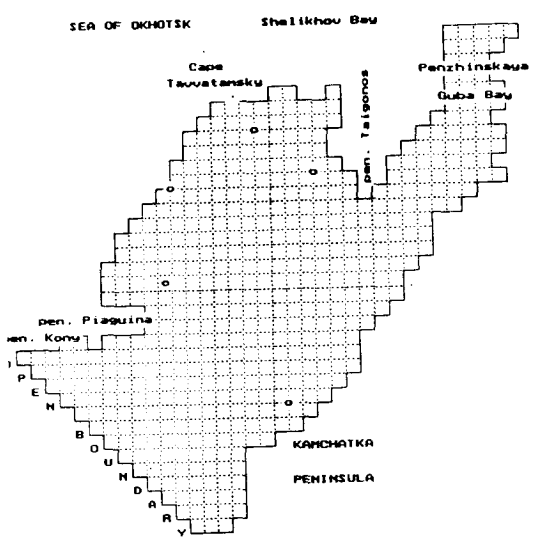


Fig.2. Schematic representation of the Shelikhov's Bay grid network. Circles denote locations of tide gauges. Step of the grid is 18,52 km.

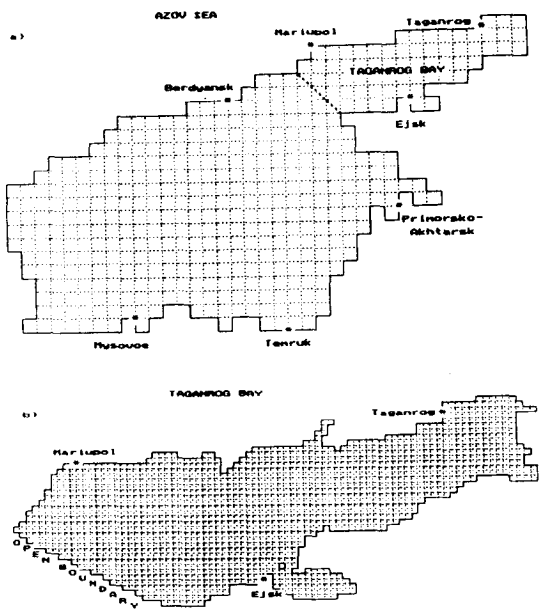


Fig. 4. Schematic representation of the Azov Sea (a) and Taganrog Bay (b) grid network used for storm surges simulation. Step of the coarse grid is 9,26 km, step of the fine grid used for storm surges simulation at Taganrog Bay is 1,852 km

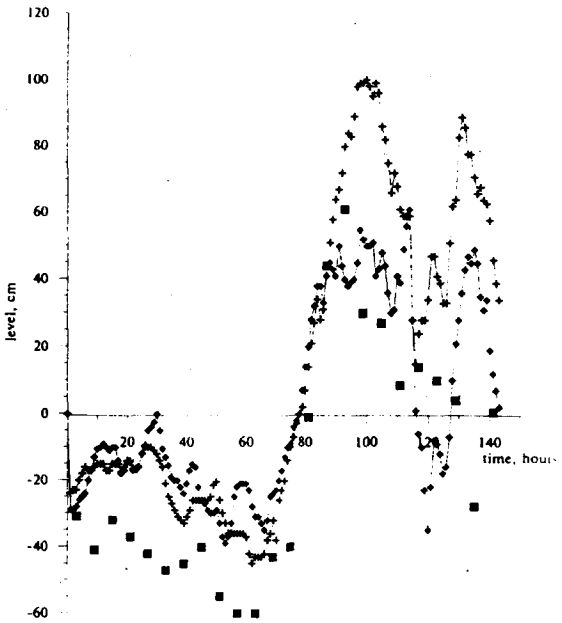


Fig. 5. Temporal variation of sea level at Taganrog, Azov Sea, during the catastrophic storm event of 1969 simulated using hydrodynamic model. Sign ■ indicates observations. Curve (+) represents sea level values calculated by the hydrodynamic model with coarse spatial resolution (9,26 km). Curve (•) represents sea level values calculated with a 1,852 km mesh size, which was used only for the Taganrog Bay.

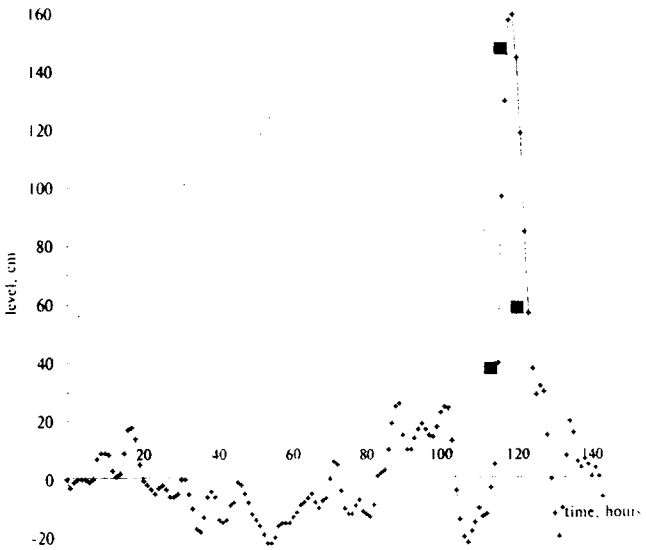


Fig. 6. Temporal variation of sea level at Temruk, Azov Sea during the catastrophic storm event of 1969 simulated using hydrodynamic model with coarse spatial resolution (9.26 km grid).

Sign ■ indicated data observations.

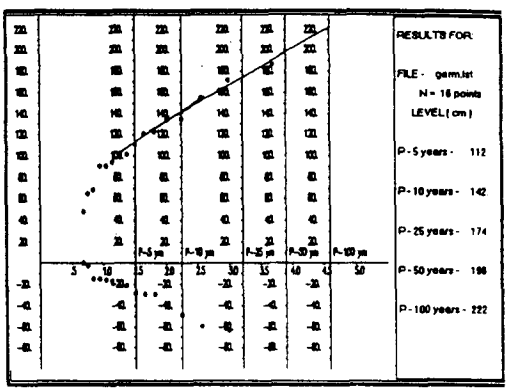


Fig. 7. Surge and negative surge heights distribution function for a point located near Varandey in the south-eastern part of the Barents Sea simulated by hydrodynamic model (11,112 km mesh size) and stochastic modelling.

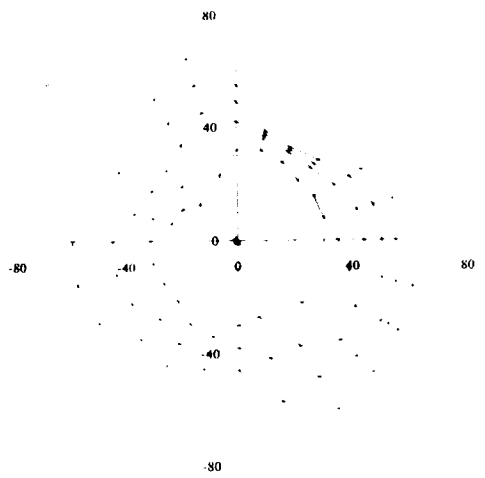


Fig. 8. Directional distribution function of total currents (cm/s) possible once in 5, 10, 25, 50 and 100 years for a point located near Varandey in the south-eastern part of the Barents Sea simulated by hydrodynamic (11.112 km mesh size) and stochastic modelling.

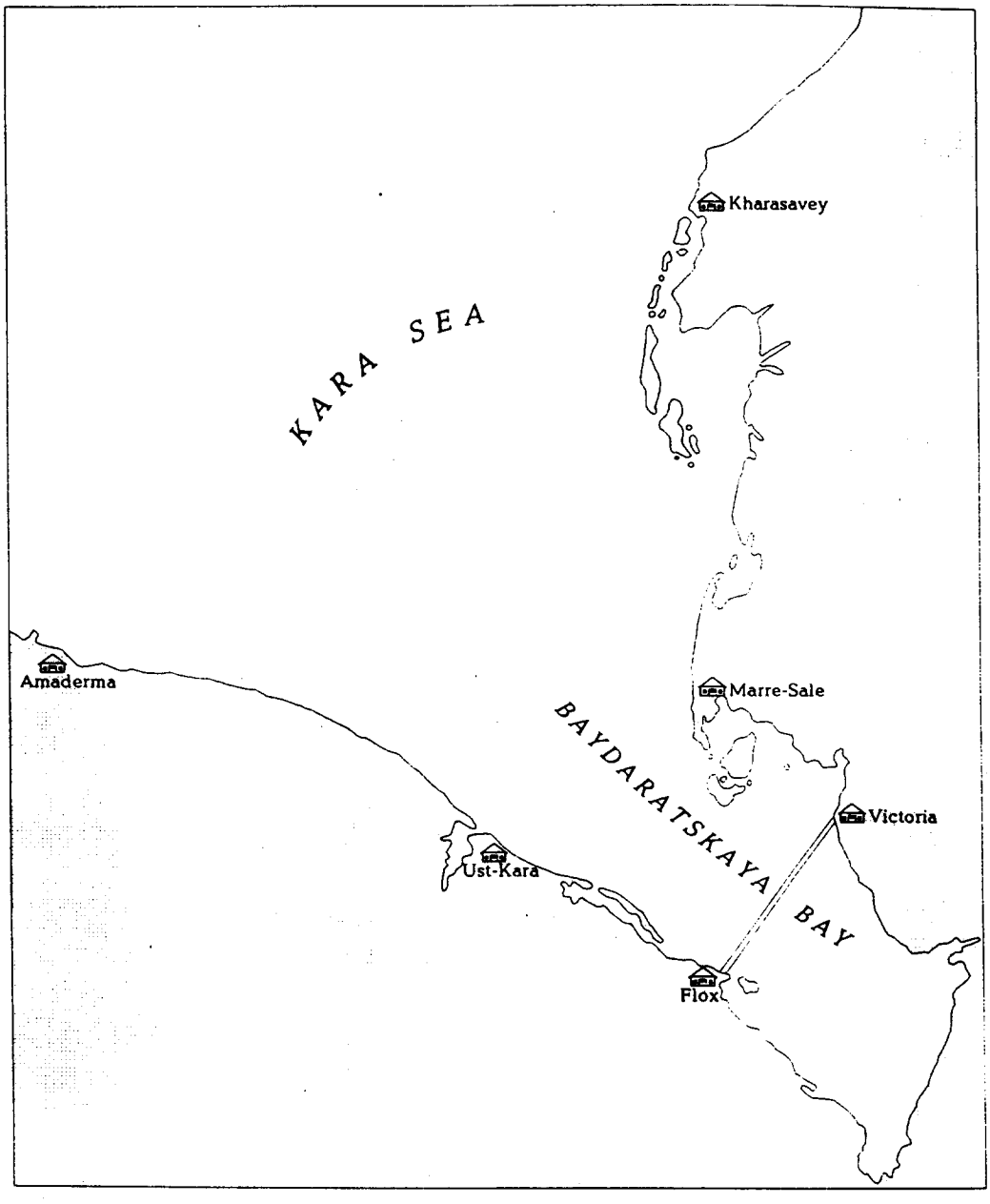
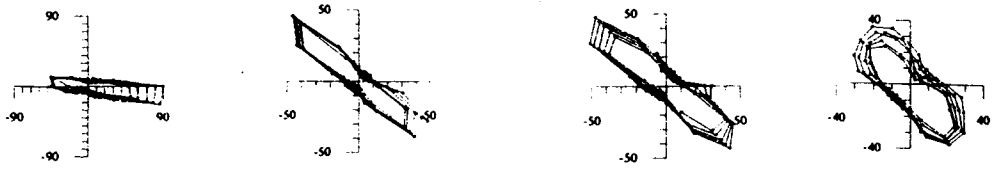
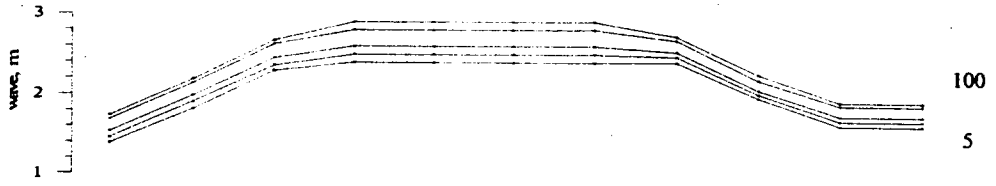


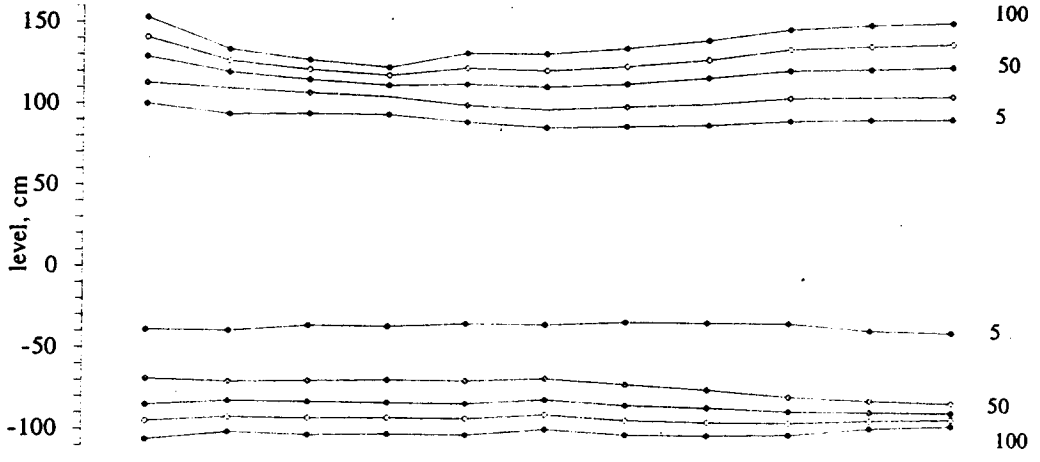
Fig.9. The chart of Baydaratskaya Guba Bay and South - West part of Kara Sea.



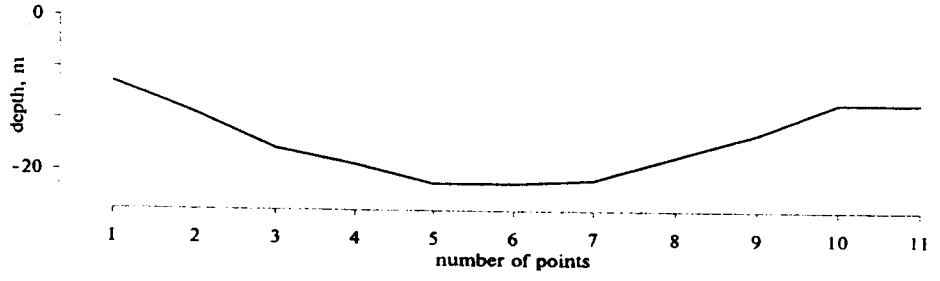
a) directional distribution functions of total currents (cm/s) possible once in 5, 10, 25, 50 and 100 years;



b) mean wave heights possible once in 5, 10, 25, 50 and 100 years;



c) surge and negative surge heights possible once in 5, 10, 25, 50 and 100 years;



d) profile of bottom relief along the pipeline in the Baydaratskaya Guba Bay. Kara Sea.

Fig.10. Extremal dynamic characteristics along the pipeline in Baydaratskaya Guba Bay, Kara Sea.

SESSION II

Mechanisms and Processes

Session II-b
Geological Framework

Chairman: I.N. McCave & M. Ergün
Rapporteur: R.A. Davis Jr.

Proc. Int. Conf. 'Coastal Change 95' Bordomer-IOC, Bordeaux, 1995, p. 79 - 91

COASTAL CHANGE: DETERMINATION OF HISTORIC AND HOLOCENE TRENDS, AS A BASIS FOR ASSESSING HUMAN IMPACTS

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ABSTRACT

An increasing proportion of the world's coasts are strongly affected by human activities, both physically and biologically. Additionally, the effects of enhanced global greenhouse are likely to cause future changes of nearshore wave climates, storm frequencies and sea level. To assess both global and local anthropogenic impacts, patterns of natural coastal changes need to be known and longer-term trends need to be separated from short-term variability. Geomorphological and stratigraphic studies of coastal changes during the last 8-10,000 years are a good basis for estimating longer-term trends and for assessing coastal responses to sea level rises. Such studies also can provide three-dimensional data on coastal changes that are useful for testing numerical models of coastal behaviour, which increasingly will be used to evaluate the effects and possible reversibility of present-day human impacts. Selected studies of longer-term behaviour and changes of several types of coast are reviewed in this paper, including wave-dominated coasts, tide-dominated estuaries, low-energy tropical coasts and coral reefs. Most of the studies come from the Australian region. Some examples of numerical modelling are also reviewed briefly, to illustrate how models can be tested by using studies of past coastal changes.

INTRODUCTION

Coasts and beaches are challenged by impacts of human activities, climatic changes, and a possible rise of sea level in future. In terms of human impacts, coasts and beaches range from pristine paradises to man-made hells, with diverse usages and human clutter in between. There is a corresponding range of coastal problems. All coasts including the most pristine are liable to affected by changes of climate and sea level, but problems such as erosion, pollution and eutrophication beset coasts that have heavy human impact. Forecasting future coastal changes is different from alleviating acute coastal problems but the underlying principles of hydrodynamics, sediment transport and ecology are common to both. Furthermore, for both categories of problem, modelling proceeds on similar lines, using similar principles.

This paper is concerned with coastal changes in the recent geologic past. Knowledge of past changes can be used to predict future trends, in some circumstances, and also can provide a basis for testing models of present coastal behaviour. Although the geologic past contains no analogues of urbanised and heavily impacted coasts, coastal responses to past changes of climate, river discharge and sea level can serve as partial analogues for changes that might happen in future. Moreover, if past changes can be simulated, then confidence in models is raised.

Coastal effects of past sea level and climatic changes are examined in this paper, including impacts on wave-dominated coasts, estuaries, low energy coasts and coral islands. Many of the illustrative examples are based on Australian studies. Most Australian coasts receive little sediment directly from rivers (sediment yield from the Australian continent is very low, owing to its tectonic stability and generally low relief), but there are substantial, dynamic exchanges between coastal and nearshore sediments, and Australian coasts emulate those found in many other parts of the world. For reference, regional patterns of coastal boundary conditions (wave energy, tides, climate, cyclone frequency and sediment type) around Australia are shown in Fig. 1. No specific scenario of future, enhanced global greenhouse

conditions is adopted, as these are as yet uncertain (Wigley and Raper, 1992).

PRIMARY CONCEPTS

Some elementary principles

Modern coasts began to develop towards the end of the last major rise of sea level, which was caused by melting of the northern ice sheets at the termination of the last ice age. To name a few major effects of the marine transgression over the continental shelves, sediment was driven landwards, valleys were inundated and coral reefs were reactivated. Commencement of inundation, subsequent changes of coastal geometry and the local rate of sea level rise varied from site to site. Most sedimentary coasts change their form at synoptic, seasonal or interannual time scales. Variations of form associated with movement of sediment represent the *morphodynamics* of the feature (de Vriend, 1991). Morphodynamic patterns vary; for example, wave dominated sandy beaches switch between different morphodynamic states according to prevailing and antecedent weather conditions (Short and Wright, 1984). Variations of shoreline form and position may occur suddenly or gradually, at time scales from days to decades (Fig. 2).

Coastal processes are complex but some simple concepts have been used to estimate how beach profiles respond to a change of sea level, and how beaches respond in planform to a change of wave direction. For a change of sea level, Bruun (1962) proposed that the form of the shore-normal profile stays constant while the shoreline migrates, with mass balance maintained by transfer of sediment from eroding to depositing parts of the profile as it migrates. In accordance with Bruun's principle, historical coastal erosion has been attributed by Bird (1993) and others to a slow rise of sea level (a sea level rise of 1-2 mm/yr this century is documented by Pirazzoli, 1986). Coastal variability, such as illustrated in Fig. 2, makes it difficult to separate the effects of other factors, however. A second elementary concept is that shoreline curvature tends to be such that longshore sediment transport is minimised, so that beach alignment will change if mean wave direction changes. As reviewed later, simple concepts such as these have been used in mass-balance models that simulate coastal responses to changes of sea level or wave climate.

Historical data

Historical coastal changes have been identified from aerial photographs, maps and other documents, archaeologic investigations and the positions of ancient dykes, docks and other coastal structures. Variability has been monitored by repeated surveys, giving time series of coastal form and position. These data indicate variability, but trends often are obscure. The 15 record of shoreline variation in Fig. 2, for example, shows that beach recovery following a major storm took about 6 years, with considerable high frequency variability, and that no trend can be identified. The interval between successive observations often is much greater than the time scales at which processes operate (Terwindt and Battjes, 1991) and multivariate statistical methods have been used to interpret changes of wave-dominated beaches in terms of tide gauge and wave climate variations at synoptic, seasonal and ENSO scales (Clarke and Eliot, 1988; Bryant, 1983). The importance of historical data and coastal monitoring programs cannot be overstated, if future changes are to be identified early.

Palaeo data

Physical and ecologic effects of past changes of sea level and climate are recorded in nearshore, coastal and estuarine sedimentary deposits and also in coral reefs. Coastal changes that occurred before 6000 years ago (when sea level was rising at about 1-2 m/100 years, owing to melting of ice sheets at the end of the last ice age) provide partial analogues for changes that may occur next century. Analogies are not perfect because (i) coastal geometry then was not the same as now, (ii) global climate was different from today, and (iii) the future rate of sea level rise may be less than it was then. Coastal changes in the last 6000 years, when sea level has been relatively stable, indicate trends that may continue in future if sea level does not rise and human impacts are small. The effects of storm waves and surges are preserved in deposits and beach ridges on prograded coastal plains and coral reef islands, and cyclone recurrence intervals have been

assessed by radiocarbon dating coral shingle ridges (Chivas et al., 1986). Variations of sediment inputs have been interpreted from prograded coastal plains in northern Australia (Chappell and Thom, 1986). Dramatic mobilisation of coastal dunes has been attributed to past episodes of enhanced storminess (Thom, 1978), although further research is needed to fully identify the causes and processes. Finally, past flood events and annual cycles of sea surface temperatures are preserved in terms of oxygen isotopes, trace elements and fluorescence in the growth bands of corals (Gagan et al. 1994; McCulloch et al., 1994). Further studies are expected to provide high resolution data about climatic conditions in tropical regions over the past 6000 years or so.

IMPACTS ON WAVE DOMINATED COASTS

Historical changes

Wave dominated sandy coasts range from simple closed compartments, through composite barrier beach - estuary systems, to series of beaches connected by sediment drift conveyors that operate in either or both the littoral and nearshore zones. All such beaches are expected to retreat shoreward if sea level rises and also will shift with any change of average wave directions and amplitudes. Gordon (1988) linked historical retreat of sandy beaches in New South Wales to the slow rise of sea level identified from tide gauges, but the relationship is noisy and has inexplicable lags. Other Australian studies have demonstrated that beaches have responded in profile and planform to sea level and wave climate variations at seasonal to ENSO frequencies (Clarke and Eliot, 1988; Bryant, 1983), and these factors doubtless account for some of the beach variability shown in Fig. 2. For Australia's wave dominated beaches in general, however, the effects of historical variations of wave climate and sea level have not been resolved clearly.

Modelling approaches

Models have been developed for the responses of wave dominated beaches to changes of sea level and wave direction. One group of models, which embody the concepts of Bruun (1962), rests on mass balance principles coupled with assumptions about the form of the shore-normal equilibrium profile. Roy et al. (1994) have used such a model to simulate development of Australian sand barriers during the post-glacial sea level rise, and a similar model was used by Cowell and Thom (1994) to give schematic estimates of the response to changes of wave direction. The weakness of these schemes is that essentially they assume a general equilibrium profile. A different approach was taken by Chappell (1981), who simulated 3-D topography of the nearshore seafloor with a model that combined wave ray equations with parameterised sediment transport functions. Generally, Australian research in this area is a subset of international research into both the equilibrium profile-based and transport-based approaches. However, a review of models by SCOR Working Group 89 (1991) found that "the status of models for the beach response to elevated water levels is far from satisfactory, and predictions of the associated shoreline recession rates yield uncertain results".

Palaeo data and modelling

Palaeo data furnish information about shoreface sediment budgets, which are necessary for all types of predictive model is used. For Australian wave dominated coasts, historical observations usually do not show whether there is net long-term sediment gain or loss (eg., Fig. 2). Longer term trends based on palaeo data from geomorphologic and radiocarbon dating studies show that some sandy coasts in southeastern Australia prograded seaward throughout the last 6000 years, but others prograded rapidly for only a few thousand years and then stabilised or even retreated (Roy et al., 1994). Such data indicate local trends that may continue if sea level and/or climate remain constant, and give basic boundary conditions for site-specific models.

Questions about effects of future sea level rise can be considered in the light of the past record. Post-glacial changes are not analogues for changes that may occur in the near future (partly because starting conditions were different), but are useful for testing models. Hence, Cowell et al. (1994) and Roy et al. (1994) describe the simulation of coastal sand barriers that formed under rising sea level, using a mass balance - equilibrium profile

type of model. Observed relationships between barrier structure, the slope of the inner shelf, and input of fluvial mud were simulated reasonably well (Fig. 3). It is not clear, however, that palaeo simulations can show whether any given model meets the standards sought by SCOR Working Group 89 (1991), because both the palaeo data and model simulations are at coarser scales than the sort of problems that may arise if sea level rises, next century.

IMPACTS IN ESTUARIES AND DELTAS

The post-glacial record suggests that most estuaries are more likely to be more affected by sea level rise than by changes of wave climate. There are many types of estuaries and deltas, ranging from river-dominated to tide-dominated, entering coasts ranging from very low energy to strongly wave dominated. Estuarine and deltaic plains and wetlands clearly will be vulnerable if sea level rises, but geologic data from the post-glacial sea level rise suggest that the likely changes vary considerably with the degree of tidal or river dominance. This is illustrated by two contrasting studies from northern Australia.

Palaeo data: two examples

The South Alligator River and the Norman River are tidal rivers bounded by wide freshwater floodplains (Fig. 4). Both are affected by fresh water floods during the monsoonal wet season of northern Australia. The South Alligator is macrotidal, with flood-dominated tides where peak flood tide velocity is greater than peak ebb velocity, peak tidal velocities are fairly uniform along the length of the tidal river, and the channel appears to be in equilibrium with tidal flows along most of its length (Woodroffe et al., 1986). By contrast, the Norman River is diurnal mesotidal; the tidal velocity is greatest at the entrance and diminishes upstream, and the channel appears to be in equilibrium with freshwater flood flows that occur in the wet season (Wolanski and Chappell, 1995).

Palaeo data obtained from stratigraphic drilling and radiocarbon dating, summarised in Fig. 4, show that the Norman and South Alligator systems responded quite differently to the post-glacial sea level rise. Rising sea level rise invaded the prior South Alligator valley, changing the fluvial river into an extensive mangrove swamp with a funnelled, macrotidal estuary. Mangrove sedimentation, with a high-tide flooding depth of 0.5-1.0 m, kept pace with rising sea until sea level stabilised. Sediment budgets show that aggradation of the mangrove plain was supported by sediment that moved in from the seaward direction (Woodroffe et al., 1986). In the Norman River, on the other hand, flooding depth increased and the shoreline migrated rapidly inland.

Modelling: a case study

Wolanski and Chappell (1995) modelled the effects of sea level rise on the South Alligator and Norman rivers, using a depth-averaged tide model based on the full non-linear equations of motion, calibrated with channel surveys and portable tide recorders. In both cases, the floodplain surfaces lie close to the present high spring tide level, so that a sea level rise produces overbank flooding. For the South Alligator, the model predicts that tidal asymmetry is reduced and the peak ebb velocity matches peak flood velocity when flooding exceeds a critical depth (Fig. 4). This threshold occurs near the mouth with 0.5 m sea level rise and moves upstream as sea level continues to rise. Bank erosion is expected to occur when peak velocities exceed the present-day value. Predictions for the diurnal, mesotidal Norman River are quite different. A small sea level rise of 0.1 m causes widespread overbank tidal flooding, tidal current velocities increase substantially throughout the length of the channel and tides become strongly ebb-dominated (Fig. 4). Bank erosion is expected throughout the channel when ebb tidal velocities exceed previous freshwater flood velocities.

The response of sedimentation also differs between the two cases. In the South Alligator, sediment liberated by channel widening and by landward displacement of the coast is trapped by the flood-dominated tidal regime, and Wolanski and Chappell (1995) predicted that this will be deposited on the tidal floodplain. Mud transport, which is complex and varies through the tide cycle (Wolanski et al., 1988), was not computed explicitly but Wolanski and Chappell (1995) estimated that sedimentation on the newly-formed

mangrove floodplain could keep pace with sea level rising at over 5 mm/year. In the case of the Norman River, which becomes strongly ebb dominated, sediment liberated by channel widening is transported seawards from the estuary, flooding depth over the former plains increases as sea level continues to rise and the shoreline moves rapidly landwards. These predictions agree with the palaeo data, summarised above. It must be noted, however, that earliest effects of sea level rise have not been modelled, such as the rapid extension of networks of tidal creeks across the plains (a process that is occurring today on floodplains of macrotidal estuaries in northern Australia: Knighton et al., 1992).

Other types of estuaries

More generally, the response of estuarine and deltaic systems to sea level rise varies across the spectrum of tide/wave/river dominance. In terms of fluvial sediment input, the South Alligator and Norman estuaries are both "sediment starved" systems that differ only in tidal parameters (Fig. 5). The study of the South Alligator and Norman systems by Wolanski and Chappell (1995) illustrates how present-day processes, modelling and palaeo data can be combined in order to predict responses to sea level rise. Other systems, lying in quite different fields in the classificatory scheme in Fig. 5, behaved differently during the post-glacial rise of sea level and during the subsequent period of relatively stable sea level. The evolution of wave-dominated barred-basin estuaries in eastern Australia has been documented by Roy *et al.* (1994), from stratigraphic drilling and dating studies, so that the effects of shoreface slope, bedrock geometry and sediment supply - from both fluvial and shelf sources - are qualitatively understood. Quantitative modelling of the responses of such systems to changes of sea level, wave climate or sediment input is in its infancy, however.

LOW ENERGY COASTS

Low energy sedimentary coasts typically have broad intertidal mudflats, seawards of coastal plains that often are marked by intermittent beach- or chenier ridges (eg., the Norman River coastal plain, Fig. 4). For low energy coasts, a greater part in sedimentary processes is played by inter- and subtidal biomes (eg., mangroves, seagrasses, and molluscs), than for wave-dominated systems other than coral reefs. Progradation of muddy sediment usually occurs during prevailing low energy conditions, while ridges are built by occasional major storms. Coarse sediment of the ridges may come either from nearby rivers, or from nearshore shellbeds and coral reefs, or from both. Patterns of progradation and coastal orientation are influenced by peninsulas, barriers and islands that protect the coast from the offshore wave fields, and by the positions of riverine sediment sources. Historically, changes of many low energy coasts in Australia are known anecdotally, but there has been little systematic monitoring of change.

Palaeo data

The effects of past changes of sea level, sedimentation and sediment compaction upon the evolution of low energy coasts have been closely examined in tropical Australia, using stratigraphic, palynologic and radiocarbon dating. In general, patterns of postglacial transgression followed by coastal regression resemble those described elsewhere (eg., the English fenlands; Godwin, 1986), although details including the effects of sediment compaction and minor changes of relative sea level are different. The landwards retreat of low energy coasts in tropical Australia, during post-glacial sea level rise, is recorded by transgressive horizons of muddy mangrove peat over the prior land surface; typically, these are buried by regressive nearshore sediments capped by mangrove and other intertidal sediments that prograded during the last 6000 years of relatively stable sea level (Chappell and Grindrod, 1984; Grindrod and Rhodes, 1984; Woodroffe et al., 1986). The effect of sediment compaction has been documented by comparing past relative sea levels at prograded mangrove coasts with results from nearby fringing coral reefs (Chappell and Grindrod, 1984).

Possible future changes

Two frequently asked questions about the future of low energy coasts are concerned with the

effects of sea level rise, and of high energy storms ("tropical cyclones", in Australian parlance). The geologic record shows that all low energy coastlines retreated landwards during the post-glacial sea level rise but cannot answer the question of whether there is a minimum rate of rise, below which sedimentation would maintain a stationary or slowly prograding coast. Beach- and chenier ridge sequences, formed during the last 5-6000 years, show that the coastal effects of cyclonic storms vary with the supply of coarse sediment. Studies in northern Australia indicate that individual storms produce new beach ridges, but may erode chenier ridges that were produced by earlier storms (Fig. 6). The frequency of ridge building is less related to storm frequency than to the input of coarser sediment from an adjacent river, or from nearshore production of mollusc or coral detritus (Rhodes, 1982; Chappell and Thom, 1986). The dependence of beach ridges on the supply of coarse sediment is also shown by ridge plains near river mouths, where deltaic channel switching has caused discontinuities in beach ridge patterns. In general, cyclonic ridges form when a nearshore supply of coarse detritus exists (indeed, cyclone recurrence intervals over the past 3000 years were estimated from sequences of coral shingle ridges, by Chivas et al., 1986). No evidence suggesting that coasts were protected by ridges during post-glacial sea level rise has been reported from Australian studies.

CORAL REEFS AND REEF ISLANDS

Of all of the world's coastal peoples, those who live on low-lying coral islands seem to have the fewest options, if sea level should rise in future. Specialist opinion is divided, however. Some predict that low coral islands will be destroyed by rising sea level; others predict that coral reef flats will be rejuvenated and will provide more sediment for building reef islands (Hopley and Kinsey, 1988).

For coral reefs, the past is a guide to the future, because the effects of post glacial sea level rise and coral reef growth are well preserved and have been widely studied. Most modern reefs are built on rather shallow foundations (5 to 20 m deep) that were drowned during the late stages of post-glacial sea level rise, but growth rates and reef structures vary. During the post-glacial sea level rise, reef growth rates varied with depth of water and location within a reef complex (forereef, crest, lagoon, etc.), and ranged from zero to more than 1.5 m/100 years (Hopley, 1982; Hopley and Kinsey, 1988). Upward growth kept pace with rising sea level in some instances ("keep-up" reefs), lagged behind sea level in many other cases ("catch-up" reefs) and, in extreme cases, some reefs ceased growing and were drowned ("give-up" reefs) (Neumann and Macintyre, 1985). It is not clear whether all reef zones could keep pace if sea level rises in future - and the capacity to do so will be affected by human impacts upon specific reefs - but, in general, the palaeo data indicate that coral framework of upper forereef zones could keep pace with a sea level rise of less than 1 m, in the next 100 years.

Reef islands and rising sea level

Essentially, reef islands are built of detritus derived from their surrounding reef. The processes that focus detritus on a reef platform clearly are important but vary from reef to reef (islands range in area from less than 1% of the area of the surrounding reef to more than 20%). Radiocarbon dating studies indicate that reef islands began to form after shallow reef platforms had developed, either when sea level effectively stabilised ("keep-up" sites) or afterwards (usually "catch-up" sites) (Hopley, 1982; Woodroffe and McLean, 1993). The effect of subsequent small changes of sea level on island growth also has varied. There is evidence that sea level relative to many reef islands was about 1 m above its present level, 3-5000 years ago (Hopley, 1987; Yonekura et al., 1988) and the subsequent minor fall of sea level may have assisted island growth and consolidation (Woodroffe and McLean, 1993). However, islands exist on Caribbean reefs that have been subject to a slow relative rise of sea level over the last 6000 years (Shinn et al., 1982). In the Great Barrier Reef, where the course of relative sea level varies owing to hydro-isostatic deflection of the shelf (Chappell et al., 1982), platform reef islands are relatively large on the inner shelf, where sea level has fallen by about 1 m in the last 6000 years, and are mostly small to negligible on the outer reefs where sea level has

risen by 1-2 m. To summarise, the relative effects of Late Holocene sea level, wave climate, and "catch-up" versus "keep-up" reef foundations upon the sizes and distribution of reef islands have not yet been resolved.

Enhanced greenhouse and other anthropogenic impacts

Prediction of the effects of future sea level changes is complicated by the fact that coral islands are subject to a substantial variability of mean water level and wave climate. Tropical Pacific sea level varies seasonally by 0.1-0.2 m, and varies by over 0.4 m with ENSO phenomena (IGOSS, 1992). Pacific island tide gauges show a slowly rising sea level average trend of 1-2 mm/year but values vary from -4.8 mm/year (Kiribati: Christmas Island) to +6.8 mm/year (Papeete) (Emery and Aubrey, 1991). Historical erosion and deposition at island sites in Kiribati and Tuvalu has been documented by the South Pacific Applied Geoscience Commission (SOPAC) (Gillie, 1993). Some changes may be caused by ENSO-related variations of sea level and wave climate (Howorth and Radke, 1991) but the longest time series of annually repeated surveys extends for only 7 years. Changes have been caused at some sites by coastal protection work and causeways (Byrne et al., 1993; Gillie, 1993).

For coral islands, the effects of rising sea level and temperatures owing to enhanced global greenhouse are likely to be worst where human impacts on reef ecology are greatest. A possible chain reaction runs as follows. For an island to keep pace with rising sea level, production of reef detritus must continue. Whether wave transport will focus the detritus on existing islands is uncertain (for similar reasons as apply to wave dominated beaches but with greater uncertainty). As a margin of uncertainty, production of detritus may have to be significantly greater than at present. However, shallow reef production may decline, if extreme high temperature events become more frequent and cause extensive coral bleaching and die-back (Jokiel and Coles, 1990). Furthermore, many reef ecosystems are being degraded by human pressures, reducing coral production (Wilkinson and Buddemeier, 1994, conclude that human factors pose an immediate threat that "may result in a lethal synergy", causing more damage than future sea level rise or climatic changes). If the islands fail to keep up with rising sea level, the freshwater lens on which island people depend is likely to become smaller (Roy and Connell, 1991).

In summary, although the ways in which coral reefs and islands responded to post-glacial sea level changes is well documented, the variation across the range of coral island types is largely unexplained, and there are no past analogues for present day human pressures.

CONCLUSIONS

Qualitative tendencies of coastal responses to changes of sea level or wave climate are known from geomorphologic studies, but for planning and management purposes specific answers are sought for specific questions, such as "by how much will this particular coastline change; how fast; is it happening already, and what can be done?". Early detection of future coastal changes necessarily will be based on data from monitored sites. Both detection of trends and decision making are aided by process-based models, supported by monitoring, historical data, and palaeo data from the post-glacial period.

The future greenhouse scenario is not yet securely predicted. In order that coastal changes are detected sufficiently early for planning and management purposes, trends must be identified against a background of coastal variability. In many coastal environments where human impacts are pronounced and wave and/or tidal energies are low, trends caused by climatic changes may be severely masked. This is particularly so in systems where biogenic production of sediment is important, such as on coral reefs. Process-based numerical models of coastal systems, that will become the key to prediction, can be tested against historical and palaeo data. In Australia, palaeo data are being used with some success in testing models of change on wave dominated coasts and tropical estuaries. However, models alone do not substitute for knowledge of ongoing coastal changes. In the author's view, coastal monitoring programs are of the utmost importance but are performed insufficiently

frequently, without commitments for their longer-term maintenance, and are done in too few places.

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Fig. 1. Generalised coastal variations around Australia. Symbols are to be read from landwards to seawards, following the symbol stack. Regions: southeast, quartz marine sand and minor fluviatile clastic input; Great Barrier Reef, coral with protected coast; Gulf and Far North, mixed quartz sand and mud coasts; Northwest, mixed rocky, quartz and carbonate sands; Western to eastern carbonate provinces, dominantly biogenic carbonate sand. Coastal types: 1, large barrier coasts; 2, mainland beach coasts; 3, small barrier coasts; 4, tidal plain coasts. Other symbols are self explanatory. Based on data in Thom, 1984) and Short, 1988); greenhouse hazard classes estimated by the author.

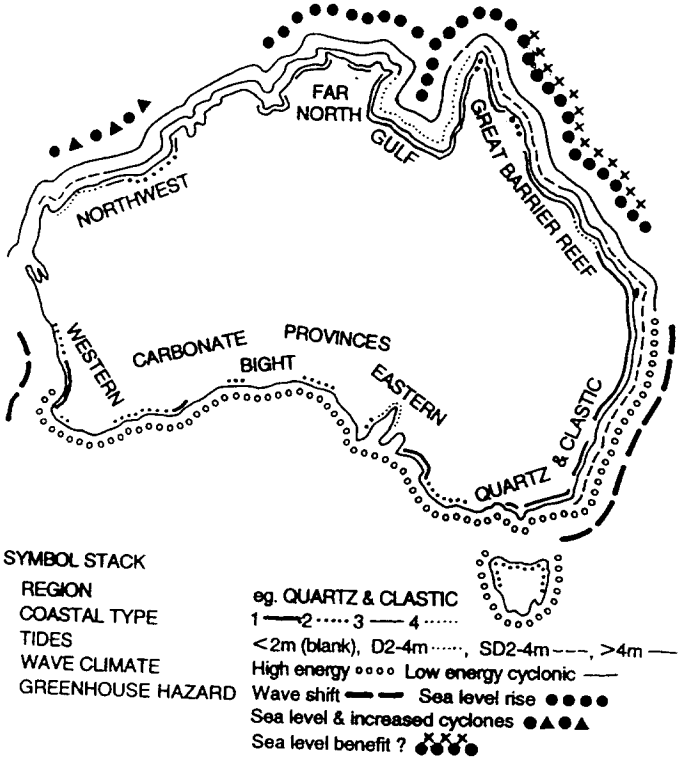
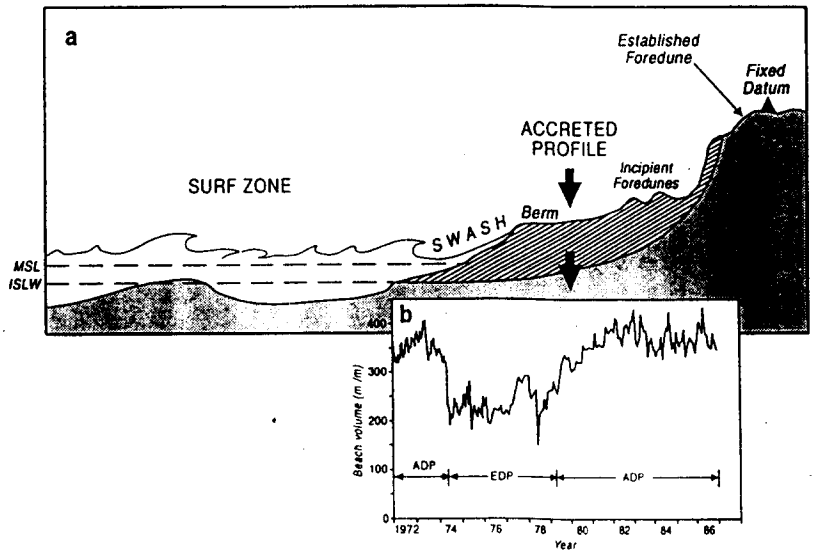


Fig. 2. Monitored variations of cross sectional volume at central Moruya Beach, NSW, over 15 years,, a) definition of sand volume monitored,, b) monthly variations, 1972-1987. The major retreat event in 1974 occurred during passage of an offshore cyclone, after Cowell & Thom, 1994).



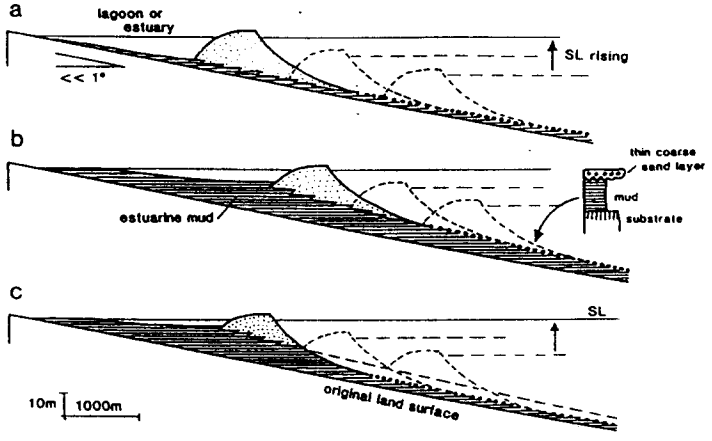


Fig. 3. The effect of post-glacial sea level rise on wave dominated coasts, simulated by a mass balance - equilibrium profile model., a) Barrier advances landwards over prior land surface;, b) barrier advances over estuarine muds, migrating more slowly, and, c) as in, b) but barrier leaks sand seawards, and thus is smaller and migrates more rapidly, after Roy et al., 1994).

Fig. 4. Left and right panels show the South Alligator macrotidal estuary and the Norman River diurnal mesotidal estuary, respectively. Estuarine plains of 6000 years ago are shown on western side of channel in both cases; present estuarine and coastal plains are shown on eastern sides. Centre panel: present tide-cycle velocity curves for South Alligator, a) and Norman, c), numbers indicate distance from river mouth), and predicted velocities with indicated sea level rises, from Wolanski and Chappell, 1995).

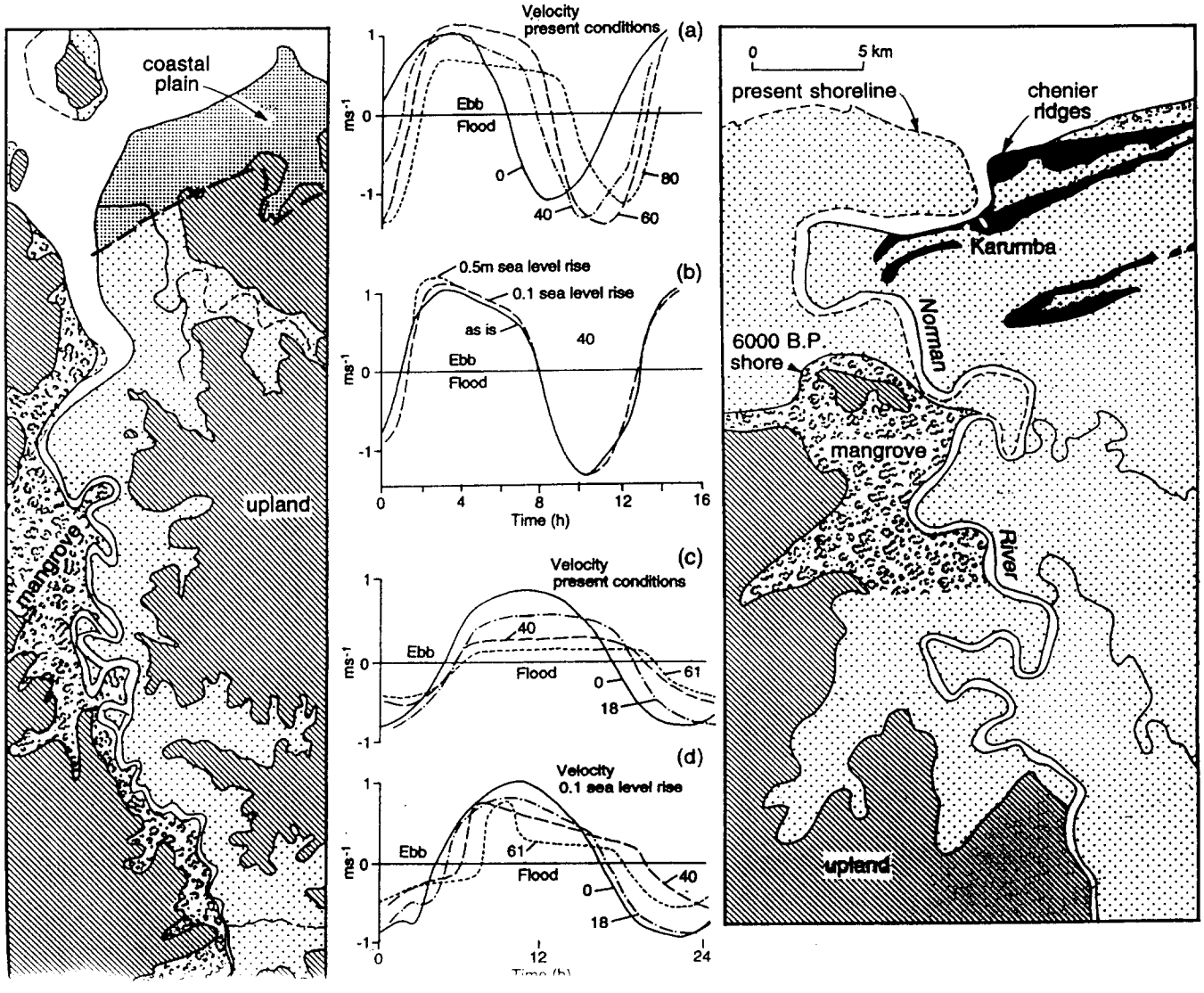


Fig. 5. Classification diagram for estuaries that are developed in Holocene sediment bodies, including deltas. The horizontal axis is the ratio of Q_t, mean tidal discharge at entrance) to Q_b bankfull fluvial flood discharge at tidal limit). The vertical axis is the ratio of V_t, total volume of fluvial sediment that entered the system during the period in which 90% of the Holocene sediment accumulated) to V_e, volume of the Holocene sediment body). Positions of some example systems are inidicated; SALL = South Alligator and NORM = Norman are discussed in this paper., After Chappell & Woodroffe, 1994).

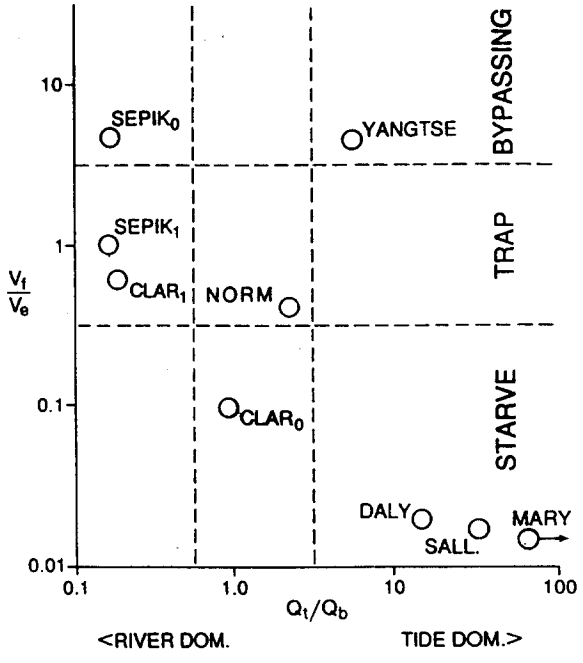
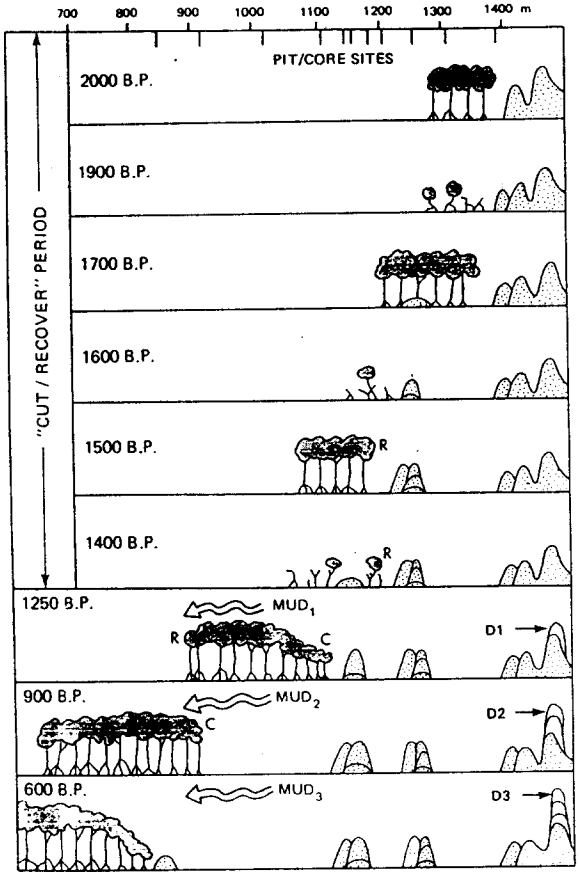


Fig. 6. Episodic progradation of a muddy mangrove coast alternating with formation of chenier ridges, at Princess Charlotte Bay, northern Australia. Chenier ridges shown stippled; R = *Rhizophora* forest, C = *Ceriops* forest; D1 to D3 = phases of clay dune formation., After Chappell & Grindrod, 1984).



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EVOLUTION OF A NEARSHORE AND COASTAL MACROTIDAL AND TRANSPORT SYSTEM, QUEEN CHARLOTTE ISLAND

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ABSTRACT

The coast of the Queen Charlotte Islands (Fig. 1) off the Pacific margin of Canada has been changing constantly since glacial times under the influence of isostasy, tectonics and sediment transport. Grounded piedmont type glaciers inundated and isostatically loaded the troughs which indent the shelf as far west as the shelf edge during the last glaciation, ending by approximately 13,000 years BP. During this period the nearshore area (at least 35 m below present sea-level) adjacent to the Queen Charlotte Islands was subaerial and supported terrestrial environments. At 10,400 years BP relative sea-level was more that 100 m below that of today and large areas of the shelf were exposed. Eustatic sea-level rise, coupled with subsidence of a glacioisostatic forebulge, allowed sea-levels to rise very rapidly (7 to 10 cm/year) and reach the present shoreline on the Queen Charlotte Islands (Haida Gwaii) by about 9,100 years BP. This rise continued until between approximately 9,000 and 7,500 years when sea-level was 15 m above present levels. Sea-levels then fell until about 5,000 to 6,000 years ago after which the rate of fall was greatly reduced.

Presently sea-levels are still falling at very slow rate (1-2 mm/year). This would account for the extensive (40 km) coastal plain which is actively prograding on the north coast of Graham Island. However, the entire 120 km eastern coast of Graham Island is actively eroding. At the junction of these two systems is Rose pit, which extends northeastward at a point of sediment transport convergence. Rose pit marks the point where Hecate Strait, a shallow, asymmetric channel lying between the Queen Charlotte Islands and the British Columbia mainland, meets Dixon Entrance, an elongate, east-west orientated strait that separates the Charlotte Island and the islands of southern Alaska north beach, while coastal bluff retreat on the east beach, determined from beach profiles and repetitive a real photography, is estimated to be between 1 and 3 m/year with up to 2 m of coastline observed to retreat in 6 hours during winter storms. This erosion has exposed gold bearing heavy mineral deposits that have been exploited on a small scale since the late 1800's. Historical bathymetric data and aerial photographs indicate that the platform seaward of the present spit has extended 10 km to the northeast and at least three portions of the offshore bank have become emergent since 1911, resulting in hazards to navigation. Initial observation would suggest that the loss of sediment eroded from the Quaternary bluffs on the eastern coast of Graham Island should account for the development of the extensive spit platform extending offshore from Rose pit. What is not clear is how three sand bars can become emergent and how sediment transport from the eastern coast bypasses the spit platform to act as the supply for the accretion on the north beaches of Graham Island.

The area is seismically active, being near the boundary of the Pacific and North American plates, and subject to storm-related sediment transport events superimposed on strong semi-diurnal tidal flows (5 m tidal range). The emergence of the offshore banks and the net coastal changes are primarily controlled by:

1) convergence of sediment transport between the waters of Hecate strait to the south and Dixon Entrance to the north;

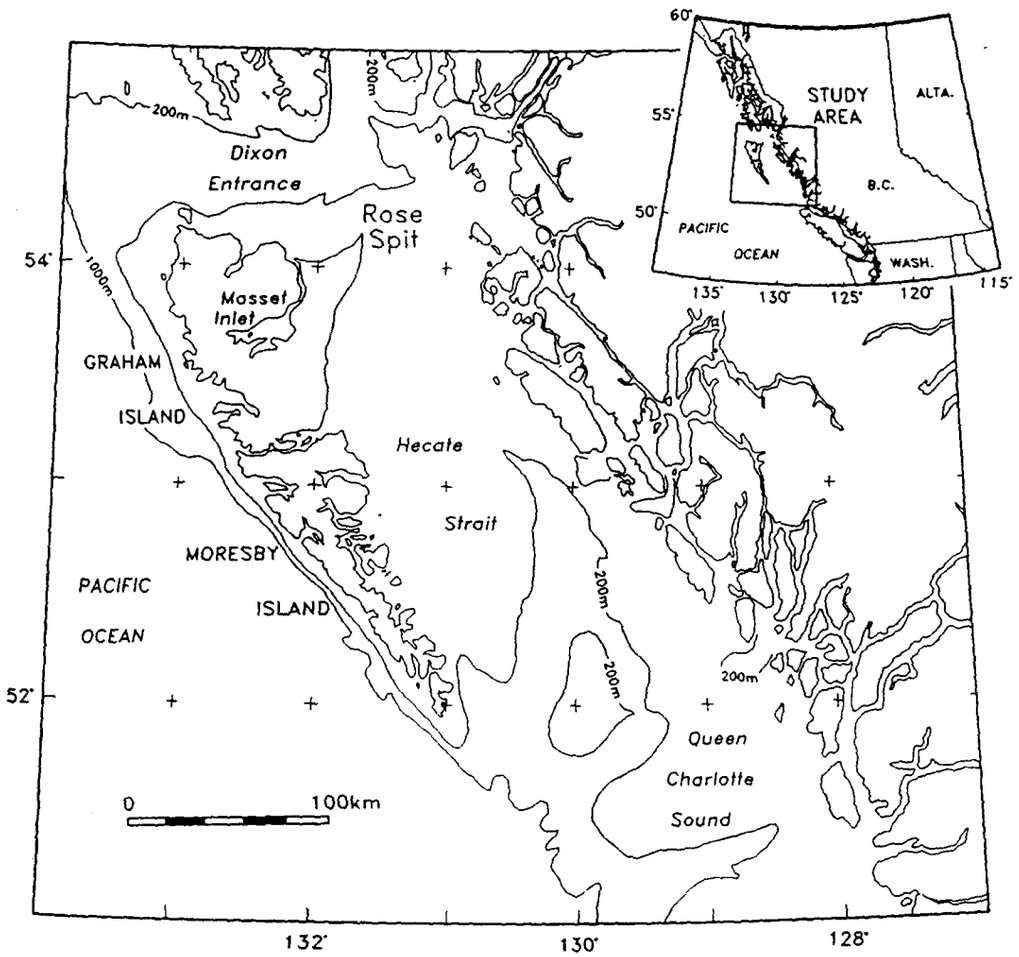
2) localised tectonic uplift; and

3) enhanced coastal erosion due to log barriers, a result of the escaped logs from the forestry industry.

Sediment is transported north from the shallow waters of Hecate Strait by southeast winter storms and east, by longshore transport, along the northern coast of the Queen Charlotte Islands to converge at Rose pit. A "hydraulic fence" has formed resulting in the prograding elongate platform with emergent sand islands, east of the spit. Transpressional folding has and is occurring in this area east of the Queen Charlotte Fault, which separates the North American and Pacific plates.

This has resulted in localised uplift since Pliocene times, augmenting the accretion process. During southeasterly storms, which coincide with ebbing tides, sediment is funnelled into the north coast through a channel directly seaward of Rose pit, providing sediment for north coast accretion. These dramatic sediment transport and sea level conditions result in a coastline that is in constant change.

Fig. 1. Map of Queen Charlotte islands, Canada.



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Shoreline Changes at the Middle-Western Coast of Taiwan Island, China

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KEYWORDS: shoreline, sand bar, wave, erosion, accumulation, submerged, sediment transport

ABSTRACT

Due natural and human effects, much erosion has occurred on the shoreline of InLin and ChiaEi. The shorelines of the InLin coast retreated about 100 m locally from 1904 to 1987; The average change rate of shorelines on the ChiaEi coast, is -18.45 m/yr in the last ten years. The sand bars located outside the coast of InLin and ChiaEi are unstable and are eroded by wave and wind gradually. Some sand bars have temporary disappeared or submerged beneath the mean sea water level, such as HaFon bar and TonSun Bar. The largest and most famous bar, the WhySunDean Bar, is shifting position toward the south-east. The maximum migration velocity is about 0.65 to 1.15 km/yr. The maximum sand volume loss is about $4x10^6$ m^3/yr.

INTRODUCTION

Taiwan is an island country with sandy shorelines, due to sufficient sediments supplied from rivers (Cheag, 1974; Liew, 1980; Hwang, 1993;)There have many sand bars located offshore in western Taiwan. Those sand bars can intercept the incident wave energy; therefore, shorelines and beaches are protected by those bars. Waves behind the bar are lower than offshore, and there are many people breeding oysters, clams, etc. However, in recent years the surface areas of those sand bars are eroding and decreasing seriously and some have even disappeared or submerged temporarily under the mean sea-level. Consequently the coast is impacted by waves directly, shorelines are eroding and some coastal disasters such as storm surge, highway collapse, etc., have happened. These phenomena not only cause the loss of land, but also threatens the safety of people's life and property. Especially, there are many people living along the coast who rely heavily on nearshore fishery, aquaculture and agriculture. Coastal disasters will cause them to lose their traditional living. Now, many breakwaters and harbours are proposed for the InLin coast for industry and economic needs. All of these constructions will change the stability of waves and sediment transport and will cause the erosion of shorelines and sand bars. Therefore, the government has attached much importance to the problems of shoreline erosion, and many projects are being carried out to find the control methods. The main purpose of this paper is to discuss the variation of shoreline change in the south-centre Taiwan and to determine the reasons for shoreline and sand bar erosion.

CHARACTERISTIC OF INLIN AND CHIAEI COAST

Fig. 1 shows the location of InLin and ChiaEi coast in Taiwan. From this figure we see there are many sand bars located along the nearshore region of the InLin and ChiaEi coast.

There are many rivers flowing through InLin and ChiaEi to the ocean. The most important are the rivers SiLo, TsouSuei, SinFuWei, ChoFuWei and PeiKung. All these rivers carry much sand to the estuary and supply the longshore transport. Therefore the shorelines of InLin coast are more regular than those of other counties. The sediments transported from rivers accumulated near the estuary to form a wide beach (intertidal land) along the coast. Fig. 2 is the verification of this coastal terrain; This figure was drawn in the eighteenth century. From this figure we can see clearly that there was a wide beach. Sands accumulated to form the sand bars, which is to say, the sand bars existed from an early age by the deposited river sands. There just two large rivers flowing through ChiaEi to the sea, the PuZe and PaZan. However, due to

the wave refraction caused by sand bars, located along the in the InLin coast, much sand transported by the longshore current is deposited in the nearshore area of ChiaEi coast, and some sediments carried by the PaZan river also have accumulated in the estuary to form the beach and sand bars, of which the largest is the WhySunDean bar. Therefore the geography of the ChiaEi coast is similar to the InLin coast in that shorelines are very curved and there are many sand bars in the nearshore region. All the characteristics of InLin and ChiaEi coast can be seen in old maps, e.g., Fig. 3 and Fig. 4, dating from 1714 and 1854, respectively. These figures show the coastal characteristics of InLin and ChiaEi mentioned above.

SHORELINE CHANGES OF INLIN AND CHIAEI COAST

From Fig. 2 to Fig. 4 we find that there have been many sand bars existing in the nearshore regions of the middle-western coast of Taiwan. That is the sand bars had been existing earlier and would be still developing if the sediments were supplied continually. These were due to many rivers flowing through InLin. All of those rivers transport sediments to the estuary and provide a source of longshore transport, sand bars growth and the shorelines are growing too. However, it has been shown that stability of the shoreline is related to stability of the sand bars. All the sand bars existing in the middle-western coast rely heavily on the sediments from rivers and the longshore current flowing to the south, but the controlling influence is the sand transport from rivers. An important verification is the change of HaFon bar. According to the old survey data and historical records, before 1890 the HanFan bar did not exist. In 1898 a reservoir at TouLinTan burst and the overflow flood generated a new waterway, the SinFuWei river. The great amount of sand, carried by this river to the coast, was deposited in the nearshore region and then the HaFon bar formed gradually. This bar reached a maximum area in 1926 (280 hectares at high tidal level, and 640 hectares at low tidal level). After this time, reservoirs were built and the waterway of SinFuWei was changed, decreasing the sand supplied from the river. Therefore, the area of HaFon bar was reduced greatly and moved toward the southeast. About 1958 the HaFon bar fell below the mean sea-level. Due to this reason, the shoreline was eroded by waves directly and some coastal disasters also occurred.

Fig. 5 shows the shoreline change of the InLin coast from 1926 to 1991 and Fig. 6 shows the shoreline (low tidal level) changes from 1902 to 1979. It can be seen that the shorelines have retreated, that is the shoreline has eroded from 1902 to 1991. The maximum retreat rate is 8.8 m/yr during 1904-1919. This was due to the fact there having been many rivers flowing through InLin carrying rich sediments to be deposited in the estuary and feeding the longshore transport, and many growing bars. However, about forty years ago many reservoirs were built up stream rivers, and soil conversation was doing better than previously, therefore the sands carried by rivers decreased rapidly. Additionally, for the economic development many harbours were built in the northern part of InLin and ChiaEi. The breakwaters of those harbours act as interceptors cutting the seasonal longshore sediment transport, having a significant impact on the shoreline sediment balance, consequently shorelines are eroded. Fig. 7 shows the shoreline change on the InLin coast, revealing both local accumulation erosion. Table 1 is the coastal area and shoreline change rate of the InLin coast from 1904 to 1987. According the report from Taiwan Land Resource Development Commission, the maximum erosive distance is one kilometre from 1902 to 1938 and the erosive rate decreased after that year.

Fig. 8 shows the change of shoreline and sand bars in ChiaEi county from 1926 to 1991. From this figure, we see that shorelines of this county are very irregular in shape and there are several bars located offshore, the largest in the middle-western coast being WhySunDean bar. These coastal characteristics are influenced by the sufficient longshore transport of sediments from the north, supplied by the rivers in InLin county. Table 2 gives the coastal area and shoreline change rate of ChiaEi coast from 1904 to 1987. We see that the erosive rate increases obviously from 1977, and the average retreat speed is 18.45 m/yr. The cause is

the decrease in the WhySunDean bar whose position shifts toward the southeast. This change causes the waves to act on the coast directly, and all the phenomena in the nearshore region such as wave energy, longshore current and sediment transport are changed, then the stability of shoreline is gradually eroded. Another set of maps, showing the shoreline changes due to the phenomena mentioned above is shown in Fig. 9.

Why SunDean bar is the largest sand bar in west Taiwan, and its formation is thought to be due to sediments transported by the rivers. Early survey data show that this bar appears after 1900, and before this time the WhySunDean bar was submerged. There was a bar called TonSun bar at the northern limit of the position where the WhysunDean bar is now. By the wave action, sands eroded from TonSun bar were carried by the longshore current and deposited to the south to form the WhySunDean bar. The processes of the decrease of TonSun bar and the formation of the WhySunDean bar can see clearly in Fig. 9. The WhySunDean bar reaches a maximum area in 1960-1970, but after this time it became unstable and was gradually eroded by waves and recently shifted toward the south. Fig. 10 shows the shoreline changes of this bar from 1900 to 1990, revealing that the area and position of the WhysunDean bar changes continually from 1900 to now. According to the field data surveyed by IHRT from 1991 to 1994, this bar has a migration velocity of about 0.6 km/yr towards the east and 0.85 km/yr towards the south. The maximum erosive distance in the onshore direction is 220-260 m from 1991-1992 and the total loss of sand volume is four million m^3 (above -4 m water depth). This result is similar to the results presented by ITRI. The ITRI used satellite remote sensing data to analyze the changes of the WhySunDean bar. They show that the average movement rate of the WhuSunDean bar is between 0.65 and 1.15 km/yr, and the most serious erosion may occur at the south end of this bar. ITRI also shows that the WhySunDean bar was eroded by waves. If there is insufficient supply of sands, the WhySunDean bar may be submerged or disappear in the future. The cause of the change in the bar was considered to be the decrease of sands supplied from rivers in the north. However, it was verified by field investigation that wind blown sand also affects the changes of WhySunDean bar. All the phenomena may be investigated in detail in the future. The other reason for accelerated erosion is reduction of the WhySunDean bar by waves. When wave climate, including wave refraction, diffraction and incident wave energy change, the longshore currents increase. Therefore, the erosion increased too. These phenomena cause the shorelines of ChiaEi to be eroded quickly.

Moreover, the excess removal of ground water by the fish breeding industry caused the strata to compact significantly and the mean sea level has risen above the land level, so many places are impacted by waves directly. When storm surges occur, sands are removed offshore; this situation is also a main cause of shoreline changes.

Two important economic constructions were carried out in the middle western coast, the InLin offshore industrial zone and the LiouChing petrochemical industrial zone. The coastal characteristics of those construction's locations are unstable and erosive. The construction will change the stability of the sediment transport system and cause shoreline variations. In particularly, the breakwaters of those structures will prevent sand transport by longshore currents from the north, and cause change of reflection, refraction and diffraction of waves. Therefore, shorelines and bars will change. These phenomena must be considered carefully, otherwise unexpected coastal disasters may occur. To solve the problems mentioned above, many projects with numerical and physical models are now being studied. Further, for control of the shoreline erosion and shifting of bars, many projects are being performed. All the parameters that may affect the coastal changes are considered, such as wave, tidal current, longshore transport, sand transport by rivers, man-made structures, etc. Also, many protection methods are being used, such as beach nourishment, detached breakwaters, sand bypass, etc.

CONCLUSIONS

Historical records and old maps show that the middle western coast of Taiwan had wide beaches in the 18th century. Those beaches were formed by

sands transported from rivers. Some beaches accumulated to form the bars located offshore. Thus, many bars have grown along the coast of InLin and ChiaEi. All those bars sheltered the shore line from direct wave action. However, the sands supplied from rivers have been reduced recently and the land has sunk below the mean sea level, causing the shorelines and bars to become unstable and to be eroded by waves gradually. Results show that the bars along InLin and ChiaEi coast have been eroded by waves. The surface area above sea level is decreased by wave erosion. The positions of the bars are shifting toward the southeast. The maximum erosive distance of the InLin coast is 100 m, and 75 m for the ChiaEi coast. The average maximum erosional retreat speed of the WhySunDean bar is about 0.6-1.15 km/yr.

The coastal characteristics of mid-western Taiwan are unstable and some local places are seriously eroded by waves. Any coastal construction may be the cause of further changes in the shorelines and bars. In addition the stratum depressions cause the seawalls or other coastal protections to lose their efficiency, resulting in shorelines being damaged by waves directly. Therefore, to stabilize the bars located along the coast of InLin and ChiaEi is important work, and determining how to reduce the erosion of shorelines is the main work for coastal researchers. Next, we will study the relationship between coastal changes and the wave energy, river sediment transport and wind speed.

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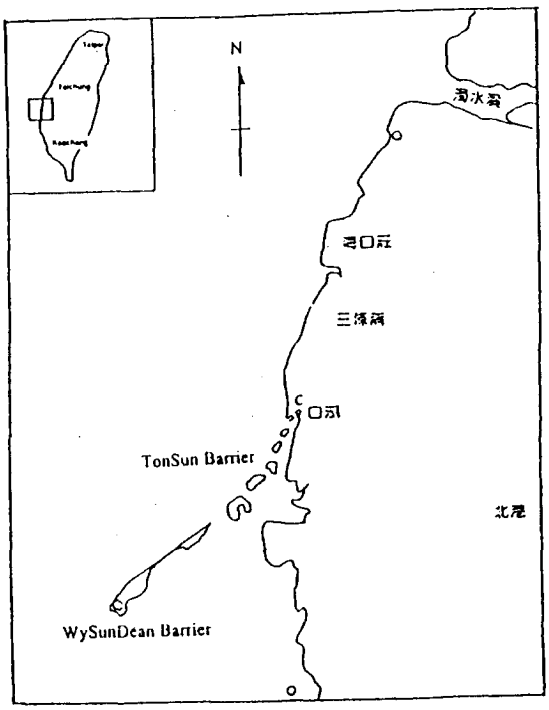
Table 1. Shoreline change velocity of the InLin coast.

Term	Variation of beach (km^2/yr)				Variation of shoreline (m/yr)			
Duration	1904-1919	1919-1958	1958-1977	1977-1987	1904-1919	1919-1958	1958-1977	1977-1987
Value	-0.2	0.13	-0.05	-0.15	-8.77	1.93	-6.5	-4.54

Table 2. Shoreline change velocity of the ChiaEi coast.

Term	Variation of beach (km^2/yr)				Variation of shoreline (m/yr)			
Duration	1904-1919	1919-1958	1958-1977	1977-1987	1904-1919	1919-1958	1958-1977	1977-1987
Value	0.92	-1.07	0.41	-0.71	20.69	-4.15	-2.32	-18.45

Fig. 1. The position of the Inlin and ChiaEi coast in Taiwan.



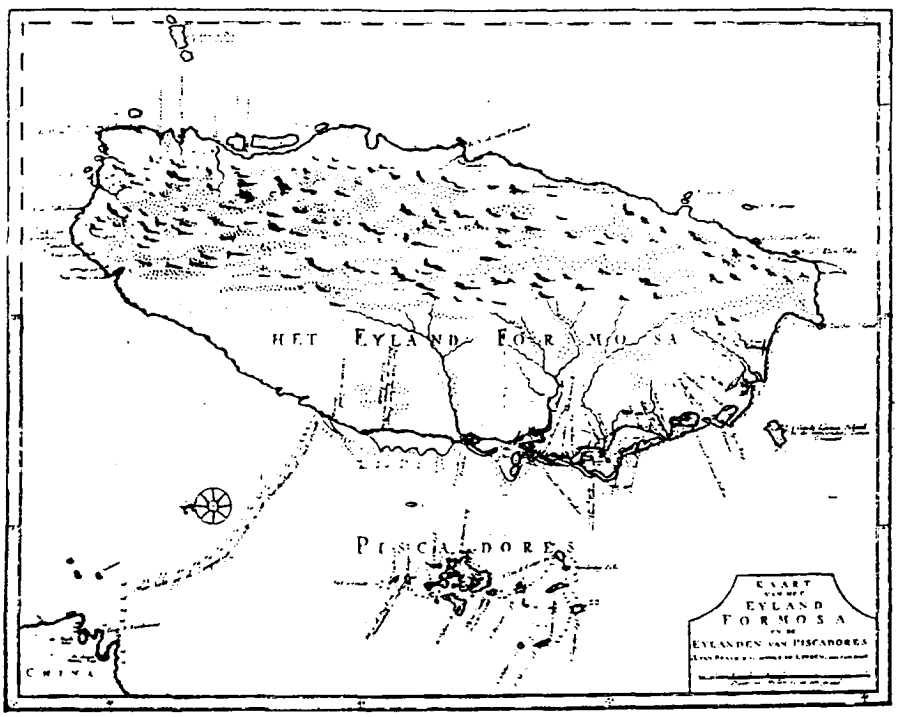


Fig. 2. Map of Taiwan (drawn before 1734).

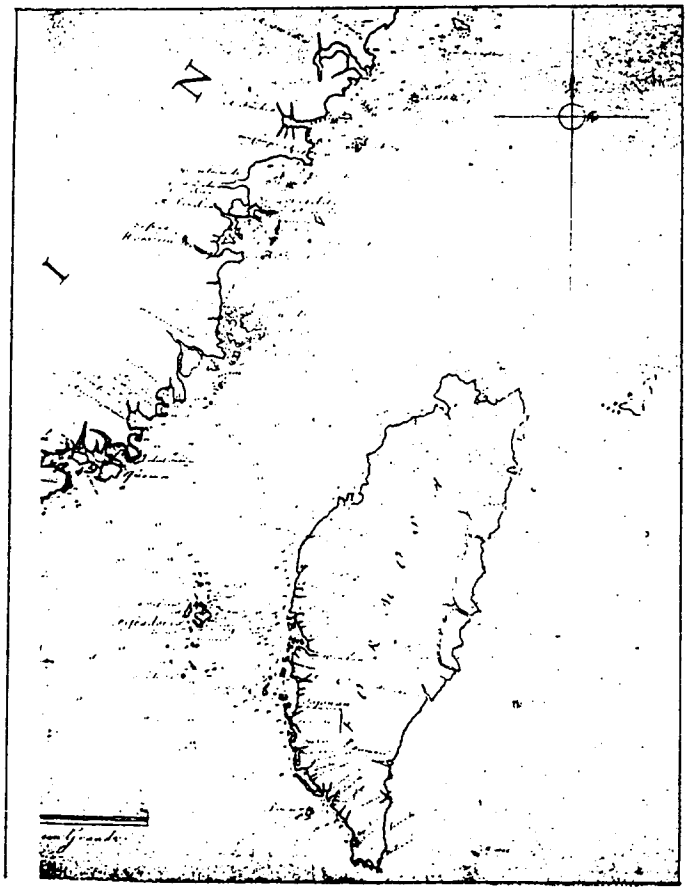


Fig. 3. Map of Taiwan (drawn in 1624-1625).

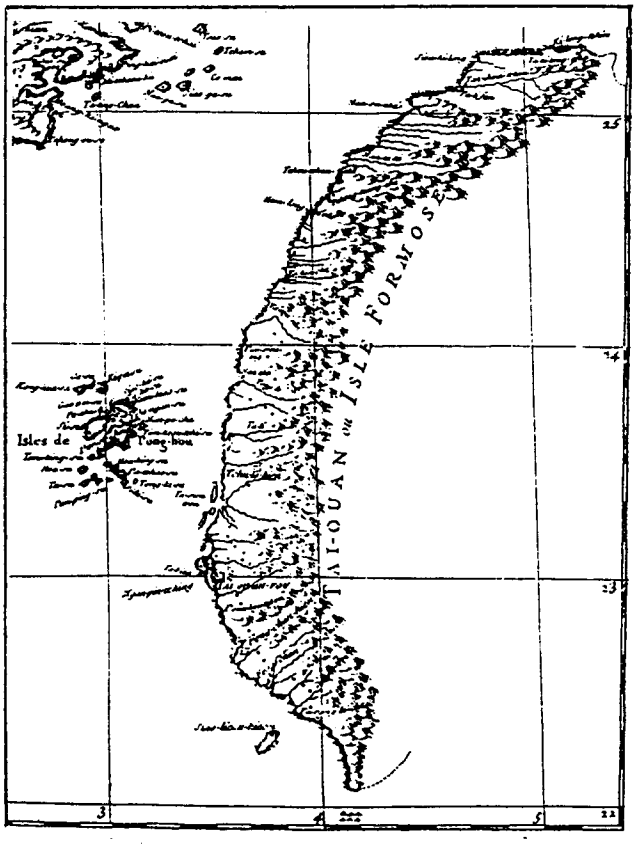


Fig. 4. Map of western Taiwan (drawn in 1714).

Fig. 5. Shoreline changes of the InLin coast.

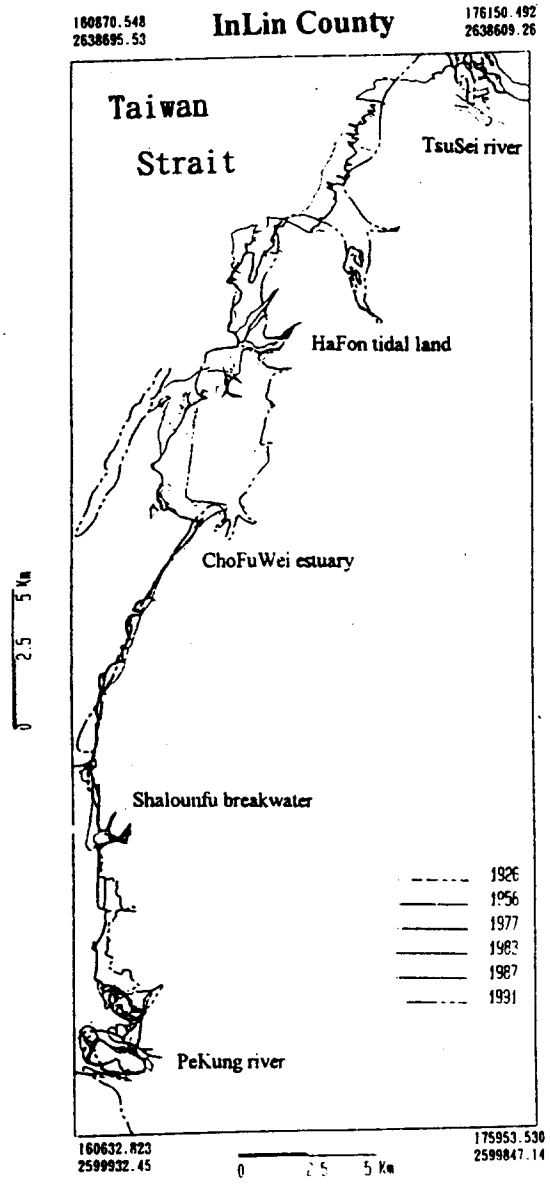


Fig. 6. Shoreline changes of the InLin tidal land.

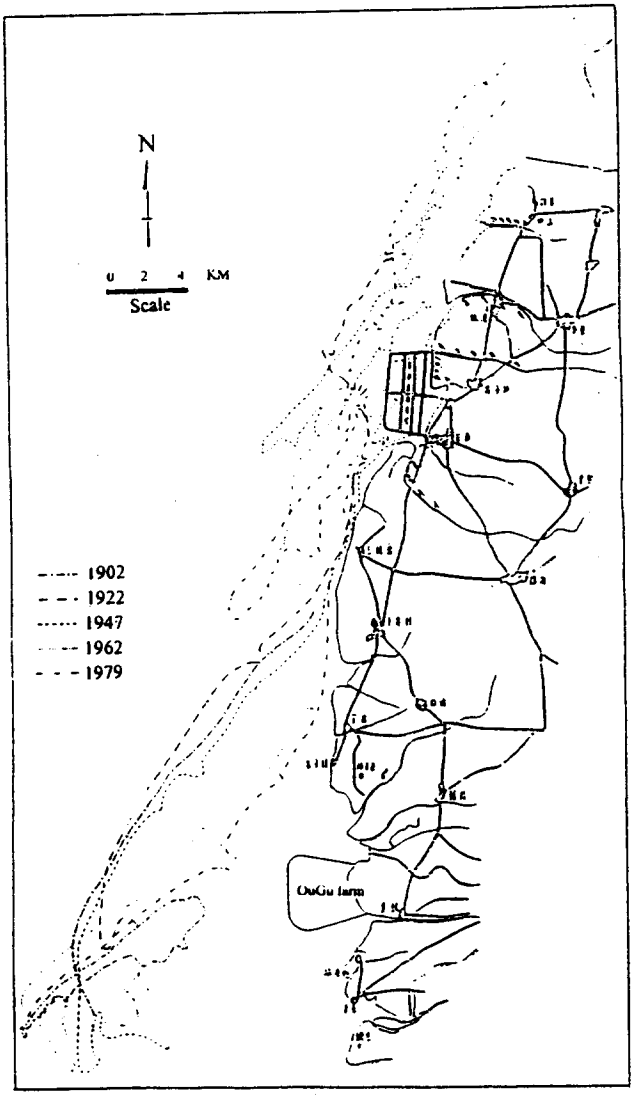
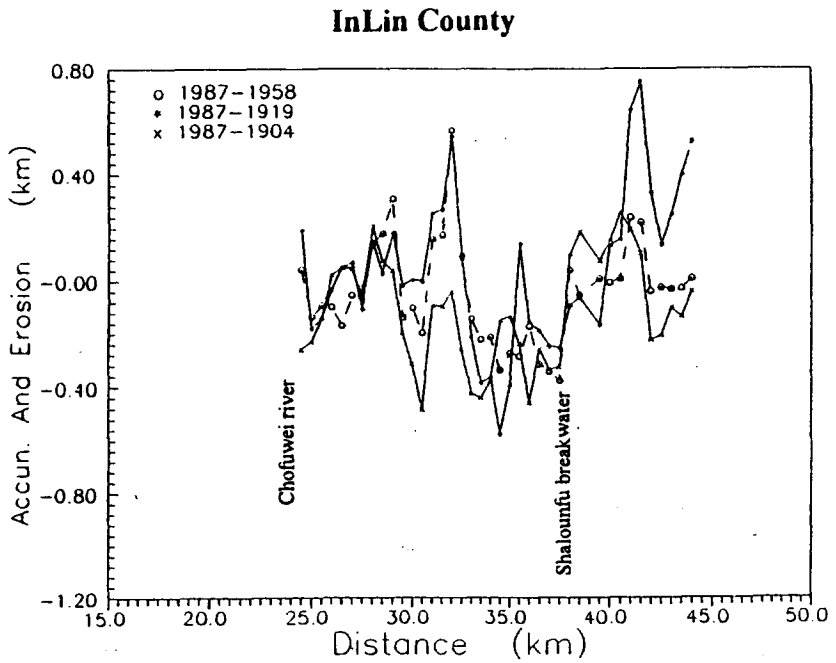


Fig. 7. The distance of shoreline change of the InLin coast.



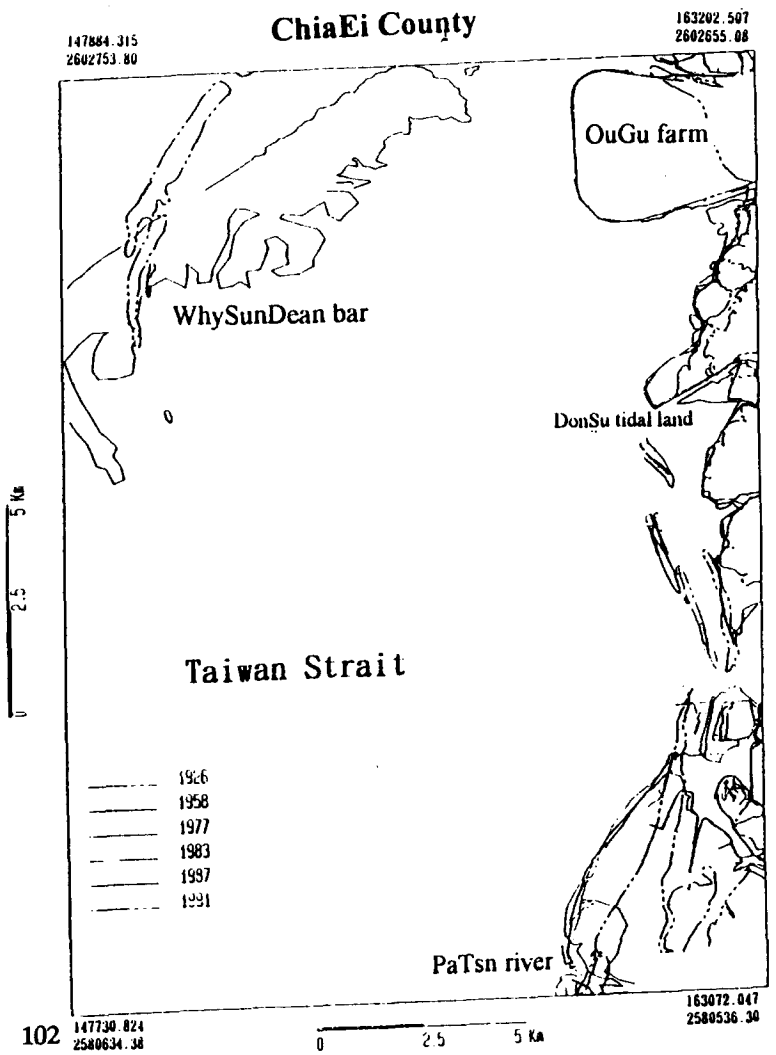
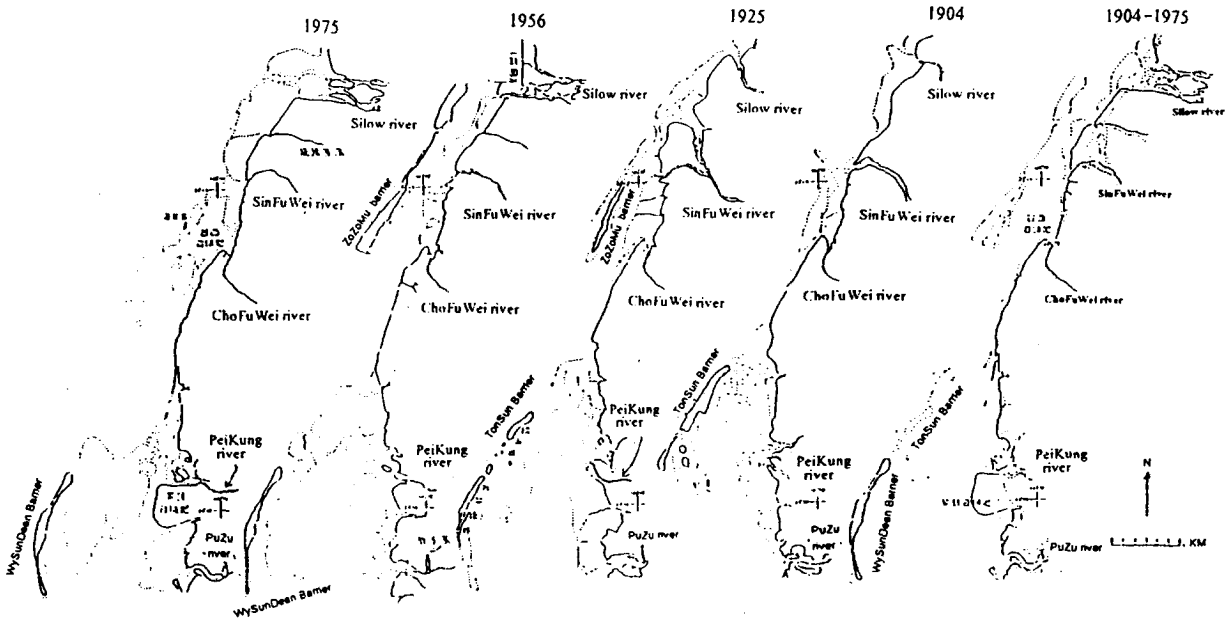


Fig. 8. Shoreline changes of the ChiaEi coast.

Fig. 9. Shoreline change of Inlin and ChiaEi coast.



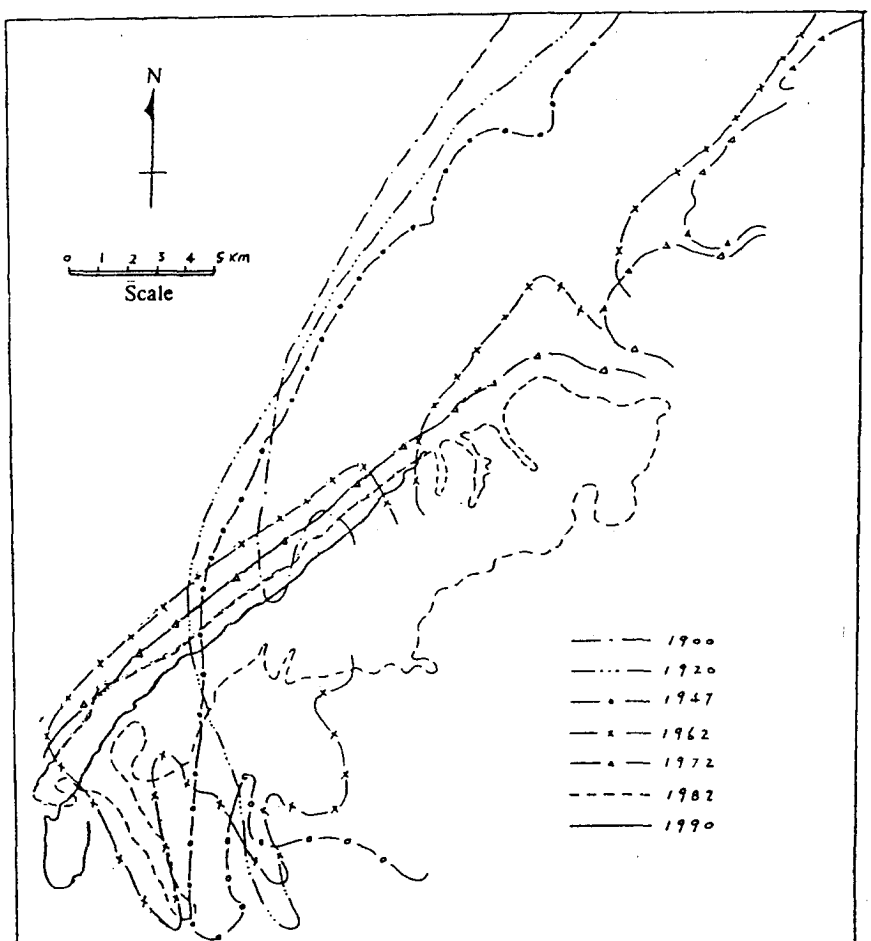


Fig. 10. Variation of WhySunDean bar.

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PAST, PRESENT AND FUTURE OF THE PINELLAS COAST: THE MOST DENSELY POPULATED COAST OF WEST FLORIDA, U.S.A.

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ABSTRACT

The 60 km long barrier island complex that comprises Pinellas County is situated on the Gulf of Mexico Coast of the Florida peninsula. It includes 10 barrier islands ranging from barrier spits to drumstick barriers, and 10 tidal inlets, from wave-dominated to tide-dominated. This coast is subjected to mean annual wave heights of 0.3 m and a tidal range of 0.7 m. Hurricanes occur infrequently and frontal systems dominate the coastal processes during winter months. Development of this coast for tourism and recreation began in earnest in the 1920s after construction of the first causeways to the islands and the devastating hurricane of 1921. Since that time this coast has become part of the most densely populated county in Florida and attracts millions of tourists each year in addition to its resident population of hundreds of thousands. It has not experienced a significant hurricane since development began. Most of the coast is lined with seawalls, jetties and groins, however, there are also pristine barriers and inlets. This combination of intensely developed barriers with natural ones provides the ideal setting for investigating the past, the present and predicting the future of the coast.

INTRODUCTION

The Pinellas County, Florida coast affords one of the best places to see a broad range in coastal morphology of any primarily depositional coast in the United States. It also displays the complete spectrum from pristine barrier islands, tidal inlets, and estuaries to those that are totally modified and developed by human activities. All of the barriers are late Holocene in age with the oldest being formed about 3000 years BP. Extensive construction and modification began in the early 1920s after the first causeways were constructed between the barriers and the mainland. The greatest rate of construction and development activity took place in the 1950s and 1960s. Except for areas now protected from development, the entire coast has been severely modified by construction.

This coastal reach includes 10 barrier islands and 10 tidal inlets combined with a complex estuarine/back-barrier bay system (Fig. 1). Five of the barriers are protected as parks but the five developed barriers comprise about 65% of the length of the open coast. The position of the barriers ranges from being only a hundred meters from the mainland to about 5 km away (Fig. 1). Although there is great range in the width of the barriers, none have elevations more that 5 m above sea level. Dunes are small or non-existent due to the general scarcity of sediment.

Coastal sediments in this area are dominated by homogenous well-sorted, fine quartz sand that has been reworked many times from Miocene through older Holocene deposits. Shell debris ranges widely throughout the area from only a percent or two in some of the dune and back-barrier sediments to more than 50% in foreshore beach sediments. Mud is rare throughout except in the quiet back-barrier environments where it is commonly about 10%.

This coast rests on a wide carbonate platform that extends for 200 km toward the west into the Gulf of Mexico. The overall gradient of the inner shelf ranges from 1:700 to 1:1300 in the study area. The coast can be classified as low mixed-energy (Davis and Hayes, 1984) with mean annual wave height at the shore of 25-30 cm (Tanner, 1960) and mean tidal range of about 0.7 m (Fig. 2). Dominant winds are from the north and are associated with the passage of cold frontal systems

during the winter months. Prevailing winds are from the south. These conditions provide for a modest rate of longshore sediment transport (<50,000 m^3/yr) that is generally from north to south but with some local reversals due to the complicated range in shoreline orientation (Fig. 1). Although tropical storms do influence this coast there has not been a landfall of a major hurricane here since 1921.

PAST

Detailed information on the morphology of this coast is limited to just over 100 years; the first accurate maps were produced in the 1870s and the first aerial photographs are from 1926. At that time the coast was essentially pristine with only scattered cottages and fishing shacks along both the barriers and the mainland. The only major hurricanes of record took place in 1848 and 1921. The typical profile across the area was one of a well-developed beach leading to small vegetated dunes. The back barrier was dominated by mangrove trees that bordered a shallow back-barrier bay. The mainland shoreline was also dominated by mangroves. Inlets ranged from being tide-dominated such as the recently formed (1848) Johns Pass and Bunces Pass (Fig. 1) to wave-dominated such as now-closed Indian Pass (Fig. 3) and Blind Pass (Fig. 1.). The back-barrier bays were no more than a few meters deep and floored with sea grasses.

During the more recent past, development began and has continued through the present. Original use and occupation of the barrier islands was for sport fishing and other forms of recreation as well as scattered residences. No significant population occupied the islands on a continuing basis until construction of the causeways from the mainland beginning in the early 1920s, after the severe hurricane of 1921. This made transportation between the barriers and the mainland easy and quickly gave rise to small communities on the islands. Bridges were built across Clearwater Pass, Johns Pass and Blind Pass (Fig. 1) in 1926 connecting the barriers to each other to further enhance travel along the coast.

As construction of houses and small tourist hotels continued there was initial attempts to control the natural processes operating along the coast. The first attempt to stop the migration of a tidal inlet was the construction of a sea wall at the south end of Blind Pass in 1936. This inlet had migrated over a kilometer during the previous 50 years (Fig. 4).

RECENT PAST

For discussion purposes, this will include the period after World War II to present. It was during this time that extensive population and tourism growth began in this part of Florida. The combination of the favorable climate, relatively low cost of living, and employment opportunities caused a virtual explosion of construction and human modification on the coast.

Erosion Problems

As homes and small hotels began to dominate the beaches, people became aware of the changes that were taking place along the shoreline; especially its retreat. Now there was a perceived shoreline erosion problem as the water's edge gradually came closer and closer to their homes and businesses. As a result, there was extensive construction of seawalls and groins along most of the developed coast during the 1950s. Seawalls were typically vertical and were constructed with poured concrete; some with rip-rap in front and some without it. Groin construction ranged in shape, size and spacing. In general, the groins did little to help the situation but the seawalls protected the buildings.

Dredge and Fill Construction

At the same time that shoreline erosion was being addressed on the open coast, there was another major type of construction taking place on the landward side of the barrier islands and to some extent on the mainland coast as well. The cost of land on the barrier islands was increasing at a very rapid rate and its availability was quickly decreasing. As a consequence the practice of dredge and fill leading to construction of uplands and finger canals was initiated in the early 1950s. This scheme includes the extensive dredging of narrow canals along the entire mangrove-dominated back-barrier environment. The dredge

spoil is placed in walled impoundments between the canals to provide an upland area for construction of homes and businesses. The result is that the usable area of a barrier island is greatly increased by converting the intertidal and very shallow subtidal area into uplands thereby increasing the areas of some barriers by 100% (Fig. 5).

This practice has been completed throughout the five barrier islands that are not protected as parks. Not only does this type of activity destroy the valuable mangrove wetland community but it also causes a severe decrease in the tidal prism in the back-barrier bays. Recall that tidal prism or tidal flux into and out of the bays is a function of the tidal range and the area of the bay served. Dredge and fill construction of finger canals reduces the area of the tidal influence in the bays by creating additional upland (supratidal) areas. It has been determined that the bays served by inlets along the southern portion of Pinellas County coast of Florida have had their area reduced by 25% since this type of construction began (Mehta et al, 1976).

Other Back-Barrier Construction

Two other types of back-barrier construction have also altered the tidal prism, especially its compartmentalization. These are the construction of fill-type causeways and the dredging of the Intracoastal Waterway. Nine causeways were constructed between the mainland and the barrier islands in this area by the end of the 1950s. Each was constructed primarily by placing fill sediment across the back-barrier bay with only narrow channels for circulation and boat traffic. The result was a tremendous influence on the tidal flux and a compartmentalization of the tidal prism. No longer was it possible for tidal flux to move without interruption along the back-barrier area. The prism was greatly reduced for some tidal inlets and was increased for others. This situation was superimposed upon the already reduced tidal prism mentioned earlier in this paper.

One example is the situation between Dunedin Pass and Clearwater Pass (see Fig. 1). The tidal prism serving each of these adjacent tidal inlets was modified by creating artificial divides in the form of the causeways. As a consequence, Dunedin Pass (Big Pass) decreased greatly after the early 1920s and Clearwater Pass (Little Pass) increased in size (Fig. 6).

The dredging of the Intracoastal Waterway in the mid-1960s also had a significant effect on the distribution of the tidal prism. This commercial and recreational waterway was constructed in protected waters along all of the Gulf of Mexico and Atlantic coast of the United States. Its design cross-section in the Pinellas area was 8 feet (2.35 m) deep and 50 feet (15.3 m) wide. This channel acts as a conduit for tidal flux behind some of the barriers and helps to reduce the influence of the causeways. In Pinellas County the Intracoastal Waterway has not had enough influence to cause noticeable changes in the inlets but it has caused important changes further south along this coast in Sarasota County. Here Midnight Pass had its tidal prism reduced by two orders of magnitude (Davis et al, 1987) causing eventual closure.

Inlet-Related Construction

The combination of the general reduction in tidal prism with the need for navigation through the inlets has caused nearly all inlets along the Pinellas County coast to be stabilized, even those that are tide dominated. The extremely wave-dominated, unstable inlets or "wild inlets" as they are sometimes called, were either closed such as Indian Pass (Fig. 3) or were stabilized very early (Blind Pass). Several other tidal inlets have been stabilized more recently, e.g. Johns Pass and Pass-a-Grille in the early 1960s and Clearwater Pass in 1974. In each case the stabilization was constructed in order to keep longshore sediment transport from impeding navigation in the inlet. Coupled with these stabilizing projects were additional jetties and extensions at Blind Pass. Initially, spoil from inlet dredging was deposited on the updrift side of the inlet. Because of the obvious problems created by this approach, dredge spoil was then placed offshore. That practice further reduced the amount of sediment in the nearshore zone. Now dredge spoil is placed in the downdrift area of the inlet in order to keep

the maximum amount of sediment in the nearshore system.

The situation at Clearwater Pass (Fig. 1) is worthy of elaboration. This inlet grew significantly in size at the expense of Dunedin Pass during the period of 1924 through the 1960s (Fig. 6). Partial stabilization occurred with a short jetty on the north side and a bridge over the inlet. The net longshore drift on the north half of Sand Key (Fig. 1) is to the north, a reversal from the regional trend. This caused continued need for dredging of inlet in order to maintain navigation. The dredge spoil was placed on the north end of Sand Key and was quickly carried back to the inlet. While the inlet was narrowing due to the influx of longshore sediment transport, it was maintaining a constant prism. This led to scouring of the channel and the pilings of the bridge were being undermined. As a consequence, a long jetty was constructed beginning in 1974 to permanently stabilize the inlet (Fig. 7). The jetty has been successful and has caused a huge fillet of sediment which is now a park.

PRESENT

Numerous laws and practices have been instituted during the 1980s and are continually being strengthened and modified. This period will be considered as the present because it includes a distinct change in the way human activity has been modified on the coast. Regulations about destruction of wetlands, hardened shoreline construction, codes for placement and construction of building, and other factors have resulted in great changes in development practices along the coast, mostly for the better. Fill causeways are no longer permitted, finger canal construction is no longer permitted, seawall construction is strictly regulated and beach sediment is cherished.

One of the most important changes that have taken place along all coasts of Florida and throughout much of the rest of the United States is the extensive practice of beach nourishment.

The first recorded nourishment along the Pinellas coast was in 1949 near the south end of Clearwater Beach Island (Fig. 1), the most popular tourist beach on this coast. More recently dredge spoil from inlet maintenance was placed on or adjacent to the beach if the sediment quality was acceptable. As erosion became more prevalent and demands for recreational beaches increased, nourishment practices increased using the ebb-tidal shoals as sources. Now beach nourishment is a widely practised means of protecting upland properties while at the same time providing for expanded recreational activities. During the past several years Pinellas County has nourished large portions of Treasure Island and Long Key, and most of Sand Key (Fig.1). The more recent projects are funded through cost sharing between the Federal, State and County governments as long as the cost of the project can be balanced by the value of the protection that it provides for property landward of the beach. Three adjacent projects have been completed on Sand Key (1988, 1990, and 1992) with the fourth and final project scheduled for construction in 1996. In all cases the primary borrow areas have been the ebb-tidal shoals associated with inlets. These are the only significant sediment sources along the entire coast. Depending upon location, it is necessary to transport the borrow material up to 30 km to the construction site. This has resulted in costs that approach US$12/m^3; high by most standards but within the cost-benefit ratios for the projects.

Beach projects along this coast have a fairly common design. The berm is constructed 6 feet (1.83 m) above NGVD, the National Geodetic Vertical Datum used on all U.S. coastal charts. The berm is typically 150-200 feet (46-61 m) wide. In most cases the pre-construction beach is nearly all intertidal and only a few meters wide (Fig. 8). Most projects are designed to have maintenance nourishment throughout their lifetime at regular intervals. The amount and interval are determined by routine and rigorous monitoring of the projects. Generally the first maintenance nourishment occurs 5-8 years after construction. Projects along the Pinellas County coast have been performing much better than predicted. This is partly due to the stabilizing influence of the rather high shell content of the nourishment sediment combined with the low energy conditions that persist along this coast.

FUTURE

Based upon the changes in policy that have taken place over the past two decades, the future for the Pinellas County, Florida coast appears to be improving. The same can be said for all coasts in Florida and the rest of the United States. The strict regulation on type of construction of both buildings and stabilization structures, locations and densities of the structures, limitations on usage of coastal land, and returning much of the coast to its natural condition will help to provide for a much better relationship between humans and the various coastal environments.

These forecasts are best viewed through several examples based upon the Pinellas County, Florida situation:

1) Extensive nourishment and maintenance of beaches will continue to provide both protection to upland environments and properties, and also expanded recreational facilities for tourists and residents.

2) Widespread planting of backbeach vegetation, irrigation and construction of walkways will encourage and protect the development of coastal dunes.

3) Regular monitoring and protection of turtle nests in the backbeach will enhance and protect these species.

4) Regulations requiring stronger construction of buildings with no occupation below the 100 year storm level will reduce the expense for rebuilding and reduce death or injury to people.

5) Strict enforcement of back-barrier construction practices and replanting of mangroves will help to maintain and expand these environments.

Although the recently implemented regulations will be very helpful, there will always be problems along the coast as long as extensive development occurs. The best we can do for the future is to minimize the negative impact on these fragile and dynamic environments through cooperation between residents, visitors and the business community.

ACKNOWLEDGEMENTS

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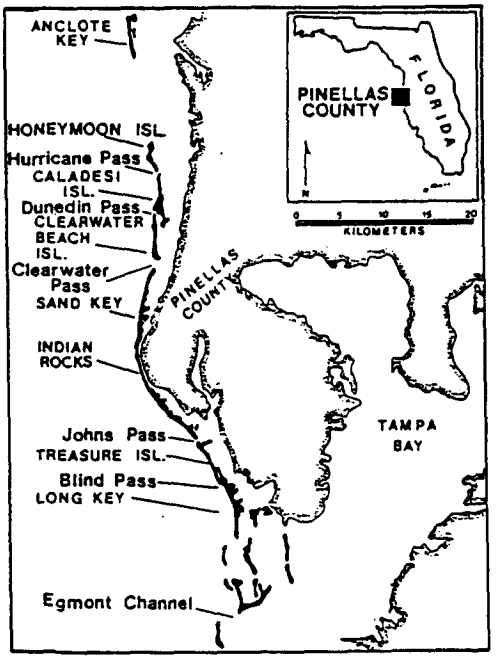
Fig. 1. Index map of Pinellas County, Florida U.S.A. showing barrier islands and tidal inlets.



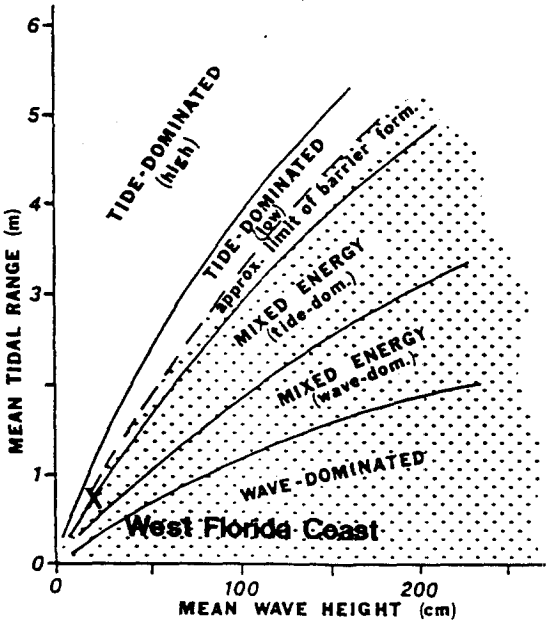
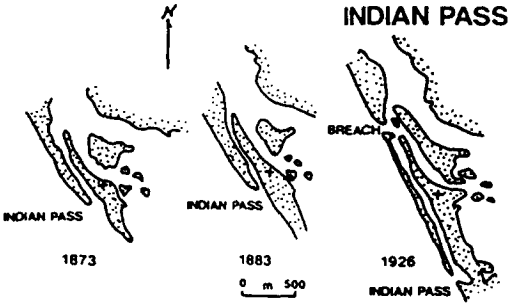


Fig. 2. Plot of wave height and tidal range as presented in Davis and Hayes (1984) showing generalized fields of coastal conditions. The Gulf of Mexico coast of Florida falls near the origin causing small changes in either tidal range or wave height to result in significant changes in barrier-inlet morphology.

Fig. 3. Tide-dominated Indian Pass formerly locate on Sand Key (Fig. 1) but now closed. (from Davis, 1994).



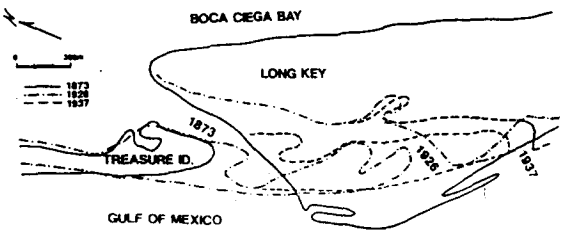


Fig. 4. Migration of Blind Pass between Treasure Island and Long Key (Fig. 1) prior to stabilization in 1936.

Fig. 5 - Map comparing Long Key, a developed barrier, with Caladesi Island a pristine barrier (see Fig. 1).

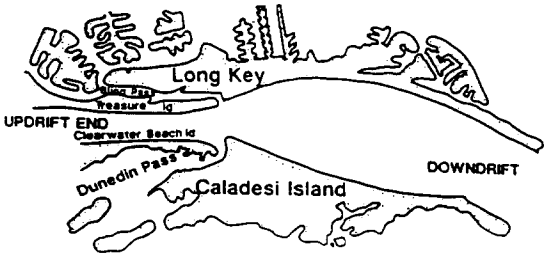
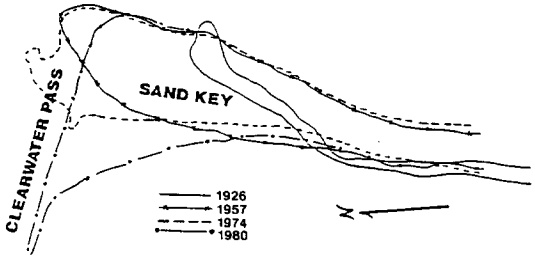


Fig. 7 - North end of Sand Key at Clearwater Pass (Little Pass) showing extension of the barrier spit prior to construction of the jetty and the subsequent development of a large fillet.



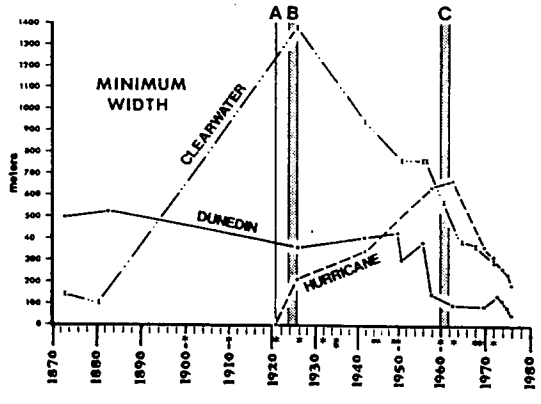


Fig. 6 - Changes in inlet width after construction of the Clearwater causeway (B) and the Dunedin causeway (C). A is the hurricane of 1921 which opened Hurricane Pass. (after Lynch-Blosse and Davis, 1977).

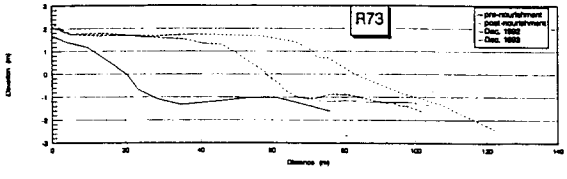


Fig. 8 - Beach profiles showing the pre-nourishment, post-nourishment and 1 year conditions at a selected location from the Sand Key nourishments projects.

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EFFECTS OF NEOTECTONICS ON THE MORPHOLOGY OF THE SEA OF MARMARA, NORTHWEST TURKEY

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KEYWORDS: Strike-slip faults, pull-apart basins, subsidence, regressive coasts, two-layer water body, strong halocline, palaeo-oceanography, seismic reflection, hemipelagic sedimentation.

ABSTRACT

The Sea of Marmara is an inland sea with the areal extent of about 11,350 km^2. The outflow of water from the Black Sea to the Mediterranean occurred before the Holocene. The gradual rise in global sea level led to the incursion of the saline Mediterranean waters into the Black Sea probably 6000 to 5000 years ago (?) through the Straits and the Sea of Marmara. The Sea of Marmara has a very large continental shelf area with many islands. There are three deep basins of about 1100 m in depth running in the E-W direction. The Sea of Marmara lies along the line of the North Anatolian Fault zone (NAF) which is about 1500 km long, seismically active right-lateral transform. The east-west line of the NAF to the east of the Sea of Marmara passes westward into a graben defining Izmit Bay and a zone of deep water within the eastern and central part of the Sea of Marmara. The origin of the circum-Marmara grabens which are dominantly pull-apart basins, is directly associated with the strike-slip tectonics of the NAF. The Sea of Marmara can be divided into five different blocks (two uplifted and three basinal blocks) which are controlled by two sets of fault systems: (i) almost E-W trending normal faults (the Northern and Southern Boundary faults); and (ii) NE-SW oriented subvertical strike-slips. The blocks are undergoing relative vertical motions and rotations. The whole area is subsiding although the subsidence rate is higher in the basinal areas in the uplifted blocks.

INTRODUCTION

The Sea of Marmara is an elongated marginal sea in the east-west direction, with a dimension of 210 km compared to a north-south extension of only 70 km. It is connected to the brackish Black Sea via the Bosphorus which is 30 km long and 35 m deep at its shallowest. To the southwest, it is linked to the saline Aegean by the Dardanelles, a 60 km long strait with a sill depth of 50 m. This quasi-enclosed basin had a restricted circulation regime during the latest Pleistocene to about 3000 yr B.P., and only since then has the two-way exchange of water masses through the Bosphorus and the Dardanelles become established (Evans et al., 1989). In recent years, the state of pollution within the Marmara coastal zone resulting from industrial waste disposals has reached alarming proportions. There are various industries along the coast of the Sea of Marmara, especially the area from Istanbul to Izmit is the most industrialized region of Turkey. The total amount of waste water discharged into the Sea of Marmara is computed approximately as 480x10^6 m^3 per year (most of it comes from the Istanbul Metropolitan area).

The Sea of Marmara lies over the North Anatolian fault zone (NAF), which is a seismically active right-lateral transform initiated in the Late Miocene to Pliocene. The grabens around the Sea of Marmara (Gulfs of Izmit, Iznik, Gemlik; and Yenisehir-Bursa-Manyas and Saros) lie along the course of N and S strands of the NAF and have very strong strike-slip components. The origin of these circum-Marmara grabens is directly associated with the strike-slip tectonics of the NAF (Barka and Kadinsky-Cade, 1988). There is an associated change of seismicity from almost pure dextral strike-slip focal mechanism along the NAF east of the Sea of Marmara to a mixture of normal and strike-slip mechanisms along the

various fault strands to the west (Üçer et al., 1985; and Eyidogan, 1988). As with the North Aegean area, the Sea of Marmara is undergoing a combination of right-lateral strike-slip and north-south extension. All the blocks are subsiding in the Sea of Marmara thus the regressive type coasts have been produced in the region.

GEOGRAPHY OF THE SEA OF MARMARA

The Sea of Marmara is an inland sea lying between Thrace and Anatolia in northwestern Turkey with the areal extent of about 11,350 km^2. It is connected with the straits of Bosphorus and Dardanelles to Black Sea in the north and to the Aegean Sea in the south respectively. It has a very large continental shelf area with many islands. The southern shelf area is much larger than the northern one. There are three deep basins running in the E-W direction. These depressions have the depths: 1,112 m in the west; 1,220 m in the middle; and 1,238 m in the east (Fig. 1).

The Thrace region makes up the north and northwest of the Sea of Marmara. This area is a peneplain with vertical oscillations . Also the Kocaeli peninsula at the east of Istanbul can be included in this peneplain (Fig. 2). The eastern side of the Sea of Marmara is made up of the Izmir Bay. There are mountains of Karadag, Samanlidag and Uludag at the southeast. The coastal morphology from the Armutlu peninsula in the east to the Dardanelles show various reliefs on the southern side of the Sea of Marmara. Most of the coastal area of the Sea of Marmara is repressive. There are terraces ranging from 4-5 m to 50-55 m with sand-gravel beach depositions belonging to these types of coasts. There are no major rivers in the Marmara Sea Region with the drainage area of 14.560 km^2 with the annual potential fresh water supply of 18.418×10^9 m^3. The main streams and rivers are in the southern side of the basin.

The shelf (0-100 m water depths) makes about 57% of the Sea of Marmara. This is the general observation in the Black and Aegean Seas since the last deglaciation. The three basins below 1000 m make only 2 % of the Sea of Marmara. The shelf area is much larger on the southern side with many islands. The shelf area is cut by the extensions of marine canyons at Izmit Bay and Gemlik Bay, coincident with the branches of the North Anatolian Fault as pull-apart basins. Also the valleys can be followed further down in front of Küçük and Büyük Çekmece, Silivri, Erdek, Gönen and Bosphorus channel.

HYDROGRAPHIC CONDITIONS OF THE SEA OF MARMARA

The lithofacies of sediments of the Sea of Marmara is a very sensitive indicator of the prevailing paleo-oceanographic and paleo-climatic conditions, since it is these conditions that control the palaeo-depo-environment. The Sea of Marmara is an area of considerable oceanographic interest lying between the brackish Black Sea to the north and the saline Aegean Sea to the south. The hydrographic regime of the Sea of Marmara is largely controlled by the rates of flow, properties, and the interactions of the two water-masses flowing into it via the Straits of Bosphorus and Dardanelles (Ünlüata and Özsoy., 1989). The outflow of brackish waters from the Black Sea leads to the formation of a thin (20-30 m) surface layer in the Sea of Marmara with a salinity of 22-25 *‰*, which is separated from the underlying saline (38,5 *‰*) Mediterranean waters by a sharp halocline. This lower water has a temperature of 14.5-15 °C. The outflow can actually be traced as far as the entrance of the Dardanelles in the Aegean Sea, although it becomes more saline along its course towards the latter. Thus, a strong density stratification of the water-column prevails throughout the year, preventing efficient aeration of subhalocline waters (Fig. 3).

The strong stratification of the water column coupled with the topographic restriction imposed by the two shallow sills of the Dardanelles and Bosphorus inhibits efficient circulation of deep waters. This situation, together with the relatively high average rate of primary productivity, estimated to be 60 g carbon/m^2.yr leads to oxygen depletion in the sub-halocline waters (Ünlüata and Özsoy, 1986). The oxygen deficiency becomes more pronounced toward the east as the only source of oxygen replacement for the sub-halocline is the underflow through the Dardanelles. Thus, the oxygen content falls to

about 0.9 ml/l O_2 at approximately 1.000 m in the eastern Mediterranean basin.

In short, the prevailing estuarine system of circulation, intense water-column stratification, and elevated level of primary productivity bring about a hydrographic situation in the Sea of Marmara which stands out in sharp contrast with that of the rest of the eastern Mediterranean basins. More investigations on the sedimentology of the region may shed light on the paleo-oceanographic conditions which led to the development of repeated phases of anoxia or suboxia in the region (Kidd et al., 1978). Although there are tectonic movements in the region, the main causes of change in hydrographic and morphologic conditions are due to the eustatic variations.

TECTONICS OF THE MARMARA SEA REGION

The Sea of Marmara occupies a key position as it lies over the direct westward continuation of the (NAF) which is about 1500 km long, seismically active, and a right-lateral transform fault (Fig. 4). However, as the NAF is traced westwards through the northern Aegean Sea it splits into several fault strands defining a broad tectonic zone with associated high seismicity (Crampin and Evans, 1986; Barka and Kadinsky-Cade, 1988; and Barka, 1992). This diffuse zone of shallow seismicity, with a clustering of microseismic activity along major fault strands, is closely similar to the pattern of seismicity in the northern Aegean Sea (Eyidogan, 1988; McKenzie, 1978; Lyberis and Deschamps, 1982; Taymaz et al., 1991; and Barka, 1992). The east-west line of the NAF to the east of the Sea of Marmara passes westward into a graben defining Izmit Bay and a zone of deep water within the eastern and central part of the Sea of Marmara. Water depths exceed 1.000 m in places and are comparable with depths encountered along the North Aegean trough.

As the Anatolian block moves west, its leading edge comes under the influence of the Aegean north-south extension and breaks up into discrete graben structures. There is major internal deformation within Turkey, possibly involving counter-clockwise rotational movements (Rotstein, 1985), and in the Aegean Sea area (Le Pichon and Angelier, 1979; and Kissel et al., 1989): "every thing happens as if Aegean were spreading away in front of Turkey" (Le Pichon and Angelier, 1979). Sengör et al. (1985) regarded the overall tectonics of northwestern Turkey as resulting from the interaction of north-south extension with right-lateral strike-slip along the NAF. They envisaged that the cumulative increase of north-south extension from east to west led to a deflection of the northern strand of the NAF to such extent that further strike-slip displacement along it was precluded, leading to the initiation of a new southern fault strand in the Pleistocene.

The relationship of the northern Aegean and northwestern Turkey areas to the adjacent Eurasian-Black Sea plate may be better described by Jackson and McKenzie's (1988) model of a deforming zone comprising rotating blocks with non-vertical faulted margins. "This is the simplest model of faulting... which can accommodate strike-slip and extensional movement without requiring movement of material along the strike of the zone" and, hence, provides a specific mechanism for "damping" the right-lateral displacement along the NAF and translating the westward motion of the Turkish block into a north-south extension in the Aegean Sea. Clockwise block rotations in the western part of the Aegean area (Kissel et al., 1989) are compatible with the above mechanism. Whatever detailed tectonic model applies, the east-west trending normal fault systems of the Sea of Marmara "appear to be related to a diffuse zone of crustal thinning" (Sengör et al., 1985) associated with an estimated 30 percent of north-south extension in the Sea of Marmara area since the Tortonian.

The seismicity of western Turkey typically displays swarm-type activity (Fig. 5) with marked clustering in time and space of low magnitude earthquakes (Üçer et al., 1985). The major swarm lineaments in western Turkey outline a triangular area bounded by the direct continuation of the NAF across the Sea of Marmara and by the Izmir-Adapazari swarm lineament (Üçer et al., 1985). According to the energy release maps (Crampin and Evans, 1986; and Eyidogan, 1988),

it was found that the Marmara Block has different seismic characteristics from the rest of western Turkey and the energy released in the Marmara province is significantly higher than the energy released in the southwestern Turkey province.

Based on fault mechanism solutions, Crampin and Evans (1986) suggested that the Marmara block is being rotated and sheared in order to accommodate the right-lateral motion of the NAF and the extensional tectonics of the southwestern Turkey province which may be resulting in graben formation and probably listric faulting. The focal depths of the earthquakes in western Turkey, in general, range from 0 to 50 km but the major earthquakes are not deeper than 10-15 km. Eyidogan (1988) indicated that the right-lateral shear in the Marmara province is associated with the dominant shear component of right-lateral displacement across the region, mainly on E-W trending strike-slip faults. The N-S extension of 7.1 mm/yr and E-W contraction of 10.0 mm/yr were calculated with the thinning of seismogenic layer, equivalent to 0.13 mm/yr.

GEOLOGY AND STRATIGRAPHY OF THE SEA OF MARMARA AND THE SURROUNDING AREAS

The structures of the Sea of Marmara have morpho-tectonic characteristics comparable to those of the North Aegean trough. The Ganosdag area of active faults joins the North Aegean trough to the Sea of Marmara. Although there are still some controversies (Alvarez et al., 1984; Brooks and Kiriakidis, 1986; Le Pichon et al., 1984; Lyberis, 1984; McKenzie, 1978; and Dewey and Sengör, 1979), the general framework of this region (The North Aegean trough through the Saros Bay to the Sea of Marmara basin) is relatively young and superimposed on older structures of an orogenic belt of alpidic origin.

The Marmara basin is the extension of the Thrace basin (Fig. 6) which is surrounded by the Istranca massif at the north and northeast, the Rhodope massif at the west and by the Biga, Kapidag, Marmara Islands and Samanlidag massifs at the south (Ketin, 1983). Doust and Arikan (1974) divided the Thrace basin into four geographic regions according to the depositional environments as: (i) Southern shelf; (ii) Middle region; (iii) Northern shelf; and (iv) Kuleli high. The Thrace basin is a Tertiary basin where the subsidence of platform took place during the Middle Eocene. This created a wide strait between the Mediterranean and the Black Sea where a delta advanced from northwestern Turkey towards Thrace during the Late Eocene and the marine basin became brackish and smaller in time. The fine-grained sandstone and sandy clay changed to deltaic deposits, with intercalations of coal seams and gravel.

The Neogene lateritic depositions are present at the borders of this basin (Ilhan, 1976). The Marmara islands at the southern shelf of the Sea of Marmara, are made up crystalline rocks of marbles and granites. The Istranca massif at the north and northeast of the Thrace basin is made up of metamorphic and crystalline rocks. Istanbul and Kocaeli peninsula regions are characterized by the Palaeozoic rocks with a progressive transgression towards the end of the Silurian from the clastics to limestones. The Devonian of Istanbul and Kocaeli are made up of nodular limestones, lydites and marls. These facies change to a marine facies in the Lower Carboniferous (Doust and Arikan, 1974). During the middle Eocene, the subsidence of basement platform occurred creating the Thrace Basin where the Sea of Marmara is the southeastern extension of this basin. Therefore it could be assumed that these extensional basins of the Sea of Marmara have existed since Eocene time.

MARINE SEISMIC DATA OF THE SEA OF MARMARA

High resolution air gun seismic data (Özel, 1992) indicate that the Sea of Marmara is under the influence of two fundamental fault systems: (i) almost E-W trending normal faults (the Northern and Southern Boundary Faults), together with a number of secondary, subparallel faults also of a normal character; (ii) NE-SW oriented subvertical strike-slips which are largely dextral (Barka, 1991). These two fault systems divide the Sea of Marmara into roughly five different rhomboidal pull-apart structures (Barka and Kadinsky-Cade, 1988) between the two boundary faults (Fig. 7).

Three basinal blocks correspond to the three deep basins respectively. These are separated by the two high blocks which are indicated by a relatively high Bouguer gravity anomaly and about 600 m higher. All the blocks are subsiding but the subsidence rates are higher for the basins.

Three different seismic facies have been recognized (Özel, 1992 and Ergün and Özel, 1994) from these high resolution air gun data. These are: (A) The facies which are not affected by the transform tectonics, are the sedimentary facies deposited before the activation of the NAF (pre-Upper Miocene) occurring in the shelf areas outside of the boundary faults. These are defined as the pre-transform facies. (B) Syn-transform facies which were deposited concurrently with the evolution of NAF, are made up two different facies units (a and b) in the basins and horst areas respectively within the bounds of the boundary faults. The uppermost part of this facies (B-a) is characterized by well-stratified, almost parallel and well-defined reflections in the subsiding basins reaching thicknesses of about 1 km in places. The second unit of the syn-transform facies occurs over the uplifted blocks (B-b) consisting of reasonably well-stratified lower but completely distorted upper parts. (C) The upper-most facies are the most recent thin sedimentary cover over the first unit of syn-transform facies (B-a) in the deeper basinal areas. The interpretation of seismic lines (Line 49 and Line 52) can be explained in terms of growth and normal fault assemblages (Fig. 8). These interpretations can be considered as the normal faults detached from the basement of Thrace in the north. The Line 49 crosses the Blocks II and I from SE to NW. The basinal area (Block I) shows the very recent facies (C) and the upper syn-transform facies (B-a). The lower syn-transform facies (B-b) are exposed at the Block II which is the uplifted area. Pre-transform facies are present at the deeper levels on the edges of this seismic section. The Line 52 (S-N) crosses mainly the Block III which is the second basin in the Sea of Marmara. The basinal area is covered with the upper syn-transform facies (B-a) as well as the veneer of recent facies (C). Even the most recent sedimentary facies are affected by the active faults. The southern boundary fault is hardly present in this seismic section whereas the northern boundary fault is very distinctive.

The seismic section 19/20 (Fig. 9) transverses the deeper part of the Sea of Marmara from east to west. All the five blocks are shown by this section. The easternmost basin (Block V) is covered by the first unit of the syn-transform facies (B-a). The Block IV is the main uplifted part of the Sea of Marmara. It is made up of the second unit of the syn-transform facies (B-b). This is a very dominant uplifted block. This structure is cut by a strike-slip fault inferred from the changes in the reflection patterns. The first unit of the syn-transform facies are well stratified in the Blocks I and III which are the small basinal areas in the western end of the Sea of Marmara. The Block II is in between these two basinal areas, made up of the second unit of the syn-transform facies (B-b) There are normal and reverse fault structures in this small uplifted block (Block II).

SUPERFICIAL SEDIMENTATION IN THE SEA OF MARMARA

Superficial sediments of the Marmara Sea basin accumulated rapidly (0.087 ± 0.012 g/cm^2 y) by hemipelagic sedimentation with only limited amounts of gravity flow or bottom current action under low oxygenated but not anoxic conditions. Their high organic carbon contents clearly reflect both the stratified nature of the overlying water column and its enhanced productivity leading to a low content of oxygen in the bottom waters (Evans et al., 1989). The siliciclastic sediments, which are essentially silt and clay, are likely to be mainly derived from the adjacent coastlines of Anatolia and to a lesser extent Thrace, as it appears that the rivers draining the southern coastal areas of the Sea of Marmara act as the main agents of terrigenous sediment supply to this land-locked and silled basin (Fig. 10). Whereas the biogenic portion and the included organic matter may be largely produced locally, some of the latter may have come from the Black Sea and the Bosphorus (Alavi, 1988).

The presence hyaline calcareous benthic foraminifers and calcareous benthic macrofauna together with abundant bioturbation throughout

the sequence clearly shows that the environment has never become anoxic during the last millennium. Although superficial deep-sea sediments of the Sea of Marmara cannot be considered as sappropels in the strict sense of the term, their microfaunal contents reflect continuous sedimentation under dysaerobic conditions. Faunal similarities with fossil assemblages in association with some late-Quaternary sappropels and related facies from the eastern Mediterranean basins suggest that they were deposited under palaeo-oceanographic conditions closely similar to those of the modern Sea of Marmara.

Sedimentation shows little change over the last millennium except for an increase in Cu, Zn, Pb, Cr and P over the last few centuries. The increase was most likely caused by increased metallurgical activity since the eighteenth century but is not at sufficient levels for the area to be regarded as polluted. On the basis of the observed lithological characteristics, and comparisons of heavy metal concentrations for the Golden Horn and the Izmit Bay sediments by Ergin et al. (1991), this work showed that the latter area is much more polluted. Whereas the heavy metal concentrations in the Izmit Bay which is on the eastern proximity of the Marmara Sea basin with limited water circulation, are largely consistent with the natural background levels.

CONCLUSIONS

The Marmara Sea basin should be considered within the integral part of the North Anatolian Fault (NAF) and of an Aegean crustal regime in which a listric-faulted upper crustal section overlies a lower crust that has been thinned in a ductile manner, the overall crustal thickness being about 25-30 km. As with the North Aegean area, the Sea of Marmara is undergoing a combination of right-lateral strike-slip and north-south extension with the formation of pull-apart basins. According to the interpretation of the geological, geomorphological and geophysical data, the Sea of Marmara can be divided into five different blocks, which are controlled by two sets of fault systems: (i) E-W trending normal faults (the Northern and Southern Boundary faults); and (ii) NE-SW oriented sub vertical strike-slips. The east-west trending normal fault systems of the Sea of Marmara is a diffusive zone of crustal thinning. However, it is obvious that the NAF affects the region at depth within the upper mantle with the formation of "negative flower structures". The blocks are undergoing vertical motions and rotations relative to one another. The whole area is subsiding although the subsidence rate is higher in the basinal areas than in the blocks. Three deep basins of the Sea of Marmara are related to the basinal blocks which are covered by the horizontally well-layered upper syn-transform sedimentary sequences. These are separated by two uplifted blocks which are made up of lower syn-transform facies that suffered compressional stresses. The strike-slip faults bring together the different sedimentary sequences horizontally.

Coasts of the Sea of Marmara are of a regressive type. Although there are tectonic movements in the region, the main cause of change in hydrographic and morphologic conditions are due to the eustatic variations. The strong stratification of the water column coupled with the topographic restriction imposed by the two shallow sills of the Dardanelles and Bosphorus inhibits efficient circulation of deep waters. This situation, together with the relatively high average rate of primary productivity leads to oxygen depletion in the sub-halocline waters. The oxygen deficiency becomes more pronounced toward the east as the only source of oxygen replacement for the sub-halocline is the underflow through the Dardanelles. Three deep basins of the Sea of Marmara become less oxygenated from west to east.

Superficial sediments of the Marmara Sea basin accumulated rapidly by hemipelagic sedimentation with high organic carbon contents. The environment has never become anoxic during the last millennium. Faunal similarities with fossil assemblages in association with some late-Quaternary sappropels and related facies from the eastern Mediterranean basins suggest that they were deposited under palaeo-oceanographic conditions closely similar to those of the modern Sea of Marmara. Sedimentation shows little change over the last millennium except for an

increase in certain heavy metals which is largely consistent with the natural background levels, over the last few centuries.

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Fig. 1. Bathymetric map of the Sea of Marmara (from IOC-UNESCO, 1991).

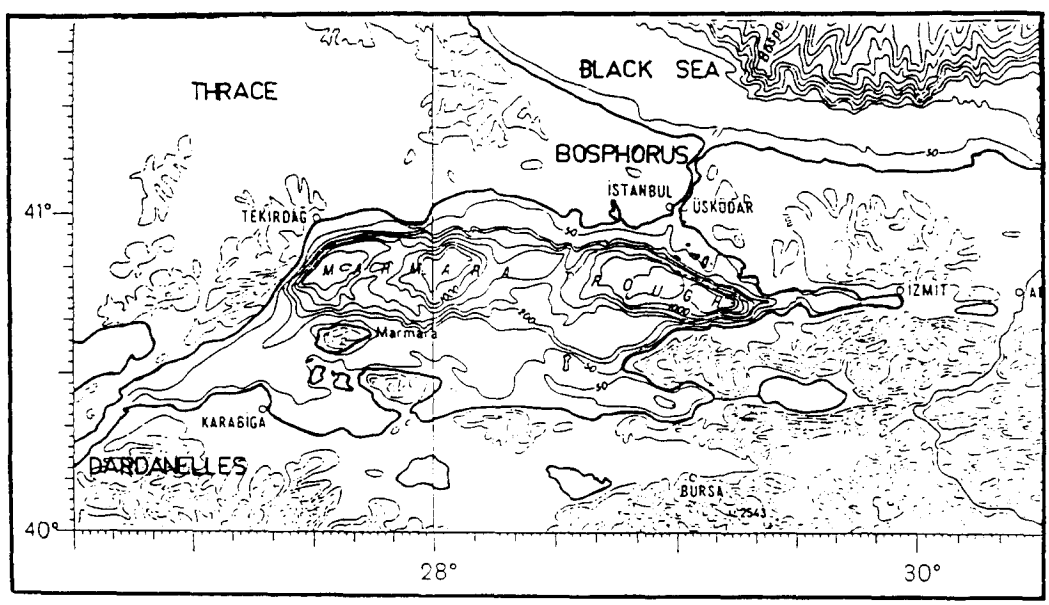
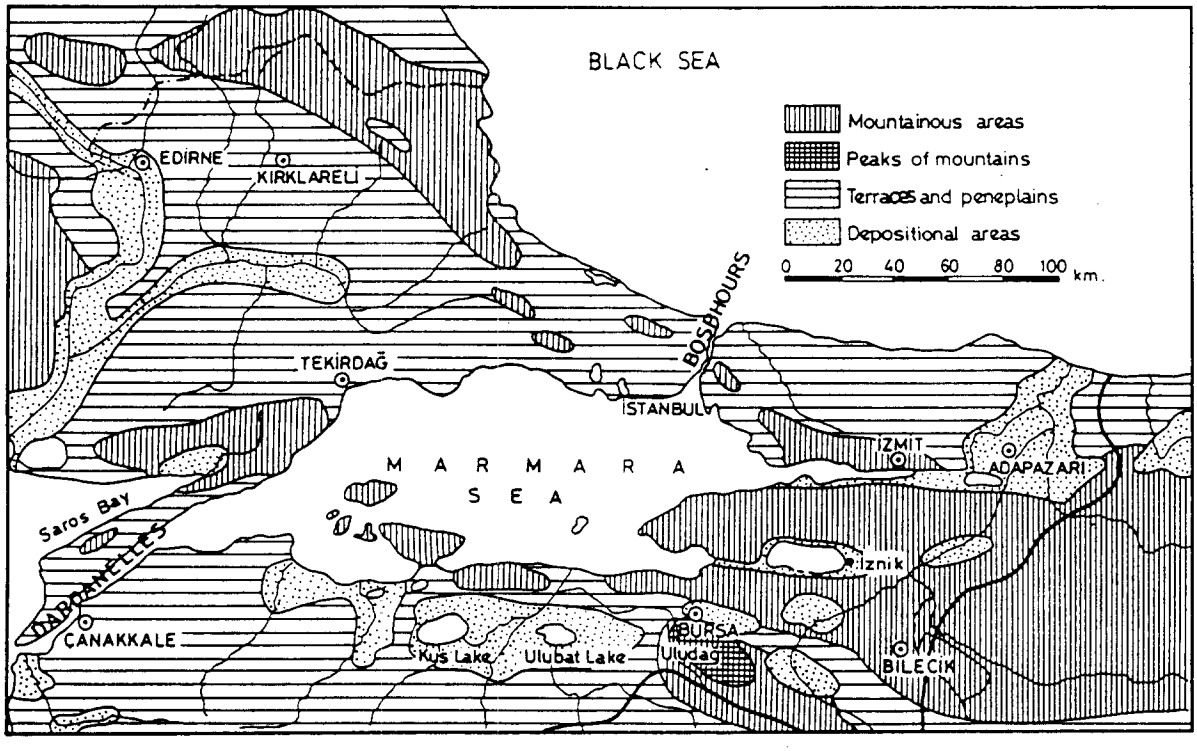


Fig. 2. Main geomorphological structures for the areas around the Sea of Marmara.



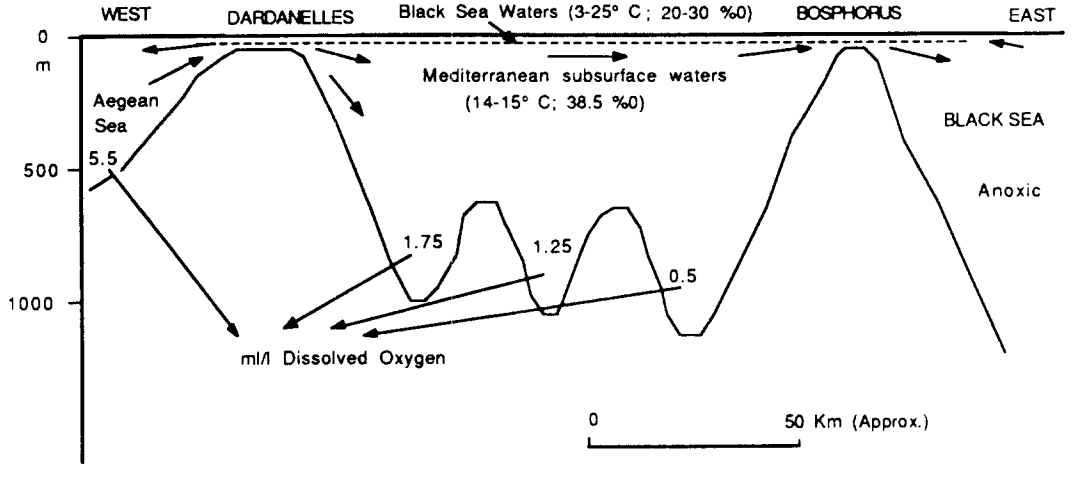
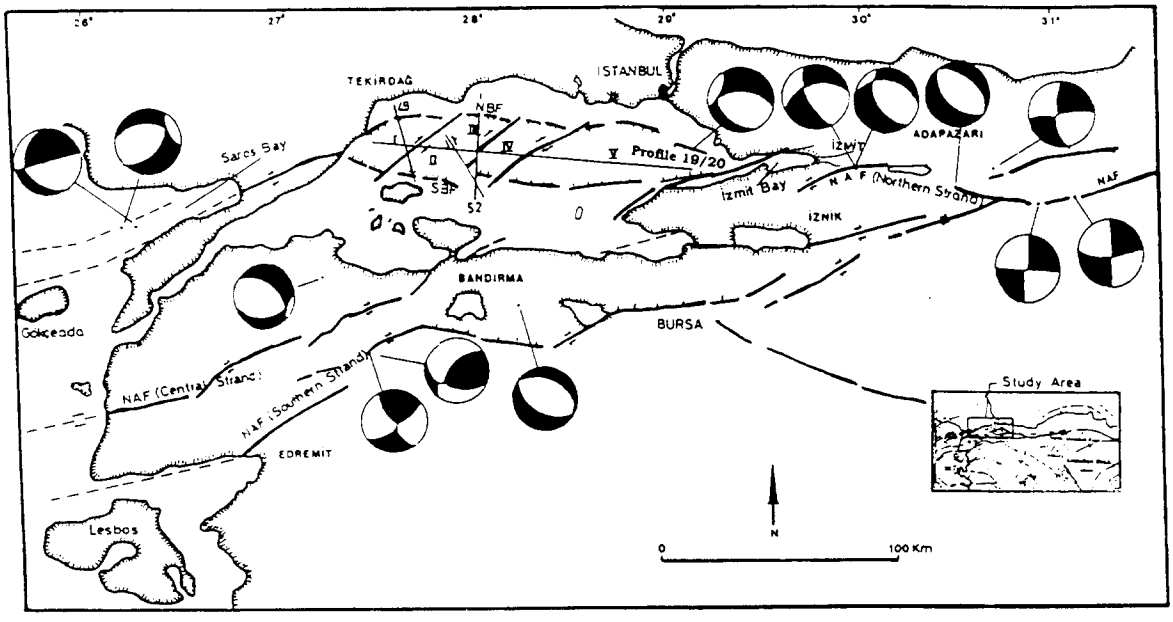


Fig. 3: Generalized oceanographic conditions of the Sea of Marmara from Dardanelles to Bosphorus (Schematic).

Fig. 4. Fault plane solutions and main tectonic framework of the Sea of Marmara and surroundings (modified from Barka, 1992). Basinal areas: I, II and V; Uplifted blocks: II and IV in the Sea of Marmara within the limits of the Northern and Southern Boundary Faults (NBF and SBF). Locations of the seismic profiles (49, 52 and 19/20) are shown.



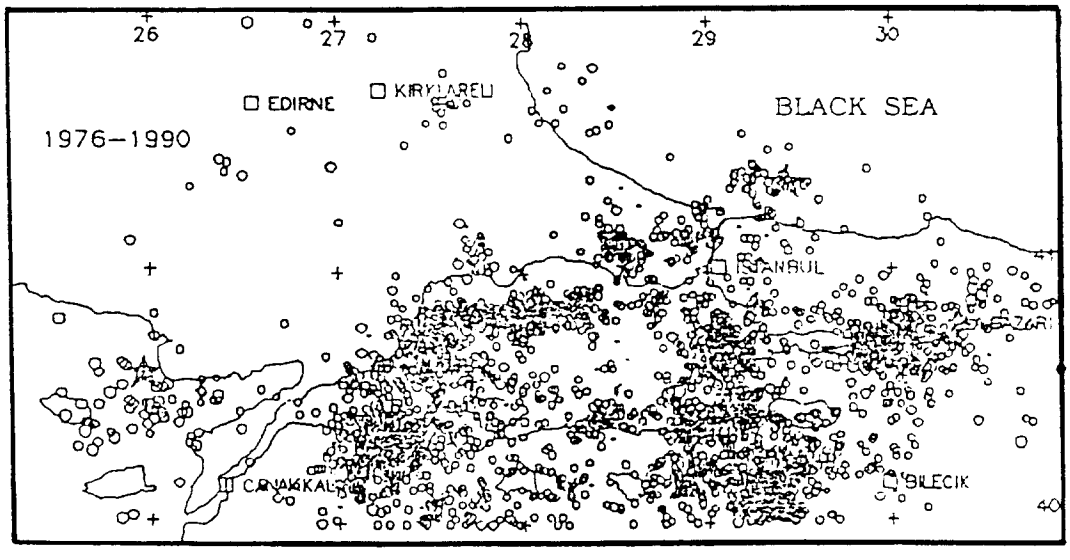
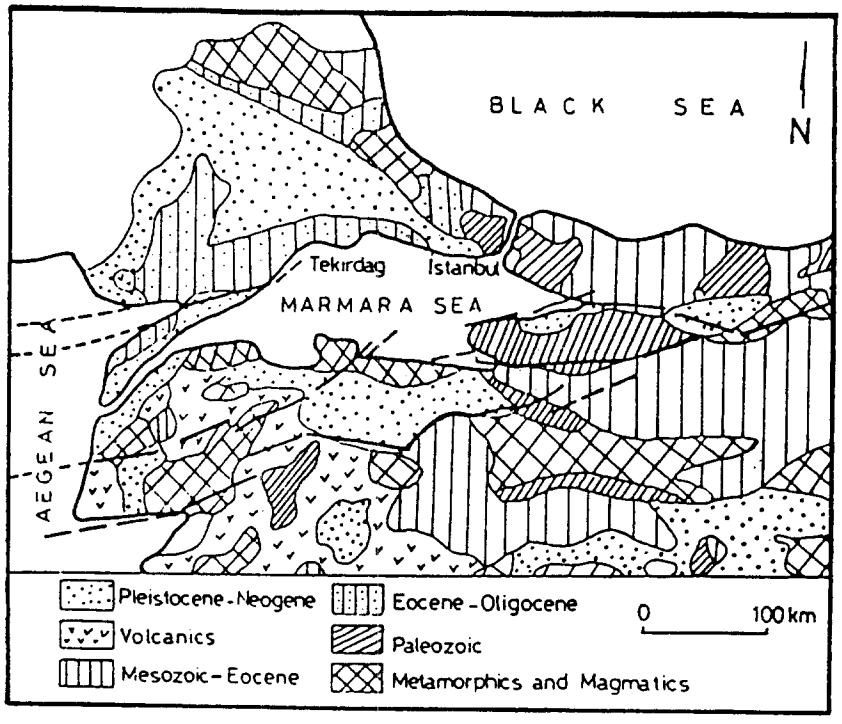


Fig. 5: Map of all earthquake epicentres in and around the Sea of Marmara reported by the Kandilli Observatory (compiled by Barka, 1992).

Fig. 6: Simplified geological map of the Sea of Marmara and surrounding areas (modified from the geological map of Turkey by MTA).



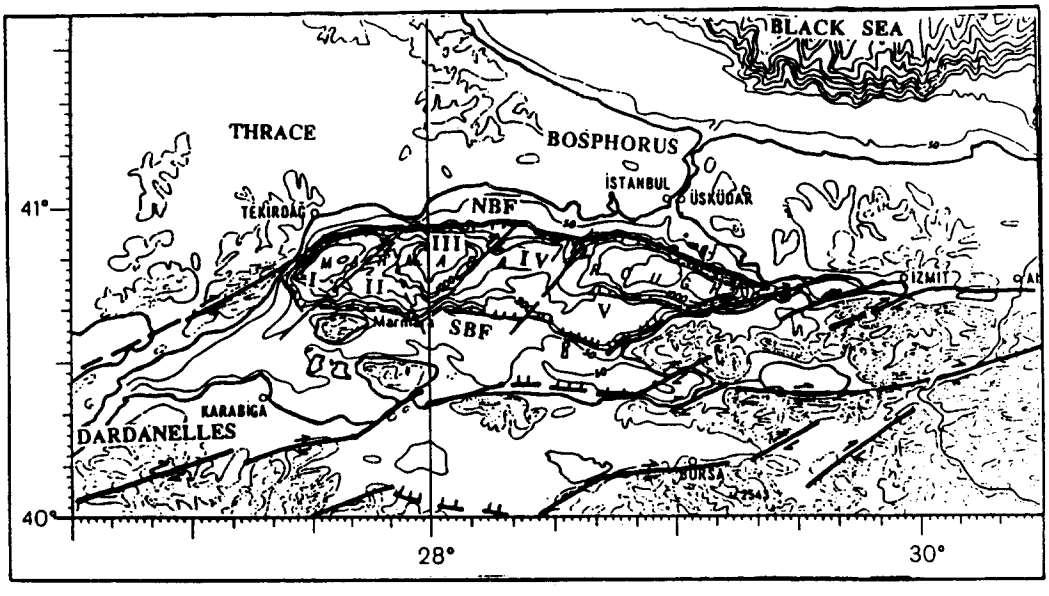


Fig. 7: Main fault lineaments and the blocks in the Sea of Marmara (Basinal blocks: I, III and V; Uplifted blocks: II and IV).

Fig. 8: Interpreted seismic profiles (49 and 52) in the Sea of Marmara. SBF: Southern Boundary Fault; NBF: Northern Boundary Fault; A: Pre-transform facies; B: Syntransform facies (a: Upper and b: Lower); C: Recent facies. Upper and b: Lower).

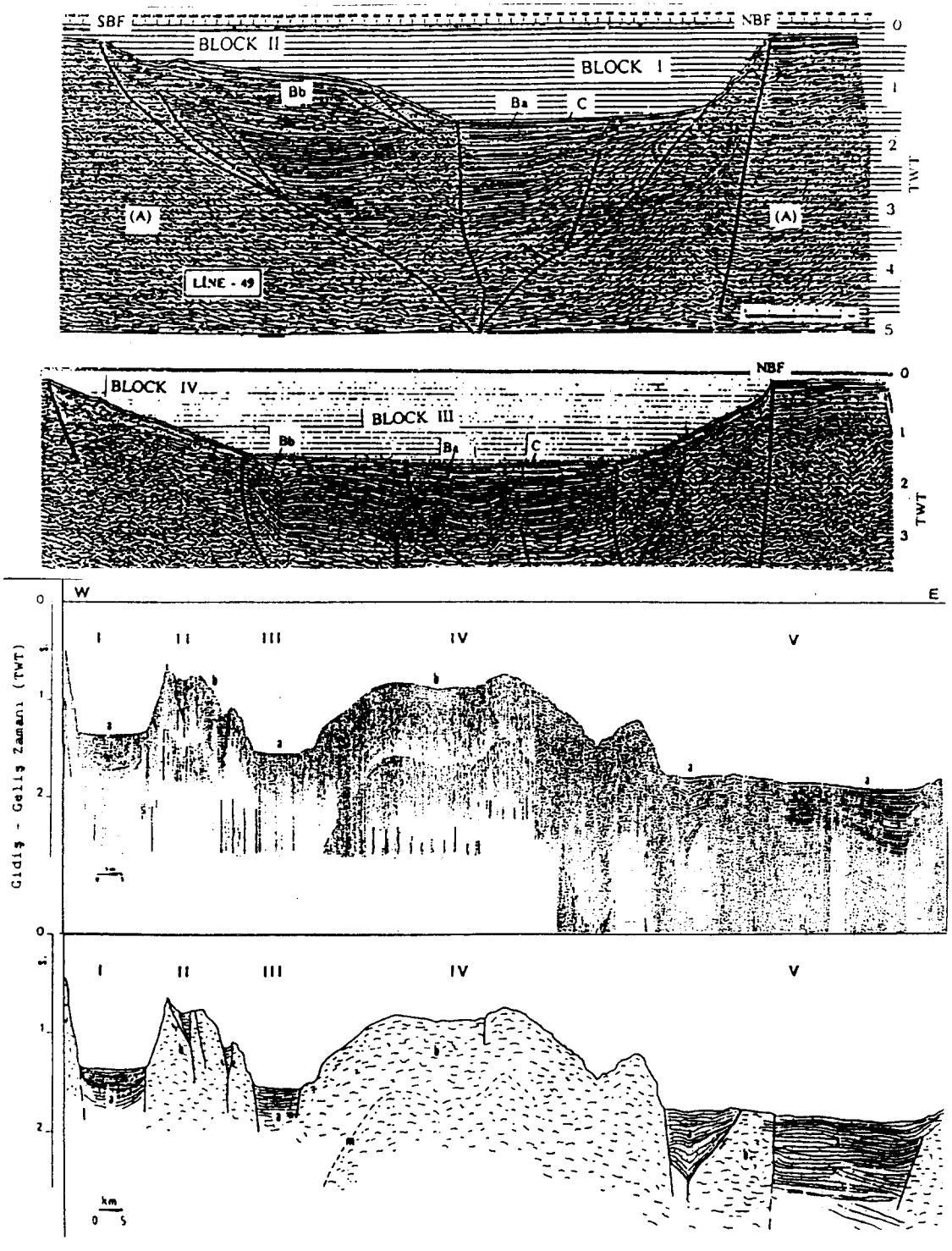
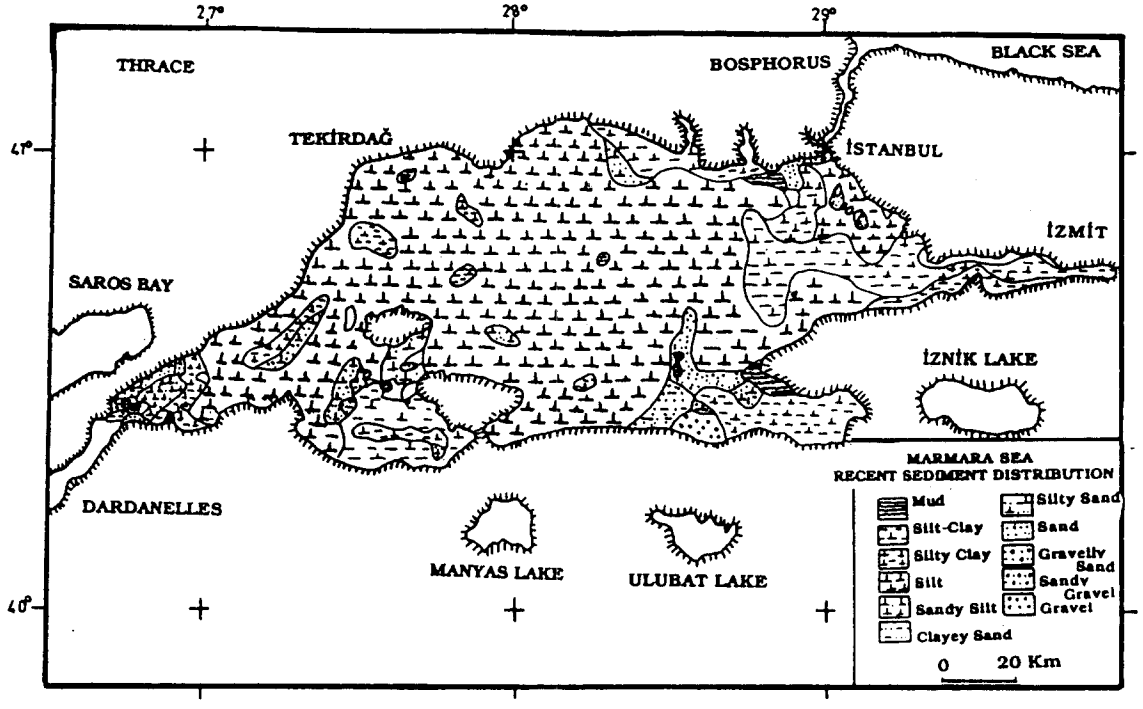


Fig. 9: Interpreted seismic profile (19/20) in the Sea of Marmara. Syn-transform facies (a: Upper; b: Lower).

Fig. 10: Superficial sedimentation map of the Sea of Marmara (compiled from the Turkish Navigation, Hydrography and Oceanography Department, SHOD).



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COASTAL CHANGE: AN OVERVIEW OF THE EAST COAST OF INDIA

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KEY WORDS: Quaternary period, Eastern Ghat Orogeny, Emergent Coast, Isostatic subsidence, Tectonic Instability, Transform faults, Ridge crests, Triple junctions, Subduction and Compression of Plates, Neotectonic activity, Strandlines, Littoral Drift.

ABSTRACT

The East Coast of India is the focal point of our study. This fairly broad coast with varying width is an 'emergent' one. Very active tectonic movements have been taking place here since the post-Cretaceous period, though it was modified considerably during the Quaternary period. The present study aims at investigating the configuration of the entire coast and its associated features which have been formed due to dynamic geological, geomorphological, meteorological and biotic processes. It uses topographical maps, aerial photos and satellite data. A certain amount of neotectonic activity is observed resulting in the abnormal meandering of the rivers besides the progradation of the deltas.

INTRODUCTION

Coastal areas have been the most favoured sites for people to establish their settlements and develop commerce, navigation and culture, for which they often require suitable land, water and agricultural resources. The main objective of Geologists, Geographers and Geophysicists is to describe physical features such as the layout and alignment of coast, subsidence and emergent aspects, sea level changes and biota, which ultimately lead to coastal change. Keeping this aspect in mind, recently an attempt was made (Jaya Raju et al, 1994) to focus the attention of earth scientists of India on the problems and prospects of the major and minor ports of coastal Andhra and their changing role. As the coastal zone represents a unique interface between the sea, land and air, sub-aerial and marine processes of erosion and deposition are clearly felt on this "flexure zone", which disturb the ecosystem.

The Indian sub-continent has two marginal seas, namely, the Bay of Bengal in the East and the Arabian sea in the West. It has a fairly long coastline of about 7500 km including its island territories (GOI, 1985). The Bay of Bengal is bounded on the North by Bangladesh and Burma, on the West by the Indian Peninsula and on the East by Thailand and the Malayan Peninsula. It extends up to 6° South Latitude (Fig. 1). This coast which has a spectacular array of fluvial, marine, aeolian and fluviomarine land forms starting from the river mouth of the Ganges in the North to the Southern most tip of the Peninsula (Cape Comorin) in the South which is 4624 km in length, is the focal point of our study. With the active progradation of the modern deltas of the Ganges, Mahanadi, Godavari, Krishna and Cauvar (KAVERI) rivers, this geometrically straight lined coast has been constantly undergoing physical changes under exogenic and endogenic processes since the time of its origin. In the Quaternary period considerable amounts of change due to exogenic processes have been noticed. The main objective of the present study is to make an investigational review of the present configuration of the entire coast and its associated features caused by dynamic geological, geomorphological, meteorological and biotic

processes. The study is confined to tracing the actual position of the shoreline at present, for which the data has been recorded through Survey of India Topographical Maps/Air Photos/Satellite pictures. In all the cases the representation of the features and their mapping have been strictly on a physical basis.

PHYSICAL PANORAMA OF THE EAST COAST OF INDIA

The breaking up of the Gondwana Land during the later Mesozoic era and the separation of India from Madagascar in the Upper Cretaceous placed the Eastern Ghat mountain chain parallel to the coast for which the East Coast is often referred to as the "Longitudinal Pacific Type" (Mathur, 1991). Lineament studies on the Krishna and Godavari basins by Biswas (1993) indicate that the dominant NE-SW trend is related to the Eastern Ghat Orogeny. It is quite possible that the complex processes of rifting and separation of the Antarctica and Australia which gave birth to the Bay of Bengal have something to do with the Eastern Ghat Orogeny. Therefore, the peculiarity in the alignment of the East Coast is that it is straight at some places and wavy with major protrusions in the deltas. Regarding the classification of the Indian littoral, Ahmed (1972) says that the West Coast is of 'Submergent' and the East Coast as an 'Emergent', though a considerable amount of 'isostatic subsidence' (geosynclinal basin) could be observed at some points of the East Coast. This East coast is often characterised by gentle sloping profile of the shelf, the continued growth of land into the sea in the form of deltas, the presence of lagoons, barrier islands, mangroves, spits, tidal inlets, harbours etc., Therefore, in a panoramic view, the entire coast looks much indented.

The continental margin along the East Coast of India has a distinct topographical and geological peculiarity. The most notable break of slope in this mud-covered shelf is approximately at 200 m contour and this is the outer limit of the continental shelf. The average width of the shelf on the East Coast is about 50 km and the maximum width of the shelf is found opposite the delta mouth of the Ganges (Fig. 2). Near Cape Comorin, there are largely Archaean rocks with a thin cover of Tertiary sediments which are also found along the Northwest Coast of Sri Lanka, thereby providing evidence of the attachment of the two, which are now separated. Further North, the shelf consists of Cretaceous and Tertiary Crocks overlain by Pleistocene sediments up to the Gangetic delta.

GEOLOGICAL CAUSES

Geological changes of the East Coast are both exogenic and endogenic. In fact, the Peninsular Shield took an active part in the Himalayan upheaval, and as an accompaniment of the same disturbance, the Peninsular Block tilted slightly Eastward causing ninety per cent of India's drainage to flow into the Bay of Bengal (Wadia, 1978). As the Peninsular Shield faces the Bay of Bengal, it is the harbinger of major modifications in the coast. This old crust block, though resistant to large scale movements, could not be immune to the small scale faults or fractures that occurred due to tensional stress. This must have caused the uplift and/or subsidence of blocks along the coast. The trough faults of the Damodar, Mahanadi, Godavari etc., are some of the notable examples (Wadia, 1978). This uplift and subsidence of blocks in the coast created a kind of 'tectonic instability' which is evidenced by the 'antecedent nature' drainage, 'geometrical straightness' of the coast, the shrinking of the Pulicat lagoon, and the subsidence of the Gulf of Manna and Palk Straits near Sri Lanka. As most of the rivers of Peninsular India have their river mouths on this coast, it is characterised by indentations owing to the constant struggle between the seaward growth of the deltas on one side and the marine erosion on the other. The deltaic tracts which are occupied by alluvium and other unconsolidated fluvial and marine material are under active sedimentation. Therefore, the local subsidence adds to the unstable nature of the coast. The presence of a number of recent faults and fractures in the underlying basement of the Southern part of the Ganges further stresses the unstable nature of the coast (Morgan and McIntire, 1959). This coast is also noted for seismic activity of minor intensities as noticed in

the recent past, because of which numerous transform faults, ridge crests and triple junctions have been found which are indicative of sea-floor spreading. Palaeomagnetic studies on the Ninety East Ridge in the Bay of Bengal by Peirce (1976 & 1978), show that the edge of the plate lies along the Sunda-Andaman Arc of the Bay of Bengal and the processes of subduction and compression of the plate create notable indentations along the continental shelf of the Andamans.

GEOMORPHOLOGICAL CAUSES

The configuration of the coast as recorded in the earlier topographical maps and the British Admiral Charts from 1857 to 1942, differs from the recent LANDSAT imagery which reveals an accumulation of sediments over the years not only at the confluence of the rivers but also at some bays. The accumulation of sediment in small quantities in the form of bars and spits encourages harbour development, and hence, a number of small and medium-sized ports have developed along this coast (Jaya Raju et al, 1994). Historical records reveal that the French colonizers of India had built a port of their own at Yanam, even before 1679 AD. The upper reaches of the Peninsular rivers have been known to swell constantly due to seasonal rains creating an unending chain of floods which have caused heavy erosion on the upper course and deposition on the lower course of the rivers. Subramanian (1993) estimates that the Peninsula's largest rivers discharge approximately a sediment load of 1137.6 (106 t/y) on the coast, where exposure to wave and wind energy is relatively high. The digital delta of the Ganges, the arcuate deltas of the Mahanadi and Godavari and the lobate delta of the Krishna were perhaps the result of such wave and wind activity on the coast. Vaidyanadhar and his associates, Sambasiva Rao and Nageswara Rao, initiated since 1977 the studies on different deltas on the East Coast using aerial photographs to start with and satellite imagery subsequently (Vaidyanadhan, 1991). Sambasiva Rao and Vaidyanadhar (1979), show the changes in the configuration of the delta near the mouth of Godavari and observed that the progradation near the north entrance of Kakinada port was about 2.4 km over a period of 85 years. A certain amount of neotectonic activity was observed by them based on the abnormal meandering of the Vainateya and Vasista which are distributaries of the Godavari near the coast. The lineament passing through Narsapur and Yanam tending ENE-WSW is presumed to be a neotectonic fault (Fig. 3).

Similarly a large number of lineaments of different magnitudes have been delineated in the Pulicat Lake area, which are supposed to have been formed by the neotectonism (Jamkhandi, 1983 and Naga Raju, 1985). Biswas (1993), has observed five strandlines in the Krishna-Godavari delta, indicating five stages in the progradation of the delta (Fig. 3). Agarwal and Mitra (1991), have identified four Quaternary divisions of the Sunderbans and shown that the progradation of the delta to the East is of recent activity (Fig. 4). Similar deltaic projections from Cape Comorin to the Sunderbans and the minor littoral projections at Pulicat and Armegan are the results of active seaward extension of the Coromandel Coast by the material transported by the rivers.

METEOROLOGICAL AND OCEANOGRAPHIC CAUSES

The predominating feature of Indian meteorology is the semi-annual reversal of the wind system, causing the Southwest monsoon (June to September) and the Northeast monsoon (October to December). These monsoon winds play a significant role in the layout of the coast by bringing about erosional and depositional activities. As pointed out earlier, the peculiarity of the East Coast of India is that it is straight, wavy and protruberant, and hence it experiences both the positive and negative effects of the monsoons by their windward and leeward nature. The detrital material brought by the rivers is washed northwards up the coast by the Southwest monsoon and down the coast by the retreating monsoon. The recently formed littoral in excess quantity has led to the formation of spits and bars. As a result, not only the general configuration of the coast has undergone changes but many ancient ports have become silted and

gone into disuse (Jaya Raju et al, 1994). The prominent shoals that can be observed today are the 'Armegan Shoal' (14°N & 80°10'E), the 'Motupalli Shoal' (15° 26'N & 80°E) and others. Mahadevan and Prasada Rao (1958) have studied the origin and extension of the Godavari spit, popularly called 'Godavari Point' at the entrance channel of the Kakinada Bay. The influence of the Southwest monsoon winds is clearly felt on the origin and development of this 16 km long spit. But at the Kakinada Bay, the spit has a tendency to recurve westwards due to the more pronounced nature of the Northeast monsoon winds. It is also noted that the Southwest and Northeast monsoon winds largely control the circulation of ocean water resulting in clock-wise and counter clock-wise motion of the warm ocean currents, seiches and internal waves which ultimately have an adverse effect when they batter the coast (Fig. 5). Sea-floor photography too shows well-developed current lineations with scour marks on sediments deposited.

Further, the meteorological effects in the form of severe cyclonic storms are also felt here. The North Indian Ocean, being a region of the lowest pressure due to the seasonal migration of the Sun in the Southern hemisphere during October-December, has been the cradle of the most destructive tropical cyclones that have ravaged the East Coast of India with a wind speed varying from 34 to 64 knots. The funnel shaped river mouths are adversely affected by the waves measuring 6.5 to 9.5 m high. As a result the configuration of the coast is changed.

BIOTIC CAUSES

The area under mangroves along the East Coast is mostly degraded except at a few places, because the vegetation there is used for fuel and fodder and part of the area is converted for agricultural, aqua-cultural and industrial purposes. As a result, erosion has taken place and changed the configuration of the coastline.

Further investigation is underway and the results are likely to be known before long.

CONCLUSION

In the present investigation, an attempt has been made to present an over view of the present configuration of the entire East Coast of India and its associated features, which are caused by the dynamic geological, geomorphological, meteorological biotic processes. In the inquiry, Survey of India Topographical Maps and LANDSAT images have been used with limited field verification. It is found that the East Coast underwent changes in the recent geological past and that the process of change is still continuing. It is further noticed that owing to neotectonic activity at many places along the East Coast, its present configuration is changing further.

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Fig. 1. Map of the Bay of Bengal.

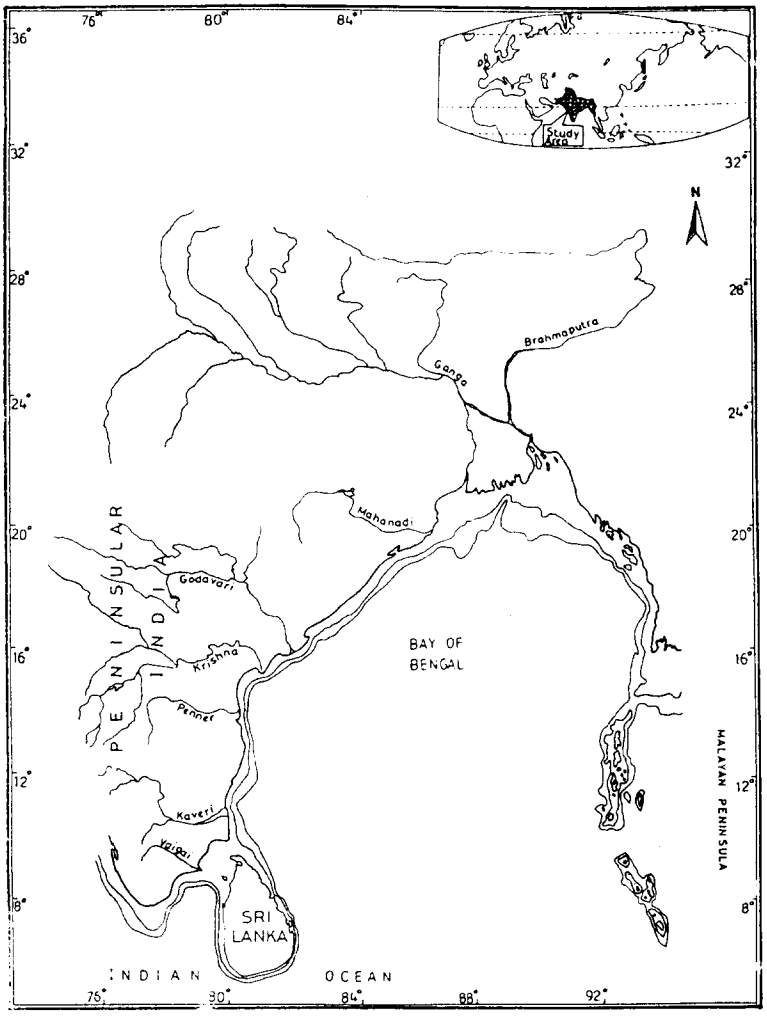


Fig. 2. Topographic profiles on the continental margin of the east coast of India after Narain et al., (1968). Source: INCOR Status Report 1985.

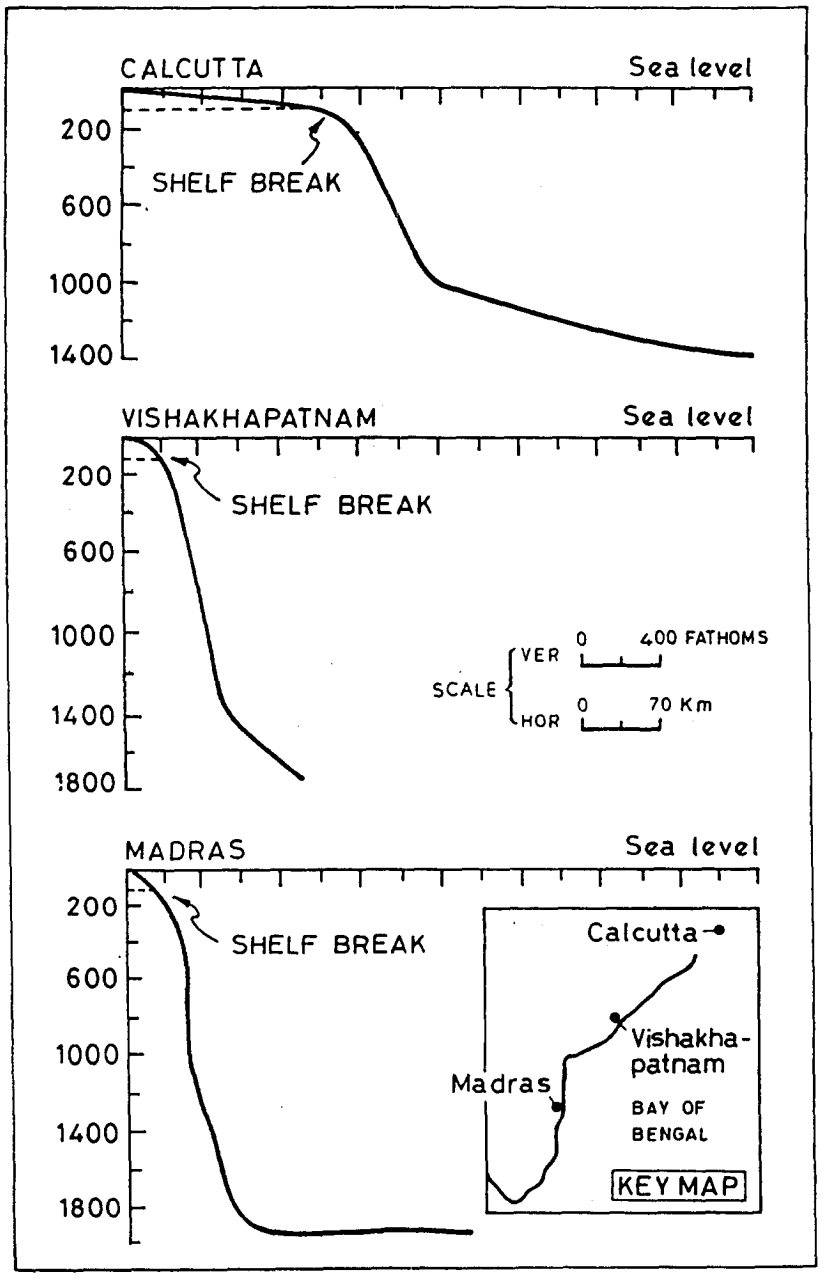
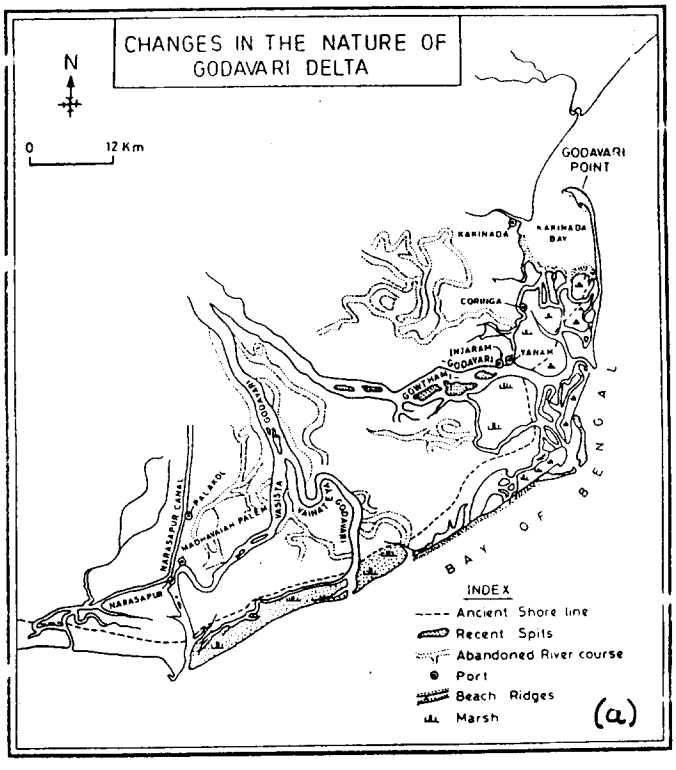
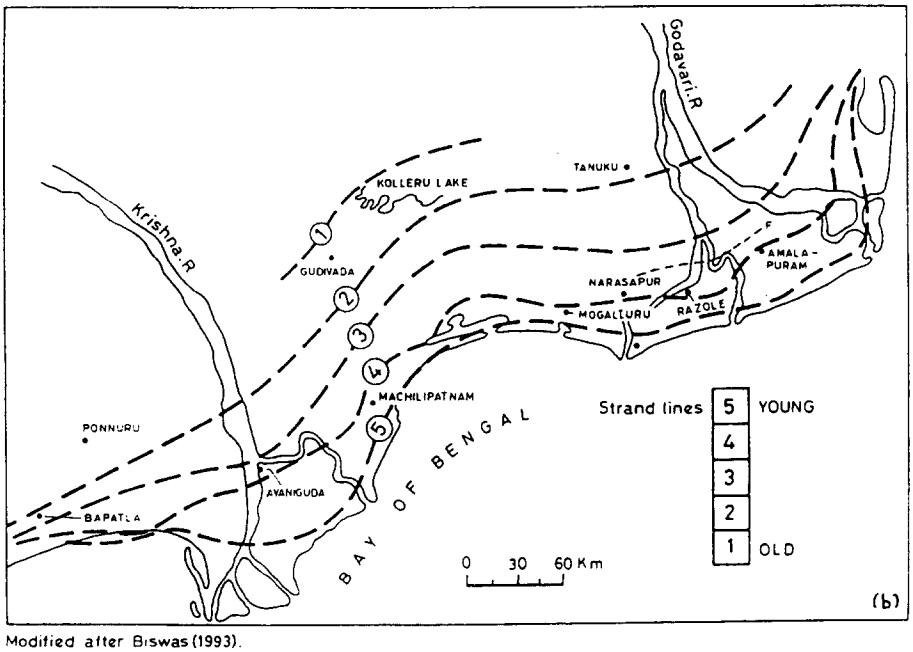


Fig. 3. (a) Changes in the nature of the Godavaru delta. (b) Probable palaeostrandlines of Krishna-Godavari deltas.





Modified after Biswas (1993).

Fig. 4. Probable palaeostrandline of the Ganges delta, modified after Agarwal & Mitra (1991).

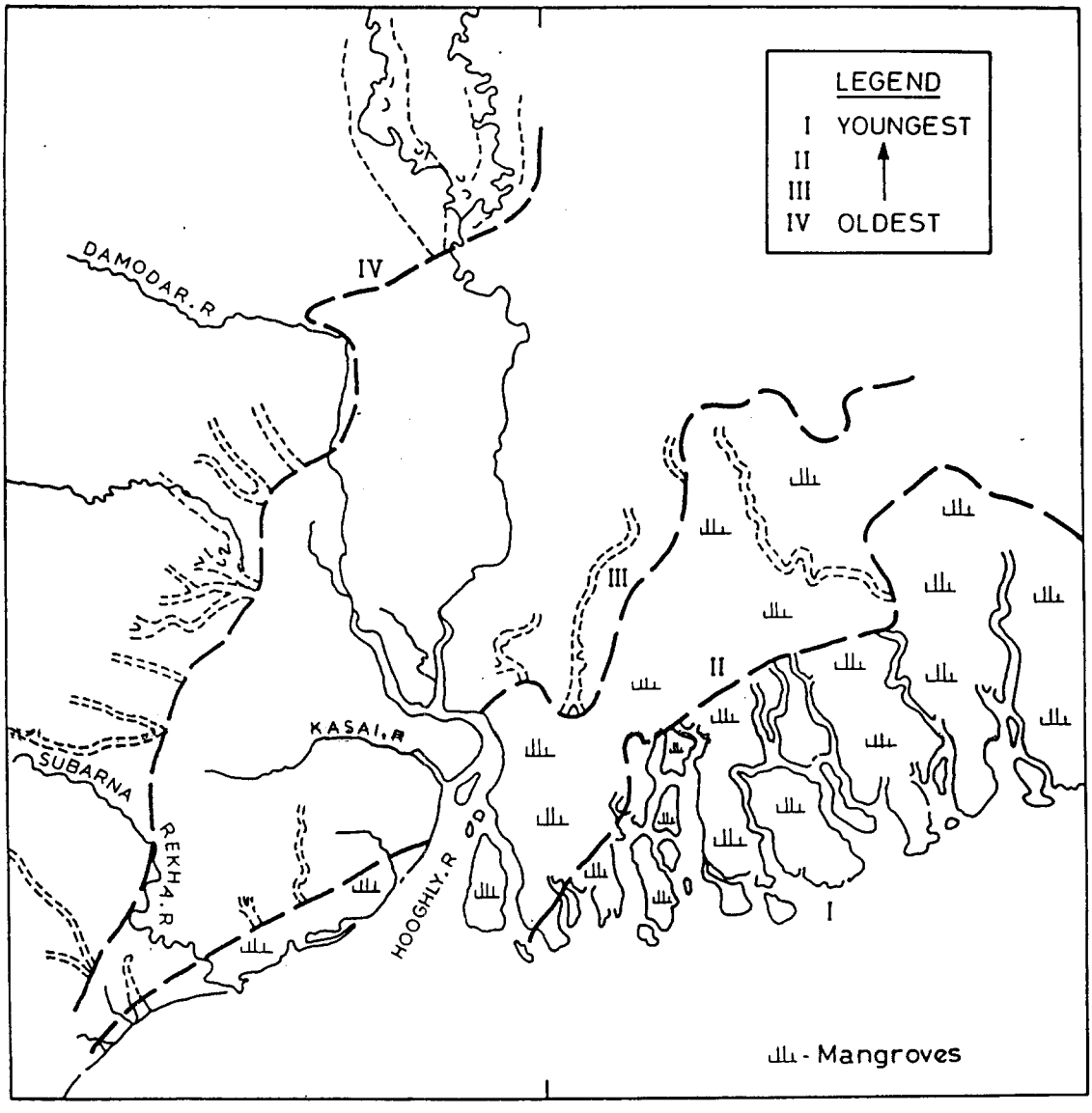
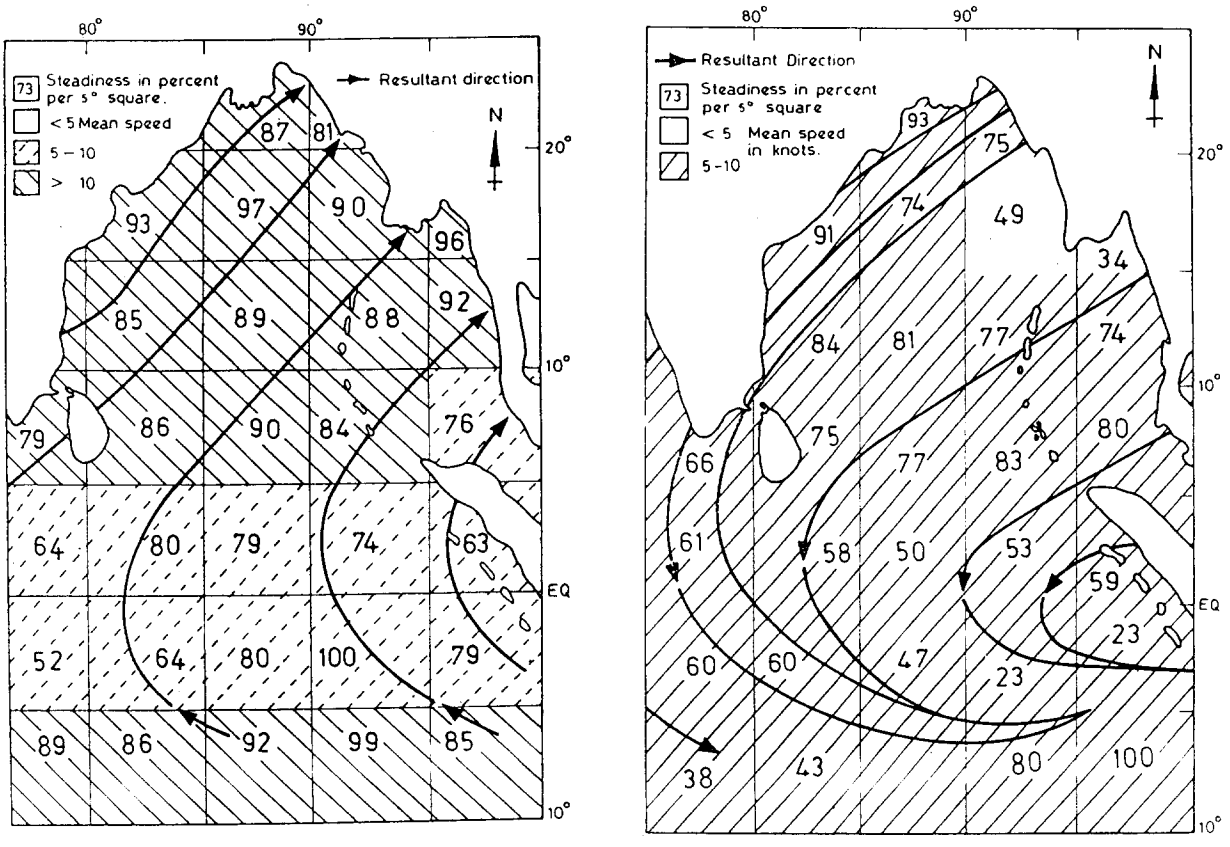


Fig. 5. Winds at the sea surface, direction, speed, steadiness. Source: INCOR Status report (1985).
(a) S.W. Monsoon period. (b) N.E. Monsoon period



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NEW TECHNIQUES FOR COMPLEX GEOLOGICAL AND ENVIRONMENTAL STUDIES OF COASTAL MARINE ZONES

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KEYWORDS: Coastal marine zones, complex geological-environmental study, portable multichannel recording and processing apparatus, modulus principle, litho-stratigrafy, bottom relief,pollution, hydrophysical, hydrochemical properties, buried technical subjects.

ABSTRACT

Coastal marine zones are specific geological-geographical objects and require special approach and complex study. To study the following aspects: litho-stratigrafy of sediments, bottom relief, coastal circulation and sediments transport, coastal erosion and siltation related to natural or anthropogenic fac-tors, elemental and integral pollution of bottom sediments and water, hydrophysical and hydrochemical properties, prospecting of technical subjects on the bottom, the authors have designed geophysical marine system ("Sprut"). It is portable digitalmultichannel recording and processing apparatus system based on modulus principle, which can be installed on a vessel of any class.

TECHNOLOGY

Coastal marine zones are of particular interest and importance from scientific and practical points of view. They are very specific geographic-geologic objects due to high hydro-and lithodynamics, very intensive contemporary geological processes, termination of river discharge, existence of physical-chemical barriers, as results of sea-land interaction, location for constructive material and placer occurrences. Besides within these zones the mankind's activity is most intensive because of fishing, transport communication, hydrotechnical and industrial constructions, and recreation spots. As a result coastal marine zones undergo the highest anthropogenic pressure and technogenic pollution. Environmental problems are very serious here and should be controlled.

Because of their specific and important role the coastal marine zones require systematic and complex study covering many objectives, including litho-stratigrafy and thickness of recent sediments, coastal topography and bottom relief; coastal circulation and sediments transport, coastal erosion and siltation related to natural or anthropogenic factors; elemental and total (integrated) pollution of bottom sediments and waters; hydrophysical properties (salinity, temperature, vectors of current and so on); prospecting of technical subjects on the bottom.

Coastal marine zones are rather difficult (sometimes impossible) to study by conventional techniques used in the open sea conditions, because they are usually shallow, have strong currents and often are unaccessible for vessels of marine class, so small boats or amphibian type carriers are more proper here. Such universal method of marine geology as continuous shallow seismic profiling is not effective in the coastal zones, because of so called "hard" bottom.

As the basic instruments for complex multidisciplinary study of coastal marine zones geology and environments we would recommend multi-functional portable recording and processing, and interpreting systems designed in our institution. These systems, founded on two-levels digital base, possess broad possibilities in the area of time spectre, measuring of many parameters, and processing of the obtained different data in thereat time scale. Uniting in one cycle of measurement such different modes of

information as acoustics, electrometric, hydrochemical, magnetometric, these instrumental systems make it possible to solve simultaneously quite a number of tasks, corresponding to the above mentioned problems in the coastal marine zones.

Using these multichannel processing system has several advantages: fast response on changing of properties, large processing power, high stability in compare with conventional automatic geophysical instrument, designed on another technological conception (central management). It is preferable to construct geophysical systems on modulus principle using single-crystal computer (8835 Intel). In such geophysical systems every single geophysical method, entering to the complex, realizes by functionally and mechanically ready instruments which can work both ways: independently or united in the system. Every instrument: echo-sounders, electrometric station, digital magnetometers, fast channels of seismo acoustic station, hydrophysical and hydrochemical sondes include special controllers,built on single-crystal computer base. Single-crystal computers fulfil two functions: management of geophysical instrument and filtration signals. In recording apparatus two-level systems of management and the data processing are used. Geophysical instruments (recorders of geophysical information) serve as the first (the lowest) level. The second level are personal computers with sufficient calculating capacity. Using of these two-level constructions makes it possible: 1) to increase efficiency of all the system by involving different parallel programs of recording and processing the data of several methods operating simultaneously, 2) to use methods functioning simultaneously with different speed at the real time scale, 3) to minimize program-apparatus volume due to modulus principle of the system construction, 4) to provide individual diagnostics of every geophysical instrument entering the system at the first level and total diagnostics of the whole system at the second level.

We have implemented the above mentioned principles in the several instrumental systems designed for marine geological and environmental investigations, such as: SSH-3, Sprut and PAK-2.

SSH-3 - provide electrometry, magnetometery, seismo-acoustic, gammaspectrometry studies for offshore geological and geophysical survey, prospecting of placers and constructive materials, and engineering survey. This system can be used aboard vessel of any class. It is supplemented by a software package,making it possible to draw resulting maps, sections, plots and tables through the use of colour plotter on board a ship.

System " Sprut " was designed mainly for environmental studies on shelf up to 250 m isobath. It combines electrometry methods with sensors of constant or slowly changing natural electric field, iono-selective electrodes for micro-elements detection in water, temperature, pressure and conductivity sensors. It works in regime of soundings at vessel stops and of profiling at vessel speed up to 7 knots. The system consists of onboard and off board parts. Onboard part includes personal computer of "notebook" class 386 DX, and block with built in computer with a processor type 1816BE35. Off board part consists of bugged container with temperature, pressure and conductivity sensors and changeable line with iono-selective electrodes and multi-functional marine sonde. The system block is adapted to echo-sounders and other interface type IRPR-M, and to 14 analogue channels. It has two recording diapasons: 1) from -2000 mV to +2000 mV, resolution 1 mV; 2) from -200 mV to +200 mV, resolution 0.1 mV. Name of measured micro-elements concentration depends on the set of chosen electrodes. The authors have measured: Eh, Cl, S, CN, Cd, Cu, Hg, Pb, Ag. Special programs make it possible to present results in form of tables, charts, maps, diagrams.

The system "Sprut" is portable and can installed on board of small ships and boats. It consumes alternating current 220 V, 50 Hz, required power no more than 50 W.

PAK-2 is automatic digital modulus apparatus combining sidescanning sonar with stripe as wide as 100-400 m and resolution -0.4 m; 16 channel digital recording modulus, high-frequency proton magnetometer MBM, slaving to electrometry modulus, echo-sounder PEL-4, computer. It is designed mainly for offshore prospecting of buried objects on the sea bottom, such as sunken ships,

containers with waste of any kind, bombs and so on. It is supplied with a package of programs, providing plotting the results.

Now we shall illustrate some results, obtained by the above mentioned instrumental systems.

By the method of measurement of natural electric field potential along profiles we study surfacial lithology. Then the data of several profiles are transformed to lithological map (Fig. 1).

By means of measurements on constant current and drilling support we obtain geological sections of loose sediments, as shown on Fig. 2 (in the coastal zones of the White Sea).

Field data records being processed by special programs provide quantity interpretation and final visualisation, as shown on the map of gravel-sand deposits thickness, drawn in the area of constructive material deposits near the coast of the White Sea (Fig. 3).

One of the very important problems in the coastal marine zones is to search and detect technical objects buried in loose sediments on the sea bottom, some of them can be hazardous, as containers with waste, mines, bombs and so on, but some can be of interest from archaeological point of view. Some successful result of this searching are shown on Fig. 4.

Finally the instrument system Sprut is capable to carry out hydrophysical and hydrochemical soundings of water layer and present information of behaviour of temperature, salinity, distribution of heavy metals and some other elements in the water column (Fig. 5), and finally to compile environmental maps.

For conclusion we would like to stress the importance of complex multi-disciplinary study of the near shore zones, including bottom sediments, bottom relief, physical and chemical properties of the bottom sediments and the water layer, prospecting of buried objects on the bottom, and mineral deposits, and on the whole to provide necessary knowledge for successful management of the coastal zones. To achieve this goal special instruments as to be multi-functional, portable and effective. We believe that instrumental systems recommended in our report, partly answer the problem.

Fig. 1. Surficial lithology along profile and lithological map (potential of natural electrical field, Baltic Sea)

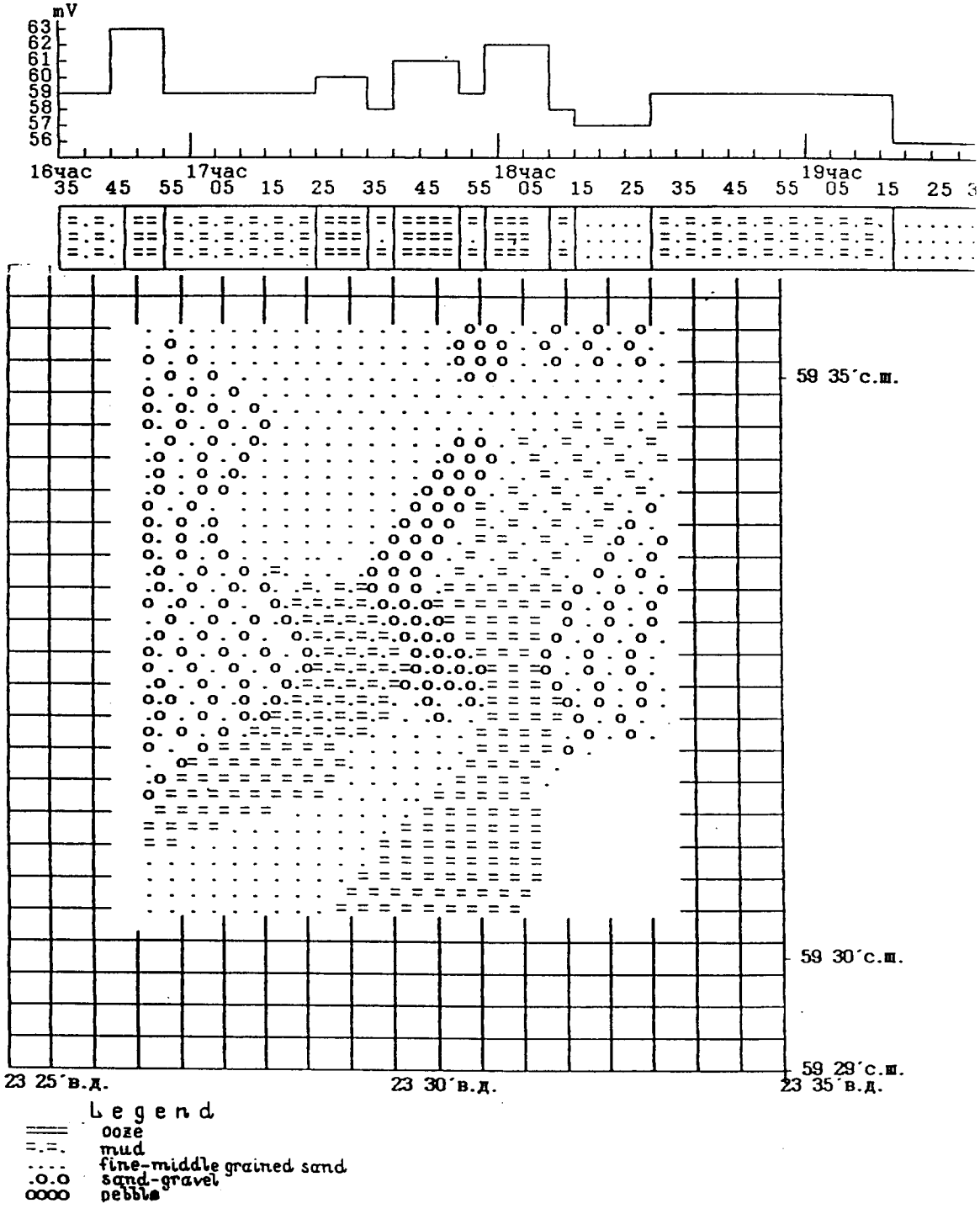
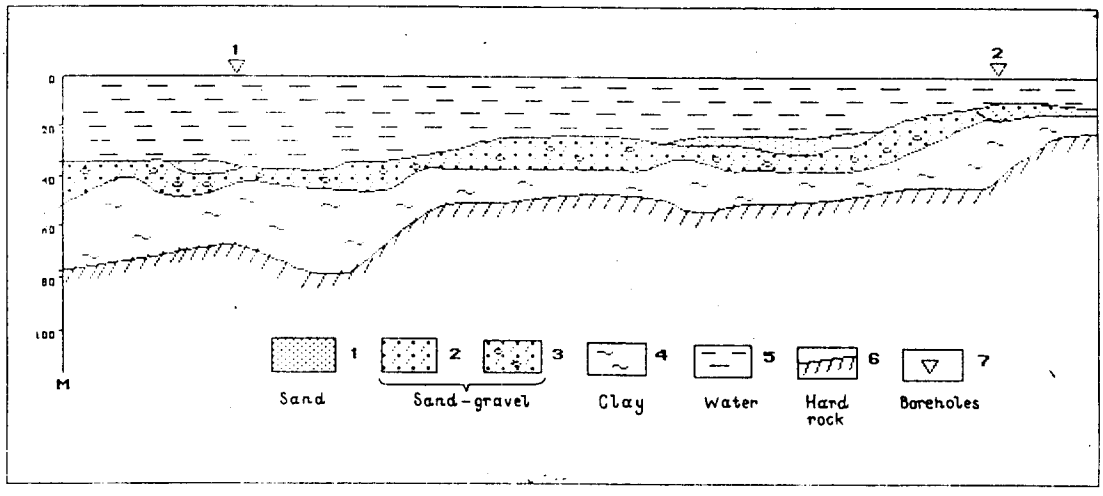


Fig. 2. Geological section (Electrometry methods and drilling, White Sea)



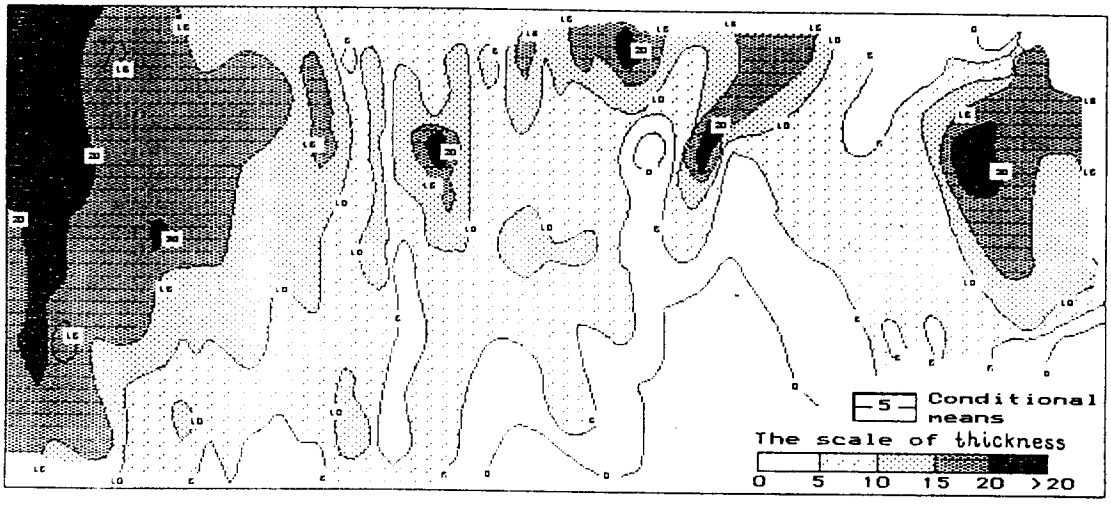
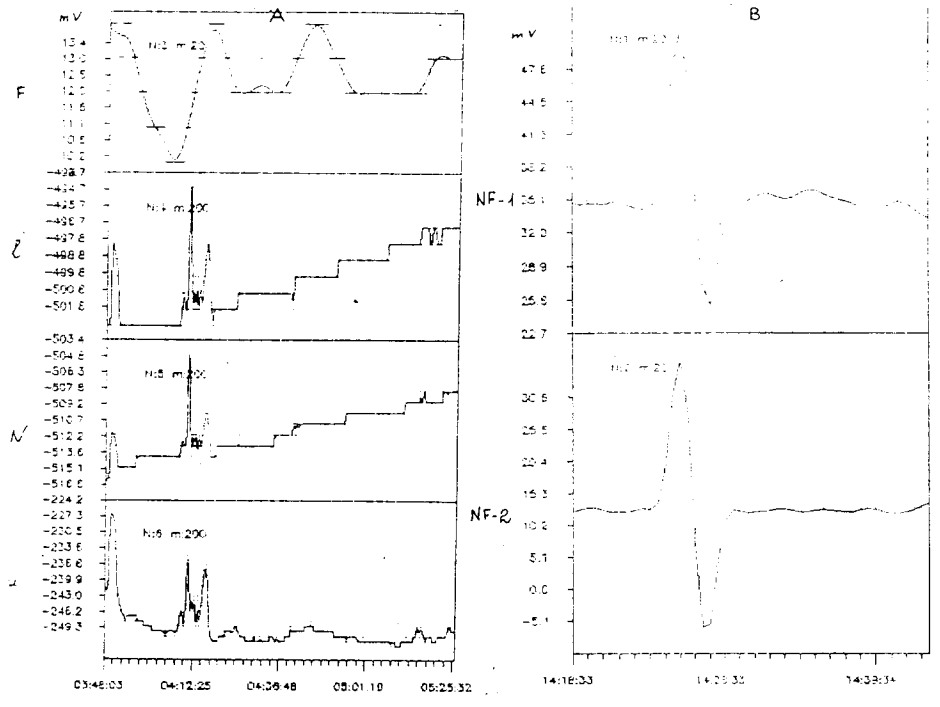


Fig. 3. Map of gravel-sand deposit thickness. White Sea (Inetsky allotment). In meters- 1:25,000.

Fig. 4. Survey of buried objects on the Baltic Sea bottom; A- Cl, CN, Cu anomalies over a container with waste chemicals; B- anomalies of the natural field potential over a ship wreck.



H (dm)	T	S	Cl	Cd	Ag	Hg	Cu
2004							
24 06 94							
07							
00 00 19	15.1	417.0	672.0	-263.0	583.0	317.0	605.0
00 00 23	14.9	382.0	675.0	-260.0	588.0	311.0	600.0
00 00 30	14.8	370.0	675.0	-258.0	593.0	316.0	599.0
00 00 33	14.7	366.0	680.0	-257.0	595.0	318.0	600.0
00 00 40	14.6	359.0	678.0	-258.0	598.0	325.0	599.0
00 00 49	14.6	347.0	679.0	-257.0	601.0	331.0	598.0
00 00 56	14.6	347.0	680.0	-255.0	600.0	331.0	597.0
00 00 61	14.5	342.0	679.0	-255.0	601.0	328.0	596.0
00 00 91	14.5	338.0	679.0	-255.0	604.0	322.0	596.0
00 01 03	14.5	334.0	680.0	-253.0	604.0	322.0	594.0
00 01 07	14.5	315.0	678.0	-252.0	601.0	322.0	594.

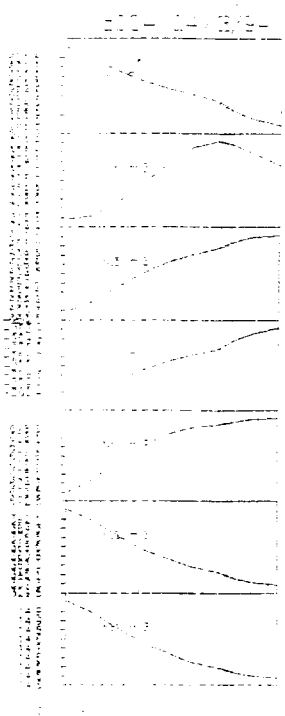


Fig. 5. Temperature and some element concentrations in the water layer of the Finnish Bay (electrometric sounding with ion-selective electrodes).

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CAN THE PAST BE THE KEY TO THE FUTURE? HOLOCENE RELATIVE SEA-LEVEL CHANGES IN SOUTHERN ENGLAND

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KEY WORDS: Sea-level, coasts, southern England, coastal management, Holocene

ABSTRACT

This paper examines how an understanding of past sea-level change can contribute to our understanding of future coastal change in southern England, United Kingdom. It is suggested that the Holocene sea-level record provides us with important information about crustal movements, which must be accounted for when estimating future net sea-level rise, and also shows us how the coasts of southern England have developed in the past under periods of fast sea-level rise. However, relating the record of past sea-level movements to the future is not a straightforward exercise, due to the many differences which exist between the current and past coastal environments of this area.

INTRODUCTION

This paper examines the evidence for Holocene relative sea-level movements in southern England and considers the implications of this knowledge for future coastal change. The study area extends from the Thames estuary to Hampshire and includes the Thames estuary, the East Kent Fens, Romney Marsh and Dungeness, the Sussex coast and Southampton Water in Hampshire (Figure 1).

SEA-LEVEL MOVEMENTS IN SOUTHERN ENGLAND

In the eastern English Channel, Lambeck (1993) has estimated that relative sea-level 16,000 years ago was between c. -110 and -130 m (Figure 2), which is similar to the estimated level of glacio-eustatic sea-level by Fairbanks (1989). Information regarding coastal evolution and sea-level changes during the Late Devensian, especially between the end of the Younger Dryas (c. 11,000-10,000 BP) and the opening of the Holocene, are of particular interest due to the rapid changes in sea-level and temperature which occurred during this period (e.g. Lambeck 1993; Atkinson et al. 1987). The evidence for sea-level changes and coastal evolution during this period are now considered, while that from the mid and late Holocene is considered later.

THE LATE DEVENSIAN AND EARLY HOLOCENE SEA-LEVEL RECORD

Rates of sea-level rise during the Late Devensian and early-Holocene were close to those expected by the end of the next century (c. 6-8 mm a-1, see below). Unfortunately, however, stratigraphic evidence for sea-level and coastal change during this period is limited, largely due to the difficulties in obtaining samples from c. -20 to -35 m OD (Ordnance Datum = mean sea-level). The existing dates are described in turn below, and are plotted on an age/altitude graph in Figure 3.

The earliest radiocarbon evidence for sea-level rise in southern England is recorded in core material collected during the Channel Tunnel excavations (Callow et al. 1966). These cores revealed a peat bed overlain by gravel at a depth of between -36.5 and -37.6 m OD. The peat was recorded in the base of a sinuous valley on the submerged dip-slope of the Middle Chalk (Callow et al. 1966); its base was dated to 10,530 ± 120 BP and its top to 9,920 ± 120 BP. Pollen analysis supported the radiocarbon age determinations. In the base of the peat were high frequencies of herbaceous pollen taxa, while in the top of the peat were high frequencies of birch and pine. Importantly, the pollen data failed to reveal any

evidence for marine or estuarine conditions during peat formation, and this, coupled with the eroded nature of the upper peat contact to the overlying gravel, makes the use of these dates for relative sea-level studies limited.

Other early Holocene sea-level indicators have been recovered from the Sussex coast by Shephard-Thorn (1975) and Jennings & Smyth (1987) in their investigations of the Holocene stratigraphy at Langney Point (Figure 1). Shephard-Thorn (1975) recorded a 3.5 m thick peat from beneath Langney Point, lying directly on the Greensand surface, and two samples of this peat from -27.3 and -24.9 m OD were dated to 9,510 ± 75 and 8,760 ± 75 BP. The upper peat contact was also sampled and dated by Jennings to 8,770 ± 50 BP from a depth of -24.7 m OD. Jennings & Smyth (1987) suggested that the early-Holocene organic deposits at Langney Point formed in the lee of a protective sand barrier and that the end of peat accumulation may have been caused by a sudden breakdown of this barrier.

One other early Holocene radiocarbon date has been collected from the south coast from Tilling Green, Rye (Figure 1), where a sample of laminated silty peat at -22.5 m OD has been dated to 9,565 ± 120 BP (Welin et al. 1974). This date has no supporting biostratigraphic data and therefore its altitudinal relationship to a former sea-level is uncertain.

The earliest radiocarbon dates from the Thames estuary are relatively young compared with the south coast dates described above. Devoy (1979) has described a laminated clayey-limus detrituosus peat recorded at a depth of -26.3 m OD from the Isle of Grain (Figure 1), the base of which has been dated to 8510 ± 110 BP. Once again pollen data indicates no clear evidence for the proximity of marine conditions at the time of peat formation, although the high frequencies of Typha angustifolia / Sparganium-type pollen recorded suggest that peat initiation was caused by a rising groundwater table, which was in turn probably related to sea-level rise.

The dates plotted in Figure 3 provide a first approximation of the net rise in sea-level recorded in southern England since c.10,500 BP. There is considerable variability in the ages and altitudes of the existing radiocarbon dates, and the most obvious explanation for the discrepancies observed is that most of the dates lack a clear marine context. Despite the rapid sea-level rise of this period (c. 6-8 mm a-1, Figures 2 and 3), organic deposits accumulated both as basal peats under the influence of a rising sea-level (e.g. at the Channel Tunnel and the Thames estuary), and also as intercalated peats recorded within marine/estuarine deposits (such as at Langney Point and possibly Tilling Green). A similar pattern is recorded in peats currently under analyis by the author, which have been collected from the offshore extension of the Cuckmere valley, at between -26.5 m and -37.5 m OD. Simple shoreline retreat under the rapid rates of sea-level rise is not apparent, and the varied coastal responses evident during this period suggests local factors (such as barrier development and breadown (Jennings and Smyth 1987)) were important in controlling patterns of shoreline development.

THE MID AND LATE HOLOCENE SEA-LEVEL RECORD

In contrast to the Late Devensian and early Holocene, many more radiocarbon-dated sea-level index points are available from the study area during the mid and late Holocene. Regional syntheses of these data have been presented by Devoy (1982) and Long (1992), and more recently, Long and Tooley (in press) have analysed a total of 57 dated transgressive and regressive contacts from sites between the Thames Estuary and the Solent, which are plotted in Figure 4. The vertical relationship between the height of each index point and their contemporary sea-level (their indicative meaning; Shennan 1982) is c.0.2m, although this will vary depending on the exact nature of the material dated and the form of the tidal curve. When other sampling errors such as sediment compaction and levelling errors are accounted for, a vertical error of ± 0.5m should be assumed for each index point. Age errors of c. ±150 years should also be assumed for each index point.

In general, a curvilinear rise in Holocene sea-level has been recorded in the study area, with mean

sea-level rising from c.-27.5 m OD at 8,800 BP to c.-6.5 m OD by 5,000 BP. After 5,000 BP, the rate of mean sea-level rise fell and remained low until c.2,000 BP before rising between c.2.5 m to the present day. Important differences are apparent in the rate of sea-level rise recorded at different sites along the south coast of England. For example, between c.5,000 and 4,000 BP the rate of sea-level rise in Sussex was faster than that recorded in the East Kent Fens and the Thames estuary, while the opposite was probably the case during the last 2,000 years. Some of these differences may be the product of differential sediment compaction and changes in palaeotidal range. However, the magnitude and direction of these differences suggests that they may in fact record differential crustal movements in southern England (Long 1992).

DISCUSSION

Having described the evidence for Holocene relative sea-level movements in southern England, the following discussion considers the relevance of these findings for our understanding of future sea-level change in southern England. This section will consider:

1. Estimates of future sea-level rise in the study area;
2. Holocene coastal responses to rapid rates of sea-level rise;
3. Holocene records of short-term changes in coastal evolution;
4. Problems in relating the Holocene record to the future;
5. Coastal management strategies in southern England.

ESTIMATES OF FUTURE SEA-LEVEL RISE

Estimates of future sea-level rise made by the Intergovernmental Panel on Climate Change (IPCC) (Houghton et al. 1990), have been revised by Wigley & Raper (1992), due to the improved modelling of global warming scenarios (e.g. by incorporating the effects of CO_2 fertilization, feedback from stratospheric ozone depletion, and the radiative effects of sulphate aerosols). Because of the uncertainties in estimating future sea-level change, Wigley & Raper (1992) calculated a range of possible sea-level scenarios. The revised 'best-guess' for future sea-level rise by the year 2100 is 0.48m. This rate of predicted sea-level rise is dependent largely on future climate warming, but as Wigley & Raper (1992) note, these projections are based on the anthropogenic component of future change and any natural background variability will be super-imposed on these changes. Furthermore, the actual rise in sea-level recorded around the world's coasts will vary depending on the background pattern of crustal movements.

In the UK, Shennan (1989) has used Morner's regional 'eustatic' sea-level curve to calculate the pattern of current and Holocene crustal movements. In southern England only limited data were then available, but Shennan (1989) identified maximum rates of current crustal subsidence in the Thames Estuary of c. 1.9 mm a^{-1}, with reduced rates of crustal subsidence in sites to the west. This general pattern has been supported by more recent data (Long & Shennan 1993), although Lambeck (1993) has criticised this approach, arguing that the adoption of a single eustatic sea-level curve is inappropriate due to the spatially and temporally variable effects of changes in gravitational potential caused by the redistribution of ice and water loads. However, during the last 5,000 years, sites distant from the former ice sheets such as those in southern England are unlikely to have been affected by such factors. Indeed, Lambeck's projections of relative sea-level movements from different sites in the eastern English Channel differ little (Figure 2), suggesting that such factors are not as significant here as in other parts of the UK (such as northwest England, Lambeck (1993)).

The Holocene sea-level data described in Figure 4 support the general pattern of differential crustal movements described above by Shennan (1989) and by previous authors (e.g. Devoy 1977). Sites to the west of the study area in Hampshire, appear to have experienced a smaller net rise in sea-level compared to sites to the east (Long & Tooley in press). Thus, at c. 5,500 BP index points from Hampshire plot between 2 and 3 m above similarly aged deposits from the Thames estuary. The most probable explanation for this pattern is

enhanced crustal subsidence of the southern North Sea Basin, although other possible factors include changes in palaeotidal range (Austin 1991) and sediment compaction.

By combining Shennan's (1989) estimates of current rates of crustal movements with Wigley & Raper's (1992) projection for future sea-level rise, a net rise in sea-level by AD 2100 of 0.58 to 0.68 m is anticipated in the study area. Rates of sea-level rise will be slightly smaller in Hampshire relative to that in Kent and the Thames estuary. This analysis assumes that rates of future crustal movements remain constant, whereas the IPCC predictions (Wigley & Raper 1992) estimate that the rate of future sea-level rise will accelerate towards the end of the next century as lag effects from global warming begin to operate. The consequence of this is that rates of sea-level rise between AD 2070-2100 in southern England may rise to as much as 6-8 mm a^{-1}.

It is interesting to note that recent tide gauge data indicate a different spatial pattern in recent sea-level rise to that predicted above, with maximum rates of sea-level rise recorded in the central Channel area centred on the Portsmouth tide gauge station (Emery & Aubrey 1985; Woodworth 1987). The cause of these differences is unknown (Long & Tooley in press), but may include hitherto unrecognised differential crustal movements in the English Channel, short-term changes in mean sea-level caused by changes in wave climate or other oceanographic factors, or measurement error.

HOLOCENE COASTAL RESPONSES TO RAPID RATES OF SEA-LEVEL RISE

Holocene sea-level data provide an important record of how coasts respond under different rates of past sea-level rise. As noted above, long-term rates of sea-level rise in southern England after c. 8,500 BP were generally slower than those predicted for the end of the next century, typically between 2-3 mm a^{-1}. However, as before c. 8,500 BP, patterns of coastal evolution during the mid and late Holocene also varied considerably. This point is illustrated in the following section, which examines a snapshot of coastal change in southern England between 6,000 and 5,000 BP, during which the rate of sea-level rise was still comparatively high (Figure 3).

In the Thames Estuary, a major removal of marine conditions was recorded between 6,000 and 5,000 BP (Devoy 1977, 1979), and after c. 5,500 BP the extensive organic deposit Tilbury III accumulated above former marine deposits. At Tilbury this deposit accumulated between 6,200 ± 90 and 3,850 ± 80 BP, and pollen data indicate the widespread development of Phragmites reedswamp and saltmarshes during this period (Devoy 1979). The onset of this phase of organic sedimentation varies within the Thames estuary, occurring at Crossness and Stone Marshes at c. 5,600 BP and c. 4,900 BP.

South of the Thames estuary in the East Kent Fens (Figure 1), Long (1992) has described the widespread development of peat-forming communities within an infilled valley to the north of Deal between c. 6,000 and 5,500 BP. The peat which acumulated during this period formed under freshwater reedswamp conditions, and was overlain by further inorganic estuarine or tidal channel deposits between 5,500 and 5,100 BP.

To the west of the East Kent Fens in Romney Marsh (Figure 1), peat-forming communities gradually spread out from the protected coastal valleys which fringe the marsh after c. 6,000 BP, replacing former intertidal conditions (Waller et al. 1988; Tooley & Switsur 1988; Long & Innes 1993; Long & Innes in press). This episode of peat formation appears to have been closely linked to the development of the Dungeness foreland, and persisted until c. 2,000 BP. Further west, in the Coombe Haven Valley, a brief episode of peat-formation occurred between c. 6,000-5,800 BP, and a second phase began after c. 5,200 BP (Jennings & Smyth 1987). At Lottbridge Drove and Willingdon Levels (near Langney Point, Figure 1), inorganic estuarine deposition continued throughout this period. Finally, at the most westerly site studied in this paper, at Stone Point in Hampshire, peat-forming communities developed briefly at c. 5,600 BP and then in a more substantial manner after 5,300 BP (Long & Tooley in press).

The above discussion provides a snapshot of coastal evolution during a thousand year period in

which sea-level was rising at a rate of c. 2-3 mm a^{-1}. The varied pattern observed may reflect the unequal distribution of radiocarbon dates and the sampling strategy employed in previous stratigraphic investigations, but the variability also strongly suggests that local coastal processes may have exerted a strong influence on patterns of coastal evolution. In a longer term analysis of coastal responses to sea-level change in southern England, Long (1992) has argued that synchronous coastal patterns of evolution have been recorded during only 1,000 of the last 7,500 calibrated years BP.

HOLOCENE RECORDS OF SHORT-TERM CHANGES IN COASTAL EVOLUTION

Future sea-level predictions anticipate an increase in the magnitude and frequency of storm events, which may in turn promote an increase in abrupt changes in coastal environment. On the south coast of England, records of abrupt changes in coastal evolution are rare, but one area which provides such a record is the Dungeness foreland, and this is now described in detail.

The Dungeness foreland is the largest gravel complex in the UK, consisting of over 500 storm beach ridges which have accumulated during the last 5,000 to 6,000 years (Figure 5) (Eddison 1983; Long & Innes 1993). Levelling of these beach ridges was first undertaken by Lewis (1932) and Lewis & Balchin (1940), and these authors argued that systematic changes in beach ridge altitude could be used as proxy data for changes in sea-level. In particular, Lewis & Balchin (1940) noted an abrupt change in the altitude of the gravel beach ridges deposited around c. 700 BP, which they interpreted as evidence for a series of storms which devastated much of the south coast of England and the southern North Sea Basin during the thirteenth century.

More recently, Long & Hughes (in press) have completed further levelling of these sediments, and the results of this study, when combined with litho-, bio- and chronostratigraphic analyses of the fine-grain sediments preserved amongst the storm ridges, lend general support to the findings of these early workers. For example, pollen data from within a peat bed recorded on the Dungeness gravel plain in the base of Wickmaryholm Pit (Figure 5) records an abrupt return of marine conditions some time between 1,000 and 700 BP (Long & Hughes in press). Accompanying this landward movement of the shore was rapid erosion of the south coast of the Dungeness barrier, and the deposition of a series of massive beach ridges in the Denge Beach area which rise to c. +6.4 m OD (Figure 6). Other evidence for this abrupt change in coastal environment is recorded by the infilling of a series of gravel lows to the west of Wickmaryholm Pit at Broomhill by Tooley (1990).

The back-barrier sediments of Romney Marsh also provide evidence of abrupt changes in coastal environment which appear to be more closely related to changes in coastal configuration and, in particular, barrier development and breakdown. Although the Dungeness barrier appears to have been established by 6,000 to 5,000 years BP and remained as a relatively stable feature until c. 2,000 BP, some time shortly after this a major marine incursion of the back-barrier environments occurred (Long & Innes 1993). A 12 km stratigraphic transect of boreholes completed across the width of Romney Marsh (Long & Innes in press), indicates that widespread erosion has occurred of the upper contact of the main peat bed in the back-marsh sediments, but whether this was caused by a sudden breakdown in the Dungeness barrier is uncertain. Gravel barriers such as the Dungeness foreland are highly sensitive to changes in sediment supply, and a relative fall in supply of gravel to the foreland, perhaps combined with an increase in the rate of sea-level rise, may have encouraged partial barrier breakdown and the major change in back-barrier depositional environments recorded at this time.

PROBLEMS IN RELATING PAST SEA-LEVEL CHANGE TO THE FUTURE

As noted above, Holocene sea-level data can show how coasts have previously responded to rapid rates of sea-level rise. In southern England, future rates of sea-level rise are expected to rise to between 6-8 mm a^{-1} by the end of the next century, but currently appropriate Holocene analogues for such rapid rates of rise are limited.

Additionally, one of the reasons why coastal advance occurred during periods of mid Holocene sea-level rise was that natural peat-forming communities were able to accrete at a similar rate (or faster than) the rate of sea-level rise, enabling thick deposits of alder and reedswamp peats to develop, which acted as natural organic barriers to marine incursions. The absence of such communities from almost all of the south coast today due to human activity, means that such natural organic defences are unlikely to exist again in the future.

A further hindrance when relating Holocene sea-level changes to future coastal evolution is that the resolution of the Holocene coastal record is not usually sufficient to identify the timing or magnitude of short-term changes in coastal evolution and sea-level. For example, even on active coastal margins such as the Pacific North West of America, where synchronous submergence events caused by subduction earthquakes are believed to have occurred, current radiocarbon dating techniques are rarely able to provide definite age correlation between sites. High precision AMS radiocarbon dating of tree rings belonging to coastal trees killed by such submergence can only constrain the timing of such events to within forty years or so (Atwater et al. 1991).

As well as problems associated with establishing the timing of changes in coastal environment, assessing the magnitude of short-term vertical sea-level changes is also difficult. No longer are age-altitude distributions of sea-level index points depicted by a single line called a sea-level curve; rather a sea-level band which provides an envelope within which sea-level has changed is preferred (Shennan 1982), and the width of this band constrains the magnitude of any sea-level oscillation which may be determined from age-altitude data alone. In general this means that it is not possible to identify oscillations in sea-level which are smaller than c. 1.5 m.

Another difficulty in relating sea-level data to future scenarios is that there has been a traditional sampling bias in Holocene coastal studies in favour of the analysis of uninterrupted stratigraphic sequences. This is because there is a general consensus that such sequences provide the most complete record of sea-level changes. In particular, cores have tended to be selected which contain gradational transgressive and regressive contacts to peat beds, and a sophisticated methodology of data collection has been developed around this approach (e.g. Tooley 1978; Shennan 1982). A consequence of this sampling bias, though, is that our understanding of the processes responsible for long-term coastal change are inclined towards those processes responsible for creating such uninterrupted sequences (Long & Dix in prep). Rapid and extreme events such as barrier breakdown and storm flooding are often invoked as the causes of abrupt changes in stratigraphy, yet the interrupted stratigraphic sequences believed to have been caused by such processes are rarely analysed.

In summary, therefore, problems exist in establishing the record of short-term and abrupt changes in environment during the Holocene, although research under the auspices of the IGCP Project 367 'Late Quaternary Coastal Records of Rapid Change' is currently seeking to rectify this deficiency. Perhaps one of the most important problems here is the disparity between the requirements of the coastal manager and the information available to the Holocene sea-level researcher. The former seek to understand how coasts will respond to future sea-level change on timescales of years or decades, and to vertical changes in sea- level which over a century are likely to be less than 0.8m. In contrast, Holocene sea-level workers tend to operate on scales of hundreds to thousands of years, and with a vertical resolution of between c. 0.5 m to 1.5 m.

COASTAL MANAGEMENT STRATEGIES IN SOUTHERN ENGLAND

Despite the problems identified above, one situation where our understanding of the past has a very strong message for the future in southern England is Romney Marsh and the Dungeness foreland. The Dungeness foreland is naturally dependent on the long term supply of sediment from updrift sites, and appears to have experienced a long-term reduction in the supply of gravel which began sometime before c. 2,000 BP.

Whether this represents an absolute fall in sediment supply or a relative fall caused by the expansion of the foreland is uncertain. However, continued sediment supply problems are testified to by the gradual re-orientation of the south coast of the foreland from what was probably once a drift-aligned barrier to one that is now swash-aligned, as well as by the high rates of current coastal retreat which on the south coast average between 1 and 2 m per year. The Dungeness foreland is also particularly sensitive to storms, as documented by coastal changes during the thirteenth century (see above), while during the last decade the south coast of the foreland has retreated up to 25 m in a single storm (Eddison pers com.).

The Dungeness foreland is backed by the largest area of reclaimed marshland in southern England, second only to the Fenlands of East Anglia and the Somerset Levels in the UK as a whole. Much of this marshland lies at between 1 and 2 m OD, and is already over 1.5 m below the current height of mean high water spring tides. Clearly, any future large scale breaching of the foreland is likely to flood much of Romney Marsh, perhaps as far inland as the relic Holocene coastal cliff line which fringes the back of the Marsh. Also, located close to Dungeness Point is the Dungeness Nuclear Power Station, which is situated on a 35 m thick sediment pile of gravel, sands, silts and clays which have accumulated during the last c. 2-3,000 years (Greensmith & Gutmanis 1990). During the last decade the compound of the power station has been flooded on a number of occasions, and coastal defence measures in the area currently consist of beach feeding with gravel being recycled from the accreting east coast and dumped on the south coast. Future sea-level rise scenarios, based on the IPCC predictions as well as our knowledge of current rates of crustal movements, suggest that this area will experience a rate of sea-level rise in the next century at least four times that recorded during the last 2,000 years. The long-term requirement for future coastal stabiity in this area (to include the time needed for decommissioning), is clearly at odds with the Holocene record of foreland instabiity.

CONCLUSIONS

The past has much to tell us about future coastal responses to changes in sea-level in southern England. For example, it provides us with information about past and future rates of crustal movements, which can be combined with future global sea-level rise scenarios to assess net rises in regional sea-level. The past also reveals the varied pattern of coastal responses to sea-level change, and documents a partial history of how coastal systems responded to short term abrupt events. There are, though, difficulties in relating patterns of Holocene sea-level changes to the future, not least because of the differences which exist between past coastal environments and those of the future. In much of southern England, the existing "hard" coastal defences are likely to stay due to the heavy capital (and political) investment in the protection of the coastal lowlands, and in many of these cases protection schemes will continue to be at odds with the long-term flexibility of this coast.

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Fig. 1. Southern England; location of main sites mentioned in text. The 10 m contour provides an approximate indication of areas of coastal lowland in the study area.

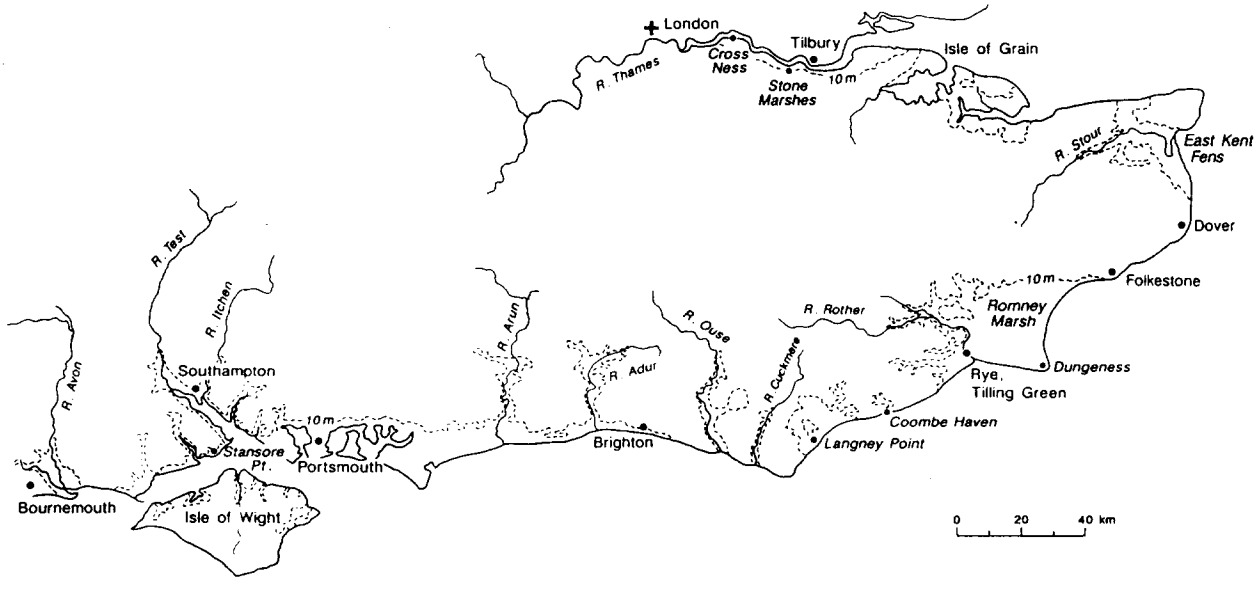


Fig. 2. Relative sea-level change in the eastern English Channel during the last 16,000 years BP (Lambeck 1993).

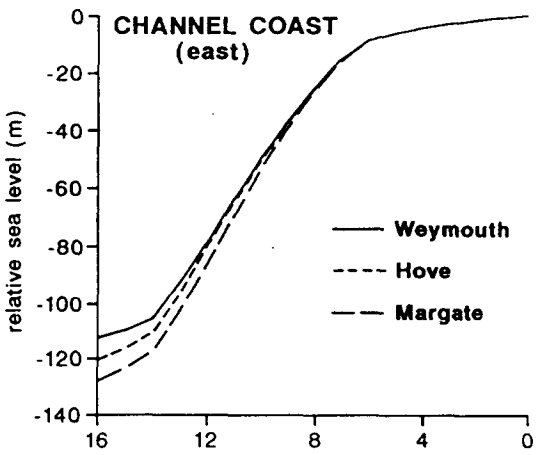
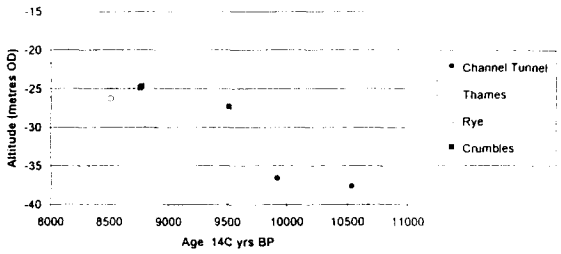


Fig. 3. Late Devensian and early Holocene radiocarbon date from southern England. The altitude of these dates have not been corrected for differential tidal range.



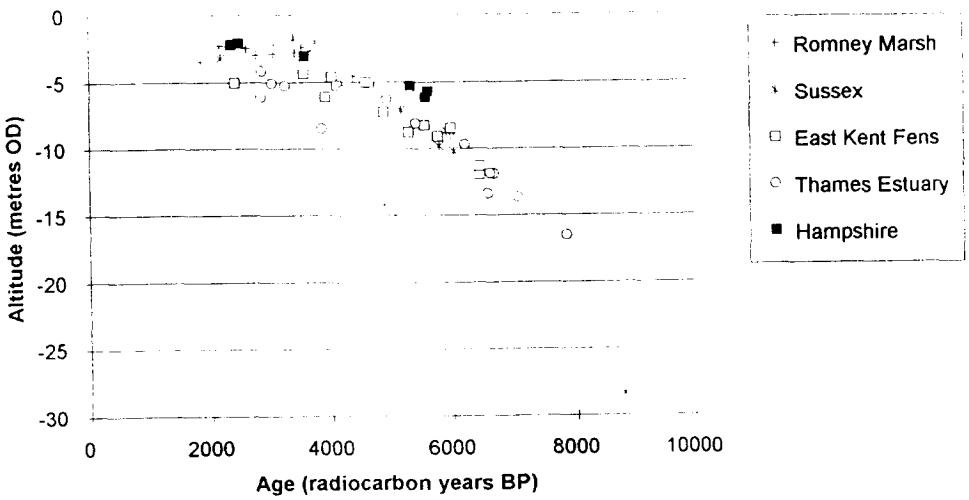
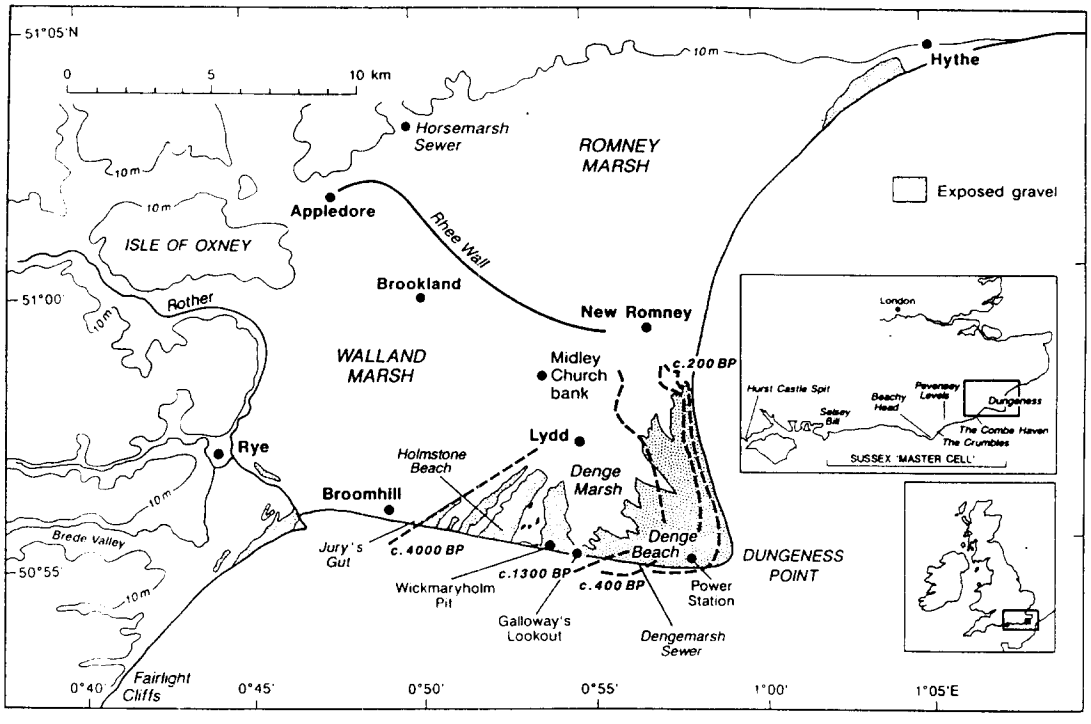


Fig. 4. Age/altitude graph of sea-level index points from southern England. The altitudes of all index points have been reduced to mean sea-level.

Fig. 5. Site map of the Dungeness foreland showing the position of sites mentioned in the text. Also shown are the approximate ages and positions of former shorelines (based in part on Lewis & Balchin 1940).



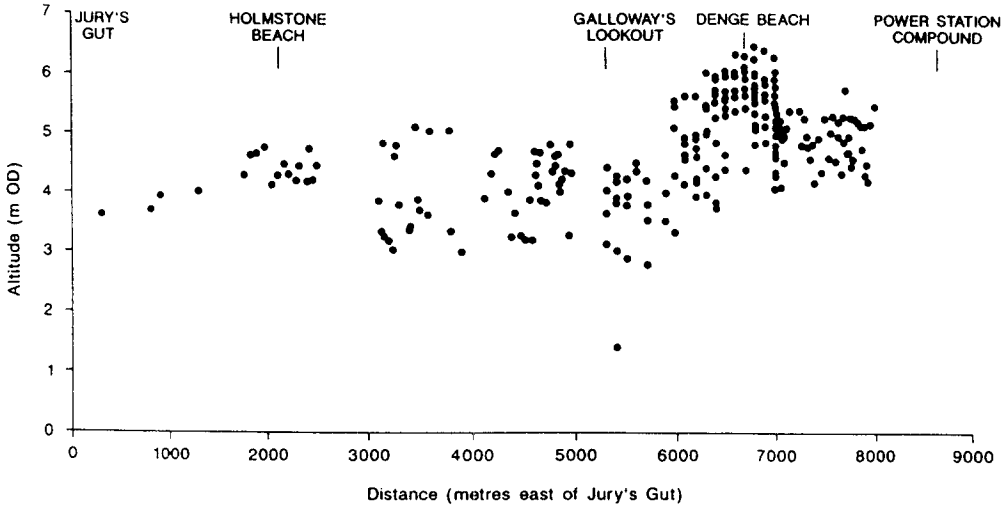


Fig. 6. Altitude of beach ridge altitudes recorded in a west/east transect from Jury's Gut to the Dungeness Power Station (Long and Hughes in press).

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MORPHODYNAMIC VARIABILITY IN A SWASH-ALIGNED, POCKET GRAVEL BEACH

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ABSTRACT

A swash-aligned pocket gravel beach near Malin Head, Ireland, was monitored over a two-year period to assess the morphodynamic variability of process and response elements.

Portmore is a 300 m long, arcuate beach composed of a heterogeneous gravel clasts rolled onshore during the Pleistocene sea level rise. The main exposure is to the northeast; the dominant wind and wave direction is south-southwest. Refraction simulation results suggest the bay is in the 'shadow zone' but observations on site show swell and wind waves entering the bay at all times. During the study period the wind direction veered to the north for the month of November 1990. The resulting morphological and sedimentological changes are presented.

In general, profile slope and volume per unit length (m^3/m) increased, while width, height of active beach and volume (m^3) decreased. Configurations (as defined by Sonu and van Beek, 1971) tended to show more lower and middle berm development. There was net erosion in November whereas in the previous and following months conditions were of net deposition.

Sediment sampling took place in October and December but inferences are drawn for November from the changes. Sedimentologically it can be shown that size grading improved and there was an increase in the size range at the lower end of the scale. Sorting was always in the moderate to well-sorted range, while the overall degree of sorting remained the same, there was a change in spatial patterns. Skewness and kurtosis remained, as for the duration of the study, difficult to explain or predict. Clast shape range and distribution defied the organisation suggested in the best-known gravel studies (Bluck, 1967; Orford, 1978); under the northerly wind flow alongshore shape sorting increased and there was an increase in discs and compact blades to the north and middle of the beach.

Statistical analysis took the form of Discriminant Analysis the complete range of sediment and morphological attributes and Factor Analysis of profile elevation data. These suggest that November had a discernible influence on beach morphodynamics. What was most interesting was the variation in response alongshore in a manner similar to the zeta-form bay model described by Finkelstein (1985).

The upper beach area is relatively small and serves as a caravan site; in management terms, were the winds to shift to the north on a more regular basis, the beach may not have enough recovery time to prevent permanent redistribution of sediment.

INTRODUCTION

The adaption of beach sediments to changing energy conditions is a mechanism which ensures its survival long after solid structures such as piers have fallen. This rapid reaction keeps the beach in dynamic equilibrium with its environment, acting as a buffer to wave energy. Response to energy variations can be traced through changes in the morphology and sedimentology, although such information may not be present in the full spectrum of variations (Carter, 1988 p. 100).

The feedback process by which the beach reinvents itself is well-documented (e.g. Krumbein & Sloss, 1963). On beaches the interrelationships amongst variables are complex, thus it is not surprising that studies of beach response to different conditions yield results with considerable scatter when the effect of one process is plotted against a response variable. Analysis of the interrelationships and the development of predictive models is the cornerstone of morphodynamics and management planning. Coarse clastic beaches are particularly interesting

in that they currently form a small subset of research despite their widespread distribution in the temperate regions of the globe.

In November 1990 the wind direction veered northerly for the whole of the month, the only time this occurred during the study (Table 1), allowing an opportunity to study the effects of this short-term change.

SITE AND METHODS

Portmore is a 300 m long arcuate pocket beach to the extreme north of the Inishowen Peninsula at Malin Head (Fig. 1; plate 1). The maximum beach height is at profile 7, reaching 7.18 m Irish O.D. (Poolbeg). Sloping at 10-25°, the seaward limit of the gravel is just above mean-low-water, with a sand apron sloping between 1 and 4°. Until recently the area was believed to be in a zone of continuing isostatic uplift, emerging at a rate of 2.3 mmy^{-1} (Todd, 1981). Extending the tidal data set to 1991, Todd's calculation is replaced by a slight uplift of 0.18 $mmyr^{-1}$ (Fig. 2). Bedrock is primarily Dalraidian-age quartzite (Davies and Stephens, 1978); beach gravels are derived from coastal erosion and the reworking of glacial till and raised gravel beaches.

The west coast of Ireland is exposed to high energy waves and winds. Significant wave height return values (H_s) may reach 16 m off the northwest coast and it is not uncommon for breakers on rocky coasts to reach 8 m (Fig. 3). North Atlantic swell dominates the wave spectrum, arriving predominantly from the west (Table 2i, iii). Locally generated wind waves (Table 2 ii, iv) with highly variable approach directions are superimposed on the swell climate but these shorter period waves are often filtered out of the breaking wave spectra since they do not refract into the deeper indentations on the coastline.

Wave refraction analysis indicated that on a large scale Portmore was effectively shadowed from the dominant wave approach (Fig. 4). Observations on site showed this to be a generalisation as swell of over 6 s in period and 2 m in height was entering the bay for much of the study period.

Nine profiles were fixed at approximately 30 m intervals along the shore. Levelling was carried out with a Sokkisha automatic level and stadia rods or a Suunto clinometer and stadia rod at monthly intervals when possible between August 1989 and March 1991. Sediments were sampled on alternate months: 30 clasts were measured for their A, B and C axes every 5 m of every profile. Cusp periodicities were measured on the intervening months.

Wave and wind data were supplied by the Irish Meteorological Office from the logs of ships passing through a designated area around Malin Head. Record was made of a number of variables of which the following were used: swell wave height, period and direction, wind wave height, period and direction, wind direction and speed. Additional wind data was available from the Meteorological Station based on Malin Head.

ANALYSIS

Wave data

From the available wave data two further parameters were derived, wave length and steepness, using the formula:

$$L = 1.56T^2 \qquad (1)$$

Wave steepness (H/L) values were calculated with the derived wave length values. Individual daily values were averaged for the week prior to surveying as the culmination of these have the most effect on the final result (Table 1).

Morphology

From the profiles information was taken on the following parameters: slope, active width, active height, volume, volume per unit length of profile, and configuration (as defined by Sonu and van Beek, 1971, and modified by Caldwell, 1983). Changes in these parameters over time for each profile are shown in Figs. 5 and 6.

Beach behaviour as a whole was also examined by calculation of mean or modal conditions. Total volumes for each visit were calculated by summing individual volumes (Fig. 7a), and the separate totals of eroded and deposited material between visits were also calculated (Fig. 7b). The modal profile configuration was taken rather than the average as the parameter is not linear and thus

not suitable for averaging. The remaining parameters were simply averaged over all profiles by visit.

Sedimentology

Sediment samples were statistically analyzed for the parameters: mean, sorting, skewness, kurtosis and shape. Sorting was calculated using redundancy in the entropy statistic, as first used by Orford (1978) for sediments:

$$H_a = -\sum_{i=1}^{N} p_i \log_2 p_i \qquad (2)$$

where H_a is entropy, p_i is the frequency of sediment in a particular class when the frequencies are converted to a probability distribution, and N is the number of classes. Redundancy is calculated as:

$$R\% = 100 - \left(\frac{H_a}{H_{max}} x 100\right) \qquad (3)$$

where H_{max} is the maximum entropy derived from the formula:

$$H_{max} = \log_2 N \qquad (4)$$

Shape was calculated from a combination of the Corey Shape Index (CSI; Corey, 1949) and the Disc-Rod Index (DRI; Sneed and Folk, 1958) on the Folk Form Triangle (Sneed and Folk, 1958). Illenberger (1991) pointed to the use of these specific indices by Factorial Analysis and their use is supported by detailed analysis of over 20,000 clasts from this study. These parameters were mapped using the UNIMAP© package on the VAX mainframe system (Fig. 8a-e).

Statistical Analysis

The form of the profile is not constant, therefore there is a need to separate out the characteristic modes of organisation (Bowman, 1981). The use of eigenfunction analysis (EF) to describe sequential changes in beach profiles was proposed by Winant et al. (1975) and further developed by Aubrey (1979). The procedure aims to separate the temporal and spatial dependence of the data so that it can be represented as a linear combination of corresponding functions in time and space. EF data of a single year could indicate significant trends. Low-frequency changes in shore-normal and shore-parallel sediment volume on Warilla Beach in Australia were analyzed by Clarke and Elliot (1988) using eigenfunctions. The procedure allows for the subtraction of short-term changes from the seasonal variability. EF was applied to every profile at Portmore and the first three eigenfunctions are graphed in Fig. 9.

Discriminant Analysis (DA) is a proven technique for distinguishing environments within and between coastal samples and in addition for identification of the most effective parameters in the process of discrimination. DA was applied to two separate groups of data: the full range of sedimentological parameters (mean, median, mode, standard deviation, skewness and kurtosis of A, B, C, and the mean of the three axes (hereafter known as size), size sorting, mean CSI, mean DRI, and modal shape), and the range of morphological parameters (width, height, tangent of slope, angle, standardised volume, configuration, volume, hypsometric integral (Caldwell, 1983), profile length, volume per unit length, standardised profile length, and standardised volume per unit length of profile).

The analysis was applied to identify the most efficient parameters for discrimination between visits and the strength of the differences. Samples were tested for spatial and temporal discrimination separately; results are given in Fig. 10a,b and Table 3 a,b.

RESULTS

Wave parameters over the whole month were a little lower in height and shorter in period than the previous month (see also Table 1); average heights of 4 m for wind and 3 m for swell. Wave periods showed a distinct peak in the trend (2.5 s for wind, 9 s for swell), though this is more marked by the following trough in December 1990.

Overall, in comparison to October, November beach morphology is marked by erosion resulting in steeper, narrower profiles (Fig. 5) with increased volume per unit length and decreased actual volumes (Fig. 6). Configurations tended towards middle and upper beach berm build-up (Fig. 5).

The total volume of sediment in the beach reduced by 4 m^3 (8%), to recover again the following month (Fig. 7a), and in terms of total erosion and deposition for each month November saw a reversal of the strongly depositional conditions (Fig. 7b). When examined for each profile (Fig. 6), change in sediment volume shows November to be almost entirely erosional (with just small amounts of deposition on profiles 1, 3, 6, and 7) whereas in previous and following months most profiles are accreting, especially those to the south.

At Portmore the sediment organisation is very evident, especially in terms of clast size (mean of three axes). Throughout the study the distribution followed a strong downbeach grading with large clasts (>50 mm) at the crest of the beach and small clasts (<25 mm) at the base (Fig. 8a). Prior to November the grading had fluctuated in intensity, reaching a low level in July 1990 and recovering again in October 1990. After the northerly wind shift the sediments in December 1990 are intensely graded, forming very tight bands of size for the length of the beach, a situation only occasionally encountered. There is a noticeable increase in smaller sizes and their distribution. Sediment sizes were smaller to the south of Portmore in all sampling surveys and after November there was a slight overall increase in size in this region which is maintained until the end of the study (June 1992).

The high degree of sorting for the duration of the study changed little with the passage of the northerly winds (Fig. 8b). In October 1990 sorting had improved to reach the very-well sorted range (>0.8) to the south of Portmore and in December this zone had moved to the northern end of the beach but levels in the south were generally higher than previously.

Skewness in the Portmore gravels was almost exclusively positive, in the range 0 to >3.5 (Fig. 8c). The period from October to December saw some of the highest values concentrated in the southern and middle regions. The difference between the two months is a general decrease in skewness in December coincident with a more strongly skewed middle region. For kurtosis (Fig. 8d) the situation is very similar; October in marked by large expanses of leptokurtic (>3) sediment in the middle and southern beach regions, and in December the overall degree is lower (platykurtic) while the middle region is intensely leptokurtic.

The distributions of clast shapes provided the most intriguing distributions of all parameters (Fig. 8e). Incidences of down-beach organisation of specific hydrodynamic shapes identified by both Bluck (1967) and Orford (1978) failed to materialise. The dominant shape was blade (49%), not disc, and the pattern of distribution lacked any definitive orientation. However, this aside, there was a discernible difference in both aspects of shape between October and December; the almost completely bladed beach in October is replaced by an increased supply of discs on the northern region, confined mainly to the lower beach, and there is also signs of downbeach grading. Compact blades, which account for a further 35% of the total shape distribution, increase in extent to the south also, mainly on the lower slopes.

Statistical Analysis

Morphological information is available for all months and discriminant analysis (DA) shows the parameters of profile slope, volume (both actual and standardised per unit length) and configuration are the main contributors to discrimination (Table 3a). DA allows the merging of data sets which are shown to be basically similar based on the centroid scores (the coordinates of the midpoint of the spread of discriminant sample scores) and the results suggested the merging of October and November data. Prior to merging November was not distinguished at all, while October scored 22% and December 58%; after merging (Fig. 10a) December improved to 65% while October / November scored only 10%.

Using sediment parameter matrices, prior to merging, DA showed that October scored only 20% whereas December could be identified correctly over 40% of the time. Centroid scores indicated that the period from October 1990 to January 1991 was very similar and thus was merged; the subsequent percent correct score was 25%. (No sediments were sampled in November). In both sedimentological and morphological terms the alongshore variation in profiles was consistently more predictable than particular visits. Again the morphological variation was more extreme and the northern and southern portions of the beach were more easily identified than the middle.

Eigenfunction analysis of the profile elevation data demonstrated that the response to the northerly wind change varied markedly alongshore. Temporal loadings for each profile are graphed in Fig. 9. A crossing of the zero line represents a change from erosional to accretional status. Taking just October to December, the position of November is a peak on profiles 2, 3 and 7, a trough in profile 4, on an accreting path on profile 8, and an erosional path on the remaining profiles.

DISCUSSION

The formula:

$$C_o - L/T - 1.56T \qquad (5)$$

where C is the wave form velocity, L is wave length and T is wave period, demonstrates that longer waves travel faster than short waves, thus in the mix of waves produced out at sea longer waves will gradually emerge ahead of the shorter waves. At the coast the implication of this is fundamental: long, fast moving waves lose little energy whereas short waves take much longer to cover the same distance and lose much of their energy before landfall. Thus the swell waves generated by the northerly wind flow will have a greater effect on the beach sediment and form.

The response of the profiles to the northerly swell identifies well with the recognised build-up of sediment under swell conditions. Throughout the rising tidal cycle the berms deposited on the lower profile slopes are gradually driven onshore and result in the middle and upper beach berm development seen in Fig. 5d. This is relatively unusual in that gravel foreshores have long been known to react differently to wave energy than conventional 'sand beach' analysis due to high percolation rates. A 3-D model of Portmore generated by interpolation on the VAX mainframe (using UNIMAP©) shows the development of the steep lower shore where current berm-building is taking place and the additional material on the upper shore, particularly to the south of Portmore (Fig. 11). This process continues on into December where the beach foreshortens as the upper beach accretes. The return to a westerly wind flow in December and lower wave energy in general would be conducive to build-up, regardless of the approach direction.

This combination of events explains the narrowing of the profiles (as sediment is pushed onshore) and the steepening of gradients. Active profile height was little changed throughout the period, except perhaps to the middle of the beach where there was a 1 m decrease.

Statistical analysis does little more than bear out the quantitative results. In discriminant analysis the low scores for the correct identification of particular months can be traced through the maps and graphs of morphological and sedimentological parameters. In contrast there is an underlying alongshore organisation which is maintained at different levels over time and allows for over 80% precision in locating profiles (Table 3). Between the sedimentological and morphological analyses, the latter consistently produced better results in discrimination. In addition the alongshore variation was much more predictable than the temporal variation. This may be partially explained by the fact that energy dissipation on gravel is achieved by the loose framework of the gravel - the high percolation of the swash reduces the power of the backwash, and so the profile tends to build up. While the profile form may remain unchanged the sediment distribution (and parameters) will have been modified. Beach erosion or accretion is not usually a mass

movement of material, rather 'each sediment size responds differently to the same hydrodynamics leading to changes in sediment parameters' (Medina et al., 1994).

Eigenfunction analysis also served to provide statistical proof that the response of Portmore to the Northerly winds was varied alongshore in terms of response (erosion/accretion) and also the importance of the event in the total beach cycle (Fig. 9). The first eigenfunction clearly shows the beach to be in equilibrium on a long-term basis and the bulk of variation is confined to the second eigenfunction. This fluctuates across the zero-line for the duration of the study with changes in the volume of beach material. The November wave regime had a varied effect alongshore and this can be clearly seen in Figs. 5 and 6. It is beneficial to coastal research to have statistical back-up for quantitative data.

Portmore conforms to a zeta-bay model (Finkelstein, 1985; Fig. 12) for much of the study until November when the waves are no longer oblique. The model divides the beach into three segments based on beach position. The shadow zone located at the 'hooked' end of the bay and is a zone of low wave energy and thus small, well-sorted clasts on gentle slopes in a generally eroding surface relative to the remainder of the shoreline. The converse is true for the centre of the beach which is subject to high wave energies and is characterised by large grain sizes, poor sorting, moderate profile slopes and a shoreline containing elements of erosion and deposition. The characteristics of the tangential (opposite 'hook') end are similar to the shadow zone but here gradients are steeper and deposition is more common. The shadow zone compares well with profiles to the north (1 to 3) which are composed of relatively fine, well-sorted material but is a little steep for the model. Erosion and deposition co-dominate throughout the study period. A possible cause could be the easy access this portion of the beach offers to the holidaymakers who balk at the 20° slopes further along.

The central beach proved to the most difficult to distinguish statistically (DA, Fig. 10) and this is borne out by the model. Sediment sizes so reach the highest values in this zone, and strong down-beach grading has developed (Fig. 8a). Sorting values are extremes of moderate to well-sorted in patches, in agreement with the model. The mix of erosion and deposition (of greater amounts than in the shadow zone) produce shallower slopes. At the tangential end there is good agreement with the zeta-bay model in terms of slope, and deposition. Thus, Portmore could safely be said to be a man-made zeta-form bay, where the building of the harbour produced a 'hook' around which the oblique wave trains must refract.

In November the northerly wind flow brings unrefracted high energy waves into the whole bay and redistributing sediment in a manner not often experienced. Fig. 11 (3-D) would appear to show a reversal of the usual sediment transport predominantly towards the tangential end from the central region.

Feedback in the beach system would effect the development of a stable equilibrium morphology in which net alongshore transport would be zero and wave crests would break simultaneously along the entire shoreline. Under a constant westerly and south-westerly wind/wave flow this situation would develop quickly but the unpredictable nature of the environment is amply illustrated by this study.

CONCLUSIONS

Portmore has developed into a zeta-form bay under the influence of the harbour development and the oblique wave trains from the west. This condition would appear to have achieved equilibrium in the long term, as shown by eigenfunction analysis (EF 1) and short term fluctuations such as the month of northerly winds in November 1990 had an immediate effect which is short-lived.

The effect of the northerly winds was to build-up a steep, narrow beach where transport pathways may be assumed to have reversed from the normal pattern to bring sediment from the shadow zone to the tangential end (Fig. 12). The is accompanied by an increase in sediment size temporarily, and better sorting. Skewness and kurtosis were of little use in distinguishing a predictable pattern of processes. The beach continued to build up after the winds backed to

the west, leading to the assumption that despite the wave refraction analysis results, constructive swell waves enter the bay from the west.

The caravan site on the upper beach is under threat from increased storminess in the North Atlantic driving high energy waves against the shore. In Plate 1 erosion is plainly seen on the upper slopes of the beach. The accumulation of material from a gradual longshore drift southwards serves to protect the vulnerable south end of Portmore but as demonstrated by this analysis, the sediment can 'flow' in the opposite direction under certain conditions (i.e. northerly winds). The removal of the site would perhaps effect an abrupt improvement in the foreshore as 'traffic' would be reduced. This remains to be seen.

ACKNOWLEDGEMENTS

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Working in the natural environment required a large pool of field assistants who gave their time for the good of science and the cost of a sandwich. Too many to mention and too valuable to omit.

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Week ending	Wave period (s)	Wave height (m)	Swell direction	Swell period (s)	Swell height (m)
Aug 9/89	2.5	0.5	W	4.5	1.7
Sep 17	4.0	2.2	W	8.0	2.2
Jan 13/90	4.6	2.6	W	9.6	3.6
Apr 4	4.7	1.3	NW	13.0	2.7
May 7	2.7	0.7	W	4.3	1.3
Jun 10	3.7	1.7	W	8.0	2.8
Jul 23	6.7	0.9	W	7.5	1.1
Aug 12	2.0	0.75	W	9.5	4.5
Sep 16	-	-	-	-	-
Oct 20	4.0	2.0	SW	7.0	2.0
Nov 18	3.0	1.75	N	8.2	2.3
Dec 20	2.0	0.5	W	4.0	2.0
Jan 20/91	-	-	-	-	-
Feb 27	2.2	1.5	W	6.3	2.5
Mar 29	-	-	-	-	-
Jun 3/92	3.0	1.0	E	8.0	1.5

Table 1. Mean wave parameters for the week preceeding each survey at Portmore. As the ships' records are not continuous there are unavoidable gaps in the record (e.g. March 29).

(i) swell wave period (seconds)

Direction	2-3	4-5	6-7	8-9	10-11	12-13	14-18
N-NE			0.97				
NE-E		0.97	0.97				
E-SE	0.24	4.12	3.89	0.48			
SE-S	0.24	4.13	0.73	0.97	0.48		
S-SW		2.44	4.37	1.46			
SW-W		5.04	**17.72**	**13.84**	2.67	2.67	0.48
W-NW	0.24	3.88	9.47	8.25	4.61	4.61	0.24
NW-N			0.7	0.24	0.24		

(ii) wind wave period (seconds)

Direction	1-2	3-4	5-6	7-8	9-10
N-NE	0.78	0.52	0.26		
NE-E	1.04	1.04			
E-SE	1.82	4.67	1.55	0.26	
SE-S	2.07	2.86		0.26	
S-SW	3.37	2.60	1.82		
SW-W	**12.95**	**18.40**	9.06	2.34	2.85
W-NW	5.45	10.63	7.51	3.11	1.04
NW-N	0.26	0.54	0.78		

(iii) swell wave height (m)

Direction	<2	2-3	4-5	6-7	7-8
N-NE	0.66	0.33			
NE-E	2.63				
E-SE	8.56	0.66	0.33		
SE-S	4.61	1.32	0.33		
S-SW	5.26	2.31	1.65		
SW-W	**13.50**	**15.79**	8.23	2.96	1.32
W-NW	6.25	10.20	9.86	1.32	0.33
NW-N	0.33	0.66	0.66		

(iv) wind wave height (m)

<2	2-3	4-5
1.63		
2.18		
5.74	1.64	
4.93	1.64	
5.20	1.64	
25.95	11.05	4.65
22.58	9.56	1.91
0.82	0.55	

Table 2. Breakdown of wave height and period data from ship data. Figures expressed as percentages of the total sample in each parameter; the two largest values are highlighted in bold print. Directions are non-inclusive, i.e. N-NE covers the sector North (0°) to North-east (45°)and NE-E covers the sector 46-90°.

A

Discrim group	Merged groups	Variables used	Percent correct
Visits	Aug, Sep 89 Jan, Apr 90 May 90 Jun, Jul, Aug, Sep 90 Oct, Nov 90 Dec 90 January week, Feb, Mar 91, Jun 92	Tan Φ, standardised volume per unit length of profile, volume, configuration	38.89
Profiles	1, 2, 3 4, 5, 6 7, 8, 9	Height, hypsometric integral, width, configuration, volume, standardised profile length, angle.	86.36

B

Discrim group	Merged groups	Variables used	Percent correct
Visits	Aug 89 Jan 90 May 90, Jul 90 Oct 90, Dec 90, Jan 91 Mar 91 Jun 92 January week	CSI, size, DRI, sorting, skewness	33.63
Profiles	1, 2 3, 4, 5, 6, 7 8, 9	sorting, DRI, CSI, size	49.03

Table 3. Cases correctly classified in discriminant analysis of merged data groups using (A) profile parameters and (B) sediment parameters.

Plate 1. Portmore, the view from profile 9 looking north.

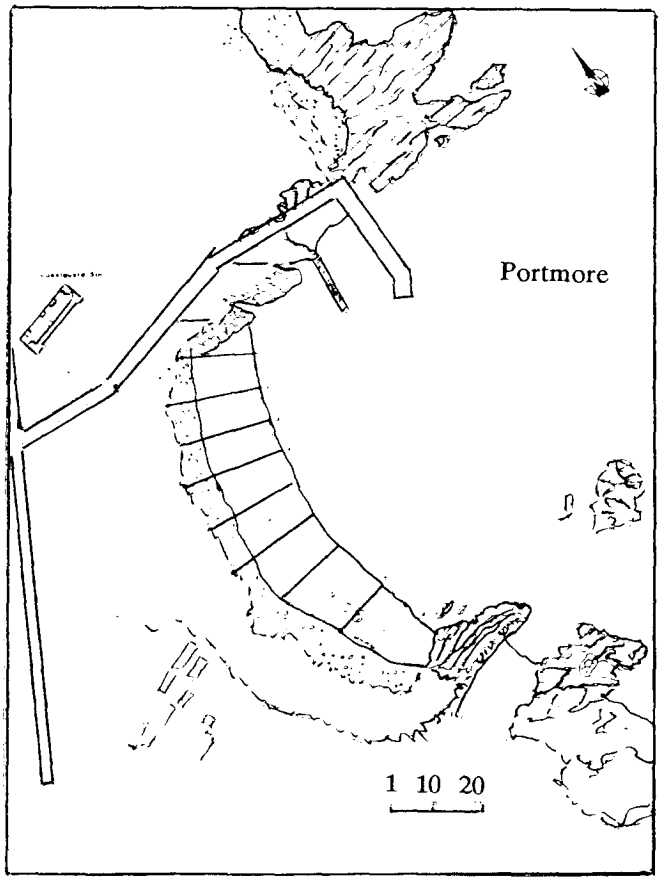


Fig. 1. Portmore- location map showing profiles and local landforms.

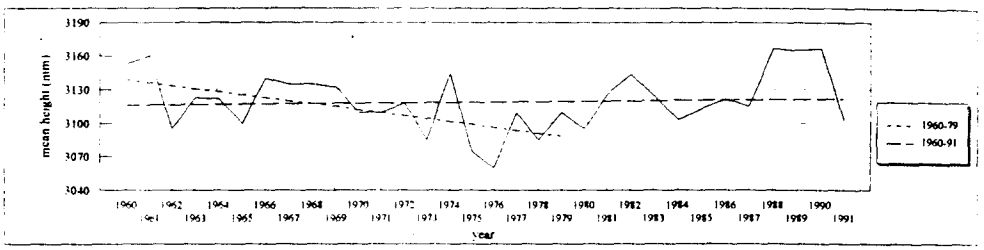
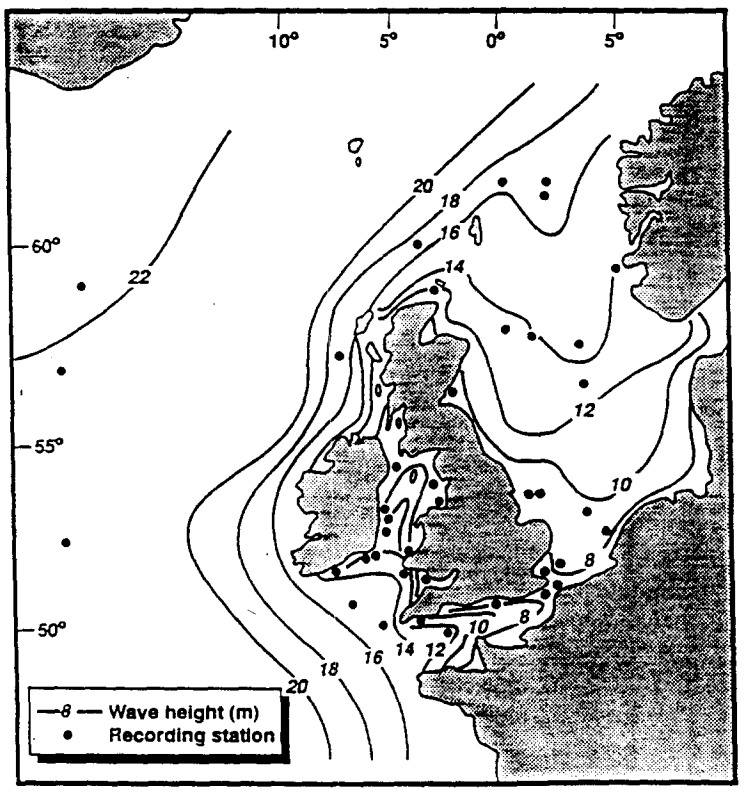


Fig. 2 Sea level rise at Malin Head. Comparison of trend from Todd (1981) for period 1960-1979 and calculated trend for 1960-1991.



Wave heights around the Irish coast (from Orford, 1989).

Fig. 3

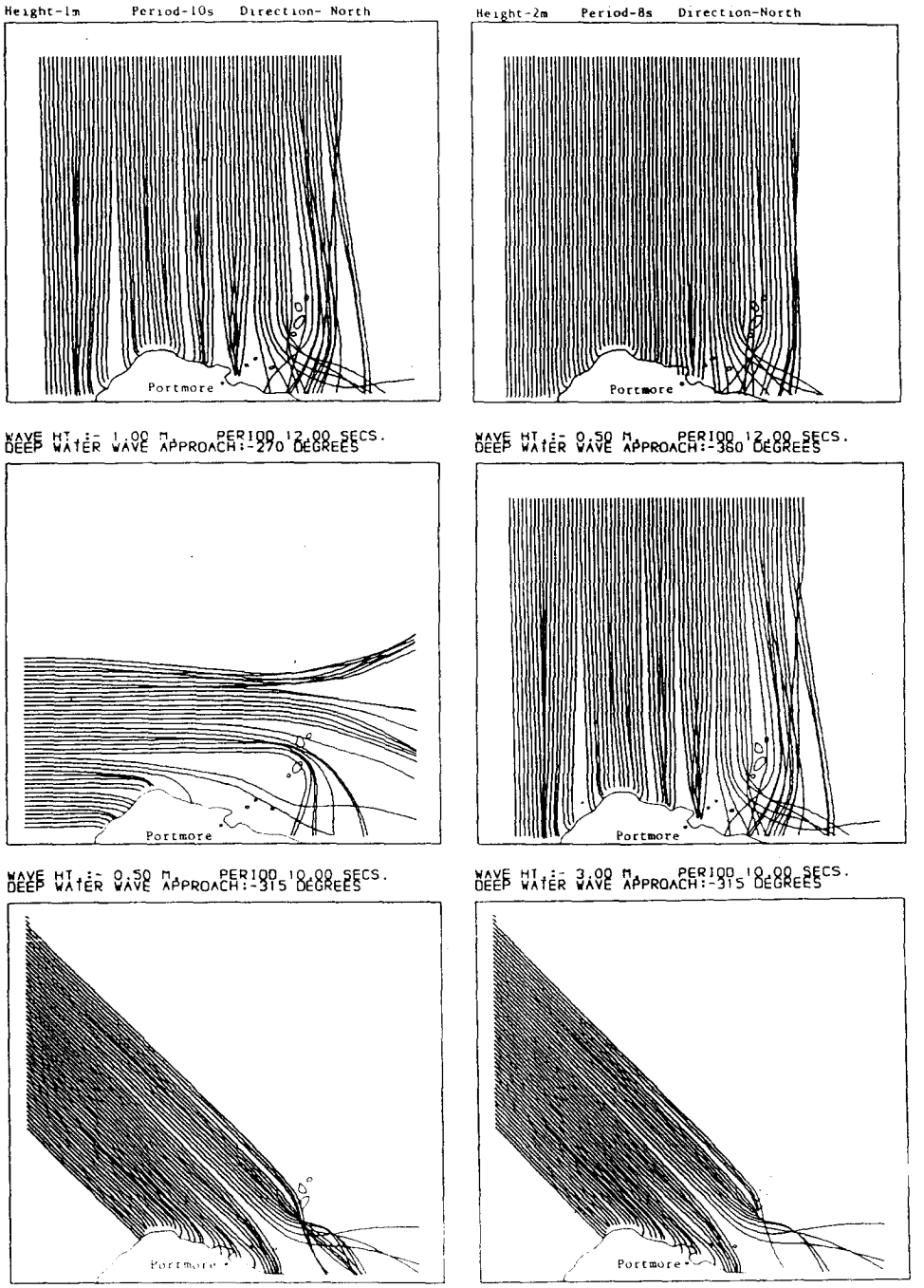


Fig. 4. Wave refraction at Portmore, showing the shadow effect caused by the headland

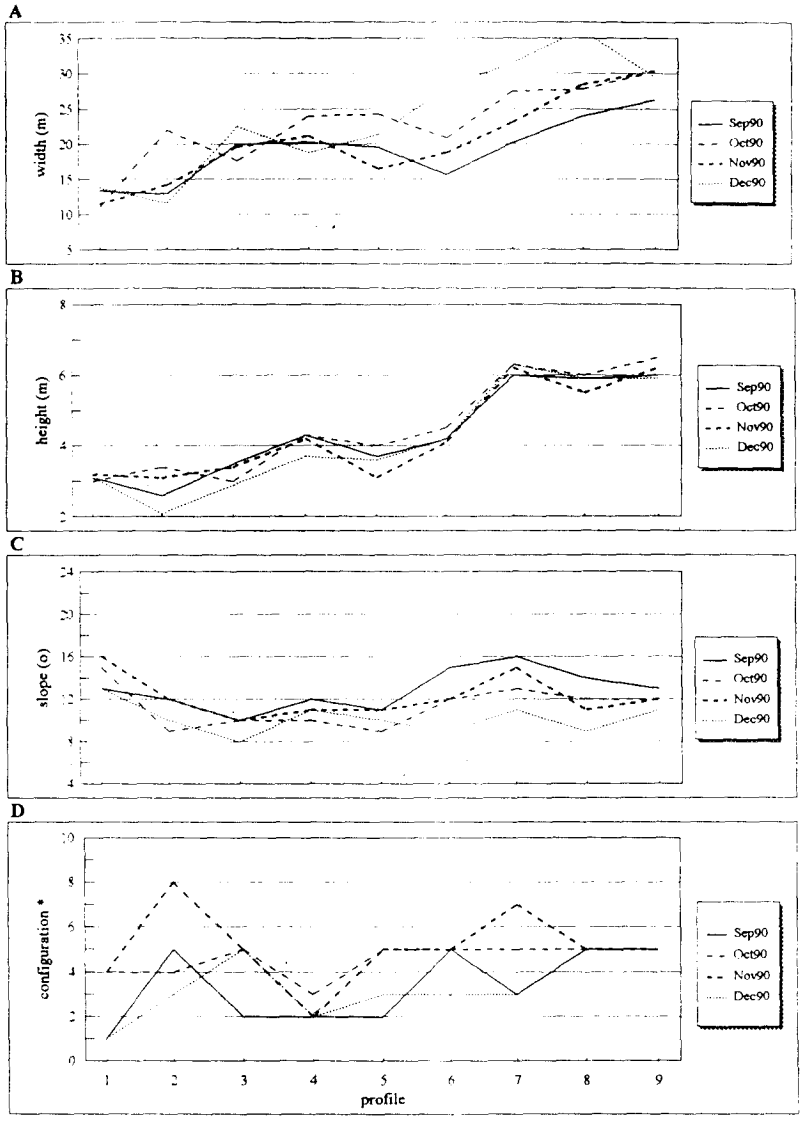


Fig. 5 A-D Change in (a) width, (b) height, (c) slope and (d) profile configuration alongshore between September and December 1990
November 1990 is highlighted with a bold line

* - configuration legend

1 - concave, no berm
2 - concave, lower berm
3 - concave, middle berm
4 - concave, upper berm
5 - concave, composite berm
6 - linear, no berm
7 - linear, lower berm
8 - linear, middle berm
9 - linear, upper berm
10 - linear, composite berm

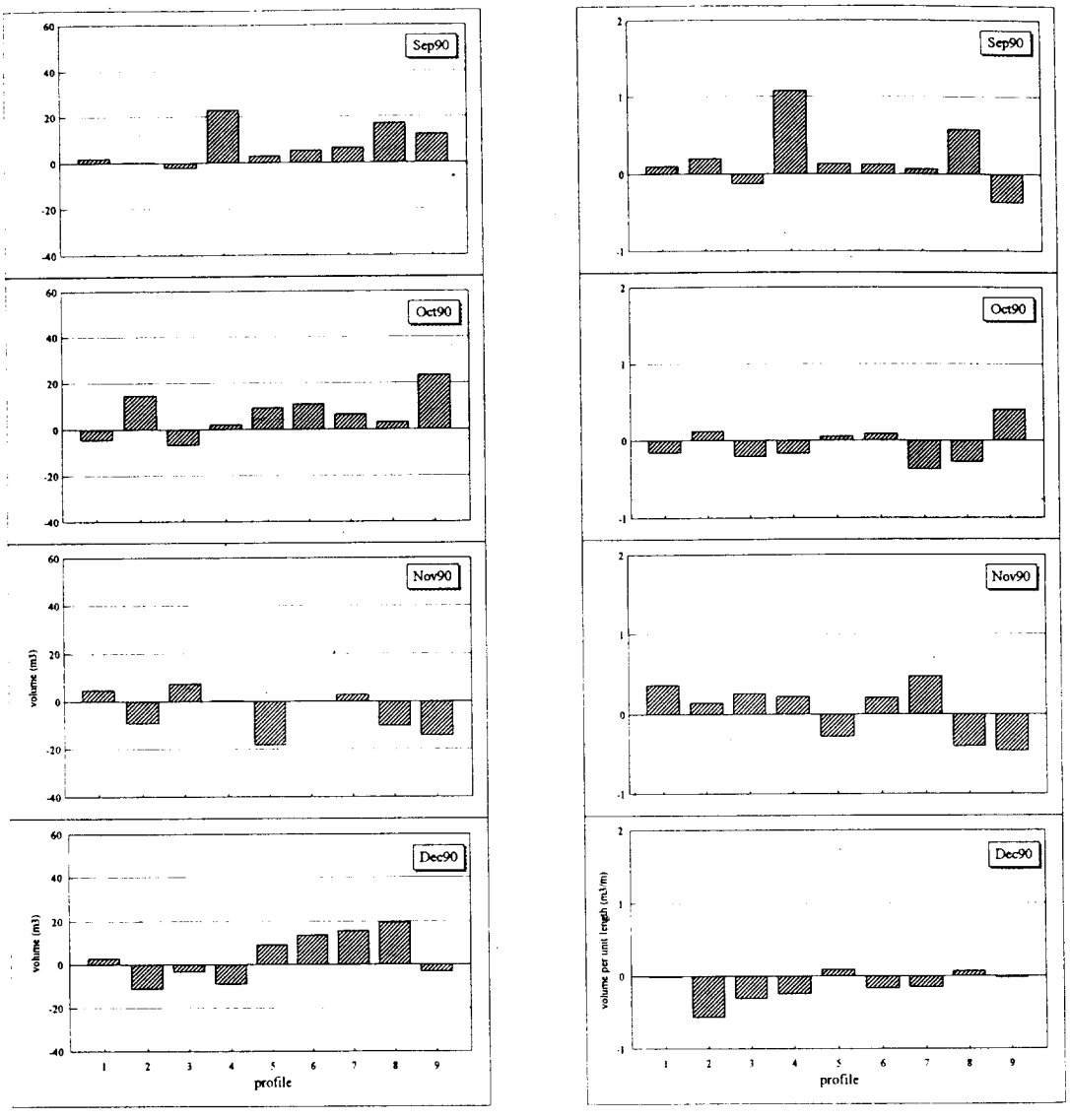


Fig. 6 **Change in volume (m3) and volume per unit length (m3/m) of profiles for each month.**

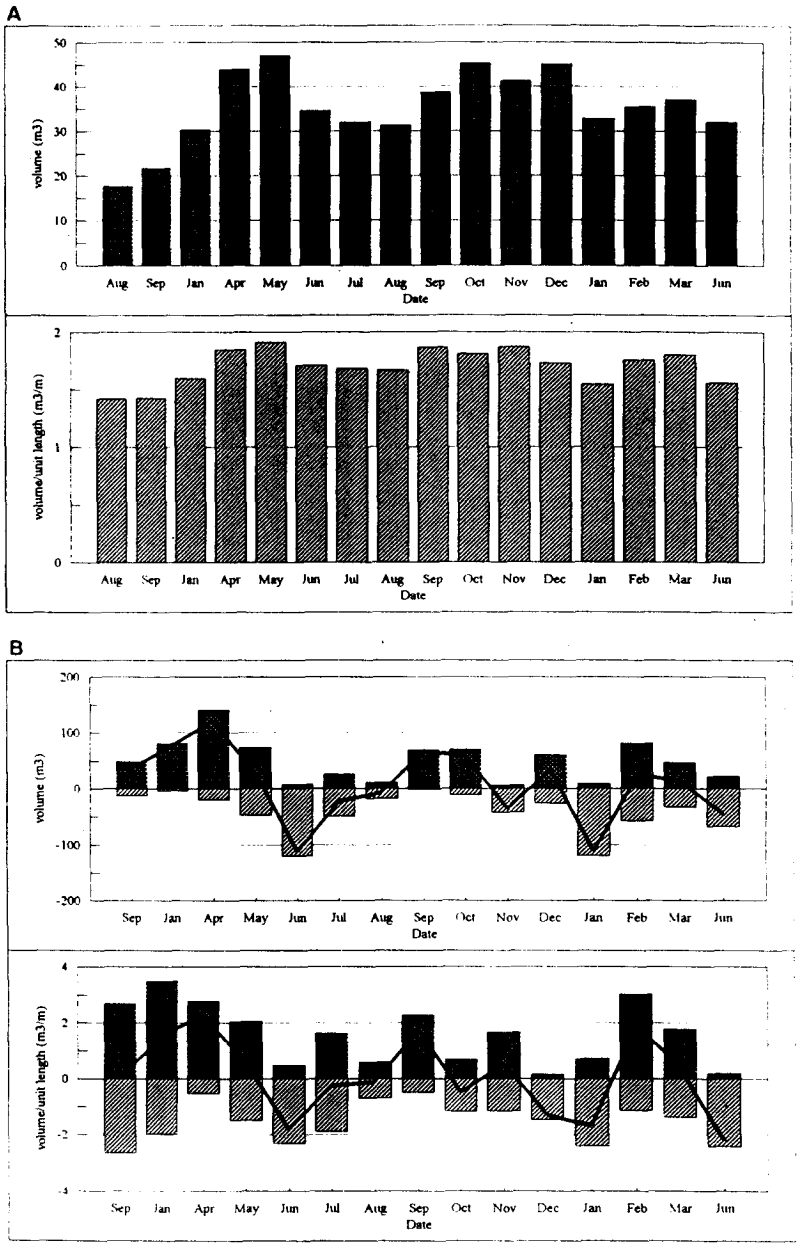


Fig. 7 Portmore - (A) mean volume and volume per unit length for each month and (B) mean erosion and deposition for each month.

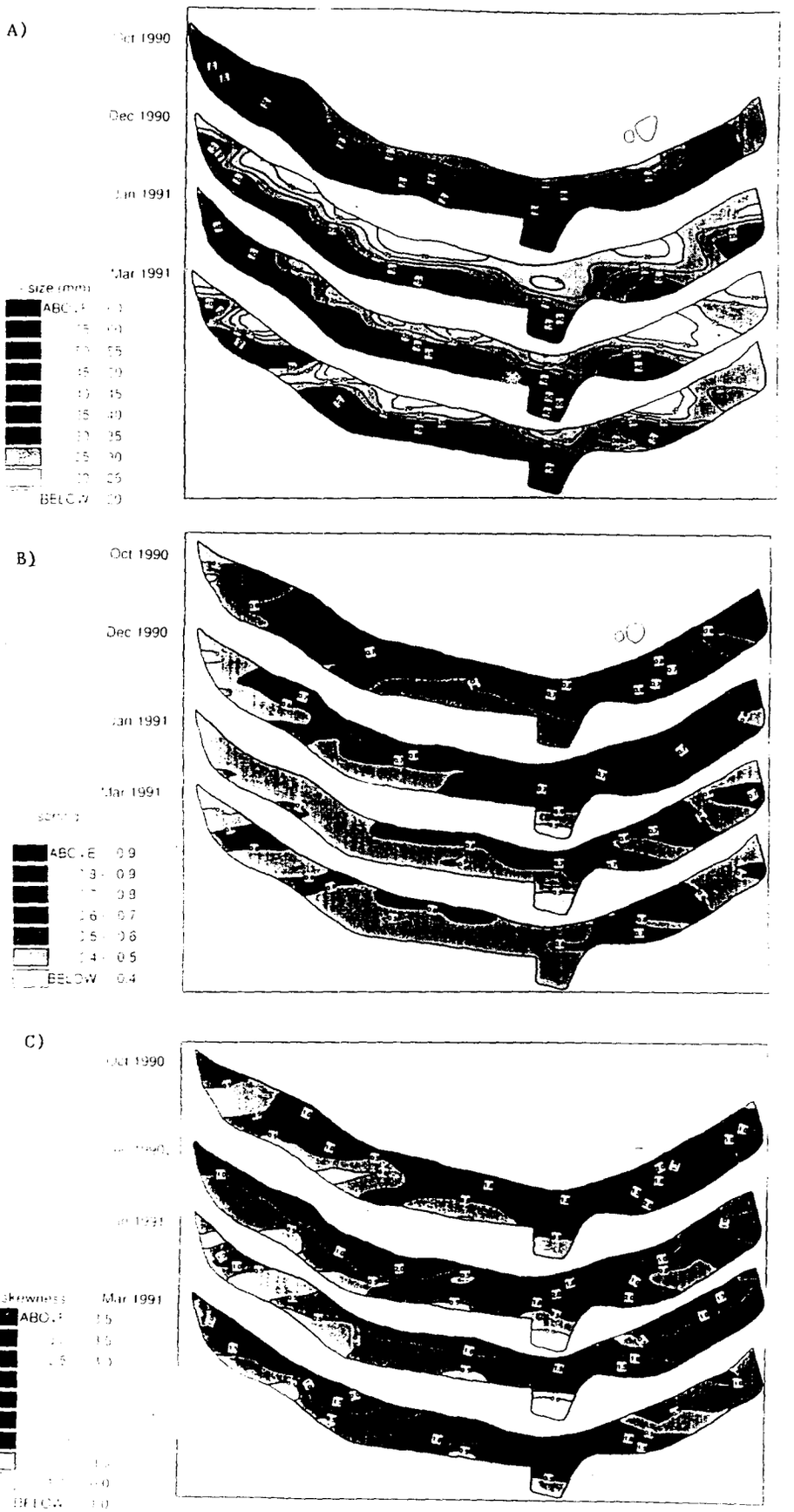


Fig. 8 A) Size (mm), B) sorting and C) skewness distributions

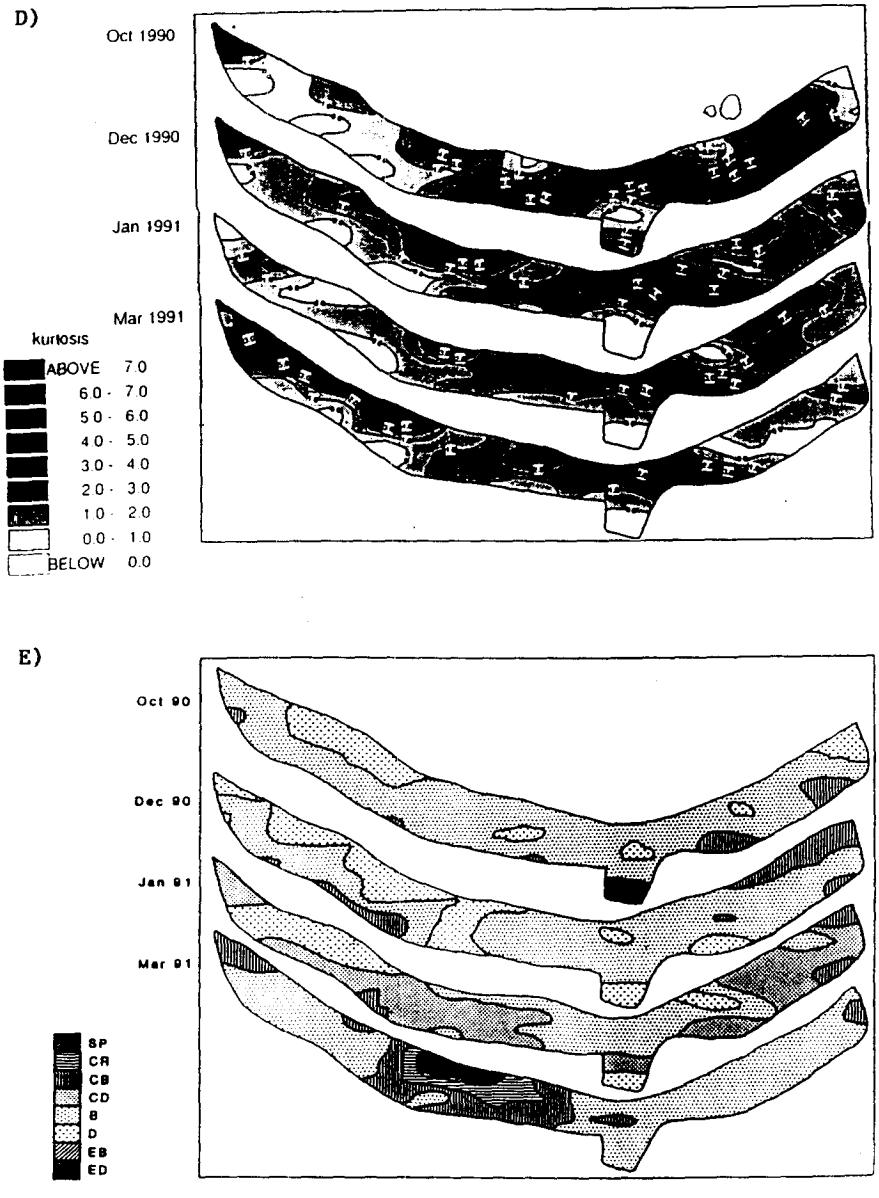


Fig. 9 ...cont'd.
D) kurtosis and E) shape distributions at Portmore.

FOR EXPLANATION OF THE SHAPE LEGEND SEE APPENDIX I.

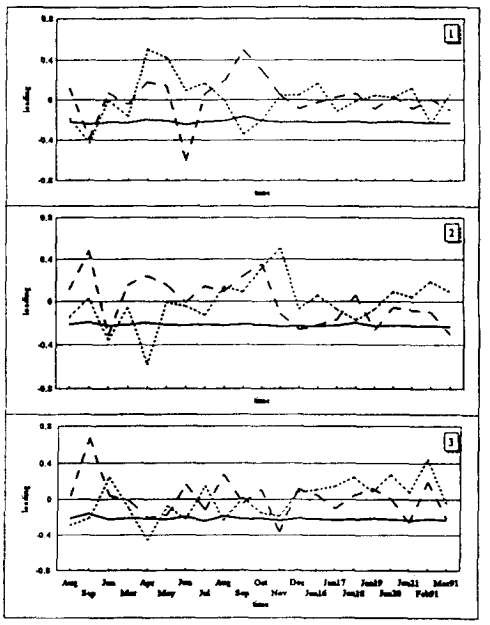
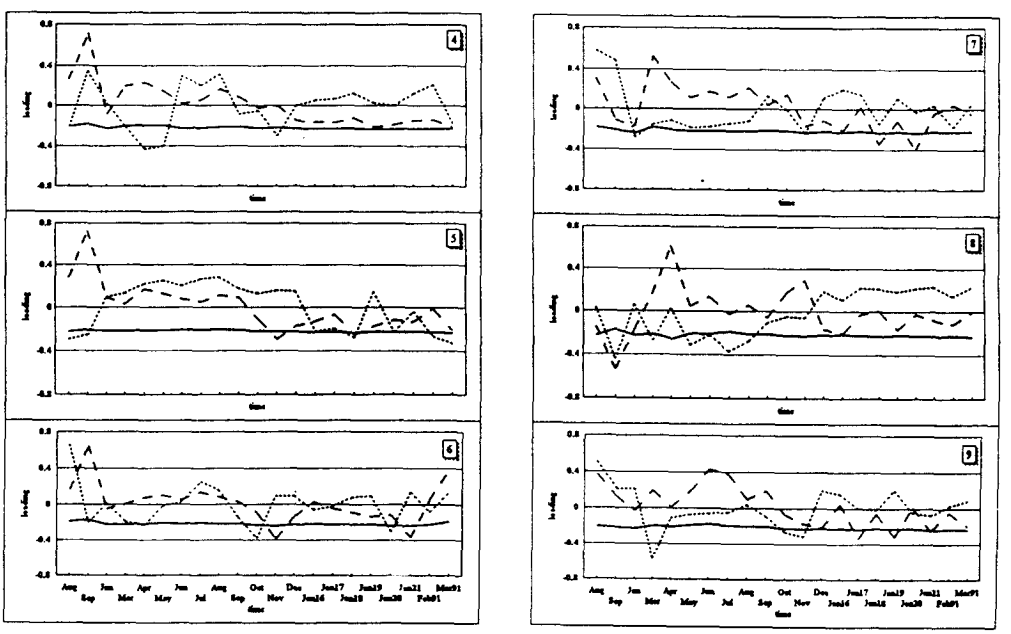


Fig. 9. Temporal component loadings for Portmore profiles.



Solid line: CI Dashed line:CII Dotted line:CIII

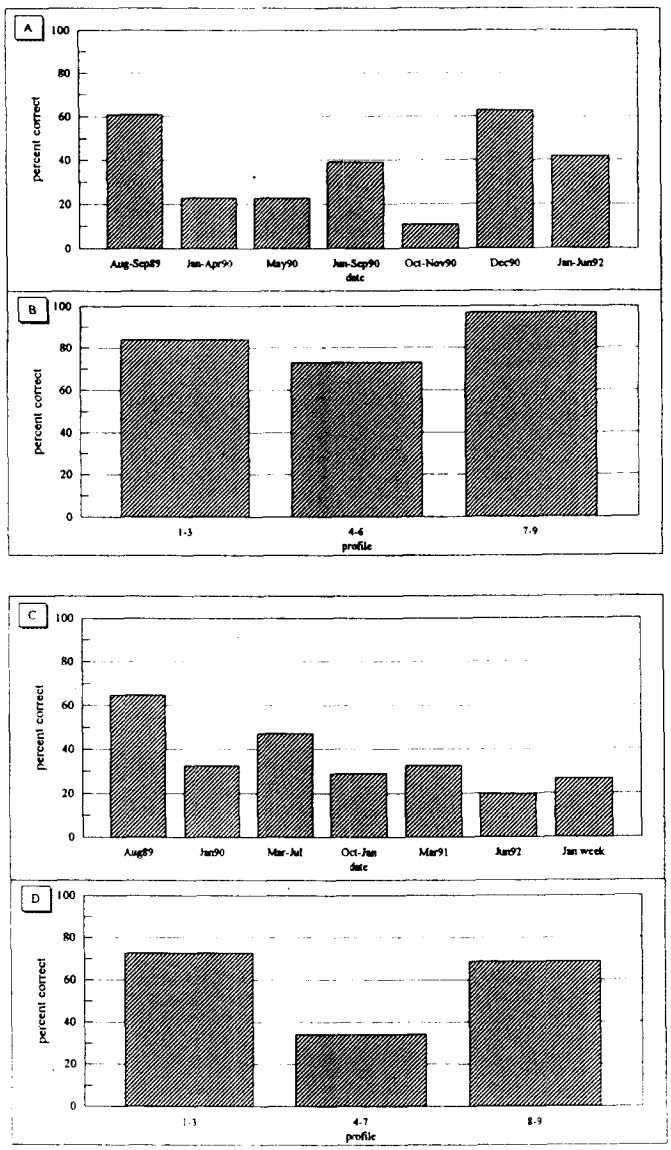


Fig. 10 Histograms of percent correspondance at Portmore.
Data merged by centroid scores. (A), (B) are grouped according to profile parameters, and (C), (D) are grouped according to sediment parameters into similar groups of visits and profiles.

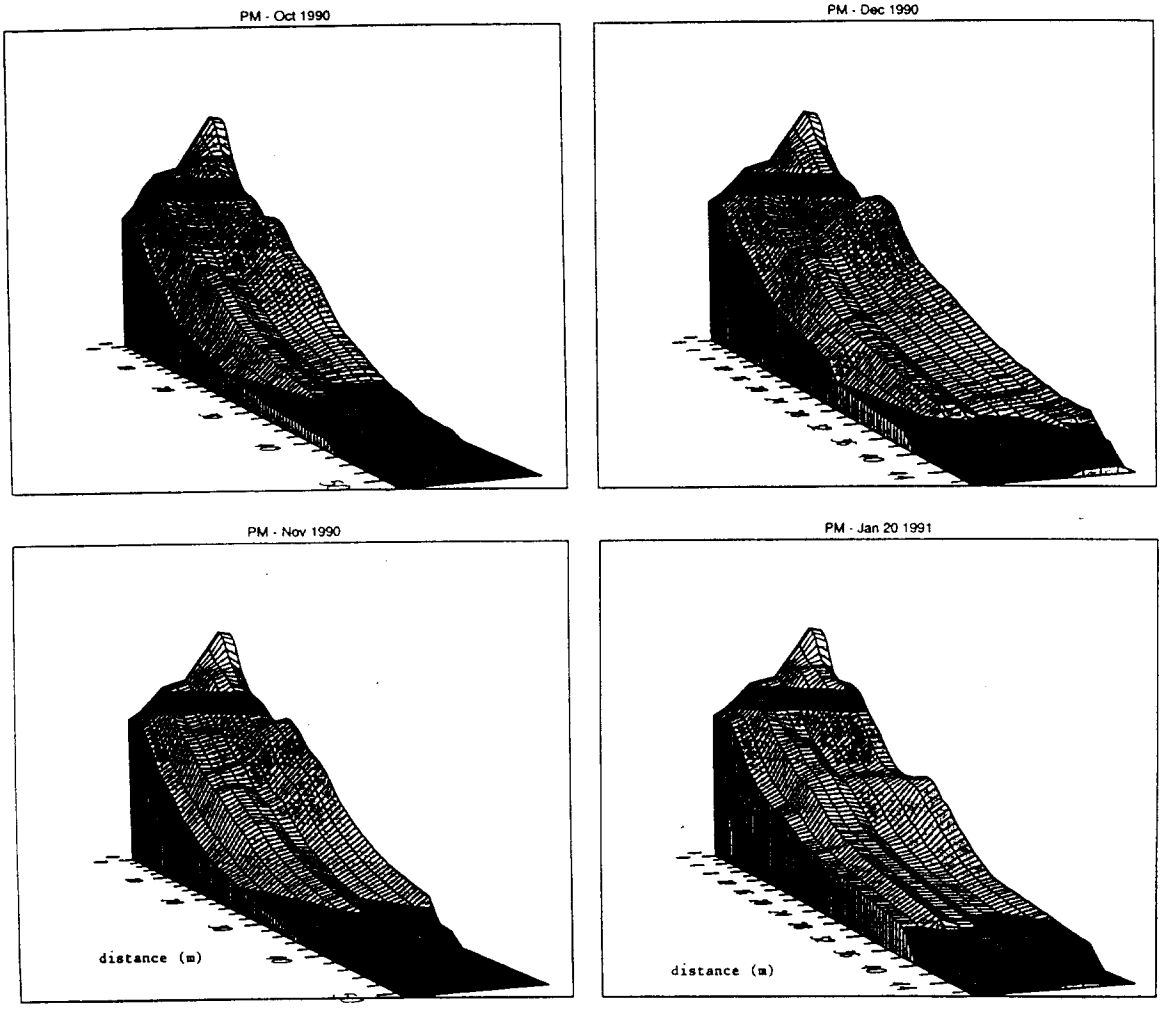


Fig 11. 3-D graphs of Portmore showing the changes in elevation and width of profiles.

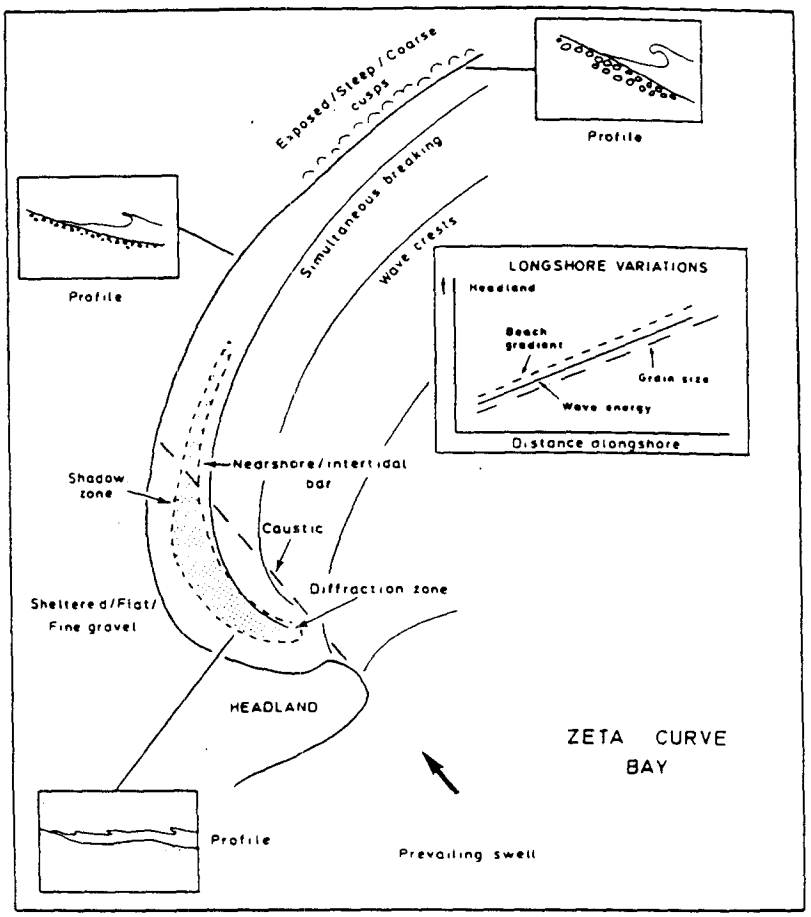


Figure 12 A zeta or crenellate bay showing the longshore variations in profiles, breaker types, sediment and beach gradient.

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PLAIN COAST CHANGES: HUMAN IMPACTS AND RIVER-SEA SYSTEM CONTROL--EXAMPLES FROM CHINA[1]

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ABSTRACT

Plain coasts are developed 2,000 km long margining the river deltas in China. With 0.9-1.2 billion tons fine sediment supplied annually to the coast water, the adjacent coastlines are prograding rapidly to form a gentle coastal slope, and tidal flats are well developed as the wave dynamic are minimal on the shore, and the tidal processes are predominant.

Plain rivers often shift in their course. The Yellow River has experienced eight major changes in its lower course since 2278 B.C., discharging either into the Bohai Sea or into the Yellow Sea via the Huai River. The shifted distances between north and south were more than 600 km long. Two major migrations were created artificially as a result of military activities.

In 1855, the Yellow River changed its course from the Yellow Sea back to the Bohai Sea. A fan-shaped delta has been formed with a coastline as 160 km long, and the total progradation of the coast has been 20.5-28.0 km, *i. e.* 23.5 km^2 of land have been accumulated each year. Tidal flats are developed widely along the coast of the Bohai Sea. The abandoned Yellow River mouth is the north Jiangsu along the Yellow Sea. A total of 1,400 km^2 land along 150 km long coastline has been lost since 1855. Mudflats have been eroded, and shell beach ridges (chenier) have been accumulated by breaking waves along the high tide line. Coastal environments and developing trends have been changed completely, as the plain coast shows the balance between wave dynamics and sediment supply of the coastal zone. Along the coast of China, sediments are mainly from river discharges. The fine silt and clayey silt deposited along these plain coasts, were mainly brought by the Yellow River from the loess plateau as a result of soil erosion caused by human activity since historic times.

A short-term example is the diversion of the Luanhe River water for fresh supply to the larger cities since 1980. As a result, the annual sediment discharges have decreased to cause the coastline of Luanhe River delta retreat and salt water intrusion changing the salinity in the delta area. To solve one problem has caused other serious problems as the River-Sea is a close related system. People should pay great attention to setting up an harmonic relation between human activity and natural environment.

INTRODUCTION

Plain coasts are developed more than 2,000 km long mainly marginal to the major river deltas in China. On the basis of genesis, the plains coast can be divided into two types (Wang, 1980):

(1) The Alluvial Plain Coast.

Most of these plains are located between the mountain ranges and sea shore, such as the alluvial plains located along the west side of Taiwan mountains, and the Luanhe River Plain located on the east side of Hebei province along the Bohai Sea. The plains consist of fluvial sediments from the mountain rivers. As the plain reaches the sea, it makes up the submarine coastal slope, with the gradients of 1/100 to 1/1,000. This results in a very wide breaker zone. The breakers, the swash and the backwash are the main types of wave action on the coast. The material movement is active in both the longshore and onshore directions. The barrier bars, sand

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spits, submarine bars and extensive sandy beaches are the typical features along this coast. The beaches may contain several beach ridges, with lagoons behind the bars.

(2) The Marine Deposited Coast.

This type of coast is very extensive, flat and located at the lower parts of large rivers. Regionally as a rule, the basement is subsiding such as the North Jiangsu Plain, North China Plain and the Liaohe Plain. The coast slopes are very gentle, with the gradients in the order of 1/1,000-1/5,000. As a result, the effect of wave action is well offshore. Tidal currents play a major role in shaping the coast. The sediment consists mainly of silt and mud brought in suspension by rivers. This fine sediment cannot be deposited in the shallow nearshore zone, but is either deposited offshore in the deeper water or carried by the flood tide to the upper part of the coast, where it may remain. In these plains, then, the sediments could have been deposited either by marine action or mixed river and marine action (delta). The geomorphological subdivisions of this type of coastline are (Wang, 1983):

1) Salt marsh. These extend inland from a shell beach ridge (chenier) above the intertidal zone. The shell beach ridges are preserved for a considerable time and are useful indicators of the location of ancient coastlines. Occasionally relict lagoons are found behind the shell beach ridges.

2) Intertidal mudflats. These can be extensive as a result of a 3 m tidal range. For example, along the west coast of the Bohai Bay, tidal flats are 4-6 km wide, with slope 0.3-1.0%.. In the middle part of the North Jiangsu Plain, the intertidal mud flat is even wider still. Zonation features of morphology and sedimentation are typically the result of tidal currents operating on the flat: sandy flat with ripples on the lowerflat; silty and mud mixed flat with erosional microfeatures around mid-tidal level; muddy flat or mud pools located below low high tidal level; and clayey flat with polygon features or salt marshes located between high and maximum high tidal level (Wang et al., 1990).

3) Submarine coastal slope. This extends below the intertidal zone. It is gentle in the order of 0.7-2%. with a concave profile. The water is shallow, only about 3-5 m at a distance of over 10 km offshore. The sediment becomes finer offshore; it is sandy silt at the lower tidal level and very fine mud in the deeper parts. Thus, the marine deposited plains are with tidal currents as it's leading dynamic action. Silt is the major component of sediment deposited on the tidal flat. Sediment becomes finer from low tidal level both landwards and offshore. These features are completely different to these of the alluvial plain coast.

The plain coasts represent a balance between wave erosion and deposition of unconsolidated sediment that is dependent on sediment supply, principally from rivers. If the amount of the sediment supplied is larger than the amount of eroded, the coastline progrades; if the sediment supply is reduced or stepped, wave erosion causes the coastline to retreat (Wang, 1980). Relative changes in sea level do not effect to any great extent the development of the plains coastline. For example, the west coast of the Bohai Bay, which receives the sediment of the Huanghe (Yellow) River, is prograding despite a steady regional subsidence since the late Mesozoic (Wang, 1980).

River sediment discharges to the ocean were and are the major sediment supply to the plain coastal formation and the dynamic processes of coastal zone in China. It is estimated that total of 20.14 X 10^8 tons of river sediment discharged to the ocean annually (Chen and Zhao, 1985; Table 1), which is about 20 % of annual sediment inputs to the ocean by the world rivers (Milliman and Meade, 1983).

HUMAN IMPACTS AND RIVER SEA SYSTEM RESPONSE

In the past, human impact on the coastal evolution has been mainly through the river-sea system, because of several large rivers across the larger area of China, from the west, Qinghai-Tibet Plateau, to the east, the China Seas, which bring great influences to the China's coastal zone. For example, the Yellow River is unique for it's extremely heavy sediment load (11.9 X 10^8 ton/yr), rather small water discharge (485 X 10^8

m^3/yr), and migrated river channel in the lower reaches (Wang *et al*, 1986). Silts are the main component of sediment, and have been carried out by the Yellow River from the Loess Plateau mainly since the west Han dynasty (2^{nd} Century B.C.; Shi, 1981). Because of immigrant cultivation, forests and pastures were destroyed, which caused serious soil erosion, and huge quantity of sediments have been carried out to sea to form the great North China Plain. As a result, it changed the coastal water environment both in the Yellow Sea and the Bohai Sea.

The Yellow River has experienced eight major changes in its lower course since 2278 B.C. (Fig. 1.), discharging either into the Bohai Sea, or into the Yellow Sea via the Huai River. The shifted distances between north and south were more than 600 km long (Wang, 1983). Two major changes of the river channel migration were created artificially as a result of human activities for military purpose.

One major event was in A.D. 1128. On November 15^{th}, the capital official of Southern Sung Dynasty excavated the Yellow River bank at Kaifeng in order to use flood water as a weapon to prevent an invasion of Jin Dynasty soldiers from the north. Even though this effort was unsuccessful, it initiated a change that caused the Yellow River to flow through the Si River, one of the distributaries of the Huai River, to the south. Since then, the river shifted often in the Huai River area and entered the Yellow Sea for more than 720 years. With the enormous sediment supply from the Yellow River, the North Jiangsu coast along the Yellow Sea were created mudflat plain coast instead of the original sand barrier and lagoon system, and the plain prograded for 40 km wide, and its associated Yellow River delta, prograded 90 km into the Yellow Sea. The total area of accumulated coastal land was 157,000 km^2. It was 1/6 of present land area of Jiangsu province. However, the coastal zone along the Bohai Sea, at the same time, suffered from erosion, with the active coastal wave action, mudflats retreated and coastal shelf beach ridges were formed instead of the original mudflat coast with tidal currents as coastal dynamics.

In 1855, the Yellow River returned back to the Bohai Sea. Since then, coastal erosion has been extensive along the North Jiangsu coast as a consequence of the cut in the huge volume of sediment supply, 15-30 m retreating annually along 150 km long abandoned Yellow River delta. A total of 1,400 km^2 of land has been lost completely, and a new rank of shell beach ridge has been formed by present day breaking wave patterns. It is still the major project of coastal defence along the delta. On the other hand, the total 160 km long coastline of modern Yellow River delta in the Bohai Sea has been prograded for 20.5-27.5 km to the sea since the Yellow River shifted back in 1855. The net and average progradation is 0.2-0.27 km per year, *i.e.*, an average of 23.5 km^2 land has accumulated each year. The new river mouth grows fast, 6-10 km in a single year, even though the sea level is rising and the tectonic subsidence in that area continuous since Tertiary time. Mudflats develop widely along the Bohai Bay and Laizhou Bay off the original chenier shoreline, with clayey silt sediment supplied by the Yellow River, and tidal currents as the major dynamic agent along the whole coastal zone. The example has shown clearly the human effects on coastal evolution through a river-sea system.

Future development of the modern Yellow River delta may be slower, because of the annual sediment discharge of the Yellow River has been decreased to 9.5×10^8 tons annually as the annual water discharge is 37.9×10^9 m^3, a consequence of water diversion for irrigation along middle and lower reaches. It is estimated that more than 150×10^8 m^3 of water/yr has been taken from the Yellow River for irrigation over the last decade, and with the volume of water about 1.74×10^8 t of sediment per year. The increasing diversion of water for irrigation and other purpose over the next decade will withdraw considerable amounts of sediment from the Yellow River. The construction of the large Xiaolangde Reservoir, for example, scheduled to be completed by 2000 A.D. could trap 3.3×10^8 t of sediment per year. Recently, sediment has been pumped from the Yellow River channel to widen and strengthen the main dikes along its lower reaches (total length

about 1,400 km). In this way, large amounts of sediment were taken away from the river. Progress in soil conservation in the Loess Plateau, about 34.8 % of total eroded area has been under control, then, 300 million tons of sediment flux have been decreased annually during recent 20 years (People's Daily. Overseas Edition, Jan. 4th, 1995). Thus, the discharge of Yellow River sediment to the sea maybe reduced 6-7x10^8 t/yr in the next 20 years.

At present, human impact on the coastal zone of China has been more and more effective because of the large scale of economic development in the coast area. Still, human impacts on the coastal environment through the river-sea system appear more and more often and seriously, because there are more than 1,500 rivers entering the coastal zone of China.

1. To divert river discharge for urban water supply, then decreasing sediment discharge at same time, mentioned in example of the Yellow River, as a result, to cause the coast erosion at the delta area because a reduction in the sedimentary dynamic balance. Such as the Luanhe River, original water discharge was 4.19x10^9 m^3 with total sediment supply of 2219x10^4 tons. After diverting the water discharge of 3.55x10^8 m^3 for water supply to Tianjing city, the sediment supply is only 103x10^4 tons, the delta coastline of Luanhe River has been retreated in a rate of 17.4 m/yr since 1988 (Qian, 1991), and the salt water intrusion changing the salinity from 27.3%. to 32.6%. in the delta area. Solving one problem has caused other serious problems as the river-sea is a chose related system.

2. North Jiangsu Plain had been previously divided by numerous canals and channel networks in the early 1950's as a strategy for frontier defence. This project changed the natural environment (Fig. 2, Wang, 1994) with the positive effect of bringing more farmland under irrigation. For preventing salt water intruding and preserving fresh water resources along plain coast area, local people dammed up river mouth for most of rivers in North Jiangsu coast plain. The constructions have caused serious under-dam siltation in the lower part of river mouth. The dams also have blocked fish, prawn and crabs breeding up stream from river mouth. As a result, local people not only lose economic income from the decreasing precious sea food, but also, the silted river mouth channels become smaller and smaller day by day, gradually losing navigable water depth, and often suffering flood disaster.

3. Using a river as a natural channel to flush out chemical wastes of industry, through irrigation of polluted water which damaged crops, and the rich nutritious water and sediment entering the sea, it causes serious red tide in the coastal zone. The red tide almost "killed" aquiculture of prawn in the plain coast area.

4. Over exploitation of underground water in the plain coastal zone. Such as in the Laizhou and Longkou county of the plain coast along the Bohai Sea, underground water table subsided 15-30 m in the late 1980's compared with 1977. Thus it destroyed the natural water balance between fresh and saline water. As a result, salt water intruded more than 100 km and caused large area of farmland to be abandoned.

Over exploitation of underground water and heavy load construction on the coastal low land and delta area have caused rapid ground subsidence to accelerate local sea level rise, for example 0.5 m subsidence has been recorded during 1966 to 1985 in the Tianjing Tanggu Harbour of the Haihe River delta according to the State Survey and Mapping Bureau data in 1992. Relative sea level rise during the same period was 2 mm/yr in the Pearl River delta; 11.5 mm/yr at Changjiang River delta, and 24.7 mm/yr at abandoned Yellow River delta (Ren, 1993).

Sea level rising and the decreasing of river sediment supply, plus the human impacts directly through the beach sand mining. This has speeded up the sandy beach erosion to the rate of 1-3 m/yr as its average in the most parts of China's coastline.

As the conclusion, human activity is one of the most dynamic agents in the coast formation, especially in the plain coast evolution through the river-sea dynamic system, where the impacts become more and more effective by using the advanced scientific techniques. The river-sea system is a natural cycle keeping the environmental balance between air and water, land and

ocean. Even though the human activities are on land, they still directly or indirectly add to the influences on the coastal waters through the river connection. People should pay great attention to setting up a harmonious relationship between human activity and the natural environment. It is urgent to set up and improve systematic regulation and management of the coastal zone to preserve natural environmental balance for a long period sustainable development in the coast area.

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Table 1. Average water and sediment discharge of the major rivers of China.

Sea Area	River	Area of drainage km^2	(%)	Average water discharge 10^9 m^3/yr	%	mm	Average sediment discharge 10^4t/yr	%	t/km^2/yr (yield)
Bohai Sea	Liao	164101	12.3	86.98	10.9	53	1849	1.5	113
	Luan	44945	3.4	48.69	6.1	108	2268	1.9	505
	Yellow	752443	56.3	430.78	53.7	57	111490	92.2	1482
	Σ " "	961492	72.0	566.45	71.7	59	115607	95.6	1202
	Σ All	1335910	100.0	801.46	100.0	60	120881	100.0	905
Yellow Sea	Yalu	63788	19.1	251.34	44.8	394	195	13.3	31
	Σ All	334132	100.0	561.45	100.0	168	1467	100.0	44
East China Sea	Changtze	1807199	88.4	9322.67	79.7	516	46144	73.1	255
	Qiantang	41461	2.0	342.39	2.9	826	437	0.7	105
	Min	60992	3.0	615.87	5.3	1010	768	1.2	126
	Σ " "	1909652	93.4	10280.93	87.9	538	47349	75.0	248
	Σ All	2044093	100.0	11699.32	100.0	572	63060	100.0	308
South China Sea	Hanjiang	30112	5.0	258.78	5.4	859	719	7.5	239
	Pearl	452616	77.3	3550.32	73.6	784	8053	84.2	178
	Σ " "	482728	82.4	3809.10	79.0	789	8772	91.7	182
	Σ All	585637	100.0	4821.81	100.0	824	9592	100.0	164
Pacific Ocean		11760	100.0	268.37		2282	6375		5421
Total	Σ All China rivers	4311562		18152.44		421	201375		467

Fig. 1 Map of migrated courses of the Yellow River

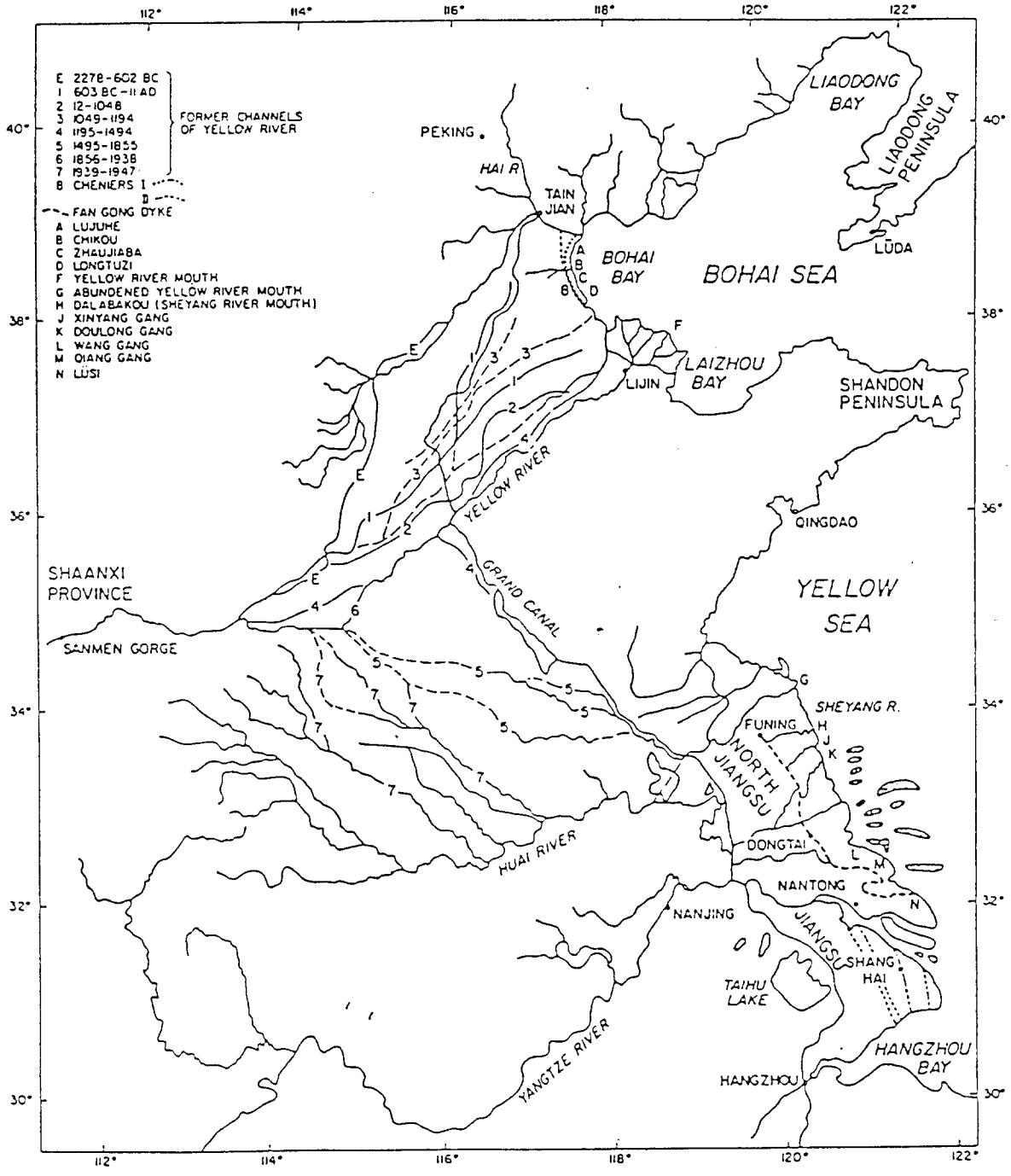
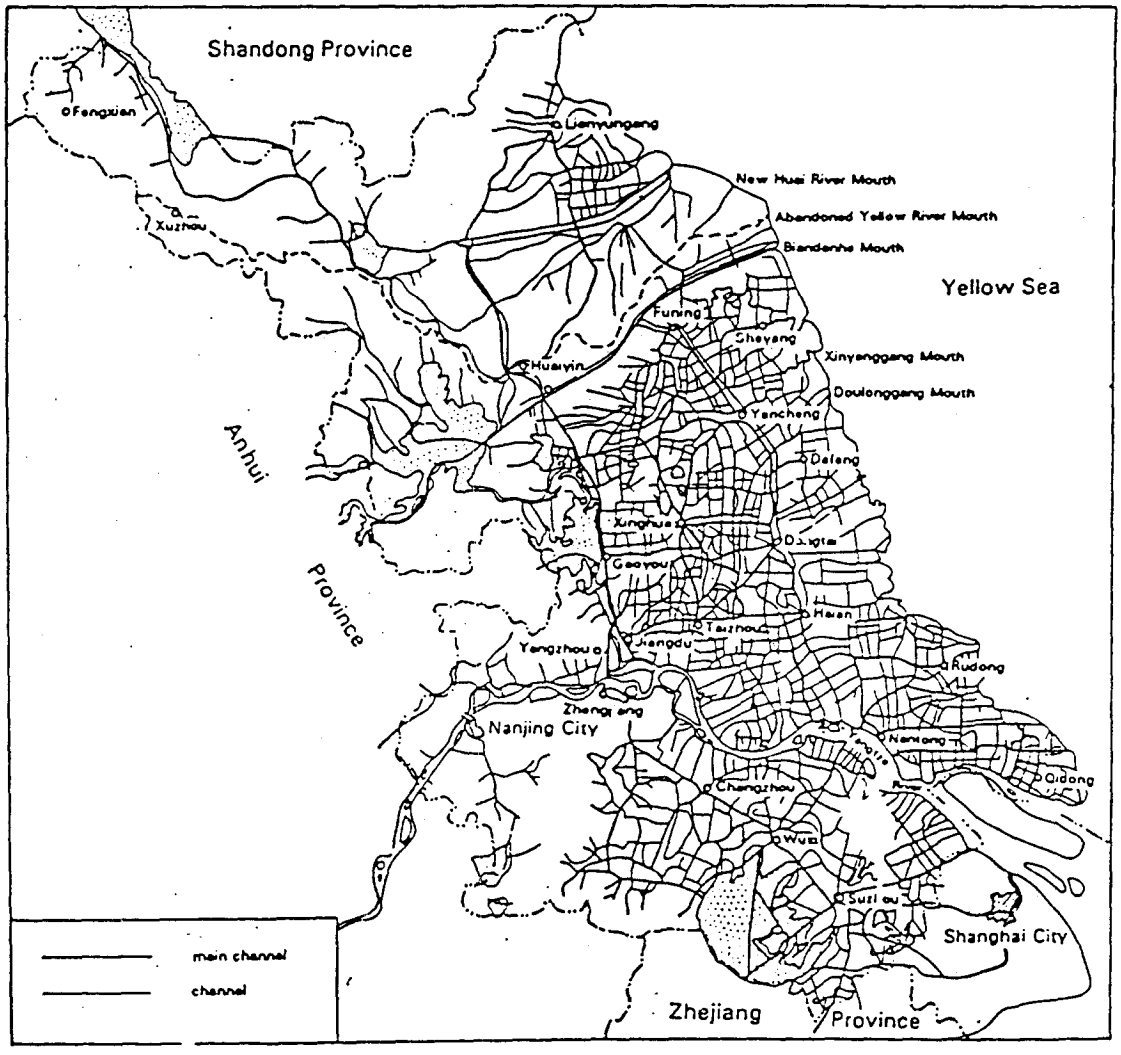


Fig. 2 Artificial channel networks of the North Jiangsu Coastal Plain



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SESSION II

Mechanisms and Processes

Session II-c
Physical Oceanography Framework

Chairman: M. Glass
Rapporteur: N. Psuty & M. Glass

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COASTAL PROCESSES AND THE SUSCEPTIBILITIES OF PROPERTIES TO EROSION

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KEYWORDS: beaches, dunes, erosion, sea cliffs, sea level, waves

ABSTRACT

The erosion of beaches and coastal properties is governed by the extreme run-up of storm waves superimposed on elevated water levels that result from high tides and other factors which affect mean-water elevations. Equally important is the morphology of the beach and its capacity to act as a buffer between the ocean and land. The objective of this paper is to review the ocean processes that are involved directly in coastal erosion, and the models that have been developed to quantitatively analyze the surf-zone processes that play a role in the erosion of foredunes and sea cliffs. These models can be employed in examinations of existing erosion, or in making sound coastal-management decisions.

INTRODUCTION

Erosion has plagued much of the world's coastlines. In most instances this erosion begins with a loss of the beach itself, together with its recreational assets that are of economic importance to coastal communities. The loss of the beach also eliminates the protection it offers to homes, hotels and other developments, recognizing that the sloping beach acts as a natural buffer between storm waves and coastal properties. Once the waves reach beyond the extent of the fronting beach, they can cut into dunes or erode the base of a sea cliff, undermining homes or other developments.

At first consideration, the factors important to coastal erosion are deceptively simple. Large storm waves, perhaps aided by high tides, crash against the dunes or cliff and wash away anything that is in their path. However, research has established that coastal erosion is far more complex than this simplistic view. In most cases the erosion of properties backing beaches is governed by the most extreme run-up of storm waves superimposed on elevated water levels that result from a combination of predicted tides and the many additional factors that can affect water elevations (storm surge, water temperatures, coastal currents, etc.). Equally important is the condition and morphology of the beach. The first stage in the erosion during a storm generally involves the waves cutting away the upper part of the beach fronting the properties, a process which involves the cross-shore transport of sediment from the dry beach to the offshore. Rip currents may contribute to this erosion by locally cutting embayments into the beach, allowing the waves to more quickly reach the foredunes and sea cliffs.

Research advances have led to a greatly improved understanding of the coastal processes important to erosion, and of the erosional responses of beaches, cliffs and foredunes. Models have been developed for wave propagation across the surf zone and bore run-up on the beach face, leading to an improved capability to quantitatively evaluate run-up elevations as functions of the deep-water wave conditions and beach slope. Those analyses in turn have led to the development of models for cross-shore sediment transport and beach profile responses to changing wave conditions, and to models that attempt to predict rates of sea-cliff or foredune erosion. Although the models require testing and further refinement, they are important in having the potential for applications in evaluating the susceptibilities of coastal properties to erosion during extreme events where large storm waves combine with unusually high water levels. The models are capable of predicting episodes of sea-

cliff erosion during storms, or the overwash and undercutting of foredunes, and as such can serve as the basis for making coastal-management decisions, particularly in establishing set-back distances for new construction and determining the need for seawalls or other structures to protect established developments.

The objective of this paper is to review the coastal research that is most directly applicable to analyses of beach, foredune and sea-cliff erosion. This will include a summary of the many oceanic and atmospheric processes that affect mean-water elevations along the coast, predictions of wave run-up on beaches, models that have been developed to predict the responses of beach profiles to storms, and finally the models that have been devised to assess the erosional extent of foredunes and sea cliffs once the wave run-up achieves that level.

FACTORS IMPORTANT IN PROPERTY EROSION

The factors involved in the erosion of properties backing beaches are illustrated in Fig. 1, in this case for the erosion of sea cliffs (Thornton et al., 1987; Shih et al., 1994). The probability of water reaching the base of the cliff is dependent on water-elevation factors which include:

1. The tide level within its predicted cycle;
2. Processes such as storm surge, water temperatures, and offshore currents that produce departures of the mean water level from the predicted tidal elevations;
3. Set-up induced by waves breaking on the beach;
4. The frequency and elevations achieved by the run-up of individual waves above the mean water level.

Important to an occurrence of erosion of properties backing the beach is the comparison between elevations achieved by the water due to these combined processes

$$(H_T + \bar{\eta} + R)$$

in Fig. 1, and the elevation of the junction of the beach face with the sea cliff or with the toe of the foredunes (H_J). Wave-induced property erosion will not occur unless the elevation of the water exceeds the elevation of the beach/property junction. Implementation of the model to evaluate the susceptibilities of properties to erosion depends on the ability to quantitatively evaluate the processes that govern water and beach elevations. These processes are reviewed below.

EROSION PROCESSES

Water-Elevation Controls

From the above list of erosion factors, it is clear that tides are an important process in controlling water elevations on the beach and thus the probability of waves reaching coastal properties. The highest predicted tides of the month, of course, are the spring tides. If a storm happens to occur, the elevated water level of a spring tide can be important in causing or enhancing the erosion. Of special interest are the unusually high spring tides that occur when the moon happens to be at perigee in its orbit, that is, when the moon is closest to the earth. The resulting perigean spring tides add about 40% to the total range, thereby significantly affecting high water levels. Wood (1977) has characterized the occurrence of a perigean spring tide as "a window for a potential flood", and has demonstrated that many of the major coastal flooding events in the past have occurred when perigean spring tides combined with strong, onshore winds that further raised water levels as well as generated large waves. He found that over 100 cases of major coastal flooding associated with these conditions occurred in North America during the 341 years between 1635 and 1976. We can also characterize perigean tides as a "window" for coastal erosion, in that the extreme water levels could place the shoreline close to coastal properties, providing ocean waves with the opportunity to directly attack the properties and cause erosion.

Water-level elevations resulting solely from tide-generating forces are predictable, but there can be significant departures from those predictions due to a number of oceanic and atmospheric processes. Some of these processes affect water

levels for only a day or two, as in the case of a storm surge, while many of the processes are seasonal and thus are reflected in the cycles of monthly-averaged sea levels.

The most dramatic increase in the water level above the predicted tide is the storm surge. A storm surge is meteorological in origin, and can be induced by the passage of a low atmospheric pressure system or by strong winds piling water against the coast. Elevated levels up to 1 meter are common in the North Sea, with the extreme storm surge of January 31-February 1, 1953, having produced a water-level increase of 3.3 m above the normal 1 m high tides at the Hooke of Holland, the Netherlands (Wemelsfelder, 1954). Large waves superimposed on the storm surge breached the system of dikes along the Dutch coast, with the North Sea waters inundating 5 per cent of the land area. More recently, when Hurricane Hugo made landfall along the coast of South Carolina on September 21, 1989, the strong winds raised water levels by some 4 to 6 meters above the predicted tide level (Leatherman and Møller, 1990). Due to the cyclonic nature of hurricanes, there can be considerable alongcoast variations in the onshore component of the winds, in the local atmospheric pressure, and thus in the generated storm surge. This is illustrated in Fig. 2 for Hurricane Carla which occurred during 1961 on the Gulf of Mexico coast of the U.S. (Nummedal, 1983). The distribution shows an asymmetry in storm-tide elevations along the coast with respect to the eye of the storm _ the peak surge is tens of kilometers to the right of the point of landfall of the eye of the hurricane. Furthermore, the water elevations decline more rapidly to the left of the point of landfall than to the right, due to the distribution of winds. The recorded storm surge elevations fall within a broad range because of local effects at the tide-gauge stations.

Storm surge from hurricanes or other extreme storms can dramatically raise water levels along the coast, but fortunately these elevated levels generally last for only the day or two of the storm duration. More routine storm systems accompanied by winds can similarly elevate water levels, but typically only by a few centimeters. Those events may be reflected in the seasonal cycles of monthly-averaged sea levels, since such storm systems are more common and stronger during the winter than in the summer. Seasonal variations in sea levels are found on essentially all coasts, Fig. 3, although storm systems are only one of several causes. The most common pattern is one where mean water levels are highest during the summer and lowest in the winter, illustrated most clearly in Fig. 3 by the example from Annapolis, Maryland. This trend results mainly from parallel variations in water temperatures produced by the seasonal solar radiation. During the summer the local nearshore water heats up, and the thermal expansion produces temporary high-water levels; the cold water of the winter is denser, and this locally depresses the sea level. An inverse relationship is seen in Fig. 3 for the monthly sea-level records from Neah Bay, Washington. This is due to upwelling during the summer, the rise of cold, deep ocean water to the surface so that the coastal water is colder and denser in the summer than during the winter.

Ocean currents can also produce sea level changes through geostrophic effects, not just by upwelling. In the northern hemisphere the Coriolis force tends to turn currents to the right (to the left in the southern hemisphere). This acts to raise water levels to the right of the flow until the cross-current pressure gradient of the sloping water surface counteracts the Coriolis force. The greater the velocity of the flow, the greater the cross-flow surface slope. Accordingly, the presence of the current can affect tide gauges to either side of the current. Important is any change in the velocity of the current, as this modifies the cross-flow slope and thus the recorded mean water levels on the tide gauges. The effects on gauges to the right of the current will be just opposite to those experienced on gauges to the left. For example, if the current speeds up, the cross-flow surface slope will increase, and this will raise mean water levels on gauges to the right of the current while at the same time it lowers water levels on gauges to the left. An example of such sea-level variations are those associated with the Florida Current, Fig. 4, a component of the Gulf Stream system off the east coast of Florida. This current flows with Florida to its left, and with Cuba and the

Bahamas on its right. Sea levels are monitored with tide gauges on both sides of this major ocean current, and the results have been utilized to infer variations in the magnitude of the current. Comparisons by Stommel (1953) and Wunsch et al. (1969) of tide-gauge records at Key West and Miami on the mainland with those at Havana, Cuba, and Cat Cay, the Bahamas, document the effects of the variable currents on the coastal water levels. The comparison between Miami and Cat Cay, Fig. 4, reveals that the seasonal variations at both locations show maxima toward the fall season, that at Cat Cay being slightly earlier than at Miami. These individual cycles may be influenced by a number of factors, but their difference indicates changes in the water-surface slope across the Strait, which mainly reflect variations in the strength of the Florida Current. The results show a maximum in July to August, with a minimum in October to November. These slopes imply that there is a maximum current in mid-summer, the lowest flow being in the fall, results that are confirmed by direct measurements of the current. Blaha (1984) and Maul et al. (1985) provide more recent analyses of fluctuations in the Florida Current based on tide_gauge records of sea level, including more detailed considerations of other factors such as monthly changes in coastal winds and water temperatures.

Another example of the geostrophic effects of ocean currents are the water-level changes associated with the Pacific equatorial currents. This is a complex system of currents flowing in opposite directions, but nearly parallel to the equator. The directions and strengths of the currents affect monthly mean sea levels recorded by tide gauges on scattered islands throughout the equatorial Pacific. Similar to the analyses of the tide gauges on opposite sides of the Florida current, Wyrtki (1973) has been able to decipher the more complex equatorial current system, and compute the monthly mean discharges of the countercurrent for a 21-year period from the tide-gauge records. Wyrtki also found that dramatic monthly changes in mean sea levels periodically occur on the equatorial islands, and also along the Pacific coasts of North, Central and South America. Those extreme changes are associated with the occurrence of El Niños in the Pacific Ocean. An El Niño is triggered by the breakdown of the westward directed trade winds along the equator. One result of that cessation of winds toward the west Pacific is the release of a set-up of the sea level which slopes upward from east to west, normally held in its inclination by the trade winds. The released water during an El Niño moves eastward as a bulge in the sea level, held close to the equator by the Coriolis force which acts in opposite directions north and south of the equator, turning the water back toward the equator rather than allowing the sea-level high to expand and dissipate. The movement of these sea-level "waves" eastward along the equator has been documented in tide-gauge records from islands near the equator (Wyrtki, 1977, 1984), and has been shown to represent sea-level variations up to 40 to 50 cm within a few months. This is illustrated by the monthly sea-level series in Fig. 5 during the 1982-83 El Niño. Sea level at Rabaul in the western Pacific reached a peak in March or April and then began to drop. In the mid-Pacific at Fanning Island, due south of Hawaii, sea level was normal into June but then began to rise, reaching a maximum in September which was some 30 to 40 cm higher than 6 months earlier. The peak of the rise passed Santa Cruz in the Galapagos during December, and finally reached Callao on the coast of Peru during January, raising water levels by more than 50 cm. On reaching the west coast of South America, the sea-level bulge split with part of it moving south along the coast of Chile, and part moving north. The northward moving bulges associated with El Niños have been followed in tide gauges along the coasts of Mexico, the continental U.S., and have even been detected on the coast of Alaska (Enfield and Allen, 1980, 1983). The sea-level waves are held to the slope of the continental margin by refraction, much like the movement of edge waves along sloping beaches. Although some energy is lost offshore, the amplitude at the shoreline itself is enhanced by the increasing Coriolis force at higher latitudes. Such sea-level waves associated with an El Niño typically raise water levels along the west coast of the U.S. by 10

to 20 cm. The 1982-83 El Niño was exceptional in magnitude _ on the California coast, the increased water levels combined with storm waves to produce extreme erosion (Flick and Cayan, 1985), while on the coast of Oregon the generated sea-level "wave" combined with the seasonal variations in water levels to produce a 60 cm rise within 12 months, 35 cm higher than average (Komar, 1986).

The combined effects of several factors affecting sea-level changes are illustrated by the study of Namias and Huang (1972), changes which spanned a decade and were associated with two large-scale, long-term climatic regimes covering the entire United States. The periods compared were 1948-1957 and 1958-1969, a rather rapid change having occurred in 1957-58. In the latter period sea level off southern California was observed to rise by 5.6 cm over what it had maintained during the earlier interval. Investigating the possible causes, Namias and Huang found that the rise was mainly due to a warming of the surface water by 1°C, causing a 3.7 cm rise in sea level due to the thermal expansion of the water. This long-term increase in mean temperature resulted from a change in the prevailing wind patterns between the two decades. Changes in the mean atmospheric pressure accounted for a 0.6-cm rise, dynamic effects of ocean currents caused a 1.0 cm change, and the normal long-term sea level rise due to melting of glaciers accounted for another 1.0 cm. The net calculated change amounted to 6.3 cm, which compares favorably with the observed 5.6 cm rise.

Long-term measurements of tides at a specific site should reflect these many factors which affect water-level elevations, in addition to the predictable portion of the tides. Such measurements can be analyzed to project extreme water levels, for example, those expected within a 50- or 100-year time frame. An example is presented in Fig. 6, derived using tide data from Yaquina Bay on the Oregon coast (Shih et al., 1994). The analyzed data are the absolute highest tides measured during a year, and the data have been modeled by the General Extreme Value distribution; the results are expressed in terms of recurrence intervals of the water-level elevations, but can also be expressed as the probability of occurrence of a specific level during a given year. Based on the measured water levels, the projected 100-year elevation is about 2.5 m above mean sea level (MSL). A similar analysis of the predicted yearly extreme tides yields a curve that is displaced well below that based on measured tides, and yields a projected 100-year predicted tidal elevation of about 2.0 m, some 50 cm lower than that based on the measured extreme tides. This difference reflects the importance of the oceanic and atmospheric processes that can affect mean water levels along a coast. Such projections of expected extreme water levels could be important to the placement of coastal developments if they are to be kept beyond the reach of the tides and waves. However, the analysis presented in Fig. 6 does not include the run-up of waves beyond the mean-water elevations, a further increase in water level that needs to be factored in when applying the analyses to specific sites of potential development.

Storm Waves and Run-Up

The second component in the erosion analysis diagrammed in Fig. 1 is the evaluation of the swash run-up on the beach face produced by extreme storm waves. The swash of waves on the beach represents the cutting edge of the sea, the zone of intense erosion during storms leading to shoreline retreat. An assessment of this factor requires a documentation of the wave climate and a capacity to calculate wave run-up elevations on beaches for those wave conditions.

Due to its importance, a number of investigations have concentrated on making measurements of wave run-up on beaches. There have been parallel investigations of wave run-up on engineering structures such as rubble-mound jetties, studies that are needed to establish design criteria including those governing the elevation of the structure in order to limit overtopping by the run-up of extreme waves. Field measurements of wave run-up have been obtained by unusual techniques. Guza and Thornton (1982) utilized an 80 m long dual-resistance wire stretched out across the beach profile and held about 3 cm above the sand by non-conducting supports. In principal this

technique is the same as employed when using vertical staffs to measure waves, but here the staff in a sense is laid down across the sloping beach. Holman and Sallenger (1985) have obtained run-up measurements by taking videos of the swash over an extended period. The position of the edge of the run-up is digitized frame by frame to follow the time-varying positions of the waterline, an analysis that has been computerized. This "remote-sensing" technique has the advantage that it can simultaneously document the run-up along an extended stretch of shoreline, and is not affected by people on the beach or by flotsam carried by the swash.

It is the maximum elevation and shoreward extent of the wave run-up that is of particular significance to erosion of properties backing the beach. It has been found that the total run-up consists of two components: (a) the wave induced set-up which determines the mean shoreline position above which the swash of individual waves occurs, and (b) fluctuations about that mean due to the swash of incident waves producing run-up and run-down. The maximum run-up height achieved by the water is the summation of these components.

Many of the studies of wave run-up have involved engineering structures such as sea walls, jetties and breakwaters. Early publications include the paper by Wassing (1957) reporting on model studies of wave run-up on dikes in the Netherlands, and that of Hunt (1959) examining run-up on rock-rubble structures. Battjes (1971) has shown that the run-up data derived from the numerous studies can be related to an Iribarren number according to the dimensionless equation (1a)

$$\frac{R_{2\%}}{H_s} = C\xi_p \qquad (1a)$$

where $R_{2\%}$ is the vertical level exceeded by 2% of the run-up heights, H_s is the significant wave height, and the Iribarren number is defined as (1b)

$$\xi_p = \frac{S}{\sqrt{H_s/L_\infty}} \qquad (1b)$$

where S is the slope of the beach or structures and L_∞ is the deep-water wave length. C is a dimensionless coefficient that needs to be established experimentally. There is now a considerable number of measurements of wave run-up upon which to base predictions using equation (1); Douglass (1990) provides a recent review, and van der Meer and Stam (1992) have undertaken a synthesis of the extensive laboratory results. Particularly important to analyses of property erosion backing beaches are the field measurements of Holman and Sallenger (1985) collected at the Field Research Facility, Duck, North Carolina; Holman (1986) has further analyzed the data specifically to derive relationships needed to evaluate extreme run-up elevations. Holman analyzed run-up levels in terms of the mean elevation, the significant level (elevation of the highest one-third), the 2% exceedence elevation, and the absolute maximum run-up elevation achieved within a measurement record. Similar to earlier studies, Holman found that the run-up elevations can be predicted by the relationship of equation (1) where C = 0.90 for the prediction of $R_{2\%}$. Since the deep-water wave length is related to the wave period T by $L_o = (g/2\pi)T^2$ where g is the acceleration of gravity, equation (1) can be modified to

$$R_{2\%} = CS(H_s L_o)^{1/2} = C\left(\frac{g}{2\pi}\right)^{1/2} S H_s^{1/2} T \qquad (2)$$

for the run-up elevation as a function of the deep-water wave height and period, and of the beach slope.

Equation (2) accounts for the total run-up elevation due to the presence of waves, that is, it combines the wave induced set-up which raises the elevation of the mean shoreline, and the swash elevation of individual waves beyond that mean shoreline. If analyzed independently, the set-up and swash elevations both have predictive equations like the above relationships, but the coefficients are respectively C = 0.35 and 0.55, which sum to the 0.90 coefficient for the total elevation.

With sufficient data for the deep-water wave climate, it is possible to project extreme run-up elevations, the analysis being much like that above (Fig. 6) for extreme measured tidal elevations. This has been done for the Oregon coast, using equation (2) to calculate expected run-up elevations associated with the 24 largest storms that have occurred during the past 23 years, storms where the deep-water significant wave height was equal to or exceeded 6 m (Shih et al., 1994). The calculation with equation (2) depends on the wave periods as well as wave heights. This emphasizes the importance of storms in that, as is commonly found, there is a broad positive correlation between significant wave heights and periods (Tillotson and Komar, in review), which combine in equation (2) to yield the most extreme run-up elevations on Oregon beaches during the past 23 years. In making the calculations, a beach slope S = 0.03 was used, an approximate average for the Oregon coast. The calculated $R_{2\%}$ values for the 24 storms were subjected to an extreme-value analysis, and yielded a projected 50-year run-up level of 1.87 ± 0.15 m, while the less reliable 100-year projection is 1.97 ± 0.17 m. These magnitudes for the extreme wave run-up are comparable to the total tidal excursion on the Oregon coast, and are much larger than water-level enhancements that result from storm surge, etc. The calculations, therefore, reaffirm the importance of run-up during storms being a major factor in causing property erosion.

The Beach Response and Elevation Controls

Having considered the mean water elevation due to tides and other processes, and the run-up of waves on the beach, the final factor in the erosion model of Fig. 1 is the elevation of the beach/property junction, H_j. This elevation can vary from one beach to another due to the total quantities of sand within the littoral zone. This factor is important on the Oregon coast which consists of a series of littoral cells, stretches of beach that are largely isolated by rocky headlands. Some littoral cells contain more sand than others, and this is reflected in their H_j elevations, in the frequency with which waves are able to reach foredunes and sea cliffs, and hence in the severity of the erosion.

Another control on the elevation H_j is the grain size of the beach sediment. This has been demonstrated in a study of the Lincoln City littoral cell on the central Oregon coast (Shih and Komar, 1994), a cell that is unusual in that there is a pronounced and systematic longshore variation in sediment grain sizes and thus in the beach morphology, ranging from low-sloping dissipative to steep reflective beach systems (Wright and Short, 1983). The coarse-sand steeper beaches have higher beach/property junction elevations, probably a result of the higher levels that can be achieved by run-up during storms due to the slope dependence in the run-up relationships. Furthermore, the coarse-sand beaches undergo larger profile changes through the seasons, and also experience greater profile shifts during individual storms as compared with the fine-sand beaches. Rip currents on the coarse-sand beaches tend to erode larger and deeper embayments into the berm, and this in particular can lower the elevation of the beach/property junction, thereby locally and temporally increasing the susceptibility of the property to wave attack. Rip embayments have been one of the most important factors in causing property erosion along the Oregon coast, both in areas of foredunes (Komar and Rea, 1976; Komar, 1983) and of sea cliffs backing the beaches (Komar and McDougal, 1988).

Embayments cut into the beach have been shown to be important factors in property losses on

other coasts as well. Dolan (1971) and Dolan et al. (1974) have documented the presence of embayments along the barrier islands of the east coast of the United States, embayments which have a wide range of sizes and a variety of origins including erosion by rip currents, associations with crescentic bars, and wave refraction over offshore shoals which focus the wave energy within the embayed stretches of shore. It was further established that these embayments can become zones of higher property losses due to erosion, and in the extreme are areas where barrier-island washovers preferentially occur, sometimes leading to island breaching.

MODEL APPLICATIONS AND PREDICTIONS

The above review has illustrated that there are multiple processes involved in the erosion of coasts, with several factors affecting the level of the sea on any given day, the run-up of the waves being governed by the deep-water wave conditions and the slope of the beach, and by the morphology of the beach such as the presence of embayments cut into the berm due to rip currents or other processes. Implementation of the model diagrammed in Fig. 1 requires quantitative assessments of these factors, or direct measurements.

We are involved in a research program to apply this model to the Oregon coast, both to develop tools for analyses of on-going erosion problems and to provide techniques for evaluating the susceptibilities of properties to future erosion events. Areas of both foredunes and sea cliffs are involved. As part of this research, we have begun a program to measure wave run-up on a number of beaches, using the video techniques developed by Holman and Sallenger (1985). The run-up measurements are analyzed to determine the maximum run-up (R_{max}) achieved during the 70-minute measurement interval, the 2% exceedence statistic ($R_{2\%}$), the 33% "significant" exceedence ($R_{1/3}$), and the mean run-up elevation (R_{av}); all of these measurements include the set-up. Thus far, three sites along the Oregon coast have been included in the measurement program, representing different degrees of beach sand volumes and buffering capacities, and different beach sand grain sizes and morphologies ranging from strongly dissipative to reflective beaches. Results from the three beaches are shown in Fig. 7, where all elevations are with respect to mean sea level as established by surveying from nearby bench marks. The tide levels shown are for the times of run-up measurements. At Beverly Beach the maximum run-up exceeded the beach/cliff junction elevation, and the extreme swash was observed to periodically surge up the face of the cliff. Beverly Beach is located within a littoral cell that is deficient in sand, and this in part is reflected in the low level of its beach/cliff junction (4.1 m, MSL) compared with the other two beach locations included in Fig. 7 (elevations of 6.2 and 5.3 m, MSL). This difference in part also results from the contrasting grain sizes of the sediments on these three beaches. The lower beach/cliff junction elevation at Beverly Beach, has resulted in a high frequency of wave run-up reaching the toe of the cliff, and in substantially greater erosion compared with most other locations on the Oregon coast.

The other two beach locations included in the run-up measurements, Gleneden Beach and 21st Street Beach, are within the Lincoln City littoral cell (Shih and Komar, 1994). Gleneden Beach is composed of coarse-grained sand, and therefore has the steeper slope so it is reflective (summer) to intermediate (winter), while the beach at 21st Street is composed of fine sand and is always dissipative. During the times of run-up measurements the swash did not reach the beach/cliff junctions at either location, and this is generally the case as cliff erosion is a relatively rare event within the Lincoln City littoral cell due to the large quantities of sand on the beaches. In that cell, rip currents play a particularly important role in locally reducing the beach/cliff junction elevation during the rare occasions of episodic erosion.

The run-up measurements can be analyzed to test the model predictions, specifically the predicted elevation achieved by the calculated $R_{2\%}$ run-up level superimposed on the measured tide, compared with the measured results. The comparisons for the three data sets of Fig. 7 are given in Table 1, where the wave run-up

component has been calculated with equation (2) using C = 0.90 from Holman (1986). In each comparison, the predicted water elevation is lower than the measured elevation, the difference ranging from about 10 to 50 cm. This difference results from the calculated run-up using equation (2), versus the measured run-up elevation, since the measured tidal elevation is the same in both calculated and measured total water levels in Table 1. This suggests that equation (2), based mainly on the measurements of Holman and Sallenger (1985) and Holman (1986) at the Field Research Facility, Duck, North Carolina, need to be revised for the present application to run-up on Oregon beaches. Such a revision at this stage is premature, as we presently have only the three measurement sets shown in Fig. 7. An objective of our continuing research is to obtain more run-up data on a greater variety of beaches, at which time refinements in the model calculations can be made.

Once the model has been revised so that it provides improved predictions of daily water elevations due to measured tides plus the run-up of waves, the approach can then be used to calculate the most extreme water levels expected on the Oregon coast, the 50 and 100-year elevations that could result in devastating flooding and erosion. The most extreme tidal elevations have already been evaluated, Fig. 6, based on the long-term measurements of tides on the Oregon coast. With refinements in our ability to make run-up calculations using equation (2), presumably using a new value for C based on direct measurements on Oregon beaches, we can then calculate the run-up elevations that presumably were achieved by the most extreme storms, the documented 24 storms that occurred during the past 23 years when deep-water significant wave heights were equal to or greater than 6 meters. This will provide us with projected extreme run-up elevations for Oregon beaches, as well as projected extreme tide levels. The worst-case situation for flooding and erosion would be the simple summation of extreme tides and run-up, but this assumes that they would occur together. This could be the case if the most extreme measured tides are due to storm surge which are generated at the same time as the most extreme wave conditions. Similarly, enhanced mean-water elevations and unusually large storm waves occur during El Niño events, so the two factors again are related rather than being independent. If the processes affecting the extreme mean-water levels are largely independent from storms that produce the most extreme run-up, then their joint probabilities will have to be evaluated in order to provide assessments of the probable 50-year and 100-year total water elevations. Such analyses specific to the Oregon coast are still in progress.

MODELS OF PROFILE VARIATIONS AND DUNE EROSION

Analyses like those above which consider water-level elevations produced by the tide plus the wave run-up compared with the level of the beach/property junction are fundamental to the occurrence of foredune or sea-cliff erosion. However, they only account for whether or not erosion might occur, and make no attempt to actually evaluate the resulting extent of the erosion. This additional aspect is reviewed here, beginning with models that have been developed to assess variations in beach profiles due to the cross-shore transport of sediment, and then to consider models that attempt to predict the erosional responses of foredunes and sea cliffs.

A series of models have been developed having the objective of predicting beach-profile changes in response to varying wave conditions and water elevations due to tides or a storm surge. One such numerical model is SBEACH (Larson et al., 1988; Larson and Kraus, 1989), which simulates macroscale profile changes including the growth and movement of break-point bars and changes in the berm. The overall direction of sediment transport (onshore versus offshore) is evaluated on the basis of empirical relationships between the wave steepness and H/w_sT, where H is the wave height, T is the wave period, and w_s is the settling velocity of the beach sediment. Empirical relationships are also used for the speed of migration of the center of mass of the bar, and its growth with time to an equilibrium volume. The sediment-transport computations are separated into four zones across the profile, the divisions

being based in part on the expected modes of sediment movement.

The SBEACH model was calibrated first with data from large near-prototype wave channels. Fig. 8 shows a comparison with measured profiles at the Field Research Facility, Duck, North Carolina, a severe test due to the changing wave conditions and tide levels. Recalibration of the model was required because the laboratory-based coefficients yielded bar migration rates that are too rapid and bars that are too pronounced in relief. The overall movement of the bar was fairly well predicted by SBEACH, although the amount of material moved was underestimated and the trough was not as pronounced as in the measured profile. The results look promising, however, especially considering that several environmental parameters were varying.

Many aspects of the SBEACH analyses are empirical, based on observed profile changes in wave tanks and on natural beaches. The development of more process-based models is a challenging undertaking. Such advanced models are provided by Brøker-Hedegaard, et al. (1991) and by Nairn and Southgate (1993). These models variously incorporate analyses of wave transformations in the offshore, wave breaking and decay in the surf zone, wave set-up effects on the mean water level in the presence of the waves, the generation of undertow which can be important to the cross-shore sediment movement. The analyses of Brøker-Hedegaard et al. versus those of Nairn and Southgate differ primarily in how they evaluate these different processes and in the computational procedures used in their models. Fig. 9 includes comparisons of the Nairn and Southgate model with profiles in large wave channels, including an example with multiple bars. The computed and measured profiles are in close agreement. Nairn and Southgate concluded that the processes related to the incident waves can be predicted to a level of accuracy that is sufficient to permit a confident estimate of the evolution of the beach-profile morphology.

Refinements in the models are still needed. Brøker-Hedegaard et al. (1992) compared six different models against measured beach-profile changes in large wave channels. They found significant differences in the predictions and varying degrees of agreement with the measured profiles. The models generally underestimated the initially rapid offshore sediment transport, leading Brøker-Hedegaard et al. to conclude that the models inadequately account for wave reflections from the beach and infragravity long waves. The models also did not succeed in accounting for swash processes leading to dune erosion, a conclusion also arrived at by Nairn (1991) in a more extensive series of analyses where his model was directed toward dune-erosion assessments.

Laboratory and field studies have been undertaken and models developed specifically with the objective of assessing foredune erosion when attacked by storm waves and elevated water levels. Fisher et al. (1986) and Overton et al. (1987) conducted a series of laboratory and field tests using artificially-constructed sand dunes to measure erosion rates due to the attack of the wave swash. They succeeded in deriving a relationship between the rate of dune erosion and the force of the wave uprush, evaluated as the product of the square of the bore velocity and its depth. Overton and Fisher (1988) discuss the various aspects involved in applying the results to dune-erosion evaluations, and compare predicted versus measured erosion rates at the Field Research Facility, North Carolina. Nairn (1991) has recommended the incorporation of this approach for evaluating dune erosion into the models that otherwise attempt to account for beach-profile responses.

Models have been formulated that specifically attempt to evaluate dune erosion during storms. The Dutch, in particular, have concentrated on these models due to their reliance on the presence of large coastal dunes to prevent inundation by North Sea storms. Edelman (1968, 1972) formulated a model for dune erosion based on numerous surveys of pre- and post-storm beach profiles. He observed that during a storm, the beach change is mainly a result of sand transport perpendicular to the shore, with erosion of the berm and dune, and deposition within the outer surf zone to the depth of the breaking waves. Following this observation, Edelman developed a model where sand eroded from the

dunes is deposited as a wedge on the beach. Using actual and idealized pre-storm profiles, Edelman established the known post-storm profile relative to the level of the peak storm surge, and then shifted the profile landward to conserve sand volumes. He concluded that the equilibrium profile relative to the instantaneous water level is approximately constant and is represented by a uniform slope that depends on sediment characteristics. Assuming an idealized profile in which the dunes are represented by a vertical face and uniform crest elevation, Edelman developed generalized graphs that relate dune recession to the storm-tide water-level change. This analysis approach has been improved upon by Graaff (1977, 1986) and Vellinga (1982), based on results from large-scale wave tank tests. While remaining conceptually similar to the Edelman model, Graaff and Vellinga derived revised relationships for evaluating the shapes of beach profiles and for establishing depths of effective sediment motion. Kriebel and Dean (1985) and Kriebel (1986, 1990) have developed models for dune erosion and beach-profile adjustments during storms that provide a better assessment of the lag time of the erosion behind the causative processes. Their models include assessments of the cross-shore sediment transport due to the disequilibrium of wave-energy dissipation produced by the storm. The transport equation together with a relationship for sediment continuity are solved numerically to predict the time-dependent, two-dimensional beach and dune erosion. Since the analysis considers sediment-transport processes, the models can account for time variations in wave heights and water levels, and therefore can be used to examine response times of beach and dune erosion. The results indicate that time scales of natural beaches may be on the order of 10 to 100 hours for storm conditions, and on the order of 1,000 to 10,000 hours when the effective limit of sediment transport is far offshore. The lag of the response, therefore, can be considerable and in general results in the actual erosion of the beach and dunes during a storm being only some 15 to 30% of the potential erosion predicted by equilibrium models based on simple geometric shifts of profiles. Comparisons with the model predictions and measured profile changes and dune erosion during Hurricane Eloise in 1975 on the Florida coast show good agreement.

SUMMARY AND CONCLUSIONS

The review presented here was meant to emphasize the complexity of coastal erosion, which was seen to involve a number of processes that can affect the mean level of the sea, the run-up of waves on the beach above and beyond the mean water level, and the capacity of the beach to act as a buffer between the water and land. Predictions of mean water levels are difficult due to the many oceanic and atmospheric processes that can produced significant departures from predicted tides. Although there has been numerous studies of wave run-up on engineering structures, there have been comparatively few field studies of run-up on beaches; our on-going research on the Oregon coast indicates that improved predictions are required if the property erosion models are to provide acceptable results. Finally, increasingly sophisticated process-based models are being developed to predict beach profile variations resulting from changing wave conditions and water levels, and also models of the erosional responses of dunes and sea cliffs when the wave run-up achieves the elevations necessary to impact them. With further refinement, these models will provide improved predictions of coastal erosion during storms, and can be expected to find use in making coastal-management decisions such as in the establishment of set-back distances and in determining the need for seawalls or other structures to protect established developments.

ACKNOWLEDGEMENTS

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Table 1: Model and Measurement Comparisons

Location	Date	Tide (MSL) (meters)	H_s (m)	T (sec)	$R_{2\%}$ + Tide Calculated	$R_{2\%}$ + Tide Measured
Gleneden	2/2/91	1.17	1.56	13.1	2.04	2.15
21st Street	1/17/91	1.49	2.76	13.1	2.31	2.88
Beverly Beach	3/17/91	1.29	3.47	14.2	2.47	3.00

Fig. 1: The basic model for the quantitative assessment of the susceptibilities of sea cliffs or other properties to wave-induced erosion.

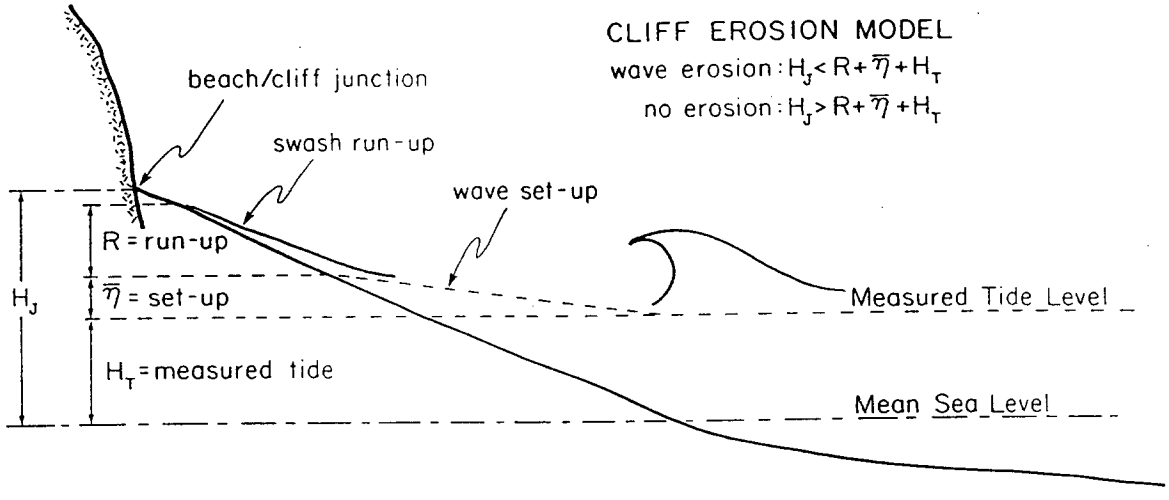
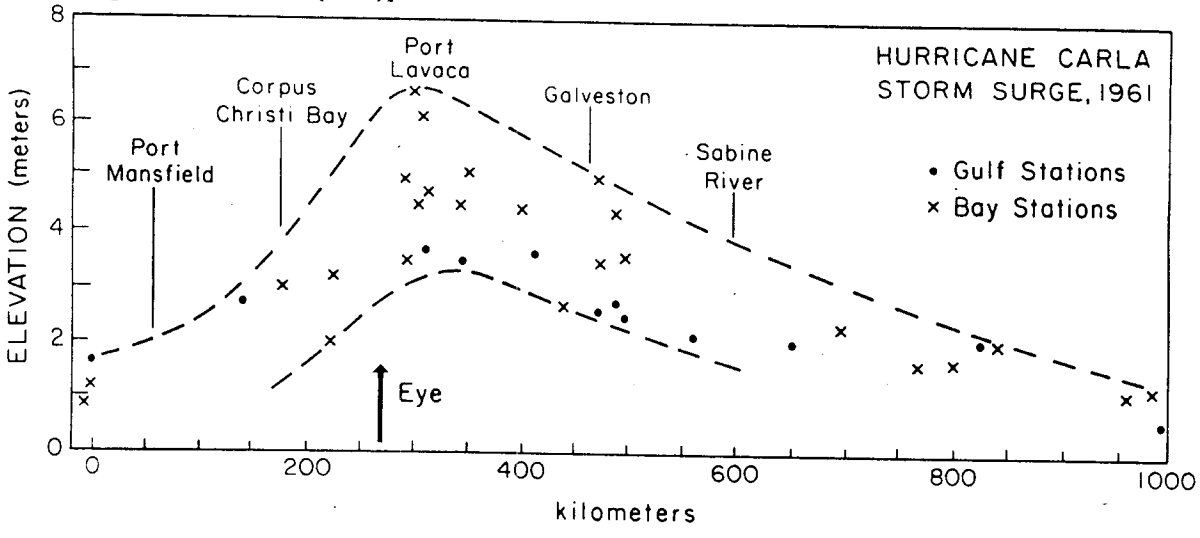


Fig. 2: Measurements of the storm surge due to Hurricane Carla along the Gulf of Mexico shoreline, showing an alongcoast variation produced by the patterns of atmospheric pressures and onshore wind velocities. [*from* Nummedal (1983)]



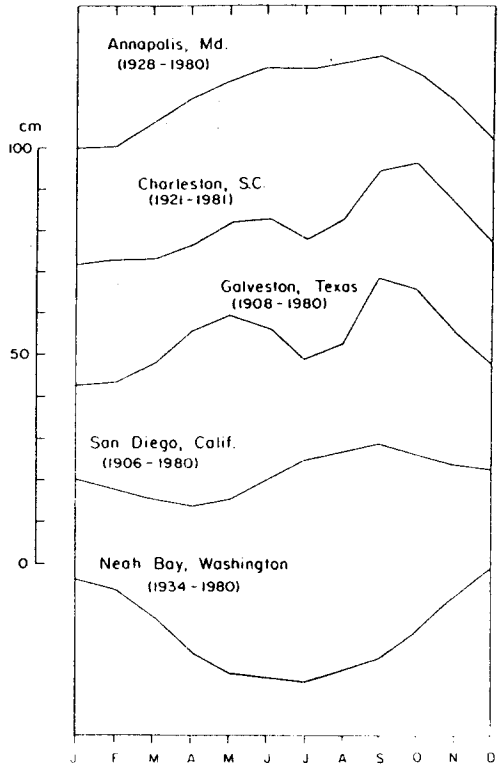
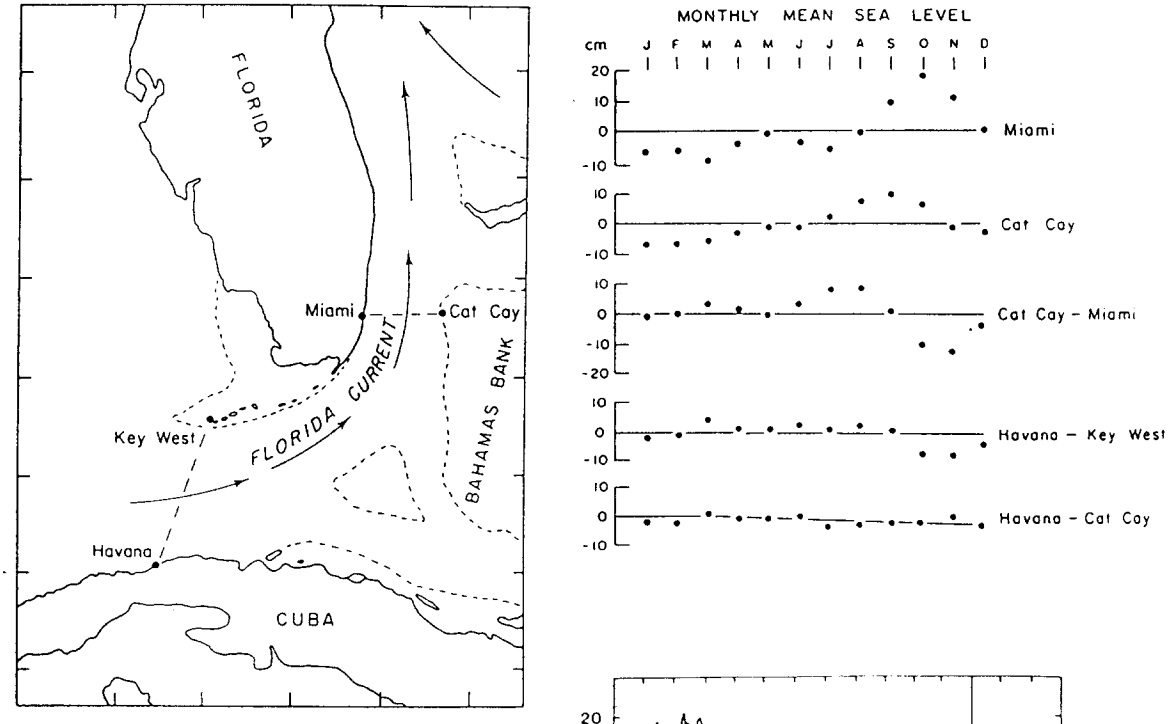


Fig. 3: Examples of seasonal variations in monthly-averaged sea levels determined from tide-gauge measurements. [*from* Komar (1987)]

Fig. 4: Annual cycles of sea levels on opposite sides of the Florida Current, the differences reflecting fluctuations in the strength of the current. [*after* Stommel (1953)]



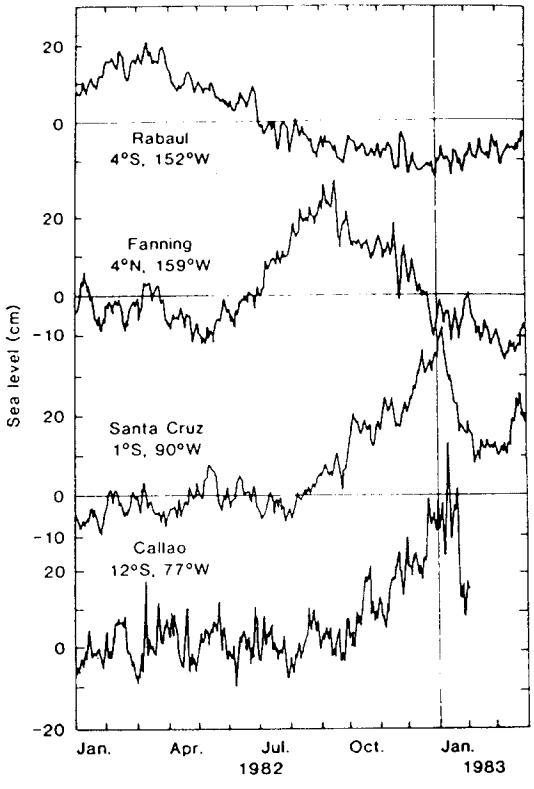


Fig. 5: The equatorially trapped sea-level "wave" associated with the 1982-83 El Niño, shown in the analyses of tide-gauge records on islands from west to east along the equator, and from Callao on the coast of Peru. [*after* Wyrtki (1984)]

Fig. 6: Analyses of predicted and measured tides based on the yearly maximum elevations recorded on the tide gauge in Yaquina Bay on the central Oregon coast, with projections of potential extreme elevations. [*from* Shih et al. (1994)]

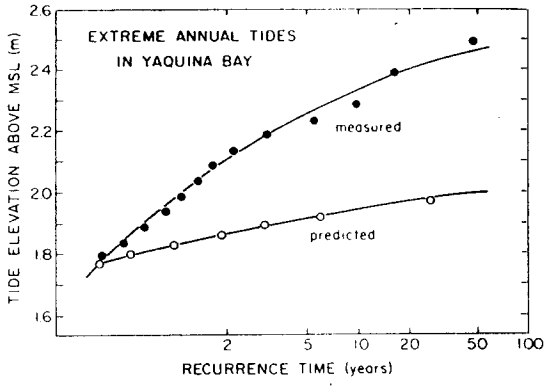


Fig. 7: Measurements of wave run-up elevations on three beaches along the Oregon coast, where all elevations are referenced to mean sea level. [*from* Shih et al. (1994)]

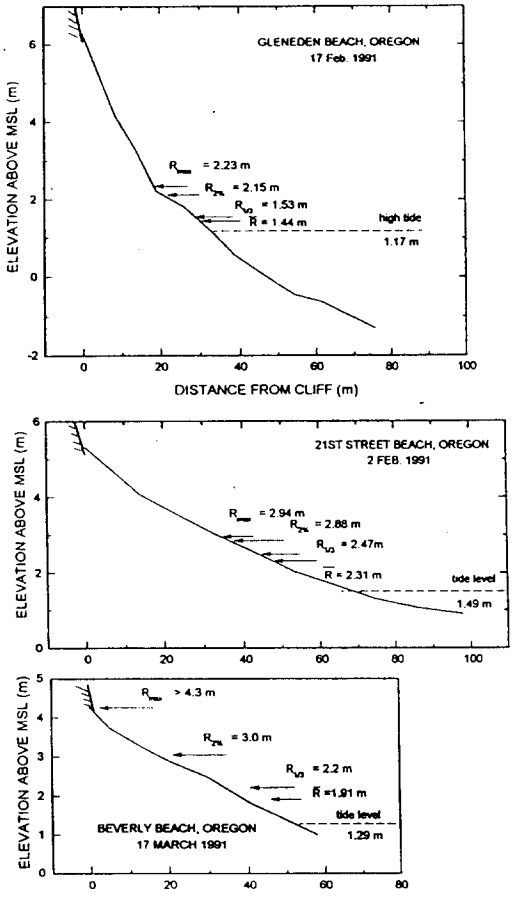


Fig. 8: SBEACH comparison with measured beach-profile variations at the Field Research Facility, Duck, North Carolina. [*from* Larson et al. (1988)]

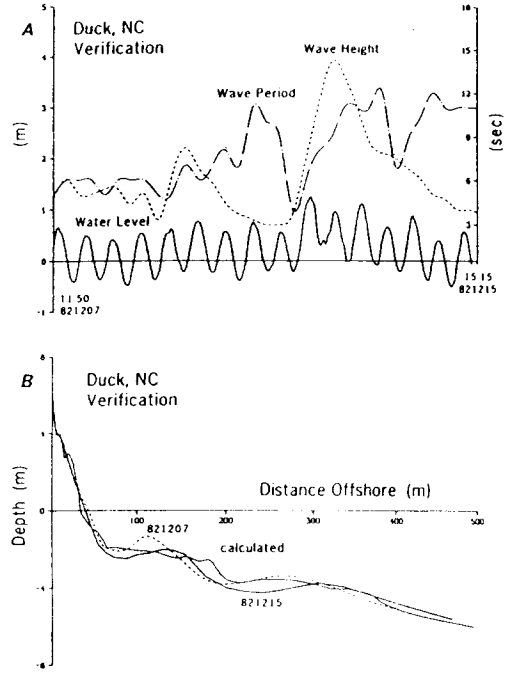
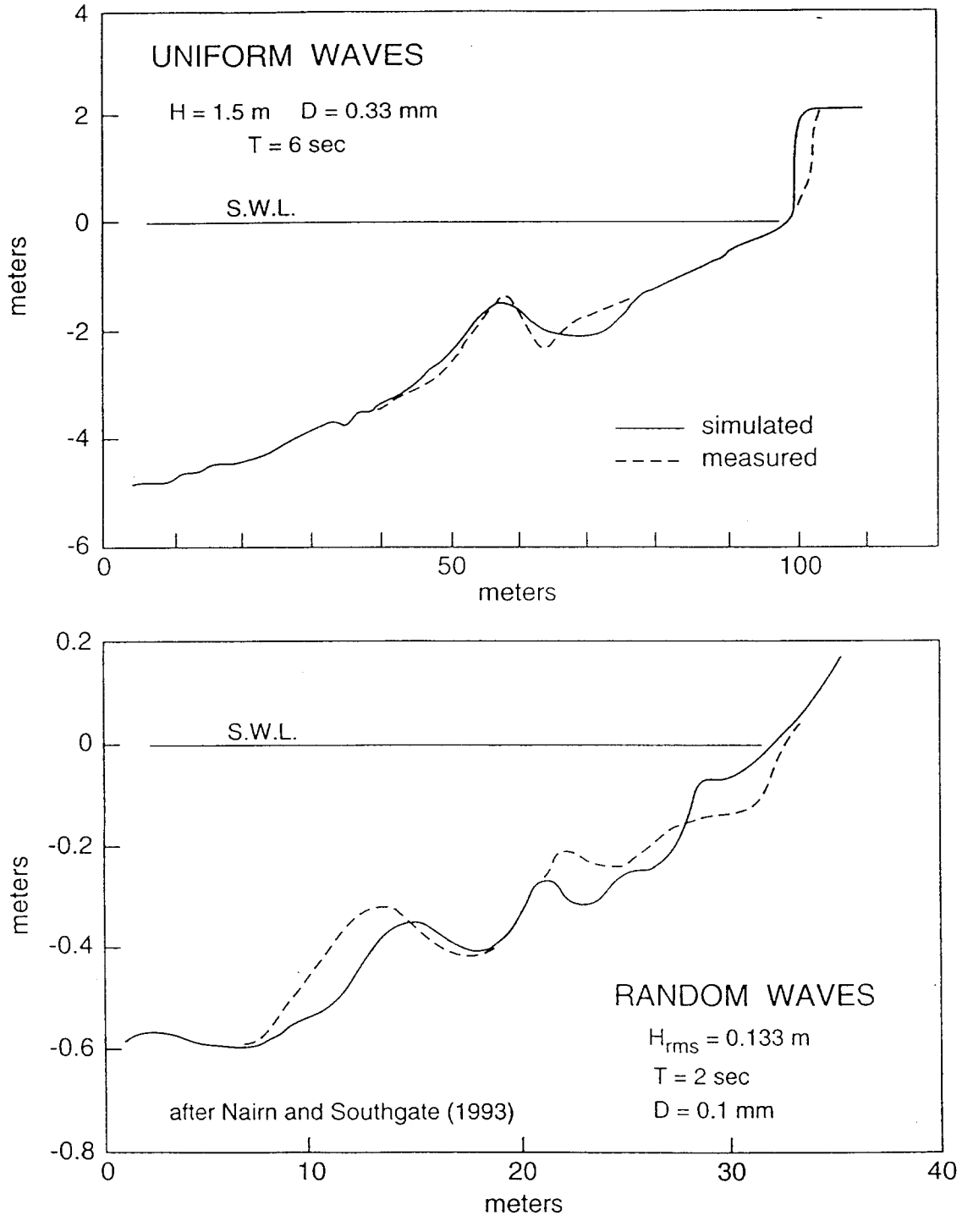


Fig. 9: Model of Nairn and Southgate (1993) compared with measured profile changes in a large wave tank.



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THE INVESTIGATION OF THE SAND RIPPLES FORMED BY THE WAVES

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This work considers the most widespread relief microforms in the coastal zone - the vortex ripples which were formed by the non-breaking waves on the sandy bed. Let us distinguish the active (formed by acting waves see Fig. 1) and passive (remaining as a trace of an earlier regime) relief microforms. The subject of the work is to determine the range of existence and to evaluate the possibility of the prediction of height and length of active and passive ripples, using either laboratory or field data.

There were many attempts to determine the range of ripple existence. The methods for determining the boundaries of the existence of ripples can be divided into some groups. The less accounted are the methods which determine the conditions of the bedform's appearance and the destruction in terms of the relationship between the grain dimension (d) and the bottom orbital velocity (u) or the orbital radius of the particle motion near the bottom (a).

It is obvious that in case of real wave action, this relationship can be used only for rough evaluations. The method which determines the range of the area, in terms of 2a/d, or in terms of mobility number, is given by:

$$\varphi = u^2 \frac{\rho}{gd(\rho_s - \rho)} \quad (1)$$

where ρ and ρ_s are the densities of the fluid and particles accordingly and g the gravity acceleration). But as shown at Fig. 2, where the data of many researchers are represented, these limitations are not reliable.

The relationship between the ratio 2a/d and the mobility number, or between 2a/d and the Shields parameter is more reliable. But even these relations, which determine one or two boundaries, do not determine the area of the relief microform's existence.

The equations, setting the limits for the area of ripple's existence, were derived from laboratory and field data for the condition of formation (see Fig. 2) by:

$$\varphi = e^{\left(1.10+2.25\cdot10^{-4}\frac{2a}{d}\right)} \quad (2)$$

and when ripples do not exist:

$$\varphi = e^{\left(5.48-1.21\left(\frac{2a}{d}\right)^{-0.8}\right)} \quad (3)$$

In special cases, these equations give the same results as the restrictions given by Brebner (1980), Dingler (1974), Vongvisessomjai (1984), Kos'yan (1987), Kos'yan and Pykhov (1991). The equations which determine the parameters of the active ripples include the same terms.

The equations given by Nielsen (1992), which were derived from a large number of data, are considered to be the most reliable. But these relationships are different for laboratory and field conditions. This fact may be due to the partial correspondence between the ripple parameters to those of the acting regime in the coastal zone. It

can be explained by the difficulties of "penetration" during storms.

But, using the data of Kos'yan, who had the opportunity to "enter" the zone of the active wave-bed interaction from the sea side and used a special test of the correspondence of the bedforms to the regime, we can offer some relationships which are similar to Nielsen's "laboratory" equations (see Fig. 3).

$$\frac{\eta}{a} = 0.36 \cdot e^{(-2.2 \cdot 10^{-2} \varphi)} \quad (4)$$

$$\frac{\lambda}{a} = 2 \cdot e^{(-7 \cdot 10^{-3} \ln^{3.8} \varphi)} \quad (5)$$

where η is the height and λ is the length of the ripples.

Application of the derived equations is possible in the range of $3 < \Psi < 240$, which corresponds to the restrictions of Brebner and Dingler.

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Fig. 1. The vortex ripples formed by waves

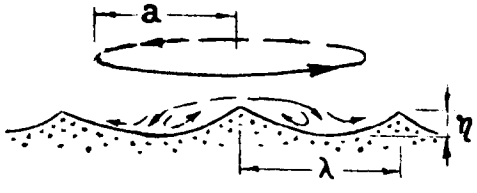


Fig. 2. The comparison of observation data with the relationships, limiting the range of the ripple existence.
1. Data from laboratory experiments by Antsyferov et al., Komar, Manohar, Miller and Komar, Keremetchiev, Nielsen.
2. Data of in situ observations by Kos'yan, Miller and Komar, Inman, Nielsen, Tanner. (Data taken from the monography by Kos'yan and Pykhov, 1991).

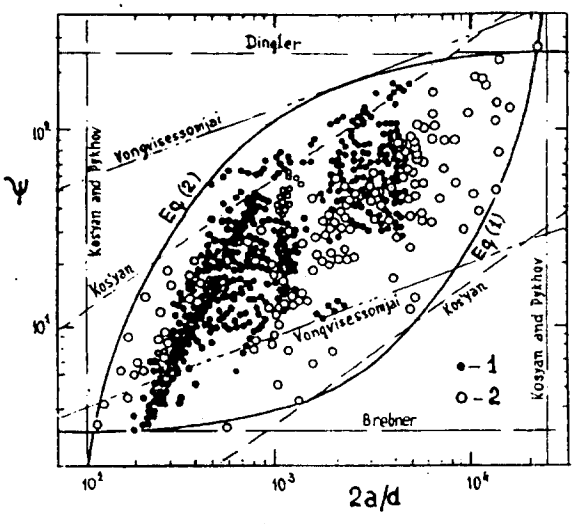
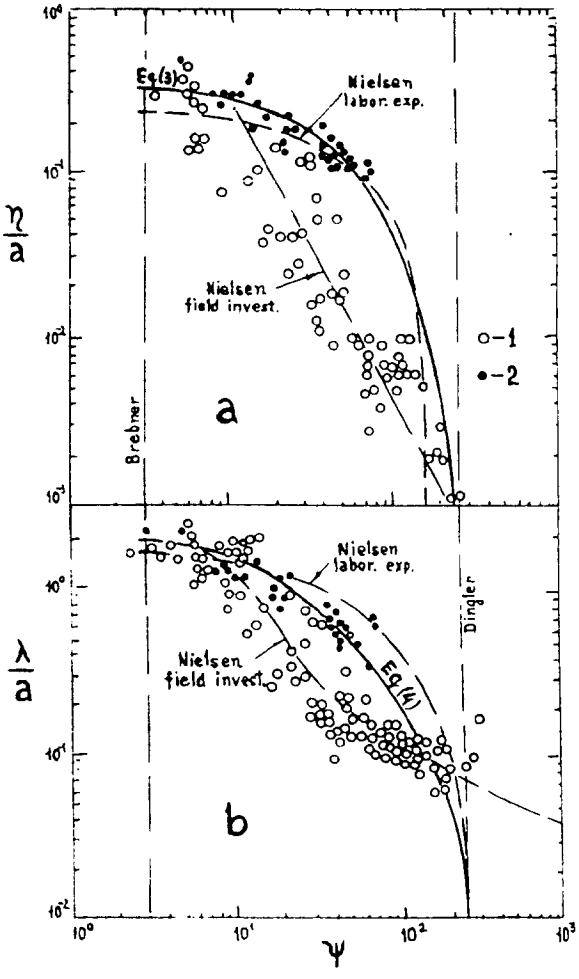


Fig. 3. Comparison of the data of the nature observations with the relationships for calculation of height (a) and length (b) of vortex ripples.
1. Data, determined by Inman, Dingler, Miller and Komar (from the monography by Nielsen, 1992).
2. Data, determined by Kos'yan (from the monography by Kos'yan and Pykhov, 1991).



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PREDICTIVE APPLICATION OF THE CONVOLUTION METHOD FOR TIME-DEPENDENT BEACH PROFILE RESPONSE IN ONE MEXICAN BAY.

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KEYWORDS: Beach erosion, storm-surge, convolution method.

ABSTRACT

Accurate estimates of beach erosion are required for a great variety of predictive, reconstructive, regulatory or managerial purposes. Different methodologies to predict beach and dune erosion have been proposed. In this study, the convolution method for time-dependent beach-profile response is applied in order to construct predictive maps for the maximum profile retreat that the beaches can attain under different storm-surges conditions. The main purpose of this work is to propose a user-friendly tool for the prevention of damage caused by the erosion or profile retreat associated with storm-surges.

INTRODUCTION

The zone where land and sea meet is composed of a variety of complex environments (e.g. river deltas, estuaries, coastal lagoons, dune fields, tidal inlets, cliff areas, rocky coast, sand beaches).

The coastal zone and all the coastal environments are collectively characterized by their dynamic character and by the strong interactions between physical, chemical, geological and biological variables.

If the beaches are considered as a natural resource, it is very important to consider their inherent variability.

The changes to which beaches are subjected may be very long in time (e.g. global sea level rise), in the order of decades (e.g. shoreline retreat); seasonal, episodic or they may be as short as a single tidal cycle or even occur from wave to wave.

The economical, ecological and social impact of this change need to be properly evaluated in order to manage, protect and regulate coastal development activities.

In recent years the phenomenon of beach erosion has become important as the coastline has become a focus of human activity.

Accurate estimations of beach and dune erosion are required for a great variety of protective or reconstructive tasks, regulatory or managerial purposes and in general for the right planning and development of the coastal zone.

The need for methodology to predict beach and coast erosion due to the impact of storms and hurricanes (i.e. extreme climatological events) has been an issue of ongoing and increasing concern, one which for the majority of the history of the discipline of coastal science and engineering has eluded satisfactory quantifying solutions. (Balsillie, 1986)

At present, our understanding of the fundamental processes that take place on beaches during storms is limited (Holman and Sallenger, 1986).

In addition to this lack of knowledge, the slow rise in sea level associated with global climatic change and related effects as the increasing incidence of storms and hurricanes caused, in part, by the warming of the ocean´s surface (Russell, 1993) make the predictive methods for storm-induced beach erosion of primary importance.

First attempts at predicting beach and dune erosion were made two decades ago by Edelman (1968, 1972). Various predictive methodologies based on different approaches (e.g. schematic methods, field and experimental empirical

relationships, numerical models and analytical or engineering methods) have since been proposed. Of the schematic erosion prediction methods, which include the work of Bruun (1962), Edelman (1968,1972), Swart (1974) and Dean (1976), none is well verified or completely adequate for practical application in estimating storm-related erosion. (Kriebel and Dean, 1985)

Experimental studies (e.g. Vellinga, 1982,1983; van de Graaff, 1983) have considerably advanced the ability to reproduce dune erosion in the laboratory and agree reasonably well with some field situations under restrictive conditions.

Most of the numerical models used to simulate the beach profile evolution solves the continuity equation for the sediment mass (e.g. Dally and Dean, 1984; Kriebel and Dean, 1985; Wen-Juinn and Ching-Ton, 1991; Nairn and Southgate; 1993). This equation related the bottom (or depth) rate of change with the spatial variations in the rate of sediment transport. But until now no one universally accepted cross-shore sediment transport formula exists.

The analytical or engineering methods for predicting beach profile changes are based on equilibrium profile concepts (e.g. Kriebel and Dean, 1985; Kobayashi, 1987; Kriebel et al., 1991; Kriebel and Dean, 1993).

Different and realistic equilibrium profile forms can be proposed and used to obtain analytical solutions for the maximum erosion potential in response to steady or time-dependent water level rise.

The parameters involved in this kind of model can be easily measured in the field, their physical bases are supported by experimental and natural evidence and these methods do not involve any sediment transport formula explicitly.

The analytical methods agree reasonably well with field events (Kriebel and Dean, 1993), have enough accuracy for engineering purposes and can be very easily interpreted and used for managerial plans.

This work presents an application of the Convolution Method for time-dependent beach profile response proposed by Kriebel and Dean (1993).

The method was applied to four measured profiles in one bay of the Pacific coast of México. The contribution to the subject presented in this work was the predictive maps for the maximum response of the profiles. These maps were generated using the convolution method for the range of possible storm conditions and graphically presented in one contour map. These maps can be used in order to plan and protect the coastal zone.

THE CONVOLUTION METHOD

The basis for the convolution method is the observation that beach response to steady-state forcing conditions is approximately exponential in time.

For laboratory conditions (e.g. Swart, 1974; Dette and Ulickza, 1983; Sunamura and Maruyama, 1987; Larson and Krauss, 1989), where an initially plane beach is subjected to a fixed water level and steady wave action or in the case of an equilibrium beach profile subjected to a sudden increase in water level with constant breaking-wave conditions, as noted by Kriebel and Dean (1985) and Larson and Krauss (1989), the response of any depth contour as a function of time R(t), may be approximated by the form (Kriebel and Dean, 1993)

$$R(t) = R_{oo}(1-\exp(-t/T_s)) \qquad (1)$$

where Roo = the maximum response on the contour (advance or retreat) that occurs after the system reaches equilibrium; and Ts = the characteristic time scale of the response.

As a result of (1), the differential equation governing the exponential beach response to steady-state forcing conditions must be of the form

$$\frac{dR(t)}{dt} = \frac{1}{T_s}\left[R_{oo} - R(t)\right] \qquad (2)$$

Following Kriebel and Dean (1993), a more general form of (2) may be obtained using the observation that the equilibrium response Roo varied almost linearly with changes in water level while the water level did not affect the rate or time scale of profile response, and assuming a time-varying erosion-forcing function.
Thus, a linear differential equation governing the profile response to variations in water level is assumed to have the form

$$\frac{dR(t)}{dt} = \frac{1}{T_s}\left[R_{oo} f(t) - R(t)\right] \qquad (3)$$

where f(t) is the forcing function.
The solution to (3) may be given by the convolution of the time-dependent forcing and the characteristic solution for steady forcing, in this case an exponential function. As a result, the time-dependent solution for the profile response may be expressed in the form of a convolution integral as (Kriebel and Dean, 1993)

$$R(t) = \frac{R_{oo}}{T_s}\int_0^t f(\tau)\, e^{-(t-\tau)/T_s}\, d\tau \qquad (4)$$

Equation (4) suggests two very important and general characteristics of a beach profile response: The lag between the beach profile response and the erosion forcing function, and the difference (damping) between the maximum response of the profile and the potential erosion of the system.
In order to obtain closed form solution to (4), in this paper we use the same forcing function proposed by Kriebel and Dean (1993) in view of his fairly realistic storm-surge form

$$f(t) = \sin^2(\sigma t) \quad for\ 0 < t < T_d \qquad (5)$$

$$where\ \sigma = \frac{\pi}{T_d}\ and$$
$$T_d = total\ storm\text{-}surge\ duration$$

Substituting (5) in the convolution integral (4), gives the time-dependent erosion response

$$R(t) = \frac{R_{oo}}{T_s}\int_0^t \sin^2\sigma(\tau)\, e^{-(t-\tau)/T_s}\, d\tau$$

(6)

The solution of (6) in dimensionless form is then a function of just one parameter, ß, as

$$\frac{2R(t)}{R_{oo}} = 1 - \left(\frac{1}{1+\beta^2}\right)x$$
$$\left(\beta^2 \exp\left(\frac{-2\sigma t}{\beta}\right) + \cos(2\sigma t) - \beta \sin(2\sigma t)\right)$$

(7)

where ß = the ratio of the erosion time scale to the storm duration, as

$$\beta = 2\pi \frac{T_s}{T_d} \qquad (8)$$

The time of maximum erosion can be found iteratively using

$$\exp\left(-\frac{2\sigma t_m}{\beta}\right) = \cos(2\sigma t_m) - \frac{1}{\beta}\sin(2\sigma t_m)$$

(9)

The phase lag of the maximum response is then given by

$$Lag = \sigma t_m - \frac{\pi}{2} \qquad (10)$$

and the magnitude of the peak response, Rmax may be found by substituting (9) into (7) which gives

$$\frac{R_{max}}{R_{oo}} = \frac{1}{2}\left[1 - \cos(2\sigma t_m)\right] \qquad (11)$$

Fig. 1 shows examples of profile response to idealized sine-squared storm surge: (a) short-duration hurricane (ß = 10.6); and (b) long-duration Northeaster (ß = 0.76).

Fig. 2 shows graphically the definition of amplitude and phase lag of maximum erosion (a); and the relation between the amplitude of the erosion response functions and the beta parameter for sine-squared storm surge (b).

The maximum potential erosion of a beach profile, Roo, can be established geometrically for many beach-profile conditions based on some simplifying assumptions.

In this work, we used the four profile forms defined by Kriebel and Dean (1993):

1) Square Berm Profile
2) Sloping Beach Face Profile
3) Profile with dune (no back-shore)
4) Profile with dune with back-shore

Fig. 3 shows the schematic form for each profile form with the corresponding expression for Roo.

Finally, the method uses an empirical expression presented in Kriebel and Dean (1993) in order to describe the erosion time scale as,

$$T_s = C1 \frac{H_b^{1.5}}{\sqrt{g}\, A^3} \left(1 + \frac{h_b}{B+D} + \frac{m X_b}{h_b}\right)^{-1} \qquad (12)$$

where A = $2.25(w^2/g)^{1/3}$; w = fall velocity, g = gravity, Hb and hb = breaking height and depth respectively, m = beach face slope, Xb = surf-zone width, B = berm height, D = dune height and C1 = constant.

FIELD EFFORT AND WORK METHODOLOGY

During 1987 and 1988, monthly measures were taken in 25 beach profiles in two bays located in the Mexican Pacific Ocean (Gonzalez-Chavarin, 1989).

This study used only information from 4 beach profiles taken during 12 months in the central zone of the Santiago's Bay located in Colima, México. (see Fig. 4)

Two criteria were taken into account for the selection of these profiles:

a) Given the orientation of these profiles, they are exposed to energetic waves produced by tropical storms coming from the south.

b) Using the data from the coast line position during the survey period, we obtained the spatial-temporal correlation matrix for the profiles and using the cluster analysis, it was shown that three of the selected profiles could be a group with a high degree of correlation.

Once the profiles were selected, the months considered were those in which their geometry matched with the ideal profiles given by Kriebel y Dean (1993).

Using the geomorphologic characteristics of the profiles and the relations of Takeda and Sunamura, 1982, we estimated the average hydrodynamic conditions that could have given form to these profiles. The Takeda and Sunamura relations are

$$B = 0.125 \bar{H}_b^{5/8} (g \bar{T}^2)^{3/8} \qquad (13a)$$

$$m = 0.12 (\bar{H}_b / g^{1/2} \bar{T} D_{50}^{1/2})^{-1/2} \qquad (13b)$$

where T = wave period, D50 = medium sand size and the other variables were defined in the previous section.

Table I shows the geomorphologic characteristics and the months used for the selected profiles.

With the help of this information, the Convolution Method was applied to each selected profile (P4, P5, P6, P7) based in the wave height and period estimated with (13 a,b) and the assumption of over-elevation of the sea level from 1 to 3 meters and storm durations from 10 to 60 hours. These values (S and Td) are typical of this region. The erosive-forcing function selected was a square-sine of unitary amplitude.

Maps of the highest maximum retreat were calculated for each profile (P4, P5, P6, P7) and for the area integrated by the four profiles (P4-P7) as a uniform response zone.

From these profiles, which were selected according to the ideal forms proposed by Kriebel and Dean, 1993, it was observed that the most common form was the type 2 profile (beach-face slope). Once the predominant form of the profile was identified, the average berm and beach-face slope values were calculated.

Using this information, we constructed three theoretical profiles: the first one (PT1) with the average berm height; the second (PT2), with the average slope. In both cases, the average position of the coast line (for the whole bay and period of measurement) was preserved. The third one (PT3), was calculated based on the average berm height and beach-face slope, modifying the coast line width.

The three theoretical profiles gave the geomorphologic information in order to obtain the maps of maximum retreat for different conditions in S and TD and for different breaking depths (1, 2 and 3 meters) with the help of the convolution method.

RESULTS

The principal results obtained in this work were the predictive maps of the maximum retreat for the measured profiles and for the theoretical profiles proposed in the investigation.

For the measured profiles, the contour maps were generated plotting the highest maximum retreat calculated (by the convolution method) for each profile (without distinction of their form) during the months considered, using the wave conditions estimated by equation (13a,b).

The maps for the theoretical profiles were generated using the average information for the berm and beach face slope for the profiles with the predominant form (form 2) for three different breaking depths conditions (1,2 and 3 m).

For the theoretical and measured profiles, we present the maximum retreat information in terms of the storm-surge level (from 1 to 3 m) and the storm duration (10 to 60 h).

Table II summarizes the maximum and minimum values for the maximum profile retreat and the necessary extreme sea level (Sext) and minimum storm duration (Tdmin) required in order to obtain the Rmax values.

The general features of the contour maps are:

1) A general curvature of the Rmax isolines in the base of the graphics followed by a quasi-linear trend as the storm durations increase.

2) The range of the Rmax values is related directly with this curvature.

3) For the measured profile results, it is clear that the profile P7 is more susceptible to erosive events.

4) For the theoretical profiles the Rmax values show clearly the change in berm retreat as a function of the wave energy (increase in hb).

5) The comparison of the contour maps for the theoretical profiles show the importance of the beach face slope and the berm height in the attenuation of beach erosion.

Fig. 5 shows the contour maps for the measured profiles P5 and P7.

Fig. 6 and 7 show the contour maps for the theoretical profiles PT1 and PT2 during two different breaking depth conditions (hb = 1 m and hb = 3 m) respectively.

As a final comment, some caution is needed working with the profile form 4, in order to obtain acceptable results (restrictions in the backshore wide). The contour maps shown in this investigation can be generated also in terms of the volume eroded, using the assumption that the relative volume eroded is the same as the relative berm retreat, and calculating the maximum potential volume eroded from above the peak storm-surge level or mean sea level, using the equilibrium beach-profile theory.

DISCUSSION

The predictive contour maps presented in this work have been generated in a very pragmatic way.

They can be constructed only with the geomorphologic information of the beach (measurements of aerial beach profiles and sediment size) and with historic, measured or estimated hydrographic information.

If the lag between the peak storm-surge level and the maximum berm retreat has a magnitude in the order of hours, the contour maps can be very useful in order to take protective measures in the areas of maximum vulnerability.

As a managing or planning tool, the predictive maps can be a good instrument in the delimitation of risk areas.

For developed countries with or without a few oceanographic instruments and wave or hydrographic measurements, the contour maps can be used as a first approach for the protection and management of the most important coastal areas.

Finally, it is necessary to look at these maps with caution because the convolution method is a relatively new methodology for the prediction of beach erosion and it needs more field studies in order to verify and/or calibrate the method.

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TABLE I. SUMARY OF MEASURED PROFILE CHARACTERISTICS

PROFILE 4

	PROFILE FORM	B (m)	D (m)	W (m)	m	M.R.P. (m)
JAN87	4	2.413	0.275	5.000	0.0950	10.00
FEB	4	2.373	0.297	2.170	0.0553	10.00
MAR	4	3.923	0.280	5.000	0.0485	10.00
APR	2	3.843			0.1680	15.00
DIC	2	2.983			0.0553	9.60

PROFILE 5

	PROFILE FORM	B (m)	D (m)	W (m)	m	M.R.P. (m)
JAN87	2	4.442			0.0785	15.00
MAY	2	4.192			0.0595	15.00
JUN	2	4.152			0.1310	15.00
SEP	4	4.482	0.490	2.400	0.1990	7.40
OCT	2	4.622			0.1740	7.25
NOV	2	4.562			0.1320	7.50
DIC	2	4.662			0.1075	7.50
JAN88	2	4.582			0.0932	7.50

PROFILE 6

	PROFILE FORM	B (m)	D (m)	W (m)	m	M.R.P. (m)
JAN87	4	3.207	0.785	14.200	0.0779	10.00
FEB	4	3.227	0.770	11.400	0.0437	10.00
MAR	4	3.207	0.780	12.970	0.0564	10.00
APR	4	3.447	0.785	10.000	0.0600	10.00
MAY	4	3.707	0.600	10.000	0.0556	10.00
JUN	4	3.287	0.820	4.980	0.0784	10.00
AUG	2	4.627			0.0723	13.77
SEP	2	3.652			0.0673	15.00
OCT	4	2.657	2.000	20.000	0.0612	10.00
NOV	2	4.312			0.1560	10.55
DIC	2	3.572			0.1480	25.00
JAN88	2	3.967			0.0920	14.68

PROFILE 7

	PROFILE FORM	B (m)	D (m)	W (m)	m	M.R.P. (m)
JAN87	2	3.615			0.1650	12.45
MAR	2	3.250			0.0616	15.75
MAY	2	3.545			0.2020	11.10
NOV	2	4.300			0.2187	3.46

B=BERM HEIGHT, D=DUNE HEIGHT, W=BACKSHORE WIDTH
m=BEACH FACE SLOPE, MPR=MAXIMUM PERMISIBLE RETREAT UNDER FIELD CONDITIONS (FROM THE TOP OF THE BERM TO SANTIAGO BEACH LIMITS)

a) MEASURED PROFILES

PROFILE	MINIMUM VALUE Rmax	CONDI S_{ext}	TIONS Td_{min}	MAXIMUM VALUE Rmax	CONDI S_{ext}	TIONS Td_{min}
P4	2.0 m	1.20 m	10 h	6.5 m	3.0 m	19 h
P5	1.6 m	1.10 m	10 h	6.0 m	3.0 m	48 h
P6	2.0 m	1.03 m	10 h	9.0 m	3.0 m	45 h
P7	3.5 m	1.04 m	10 h	12.5 m	3.0 m	38 h
P4-P7	2.0 m	1.05 m	8 h	8.0 m	3.0 m	18 h

b) THEORETICAL PROFILES

hb=1.0 m

PROFILE	MINIMUM VALUE Rmax	CONDI S_{ext}	TIONS Td_{min}	MAXIMUM VALUE Rmax	CONDI S_{ext}	TIONS Td_{min}
PT1	0.6 m	1.1 m	10 h	2.0 m	2.9 m	10 h
PT2	0.4 m	1.0 m	10 h	1.6 m	3.0 m	20 h
PT3	0.1 m	1.2 m	10 h	1.3 m	3.0 m	10 h

hb=2.0 m

PROFILE	MINIMUM VALUE Rmax	CONDI S_{ext}	TIONS Td_{min}	MAXIMUM VALUE Rmax	CONDI S_{ext}	TIONS Td_{min}
PT1	2.0 m	1.0 m	10 h	7.2 m	3.0 m	18 h
PT2	2.0 m	1.3 m	10 h	7.0 m	3.0 m	30 h
PT3	1.6 m	1.1 m	10 h	6.0 m	3.0 m	50 h

hb=3.0 m

PROFILE	MINIMUM VALUE Rmax	CONDI S_{ext}	TIONS Td_{min}	MAXIMUM VALUE Rmax	CONDI S_{ext}	TIONS Td_{min}
PT1	3.5 m	1.1 m	10 h	13.0 m	3.0 m	28 h
PT2	2.5 m	1.0 m	10 h	13.0 m	3.0 m	43 h
PT3	3.0 m	1.2 m	10 h	11.0 m	3.0 m	28 h

TABLE II. GENERAL INFORMATION OBTAINED FORM THE CONTOURN MAPS

Fig. 1. Examples of profile response to idealized sine-squared storm surges: short-duration (TD=8h) and long-duration north-easter hurricane (TD=66h). From Kriebel & Dean (1993).

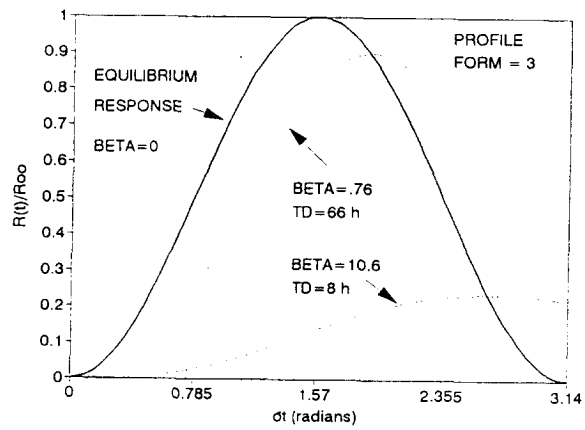
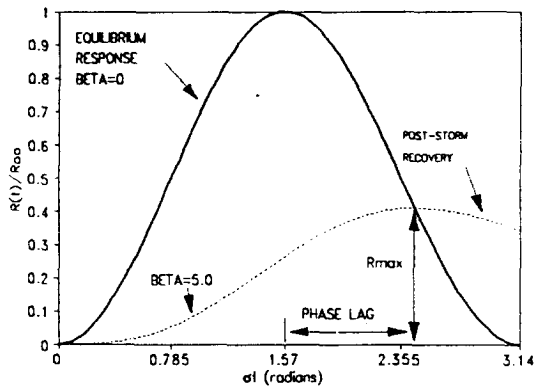


Fig. 2. (a) Definition of amplitude and phase lag of maximum erosion and (b) Erosion for sine-squared storm surge: amplitude and phase lag. From Kriebel & Dean (1993).

(a)



(b)

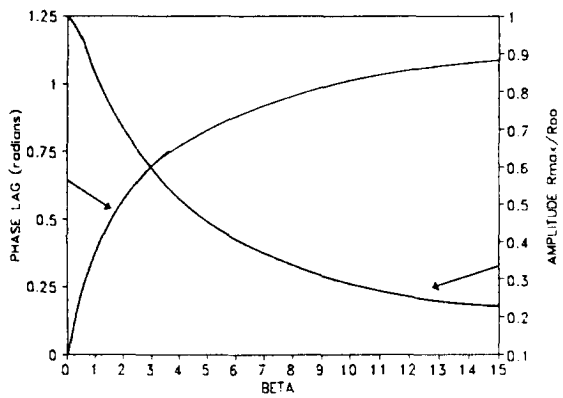
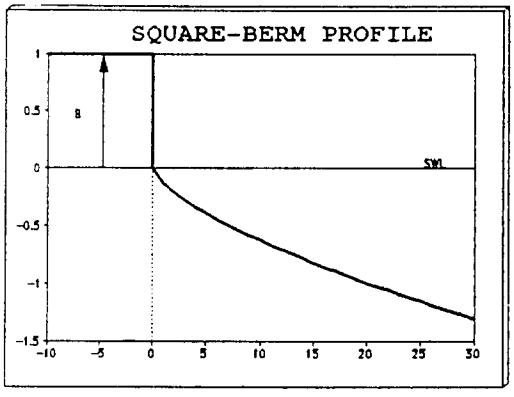
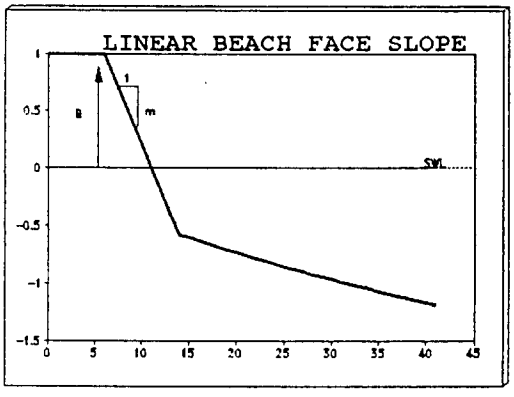


Fig. 3. Definition sketch for the idealized equilibrium profile forms and their respective formulas for the maximum erosion potential. Adapted from Kriebel & Dean (1993).



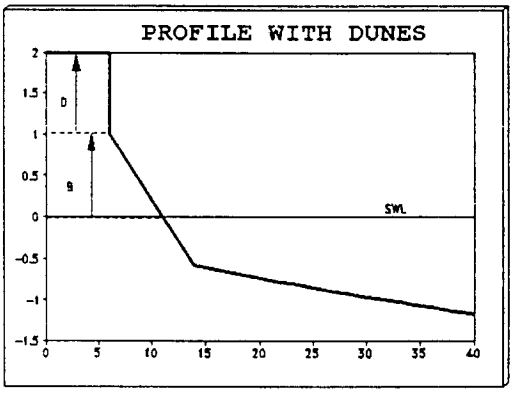
(1)

$$R_{oo} = \frac{S X_b}{B + h_b - \frac{S}{2}}$$



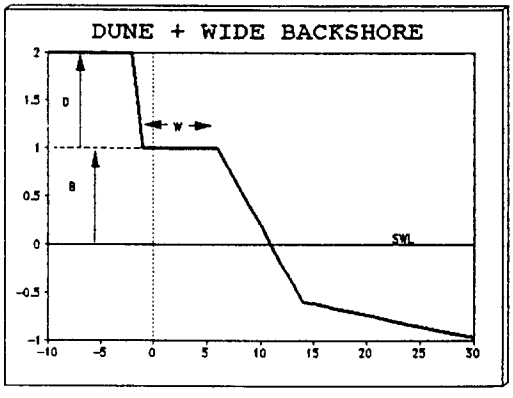
(2)

$$R_{oo} = \frac{S\left(X_b - \frac{h_b}{m}\right)}{B + h_b - \frac{S}{2}}$$



(3)

$$R_{oo} = \frac{S\left(X_b - \frac{h_b}{m}\right)}{B + D + h_b - \frac{S}{2}}$$



(4)

$$R_{oo} = \frac{S\left(X_b - \frac{h_b}{m}\right) - W\left(B + h_b - \frac{S}{2}\right)}{B + D + h_b - \frac{S}{2}}$$

Fig. 4 Study area. Santiago bay, Mexico.

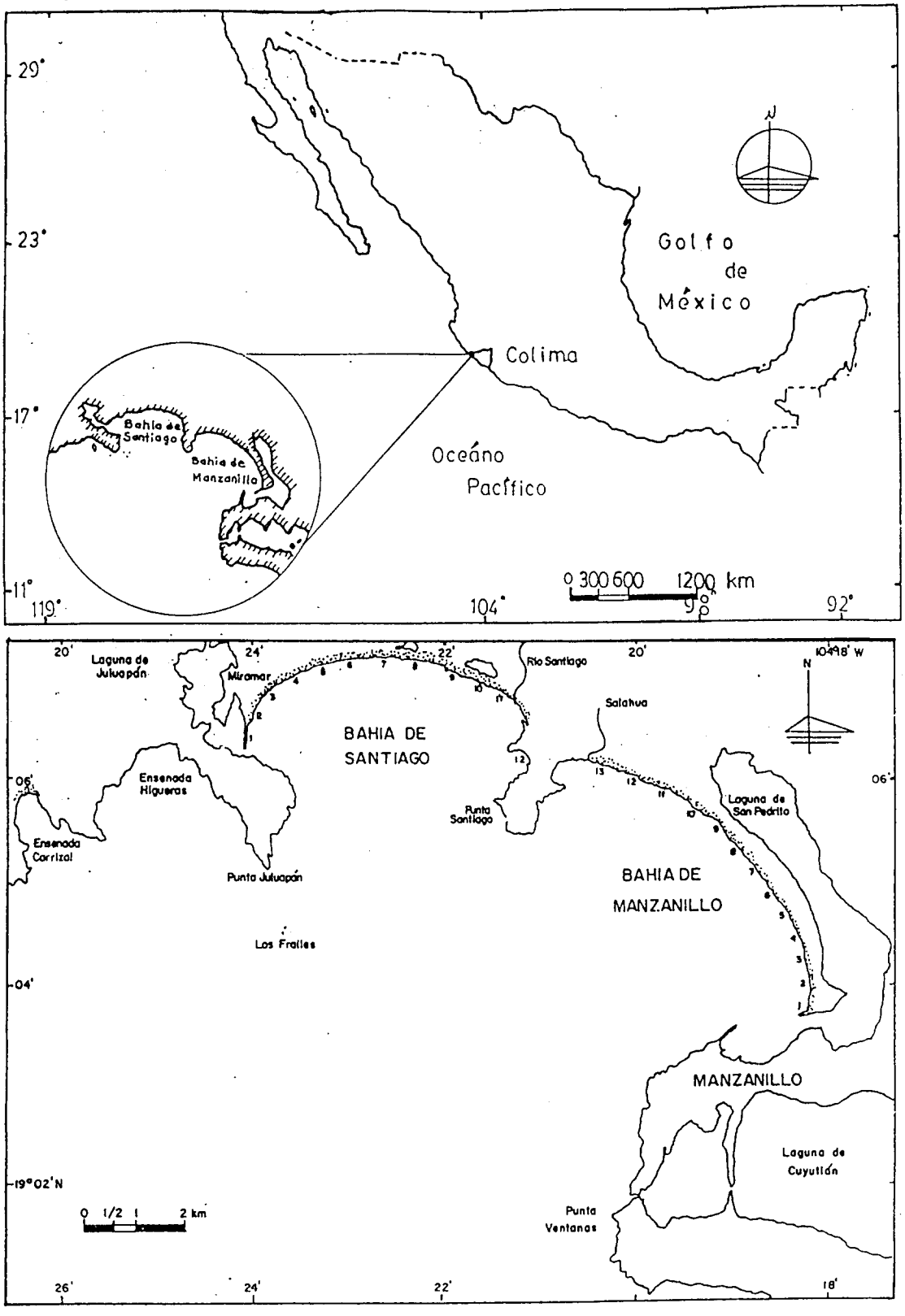


Fig. 5. Countour maps for maximum bern retreat (Rmax) as a fuction the peak storm-surge level (S) and strom duration (TD) for: (a) Measure profile P5 and (b) Measured profile P7.

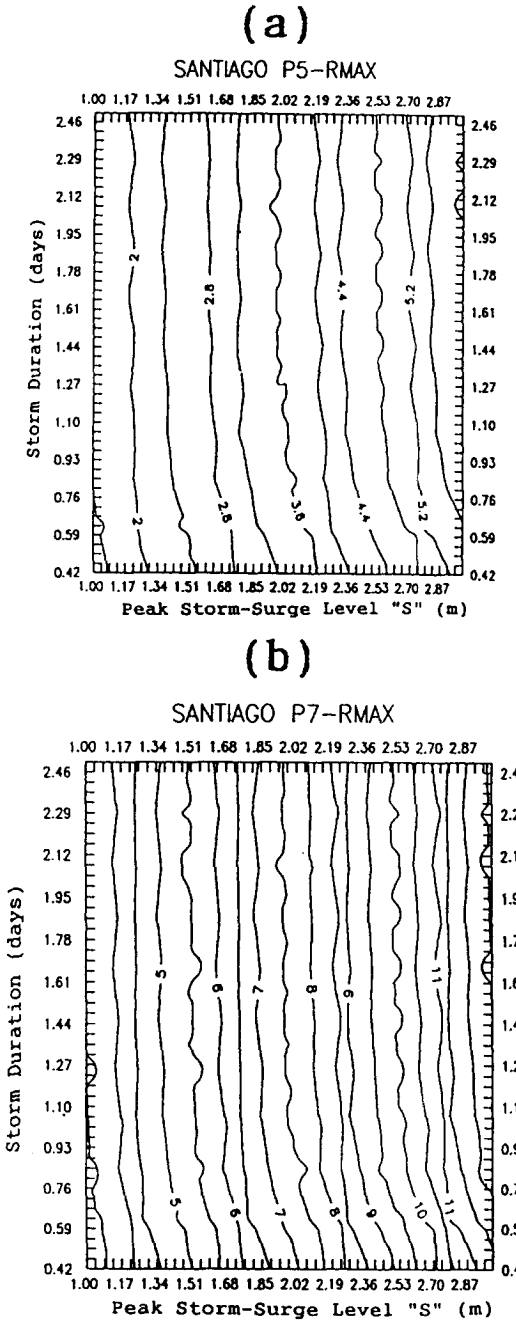


Fig. 6. Countour maps for Rmax(S,TD) for the theoretical profile PT1. (a) hb = 1.0 m and (b) hb = 3.0 m.

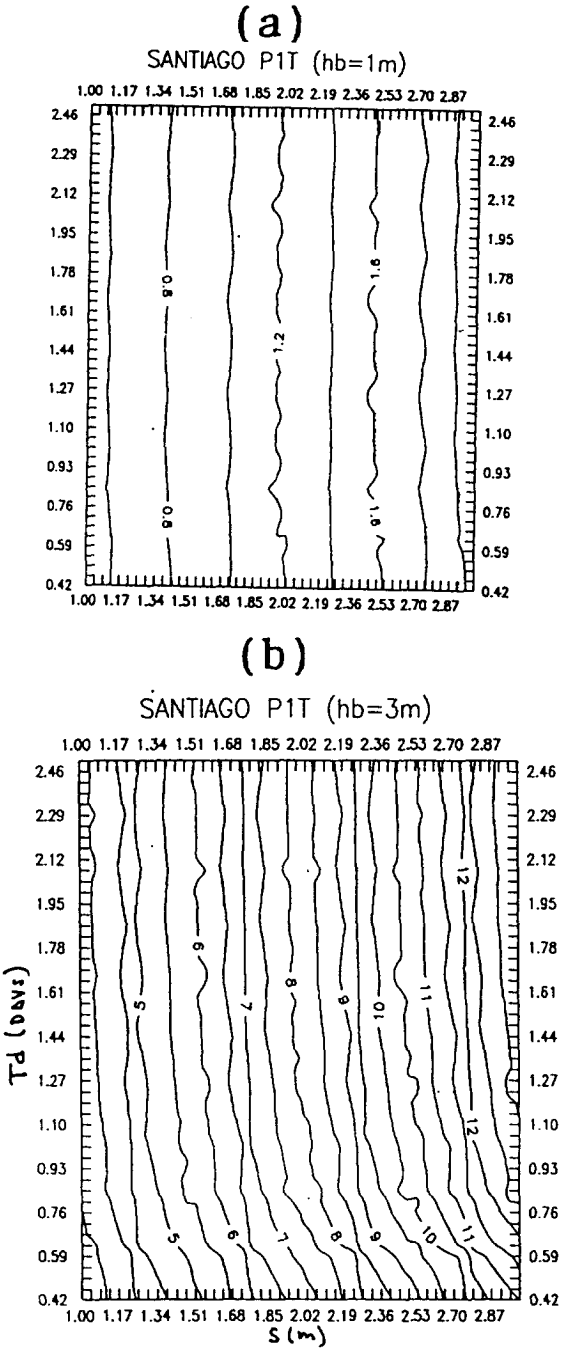
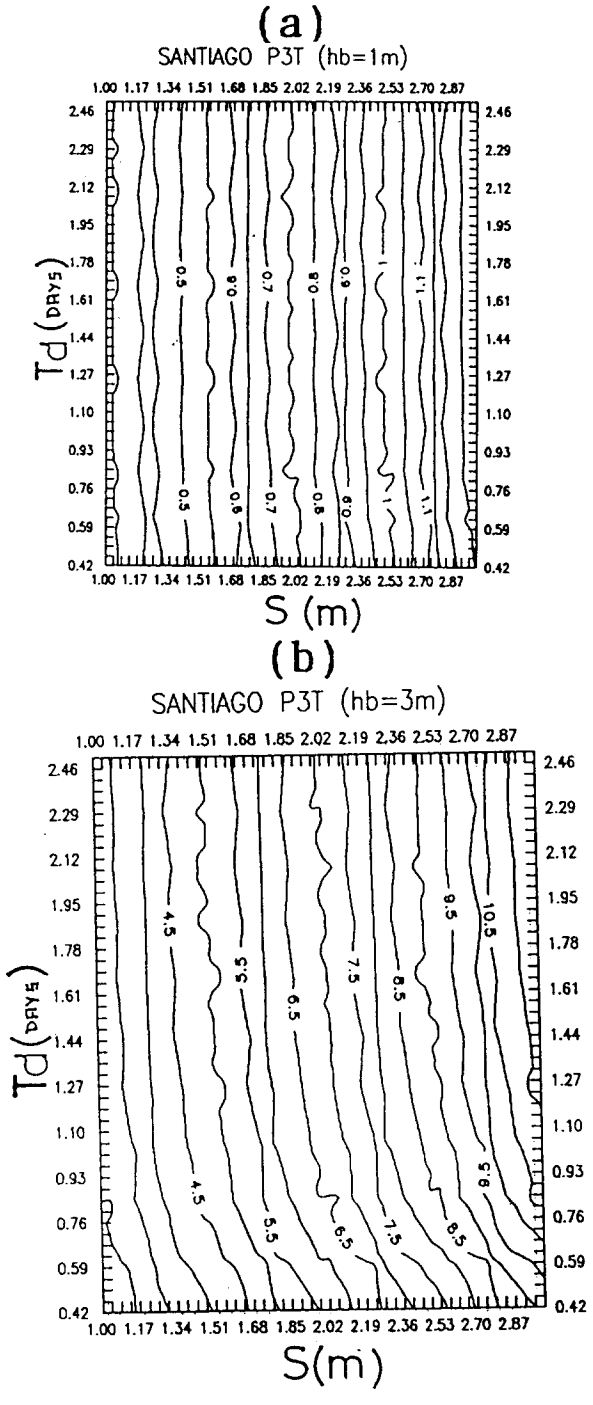


Fig. 7. Countour maps for Rmax(S,TD) for the theoretical profile PT3. (a) hb = 1.0 m and (b) hb = 3.0 m



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SEDIMENTOLOGY APPLIED TO COASTAL MANAGEMENT OF THE STATE OF SÃO PAULO, BRAZIL

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KEYWORDS: Net shore-drift, drift-cells, longshore currents, nearshore circulation pattern, geomorphic and sedimentological indicators, remote sensing, coastal management.

ABSTRACT

The Caraguatatuba area was studied with the objective to determine the local nearshore circulation pattern. Net shore-drift directions and marine circulation were determined by geomorphic and sedimentological characteristics of beaches, sedimentological data and bathymetric configuration of the Caraguatatuba Bight, and remote sensing analyses (satellite images and aerial photographs taken during different years and seasons). We concluded that the wave systems approach the coast from the SE, produce a northward longshore current at the Massaguaçu beach, southward longshore currents along Martim de Sá and Caraguatatuba beaches, and a southward longitudinal current at the west side of the Caraguatatuba Bight. Besides, there is a closed interaction between marine circulation and sedimentation patterns in the inner bight and those in the São Sebastião Channel.

INTRODUCTION

Coastal management is of serious concern for the Brazilian Government. In the State of São Paulo, for example, sands of several beaches are irregularly mined by municipal authorities; seawalls and submarine or sub-aerial sewage disposal systems are built without previous oceanographic investigations. The impacts caused by disposal of non-biodegradable garbage, pollution of groundwater and coastal waters, and petroleum accidents in nearshore zone are serious and are very difficult to control. These problems have caused irreparable damage to the ecosystems and pose environmental threats to people living in coastal zone.

The shoreline of the State of São Paulo has a length of 500 km (Fig. 1). The northern coast has submerged characteristics while the southern coast has emerged. Both sectors have important urban centers and tourist activities. In 1990 we concluded a pilot study of an area of the northern coast, including the bight of Caraguatatuba and local beaches (Souza,1990). At present, we are undertaking a geomorphic-sedimentological study of all the beaches of the São Paulo coast, which includes the Caraguatatuba area. The main objective of both investigations has been to identify circulation cells on the shore and sea-level change evidence, and to provide data relevant to coastal management. With the method used it is possible to determine the impact of coastal sediment-transport regimes on shorelines. An additional objective of this study was to develop a method for determining the nearshore circulation pattern in a pilot-area, which surely could be used to all coasts of the State of São Paulo.

THE PILOT-AREA: THE CARAGUATATUBA COAST

The Caraguatatuba Bight is located in the northern coast of the State of São Paulo (Fig. 1). It faces south-eastward to the open sea. At the continental shelf of São Paulo wave systems come from five different directions (Souza, 1991): SE, S, SW, E and NE. Waves approaching the coast from the SE direction are prevailing and predominant (according to the sense of Jacobsen & Schwartz, 1981; Souza, 1994). During the winter

S/SW systems are predominant, but not very effective in the inner bight, because of its physiography. Systems from NE/E are associated with weak and intermittent winds. In the inner part of the Caraguatatuba Bight wave-trains approach the coast obliquely and their energy is weakened by refraction and diffraction processes. São Sebastião Island is the major island of the São Paulo coast. It is a natural barrier to the direct attack from the SE waves in the south-western sector of the bight. Between this island and the continent there is a large channel (São Sebastião Channel), the origin of which is tectonic and related to continental drift (Almeida, 1976). Along this channel are deposited two kinds of sediments: at the continental side occur muds, while at the island side sediments are coarse (Furtado, 1978). Along this side occurs a strong and continuous flow (main flow) northwards to the Caraguatatuba Bight, where it develops anti-clockwise rotation. At the continental side dominates a weaker southward secondary and intermittent flow (Furtado, 1978). Between both flows there is a long submerged sandy bar, which according to Souza (1990, 1991) can be a Holocene feature and results from a balanced interaction between both channel flows and nearshore circulation pattern in the inner bight, as it will be explained below.

The main beaches that were investigated are called Massaguaçu, Martim de Sá and Caraguatatuba. Massaguaçu and Martim de Sá beaches are oriented in the NE-SW direction, while the Caraguatatuba Beach has a NNE-SSW orientation. The last one can be assumed as a headland-bay beach (Taggart & Schwartz, 1988) or a log-spiral shaped one (Yasso, 1965).

The Massaguaçu beach has a very high wave energy in the southern sector, which decreases to moderate northward. At Martim de Sá beach wave energy is high to moderate in the north and decreases to moderate southward. The Caraguatatuba Beach has a low to moderate wave energy in the north and very low energy in the southern segment. Because of this very low wave energy, in spite of a regional microtidal regime (tidal range <2 m), weakened tidal current action predominates in this area, where a sandy tidal flat has been developed (Souza & Furtado, 1987).

The Massaguaçu river mouth, in the southern of the Massaguaçu beach, has a particular characteristic feature. Because a spit-bar has been growing, in spite of the season, this mouth remains almost permanently closed, which encloses a brackish lake called "Blue Lagoon". Modenesi et al. (1983) discussed the dynamics of this feature and they concluded that sand-ridge growth is due to a longshore current action and its erosion is caused by the rise of the river flow during the storms related to polar air mass approach. However, our conclusions for this subject are a little different, as we will see below.

In 1967, because of a catastrophic landslide that occurred in the northern part of Caraguatatuba, 2 million tons of terrigenous material buried the city and adjacent nearshore zone. Cruz (1974) documented the event and later she monitored sedimentary changes along coastline (Cruz et al., 1985). Some southward oriented spits grew up on the area and there was a quick sorting process. However, at the end of 1976 four moles (breakwaters) were built between the extremity, north of the Caraguatatuba coastline and Santo Antonio river mouth, to protect this area against coastal erosion. Today no spits and erosion processes have destroyed the seaward parts of the moles and have advanced to the garden beach.

The inner-shelf deepens slowly seawards to 20-22 m at the bight mouth (Fig. 2). At São Sebastião Channel the depth is from 1 to 6 m along the continental side, but it can reach 27 m at the island side.

METHODS

Net shore-drift is the direction in which the majority of the beach sediment is transported along the shore over a long period of time (years), in spite of short-term seasonal transport in opposite direction (Jacobsen & Schwartz, 1981; Taggart & Schwartz, 1988). In American terminology net shore-drift results from two components: beach drift and longshore drift. Each coastal segment with a particular net shore-drift direction forms a discreet unit called a drift-cell. An idealized drift-cell consists of three broad

zones in which there is no clear demarcation between them: zone of erosion, zone of transport, and zone of accumulation (Taggart & Schwartz, 1988). According to these authors the systematic use of geomorphic and sedimentological indicators to determine the direction of net shore-drift (long-term sediment transport) along a coastline is a low-cost, efficient, quick and accurate method with which to determine the impact of coastal sediment-transport regimes on shoreline management decisions.

Local beaches of the Caraguatatuba coast and the bottom surface sediments in the inner the Caraguatatuba Bight were studied for determining net-shore drift directions and nearshore circulation patterns. It was made possible by using geomorphological and sedimentological characteristics of beaches and bight sediments, and remote sensing analyses (satellite images and air photographs).

Shore-drift trend indicators, used in this research, were: sedimentological data (grain size and morphometrical parameters), beach slope and beach width, direction of approach of waves to the shore, headland-bay beaches, stream mouth diversions, spits growth, nearshore and longshore bars, and structures interrupting shore-drift. Sedimentological data, beach morphology and approach of wave-trains measurements consist of field techniques or direct method, while the other indicators are related to the remote sensing method of analyses or indirect methods (Souza, 1993a, 1994).

Beaches were investigated during summer and winter periods. Through profiles perpendicular to shoreline, samples were collected from backshore, foreshore and upper shoreface zones. Field measurements of beach morphological parameters and wave-orthogonal direction were also made at each profile transect. Field observations were made between 1984 and 1988, and more recently from 1992 to 1994.

On five different sets of aerial photographs taken during different years and seasons (winter of 1962, 1965 and 1977; autumn of 1966; and summer of 1973) and satellite images (winter of 1976 - Landsat-MSS, and 1987 - Landsat-5 TM) we could analyze and compare longshore transport trends through the indirect geomorphic indicators mentioned. On a digital satellite image (1987) we made a thematic classification of suspended sediments on the waters of the Caraguatatuba Bight (Souza & Bonetti Filho, 1994), and also it was possible to make interpretations about transport directions. Obviously, tidal phase and meteorological conditions before and at the day that these documents were taken were also investigated.

The Caraguatatuba Bight was studied through sedimentological data and bathymetric configuration analysis. Sedimentological characteristics investigated that were chosen to be presented here were: grain size parameters (mean diameter and standard deviation/sorting degree according to Folk & Ward, 1957); modal classes distribution; and morphometrical parameters of quartz grains (roundness degree and surface texture).

Although morphometrical parameters were analyzed in all sediment fractions, here we show only 0.5 mm fraction for the beach sediments and 0.125 mm fraction for the bight sediments. Beach morphometrical parameters were analyzed only for foreshore zone sediments.

RESULTS

The Caraguatatuba Shoreline

We made fifteen beach profiles along the Caraguatatuba coastline. Three of them are on the tidal flat (CI, CJ and CK). Locations and morphological characteristics of the beach profiles are shown in Fig. 3. Grain size parameters are in Fig. 4, while quartz grains morphometrical characteristics are shown in Fig. 5.

The Massaguaçu beach presents different characteristics along is length. Near the Massaguaçu river mouth, sediments consist of very coarse sands to granules with rocky fragments and these are very poorly sorted. When a spit-bar is present, the foreshore slope can reach to 30°, but it becomes 7° when the spit-bar is eroded. In general, in winter as well as in summer, beach widths increase northwards, while beach slopes decrease northwards. Sands are coarse at MC and medium at MA profile, therefore grain size also decreases northwards. Sorting degree is very poor in the south and

increases to moderate in the northern sector, because there is a decrease of modal class number in this direction. Comparing three beach zones of Massaguaçu, on average MA profile sediments are most homogeneous. A better sorting degree and the lowest modal class number were found at upper shoreface zone of MB profile. Quartz grains are predominantly rounded to sub-rounded, mammary to smooth and polished in the southern sector, while in the north they are only sub-angular, saccharoidal and polished. Therefore, textural maturity increases northward while morphometrical maturity decreases in the same direction. The Massaguaçu beach always presents well developed berms and beach cusps. Wave-trains approach the coast from SE directions.

At Martim de Sá beach sediments are, in general, homogeneous, but it was possible to observe some differences between northern and southern sectors. Southward there occurs a small decrease of grain size and increase of sorting degree. At MS profile sedimentological and morphological characteristics are similar to MB profile. Martim de Sá also presents a well developed beach berm and the wave-train also approaches the coast from the SE.

At the Caraguatatuba Beach morphological and sedimentological characteristics change along its length. From CA to CC profiles a decrease of beach width and an increase of beach slope (from 7° to 13°) was observed; sands are medium to fine moderately to well sorted. From near Lagoa stream mouth to the southern coastline, morphology and sediments change strongly: the beach becomes larger and slopes become very gentle; sands are fine to very fine, well to very well sorted. Then, textural maturity of sediments increases southward. Along the Caraguatatuba Beach quartz grains are predominantly sub-angular, saccharoidal and polished. However, there is a small decrease in morphometrical maturity southward to the Juqueriquerê river mouth.

Tidal flat sediments are homogeneous, with very fine sands very well sorted in tidal creeks, or fine sands moderately to well sorted on sand waves and in the upper tidal flat area. Silts and clays are rare in these sediments. The tidal flat is bordered by a beach on which the sedimentological and morphological characteristics are very different. In the southern sector sands are coarse to very coarse, very poorly sorted, and slope is steepness. Beaches like this are common behind sandy tidal flats (Reineck, 1967).

At the Caraguatatuba Beach, berms occur only in the northern sector, however, they are worse developed than at the Massaguaçu and Martim de Sá beaches.

The Caraguatatuba Bight

The Caraguatatuba Bight can be divided in four compartments (Fig. 6) which have different sedimentological and bathymetric characteristics (Figs. 2, 7, 8, 9 and 10). Sector I corresponds to the Massaguaçu and Martim de Sá nearshore; Sector II is Caraguatatuba nearshore; Sector III is the bight mouth area; and Sector IV is the São Sebastião Channel influence area. Fig. 6 shows also sample locations and the kinds of analyses made in each of them.

The bathymetric configuration (Fig. 2) is a reflection of predominant wave systems approaching the coast from SE. Irregularities in isobaths occur at São Sebastião Channel mouth and are sparsely distributed by bight-like small and elongated valleys and isolated depressions, which can represent relict features of a palaeotopography when sea level was lower than at present.

At the sector I depth changes from 2 to 15 m, but it is not very regular. Sediments are very fine sands, very well to moderately sorted; modal class predominant is very fine sand. Quartz grains are angular to rounded, saccharoidal and polished, yet frosted grains occurred in almost all samples. Sands are better sorted and less immature between southern of the Massaguaçu and Martim de Sá nearshore areas.

Sector II has a bathymetric distribution more regular and smooth than sector I. Depths changes from 1 to 7 m. Sediments are coarse silts, poor sorted, but modal class predominant is very fine sand. Quartz grains are angular to sub-angular, saccharoidal and polished.

At the sector III bathymetry distribution is very smooth from 15 to 23 m. Sediments are coarse

and medium silts, poorly to well sorted. In the northern and southern sectors predominant the modal class is silt, while in the central portion of the bight mouth very fine sands predominate. Clay fraction occurs only at the northern and southern ends of the bight mouth. Quartz grains are angular, saccharoidal and polished, therefore immature.

At the sector IV, the bathymetry is very irregular and deeper than other areas. There is a close relationship between this pattern and sedimentation behaviour. Boundaries between this sector and others are abrupt. Sediments are different from the rest of the bight sediments. Sands are coarse, moderately to poor sorted. In general, there is no predominant modal class because sorting is chaotic, from granule to very fine sand. Quartz grains are whichever angular, saccharoidal and polished, or sub-rounded, mammary and polished, but mixtures of different types of grains are common.

Therefore, comparing these four compartments, we observed that there is a better reworking of sediments and consequently better textural and morphometrical maturity at sector I than other areas.

Remote Sensing Analyses

We compared several features on aerial photographs and satellite images. They are: river mouth bars and spits growth direction; transport direction of suspended sediments transport; longshore bars and their kind; changes of width along each beach; beach cusps, spits and other bars and their growth direction; direction of wave-trains approach the coast; and wave-cut terraces. We observed also the changes in the tidal flat, in the northern segment of the Caraguatatuba Beach and in the Massaguaçu river mouth (Blue Lagoon) during three last decades.

A detailed explanation of these changes from 1962 to 1987 is given by Souza (1990 and 1993b). Results show that a predominant transport occurs northward at Massaguaçu and southward at Martim de Sá and the Caraguatatuba beaches and nearshore areas. It was interesting to observe records of the growth of spits in the extreme north of Caraguatatuba after the landslides that occurred in 1967, and their erosion over the last two decades. By the same manner we could notice changes in the tidal flat with growth of shallow sandwaves and coastal progradation, at least until 1977, followed by their later erosion. On the other hand, on satellite images from 1987, we could observe the growing up southward of a long spit connected to Ponta Massaguaçu. Suspended sediment transport at the Caraguatatuba Beach reaches São Sebastião Channel along the continental side. A northward transport in the Massaguaçu area can be seen on aerial photographs and especially satellite images.

DISCUSSIONS AND CONCLUSIONS

All the results obtained from the Caraguatatuba Bight and beach sedimentation and remote sensing analyses presented a very good correlation. These studies were important to evaluate a method to be used for determining of net shore-drift cells along all the São Paulo littoral.

Massaguaçu and Martim de Sá are reflective beaches. The Caraguatatuba Beach has a intermediate regime, from dissipative to reflective, between the northern sector to the Lagoa stream mouth and a dissipative regime along the remainder. Wave energy is weaker in the southern part of the Caraguatatuba shoreline where, in spite of the microtidal regime, tidal currents are predominantly present in this area which develops a sandy tidal flat. In addition, the Juqueriquerê river is the main source of finer sediments, which contributes to sedimentation on the tidal flat.

At the Massaguaçu and Martim de Sá beaches sediments are coarse to medium sands, moderately to well sorted; beach slopes are steep and beach widths are small. Textural maturity increases northward at Massaguaçu and southward at Martim de Sá, while morphometrical maturity decreases in the same directions. At Caraguatatuba Beach, sands are medium to very fine, moderately to very well sorted; beach slopes are moderate to very gentle and beach widths are greater. Textural maturity increases and morphometrical maturity decreases southward. Sediments are better reworked in the south of Massaguaçu and in the north of the Martim de

Sá beaches, but they are less reworked in the northern part of Caragutatuba Beach.

Therefore, there is longshore transport (longshore currents) northward along the Massaguaçu Beach and southward along the Martim de Sá and the Caraguatatuba beaches. However, in general, between the Santo Antonio river and the Lagoa stream mouths occurs a northward small drift-cell. Local reversals in the net shore-drift direction like this occur mainly along the Caraguatatuba Beach, between Santo Antonio river and Juqueriquerê river mouths. They are due to seasonal effects and changes in the approach angle of wave-trains on the coast caused, for example, by the approach of polar air masses. In up-drift zones wave energy is more effective and strong, and it decreases down-drift.

Caraguatatuba Bight sediments are predominantly very fine sands to coarse silts, very well to poor sorted, and texturally and morphometrically immature. However, sediments are more reworked and less immature in the Massaguaçu and Martim de Sá nearshore areas. We could identify samples (V-11, V-13 and V-22) with a mixture representative of sediments eroded from the recent beaches and deposited on the nearshore zone. Near São Sebastião Channel mouth (sector IV), sandy sediments are coarse, poorly sorted and immature, which is related to an influence of the channel sedimentation.

Shore-drift along the beaches as well as the inner bight circulation pattern has a close relationship with the predominant wave systems as they approach the coast from SE (Fig. 11). We could identify nearshore transportation northwards and southwards in the south of the Massaguaçu area. Generally in this area, there is a crossing of two wave-trains. They have an oblique approach to the coast from the SE and they result in wave refraction and diffraction around Tamanduá Island. One of them produces a longshore current northward along Massaguaçu Beach, while another produces a longshore current southward, feeding another longitudinal current that we called the Caraguatatuba Southward Current (Souza, 1990). This current could be responsible also for the presence of a long spit connected to the Ponta Massaguaçu, studied through sample V-16. The longshore southwards current also supports the spit-bar development of "Blue Lagoon". When the approach angle of a wave system changes, due to seasonal effects or wind oscillations, the locality at the shoreline, where crossing of wave-trains occurs, also changes. This phenomenon produces up-drift migrations southwards or northwards along the shoreline and it interferes with the spit-bar development.

The sector IV really is a zone of influence of the São Sebastião Channel sedimentation in the inner Caraguatatuba Bight. There the channel main flow loses its energy because it finds an open area and the depths are smaller than in the channel. Then coarse sediments are deposited, which can not be moved by weaker local currents. The Caraguatatuba Southward Current and the longshore current southward along the Caraguatatuba Beach form the Caraguatatuba Southward System. This system transports finer sediments out Caraguatatuba Bight which are deposited along the continental side of the São Sebastião Channel by its secondary flow. Therefore, the Caraguatatuba Southward System causes the anti-clock wise rotations in the channel main flow and it feeds the secondary flow.

Finally, we could identify a broad drift-cell along each beach studied, which consists of three zones:

- zone of erosion,
- zone of transport and
- zone of accumulation.

- *Zones of erosion:* occur at rocky cliffs and along beach segments in the southern part of Massaguaçu and in the northern part of the Martim de Sá and Caraguatatuba shorelines. There is a good disposability of sediments to transport; wave energy is more effective and feeding up-drift longshore current. Sediments are coarser and poorly sorted, and then texturally immature, but they are morphometrically more mature than the rest of the beach.
- *Zones of transport:* are present in the central segments of the studied beaches. Wave energy can remove and transport finest sediments to the accumulation zone; sediments are sorted.
- *Zone of accumulation:* can be found in the northern sector of Massaguaçu Beach and in the southern segment of Caraguatatuba Beach. There

is a decreasing of wave energy and suspended sediment transport becomes predominant. Sediments are finer and better sorted, and then texturally mature, but they are morphometrically less mature.

Apparently, along the coastline of Caraguatatuba Bight erosive processes has been more effective than accumulative processes, at least, during the last decade. This seems to be occurring all along the coast of the State of São Paulo (Souza & Suguio, 1995) and also along the Brazilian coast. Coastal geologists and geomorphologists have reported that shore erosion dominates over shore accretion (Bird,1980), and many of them believe that rate of erosion has increased in recent decades or centuries (Galvin, 1983). The long-term and progressive rise in sea level has been cited as a major cause of erosion along the world's coastlines. We have developed detailed studies along the coast of the State of São Paulo for investigating that subject.

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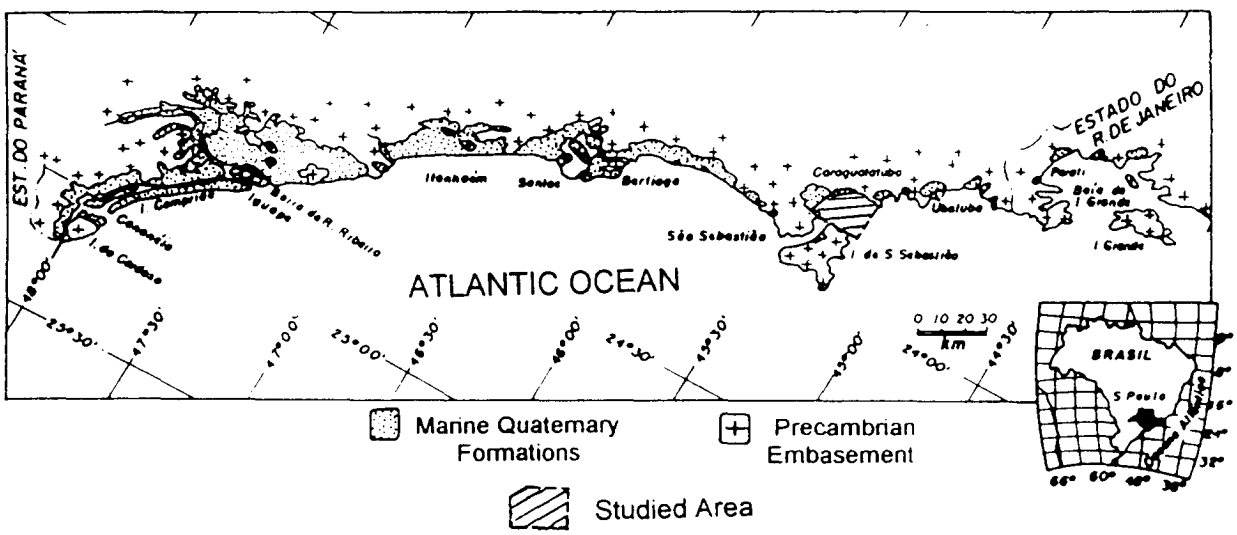


Fig. 2. Bathymetric configuration of the Caraguatatuba Bight

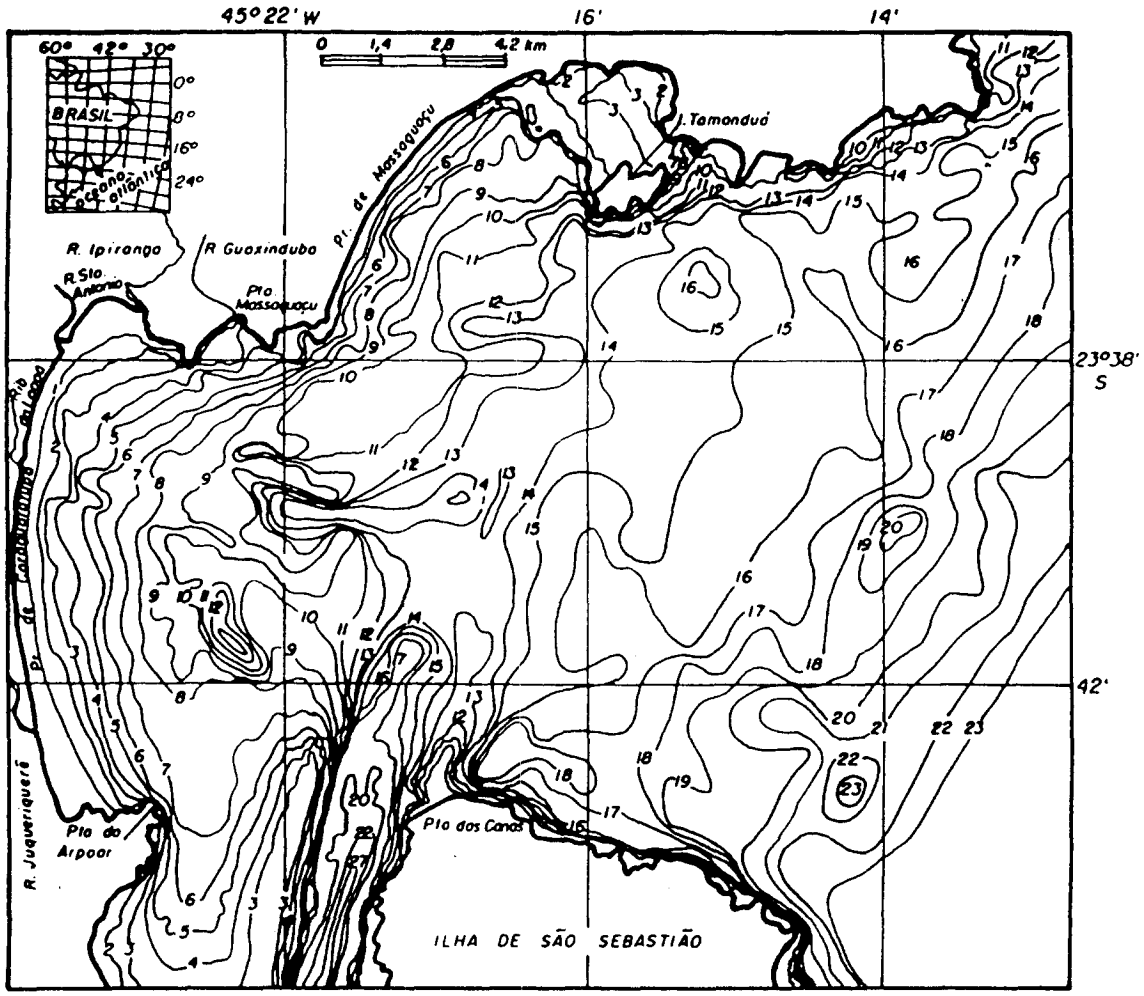


Fig. 3. Location and morphological characteristics of beach profiles

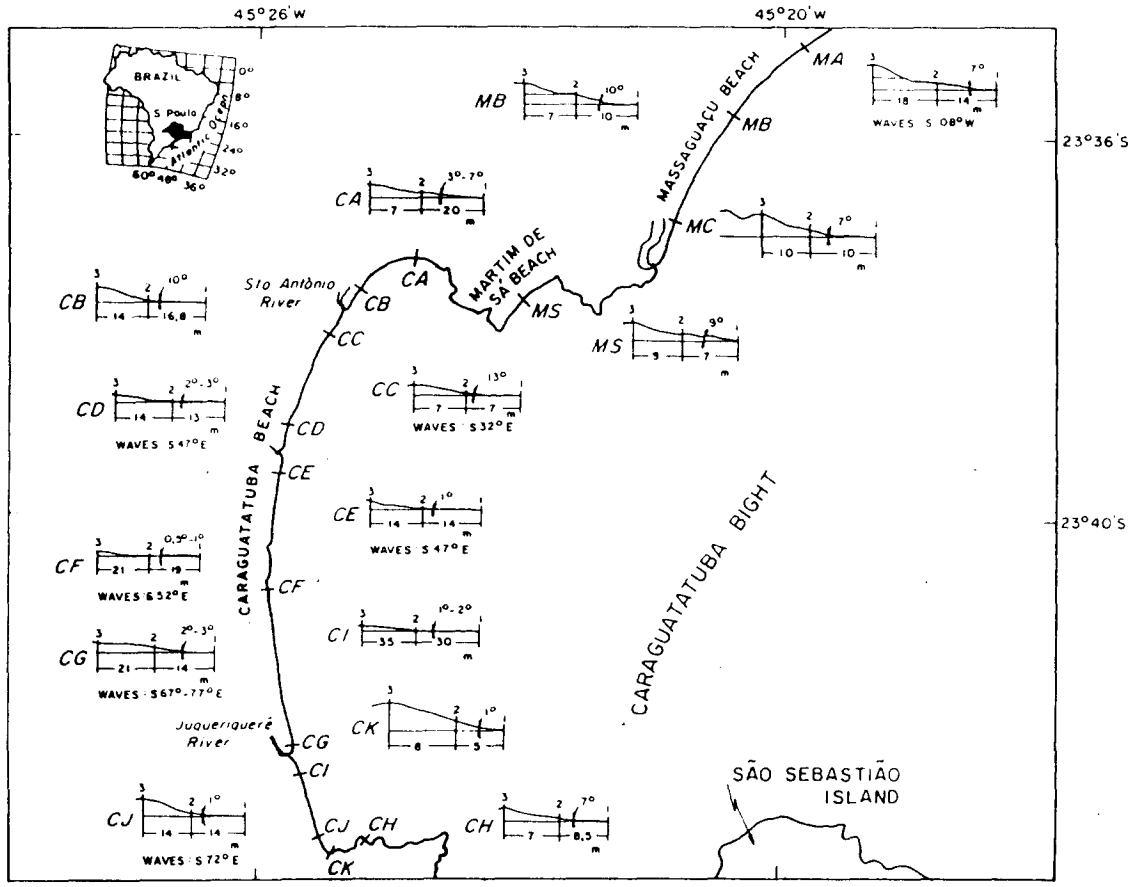


Fig. 4. Grain size parameters of beach sediments

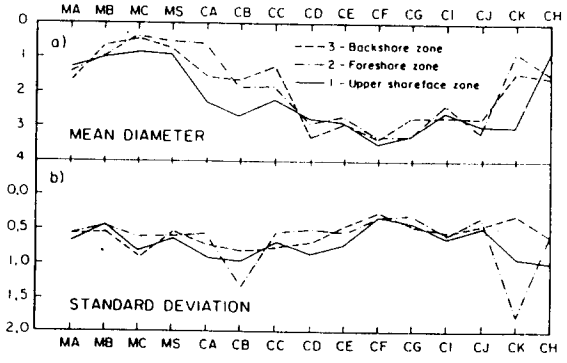
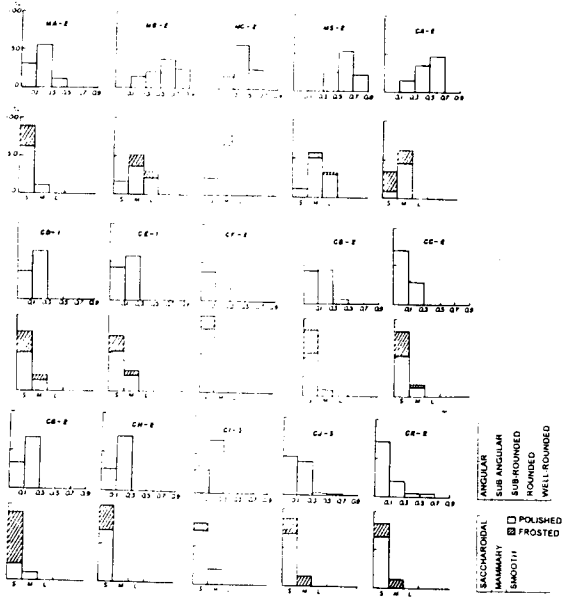


Fig. 5. Morphometrical characteristics of beach sediments



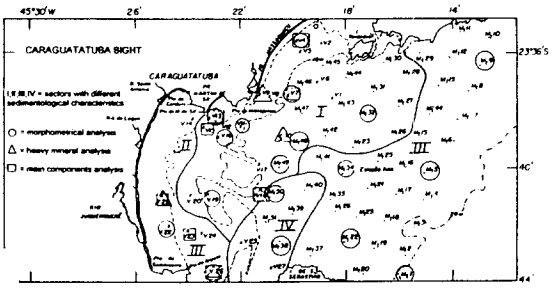


Fig. 6. Locations of collected samples in the Caraguatatuba Bight and kinds of analyses made.

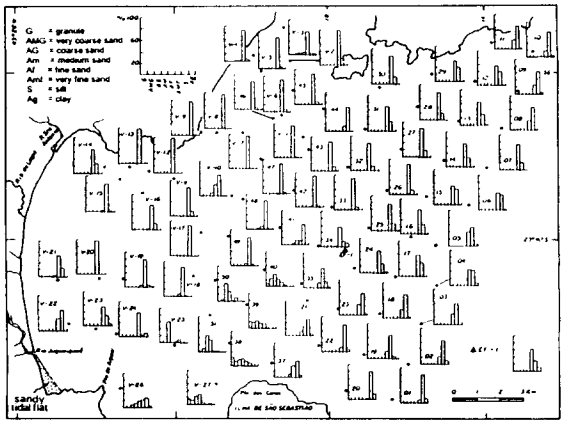


Fig. 7. Modal classes distribution of bight sediments

Fig. 8. Mean diameter distribution of bight sediments.

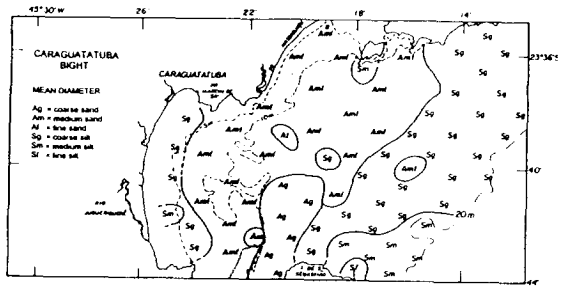
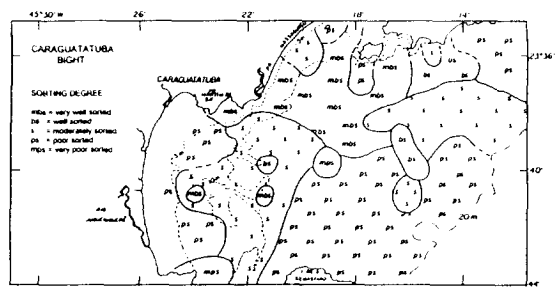


Fig. 9. Sorting degree distribution of bight sediments



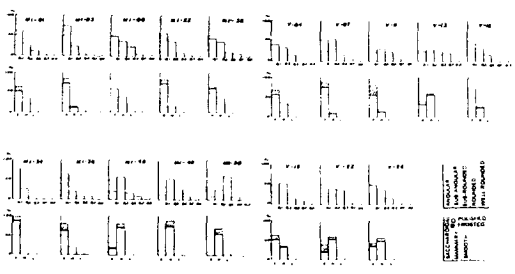


Fig. 10. Morphometrical characteristics of bight sediments.

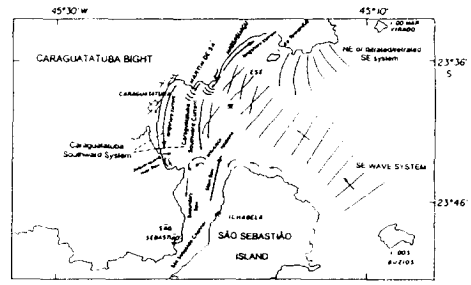


Fig. 11. Map of circulation pattern in the inner Caraguatatuba Bight.

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SEDIMENT BALANCE OF THE SEA COAST ZONE AND ITS REGULATION; THE EXAMPLE OF THE EASTERN COAST OF THE BLACK SEA[1]

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ABSTRACT

The process of coastal zone formation of the Georgian eastern part of the Black Sea is investigated. The quantity of riverine, beachforming sediments, moving from rivers to the sea is determined, including the sediment balance of the coastal zone. A new method of protection from coastal erosion by means of sediment-balance restoration and artificial beaches is proposed for the coastal zone.

SEDIMENT BALANCE AND RESOURCES

Wash-out and destruction of sea coasts are global in character and become menacing nowadays. The urgency of this problem will in due course increase in connection with a forecasted acceleration of the rates of a global ocean's level rise, control of the river flow by the reservoirs and intensification of the other anthropogenic effects. The sediment balance of the coastal zones of seas and oceans is composed of various elements. River sediments are dominant in the balance for the alluvial-accumulative coasts. Rock destruction products, transported from the highest marks to the lowest ones across the catchment, are the main contributors from land. The ultimate accumulation of detrital rock fragments occurs in the seas and oceans. A part of alluvium lodges in the coastal zone forming the alluvial-accumulative sea coasts.

The coastal zone of the eastern part of the Black Sea is formed as a result of rivers delivering sand, gravel and pebbles on the one hand and sea waves spreading it along the seashore on the other hand. The river mouths are dominant in this process and the alluvial material at the "river-mouth-sea" boundary is filtered and sorted. Consequently, the system "river-mouth-sea" is to be considered as a whole and the coastal zone as a result of the interaction.

The formation of alluvium deposits in mountainous rivers is a diverse and complicated process. High slopes and high energy of river flows promote sediment transport. Nevertheless, river sediment transport is heterogeneous. In this sense the morphology and dynamics of river beds play a particular role. This is particularly obvious with mountainous rivers having their courses in the snow-ice zones and their river mouths at the sea level (Chalov, 1979).

Each river delivers to the sea several rock derived materials, characteristic of the basin. Such rocky markers allow the tracing of sediment migration in each particular river. These drifts are revealed in mineralogical, petrographical and granulometrical investigations (Kiknadze, 1971).

The river alluvium sediments that have settled on the river mouth and sea coast are subject to a mechanical differentiation affecting simultaneously both suspended and bed loads. Therefore it is more reasonable to divide drifts in this zone into beach-forming and non-beach-forming ones. The latter participates in the modern process of deep-water sedimentation. On gentle sandy shores, beach-forming material is coarser than 0.1 mm, on steeper pebble shores it is coarser than 0.25 mm. Generally, the shores and beaches are formed by the entire bed load and part of the coarse suspended load (Jaoshvili, 1984).

There are more than 150 small and large rivers that flow into the sea over the whole 314 km coastline of Georgia. They differ by water discharge and regime. About 50 of them bring

[1] See also the poster abstract of Kiknadze *et al.*

beach-forming materials into the sea. The carried-over alluvium forms eight closed dynamic systems as independent near-coast drifts. The source of these drifts is usually matched with the mouths of the large rivers.

The total volume of river sediment with respect to beach-forming sediment is 4.6 million m^3 (about 3.9 million m^3 of sand and 0.25 million m^3 of pebbles). Out of this more than 90% is delivered by the large rivers: Chorokhi (0.25 million m^3), Rioni (1.35 million m^3), Kodori (0.27 million m^3), Bzibi (0.1 million m^3). From these beach-forming sediments about 2 million m^3 is delivered into the submarine canyons and hence lost. Additionally 7.7 million m^3 of the fine non-beach forming river sediment transit the coastal zone and settle at the deep-water area of the sea (Table 1; Jaoshvili, 1986).

During floods, new beachforming sediments form submarine alluvial cones in the mouth's shores. Here the sediments are both exposed to river and sea influences (Zenkovitch, 1962; Mikhailov, 1971).

In view of this, the sediment balance of the eastern part of the Black Sea is mainly determined by drifts of river origin. The part of other components is insignificant. The structure of the balance changes each year and depends on the river runoff (Dzhaoshvili et al., 1993).

Building dams on rivers, where in the water storages great volumes of alluvium are deposited, has an unfavourable effect on the sediment balance. For that reason the volume of beach-forming sediment is reduced by as much as 92% in the Inguri river, by 35% on the Rioni river and by 25% on Gumista river. Removal of sediments from the river-beds for building purposes also breaks the balance. This factor is exhibited especially in the mouth regions of the Rioni and Chorakhi rivers. The total volume of the removal of alluvial sediments from the river-beds runs to 1.5 million m^3.

Finally, about 2 million m^3 of beach-forming alluvial sediments remain in the coastal zone and takes part in the beach-forming processes. This volume of sediments is not enough for establishing a stable balance especially as the indicated material is distributed along the shore irregularly. Because of this there are eroded beaches in the Georgian coastal zone, which are a cause of financial losses.

A change in the sediment balance of the rivers not only disturbs the natural dynamics of the seashore, but also limits coastal development. For example, after the construction of port piers in Batumi and Poti on the leeward side a significant drift of sediment occurred and submarine canyons were formed in the coastal zone (Zenkovitch, 1958) The dynamics of the Poti submarine canyon are closely related to the quantity riverine sediments delivered to the shore (Jaoshvili et al. 1985).

From the total Black Sea coastline of Georgia, 155 km had been washed out in 1961, 183 km in 1971 and 220 km were in an emergency state in 1981. During that period the sea washed out 1.4 thousand ha of useful near-coast territory, including the densely populated blocks of the town of Poti, roads, communications, agricultural land, etc. This phenomenon took place in spite of attempts to protect these coast with the help of various hydrotechnical constructions and a total expense exceeding hundreds of million of roubles. Worldwide sea coasts of accumulative origin are usually protected by traditional methods using hydrotechnical constructions (spur dikes, piers, breakwaters, walls and fillings made out of tetrapods, blocks, stones, etc.) This method of coastal protection is rather expensive, is inefficient, short-lived and absolutely inadmissible from an ecological point of view, having the protected coasts cluttered up with concrete and ferro-concrete. This causes also a disturbance in the natural water circulation and pollution of the water media.

The particular experience of sea coast protection with hydrotechnical constructions on the Black Sea coast of Georgia showed that these structures protected a local section of the coast (while the adjacent sections were exposed to the more severe wash-out). They were at the same time short-lived because they collapsed and went out of service due to wave effects in a 7-8 year period.

Since 1981 when the Scientific-Industrial Association of coast protection was established, the methods of sea coast protection completely

changed. A set of works has been started at the Black Sea coast of Georgia in the conditions of a disturbed natural balance in order to restore the natural structure of the drifts' balance within the coastal zone. The volumes of alongshore drifts were approximated to the natural ones by inserting the beach-forming material. Thus, a restoration of the natural beach morphodynamics has been started. The artificial wave suppressing beaches reliably protect dry land from wash-out and increase the seaside's recreational value by restoration of a near-coast landscape. Here one of the main tasks is the quarrying of beach material without any harm to nature, which is important for the development of a coast protection principle. Therefore methods of optimization of river mouths, ensuring a positive material balance and the ways of a rational use of alluvium have been developed.

The optimal control of the drifts' balance in river mouths includes a rational use of material lost in canyons, while the natural landscape is preserved. One could use crushed wastes formed after the automobile roads and tunnels had been constructed. Also if necessary, open coasts of inert material may be developed on the dry land but subject to restriction, so cultural landscapes will be created when the operations in the place of a former open coast are completed.

After these new methods of restoration of the natural coastal zone had been adopted, 100 km of the coastline were stabilized; 150 ha of dry land has already been restored. Besides, the coastal protection by the artificial beaches is half the cost of building coast protective constructions.

Artificial beaches also provide cleanness of sea water in the coastal zone. During storms the water is filtered into beach ledges, and bacteria on the surface of a beach die because of the direct sunlight radiation.

The ten years' experience of the Georgian Black Sea coast protection by continuous beaches makes it possible to conclude that in the case of coasts of accumulative origin, the artificial beach lines are the most efficient and economic coast protective structures that restore the coastal zone and improve the near coastal landscape. Besides that the dynamic system is more practicable and there exists the possibility of controlling its morphodynamics as well as the longevity of beaches and coastal protective structures.

Thus, if the natural equilibrium of the alluvial-accumulative coast is disturbed, the only real way to preserve the coastal zone is to restore the natural dynamics of the sea coast by the artificial elimination of sediment shortage.

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Table 1. Annual sediment load to the sea from the major west Georgian rivers.

Rivers	Basin area km^2	Suspended load m^3	Bed load m^3	Beach-forming sediments m^3
Psou	421	75000	15800	38000
Mechadir	25	2500	1700	2900
Khashupse	200	35000	11050	25000
Jove-Kvara	72	232000	7500	15000
Gagripsh	35	10000	4000	8000
Bzibi	1510	285000	40000	100000
Khipsta	166	15000	4700	11000
Aapsta	243	16600	5000	9500
Gumista	576	66500	13000	25000
Besleti	81	5000	1850	2500
Celasuri	220	21600	5750	15700
Majarka	114	6650	2400	5000
Kodori	2030	485100	66800	270000
Mokva	336	21600	5950	8300
Galidzga	483	45300	9300	21700
Okumi	265	14900	4850	7200
Inguri	4060	75000	15000	29000
Khobi	1340	120000	13000	39000
Rioni	13400	4000000	400000	1350000
Supsa	1130	103000	14800	39000
Natanebi	657	34900	7000	18000
Kintrishi	291	8300	4260	6850
Dekhva	45	2500	2230	2500
Chakvistskali	173	5000	5600	8500
Korolitskali	55	2200	2400	3500
Barzchana	20	2000	1700	2500
Chorokhi	22100	4850000	485000	2500000

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RESEARCHES AND MEASURES FOR BEACH PRESERVATION: THE CASE OF VARADERO BEACH, CUBA.

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KEYWORDS: Beach; erosion; Varadero; Cuba; regulations; artificial beach nourishment.

ABSTRACT

Varadero Beach, with an average sand loss of 50 000 m^3/yr, and estimated erosion rate of 1.2 m/yr, could be included into "Critical Coastal Areas" of the Caribbean Region.

The plan for the Preservation of Varadero includes Artificial Beach Nourishment as the main measure. Supply of sand has been developed since 1987 with a total of 688 000 m^3 until 1992. The plan also includes regulations for adequate management of all activities related to beach use. In this direction the establishment of "The Coastal Construction Control Line" has been one of the most important measures to preserve and protect dunes from imprudent construction.

RESEARCHES AND MEASURES FOR BEACH PRESERVATION: THE CASE OF VARADERO BEACH, CUBA.

INTRODUCTION

For an important part of the community (scientists, environmental managers and policy-decision makers) the general character of the shoreline retreat has been associated, to some extent, with climate changes, and in particular to the continuous sea level rise. But, it is already accepted that shoreline retreat is, particularly for beaches, the immediate response of the coast to many human induced activities, including not only those resulting from an environmentally erroneous planning of the coastal space, but also those arising from mitigation actions improperly implemented.

In the particular case of Cuba, coastal erosion has been evident with the sea penetration in the mangrove lower zones of the southern coast and with the loss of sand at beaches that extend along the northern coast, particularly at Varadero beach, located at the Hicacos Peninsula about 130 km East of Havana, (Fig. 1). This peninsula is characterized by long and broad sandy beaches and well developed dune fields, all along the shore.

Varadero had been historically the main tourist resort of Cuba, and it generated in the last three years gross incomes of 138.2 million US$ in 1992, 165.66 million US$ in 1993 and 191.4 million US$ in 1994.

However in Varadero beach, the falling of trees, the outcrop of rocky surfaces and the destruction of tourist facilities under the force of sea waves, are the best evidence of the advance of the erosion processes during the last 30 years.

As a consequence of this, a research program was designed and implemented since 1978 to establish the general scheme of sediment dynamics in this region, to find the causes and rate of erosion, to define the ecologically sustainable measures to mitigate the effect of the erosion and to restore as far as possible, the natural conditions of the beach.

The positive results obtained in this work are presented.

1- BEACH EROSION RESEARCH

Systematic research work on the erosion at Varadero beach started in 1978, and the basic

scientific purposes of this research were directed towards the knowledge of:

1- Seasonal and spatial morphological variations of beach profiles.

2- Geomorphological characterization of the shelf.

3- Composition and distribution of sand.

4- Tendency of sediment transportation.

Topographic measurements of beach profiles made monthly since 1978, allow us to identify seasonal and long term erosion (Juanes et al., 1985). In winter, cold fronts in the Gulf of Mexico generate high waves which travel south as swell waves towards Cuba's northern coast, causing extensive beach erosion. In summer, the beach accretion reaching its maximum, regularly represented in profiles of October and November (Fig. 2).

Shoreline measurements showed an erosion trend of 1.2 m/yr, while the erosive trend in terms of sand lost has been demonstrated by seasonal calculations over fourteen years of monitoring at eleven profiles along the 22 km beach. Calculations show a general erosive tendency, with an estimated loss of sand of about 50,000 m^3/year. A graphic (Fig. 3) shows this erosive trend at three chosen points (Juanes & García, unpublished).

Seismic profiles were useful to describe the way in which sand at the shelf is distributed in the different basins (Foyo, 1982). It was determined that these basins are limited by rocky ridges that served as a plinth to the actual reef formations, and the accumulation of sand cover totally covered the space in the basins. The three main basins described, are located all along the north shore of the Peninsula, and are also characteristic due to its narrow extension to the South West and to its wide extension to the North East. Observations made on board the research mini-submarine "Argus", up to a depth of 600 m, allowed us to know the existence of depressions perpendicular to the rocky ridges like small submarine canyons, through which the sand could go out to the shelf.

The studies of composition and distribution of sand in the region were based on granulometric analysis and microscope observations of more than 1000 samples, obtained from the shelf and the beach during different expeditions. The samples thus obtained, allow us to show that 90% of the sand content is formed by very thin fragments of benthic organisms, among which the algae Halimeda are predominant in 40%, the foraminifers in 25% and the molluscs in 20% (Juanes, 1986).

In this way, is important to emphasize two particular features of this type of shore. The first one is that the source of sand is associated with the benthic communities located at different deeps and consequently the granulometric distribution of sediments along the submarine profile is very complex (Fig. 4). The second feature is that coarse sand composed by fragments of benthic organisms, particularly the green algae Halimeda, possesses a hydraulic behaviour comparable to much smaller sand grains due to a low settling velocity and ease of resuspension.

The typical coastal engineering solution to control beach erosion had been established attending to the features of continental shores. In these cases the rivers and abrasional cliffs, are the main sources of materials and consequently the sand distribution along the submarine profile is different to the model shown in Fig. 4. Also it should be emphasized that silicate sand is the main component of the continental beaches and it presents different hydraulic behaviour compared with organic carbonate sediment.

Taking into account the considerations described above, it is important to study carefully the traditional engineering solutions in order to select the best option to mitigate beach erosion in small islands of tropical regions, where frequently the beaches are formed by organic carbonate sand.

The study of sediment transportation trend, based on the wind's characteristics, was made through the use of Knaps methods (Juanes et al, 1986). In this method a non-dimensional index of energy (E) transferred by the wind to the sea surface is established; while the directional analysis of this index allows us to obtain its components parallel (Tr) and perpendicular (B) to the coast.

The results obtained by the application of this method (Fig. 5) suggest that the greatest tendency of sediment transportation at the Peninsula is established from East to West during most of the

year, even though there is transport in the contrary direction during winter months. Moreover length of vector B shows that the onshore-offshore transport is as large as longshore transport. In this manner, the results obtained with this study were useful to indicate that the hard structures as groins and breakwaters, which are designed only to trap longshore drift are not the appropriate solutions to mitigate erosion at Varadero beach.

BEACH EROSION CAUSES

The most common causes of erosion that have been postulated for Varadero beach are:

1. Mining of beach sand
2. Interference of bulkheads and jetties
3. Buildings, houses and other hard structures built over the dunes.

Mining of beach sand in Varadero beach, was a normal practice until 1978, with an estimated of 2,000,000 m^3 of sand removed. As is clearly obvious, this practice, driven by the needs of the construction industry, was the cause of depletion in natural sand reserves not only in the submerged zone, but also in the dune fields, given the natural sediment exchange between beach and dune. It has to be borne in mind that this exchange is, probably, the most important natural process for beach stability.

Besides this, the "Canal de Paso Malo", built in 1956 to provide fishing boats in the lagoon with a shorter route to the open water of the Strait of Florida, became an important factor disturbing the normal shore dynamics. The channel entrance to the north is protected by two jetties, both projecting more than 100 m into the sea, and starting sand deposition on the updrift side of the longshore current and erosion downdrift.

However, sand deposition on the updrift side of the longshore current (east side of the Canal) is also influenced by the erosion that is originated by the "seawall" design of the channel and the effect of the wave front hitting nearly perpendicular against this side.

But, the major cause of beach erosion in Varadero is the presence of more than 150 buildings, houses and other hard structures that were constructed near the shoreline or even over the dune, over a length of 5 km beach. Due to an environmentally erroneous planning of the coastal space in former times, the effects created by these tourist facilities and private houses, are as follows:

a) Reflection of sea wave energy which can scour the beach nearby.

b) Interference with local coastal processes, affecting the shore current system and hence sediment transportation occurs in the wrong direction.

Although very destructive, the erosive mechanisms of these effects are simple: sea wave energy is reflected on hard structures located on the coastline; more sediments (than normal) is introduced to the affected shore current system; and sediment transportation offshore is more intense, reaching deeper zones, where beach sand is out of the long term natural system equilibrium (Fig. 6).

Sediment input deficits from benthic communities may be another cause of erosion on beaches formed by organic carbonate sand. The processes that provoke this deficits are poorly understood but in many cases can be related to pollution of the nearshore water, mining and other human activities. The rise in sea level is one of the "natural" causes of beach erosion, although it does not reach the magnitude of other human induced factors.

BEACH EROSION SOLUTIONS

It should be pointed out that mitigation actions against beach erosion have to be properly implemented. Any action carried out in the wrong way is a new source of trouble for the coastal system. That is why beach erosion solutions have to be, in the first place, those which could be oriented to eliminate the factors originating the erosion.

The results obtained in Varadero Beach were fundamental for describing its main characteristics, to understand the natural functioning processes of the beach, and to select the proposal of artificial beach nourishment as the most appropriate solution for mitigation, because its well recognized ecological and aesthetic advantages over other different techniques (Manual on Artificial Beach Nourishment, 1990).

Hence, the basic parameters for our artificial beach nourishment project (like borrow area, necessary sand volume, sand characteristic, etc.) were easily determined, thanks to the results of this research program. An example of a typical project on this matter could be found in Juanes et al. (1993).

The selection of the borrow area is a particularly important step in the process of designing the project. The seismic characterization of the shelf allowed us to locate a suitable sand basin, with over two million m^3 of reserve at 20 km from the beach. This basin was described (Instituto Cubano de Hidrografía, 1988) as a sand accumulation deposit at 10 m average depth, and with sand characteristics very similar to those of the beach. It was also determined that this deposit does not belong to the natural sand sources of Varadero Beach; it means that this basin is out of the dynamic system of the beach.

Another important step is to determine the correspondence between the native sand and that to be introduced. This was done by means of microscopic analysis of a set of samples of both places (Table 1) and by the determination of the Overfill Factor, (Shore Protection Manual, 1984) which allowed us to quantify how much the volume of sand has to be increased in order to compensate for sand lost due to granulometric differences.

From 1987 to 1992, five campaigns for artificial nourishment of the beach were done over a shoreline of about 4 km from Canal de Paso Malo to El Caney, with a total of 700,000 m^3 of sand nourished. The results of the two first years of replenishment works could be found in Schwartz et al. (1991).

The studies of sand volumes on the beach one year after the mitigation works showed that sand lost was not greater than 20%. According to the international experience, this result is satisfactory (Leonard et al., 1990). Fig. 7 is only one example of how the aesthetic and recreation conditions of the beach have been recovered and also on the protection given to many buildings and houses. It has to be pointed out that in October 1985 around 20 of these installations were partially or totally destroyed due to the effects of big swell waves associated with the hurricane "John", but in March 1993 similar effects associated to the "Storm of the Century" did not cause any damage, demonstrating not only the effectiveness of the method employed for mitigation, but also how the beach recovered its capacity as the more efficient natural defense of the coast.

It could be added that mitigation actions should also include those directed to regulate or forbid any human activity that could be a source of trouble for the coastal zone, and the beach in particular. In Varadero Beach different steps have been taken in order to reduce the human influence as far as possible. As a consequence, a plan was established for the general and adequate management of all activities related with the environment, including the following:

1. Sand mining is strictly forbidden.
2. Construction works are prohibited in a precise zone inside the beach and dunes.
3. Any building or house over the beach or dune, damaged by the sea action could not be automatically rebuilt, instead it should preferably be demolished.
4. All development action or work in the Peninsula have to be coordinated with, and approved by, the management authorities.

The application of these regulations have been very useful in the process to elaborate the project of the Shores Act of Cuba, which is at present under study.

In the project of the Shores Act, the extension of "The Coastal Zone" and "The Coastal Protection Zone" are defined according to the type of shore. In the case of the beaches, "The Coastal Zone" does not extend beyond the landward toe of the dune and "The Coastal Protection Zone" included the next 30 meters landward. In both zones, the construction of hard structures is forbidden. Then "Control Construction Line" is established to indicate the boundary of "The Coastal Protection Zone" landward.

CONCLUSIONS

The experience and results thus obtained suggest that in beaches formed by organic carbonate sand, very frequent in tropical regions, the traditional

engineering solutions should be studied carefully before their application.

The results obtained from the application of rules proposed in "The Shores Act" and the implementation of artificial beach nourishment constitute an example of the effort carried out in Varadero beach in order to reach an appropriate reconciliation between the needs of development and preservation imperatives.

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Table 1. Composition of beach and borrow area sand.

	Beach (Native)	Borrow area (introduced)
Diameter (mm)	0.10-0.25	0.25-0.50
Composition		
Calcareous algae	40%	41%
Foraminifera	25%	23%
Molluscs	20%	28%

Fig. 1. Varadero beach, located at the Hicacos Peninsula. Northern coast of Cuba.

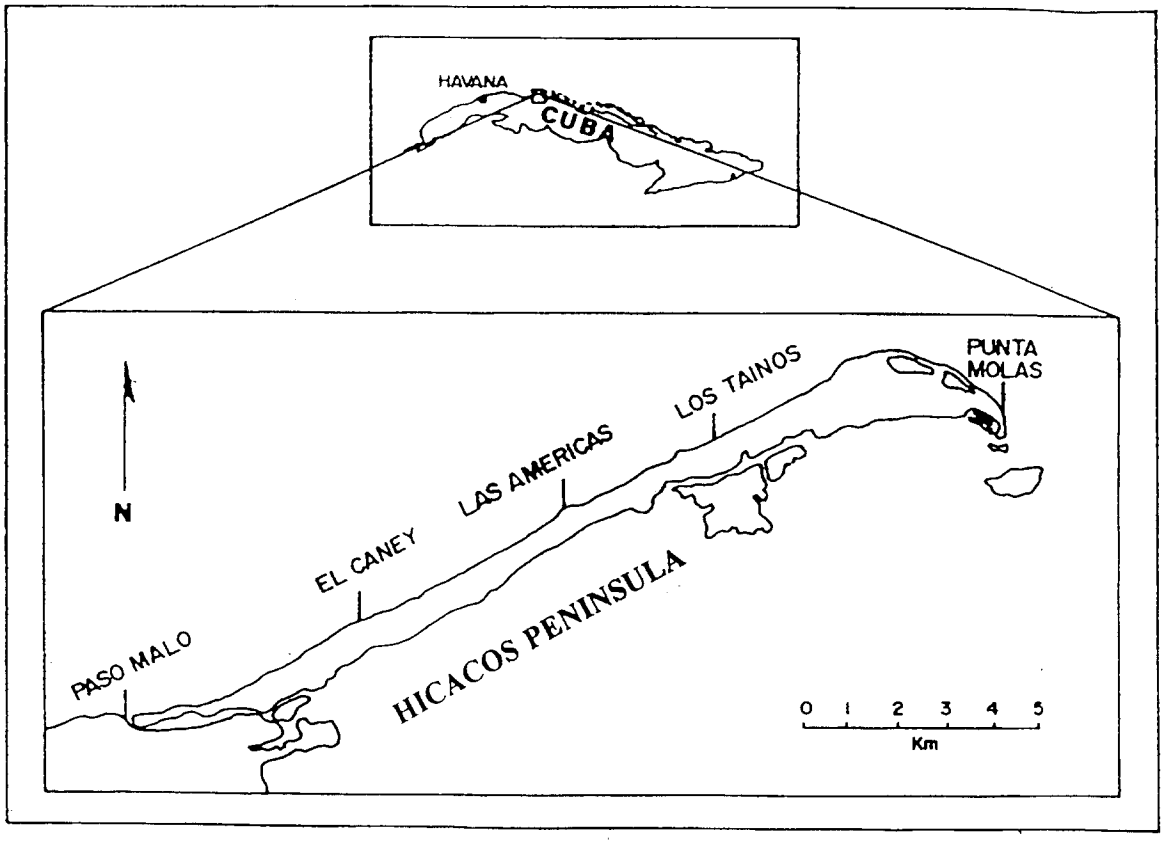
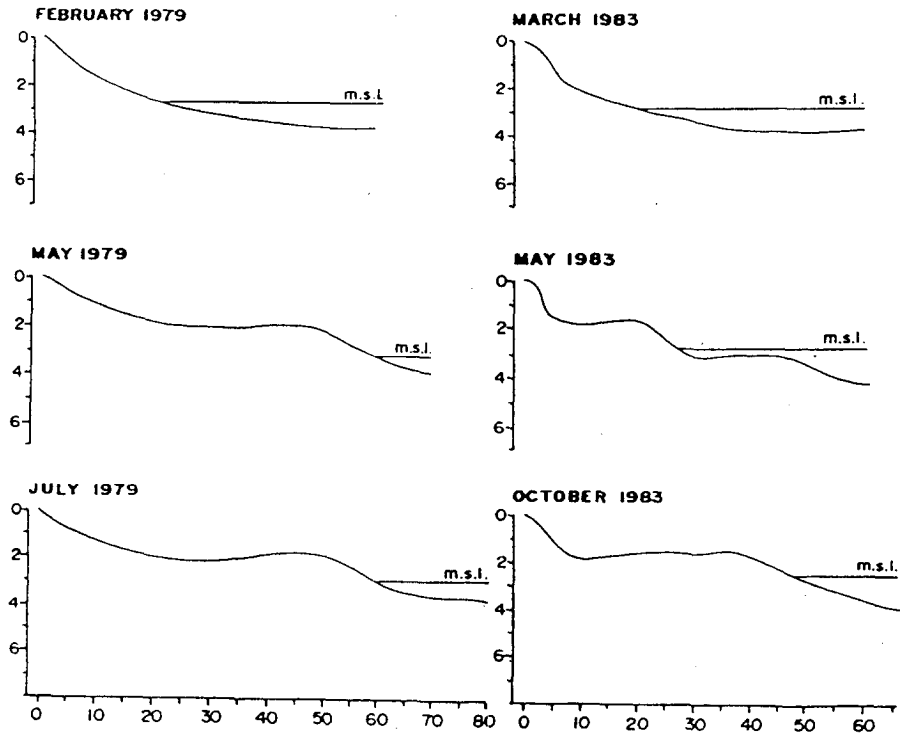


Fig. 2. Seasonal variations of the beach profile in "Las Américas".



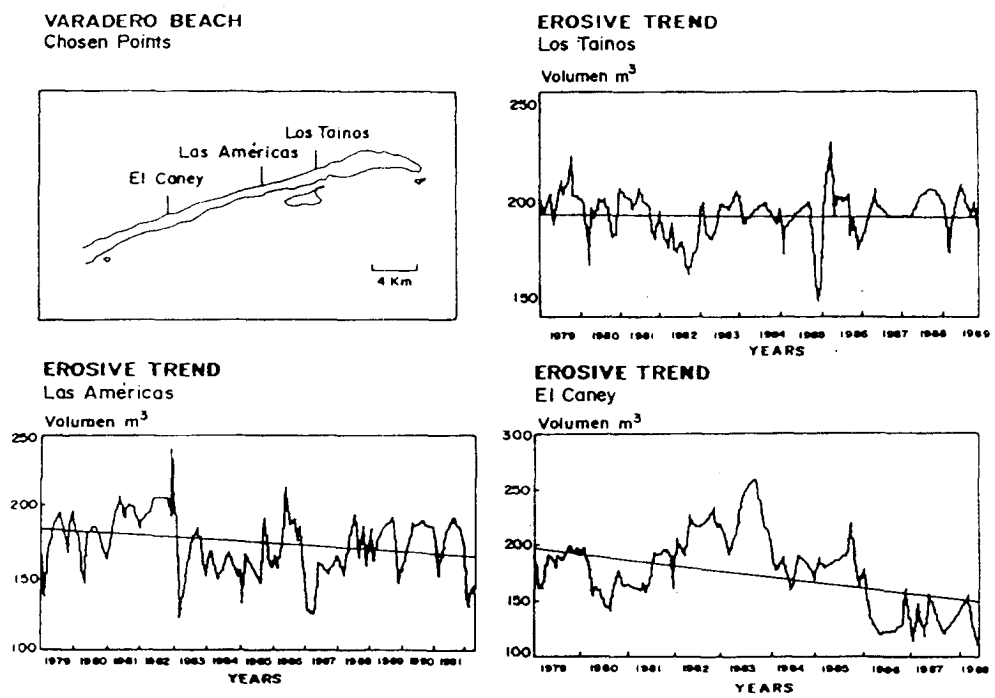
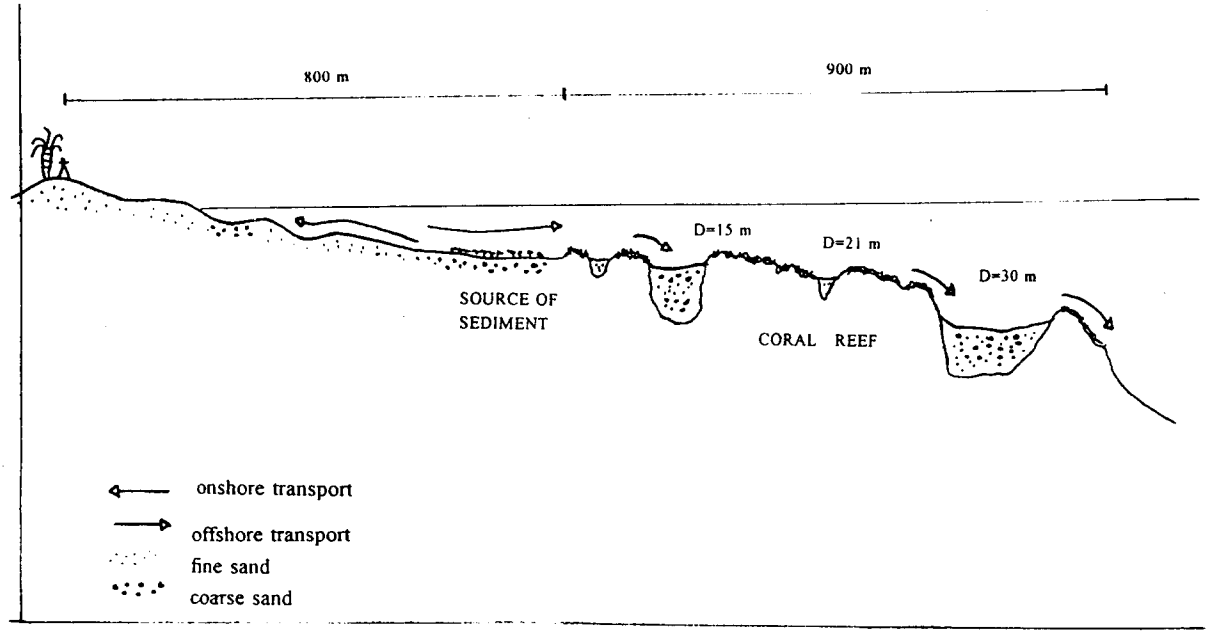
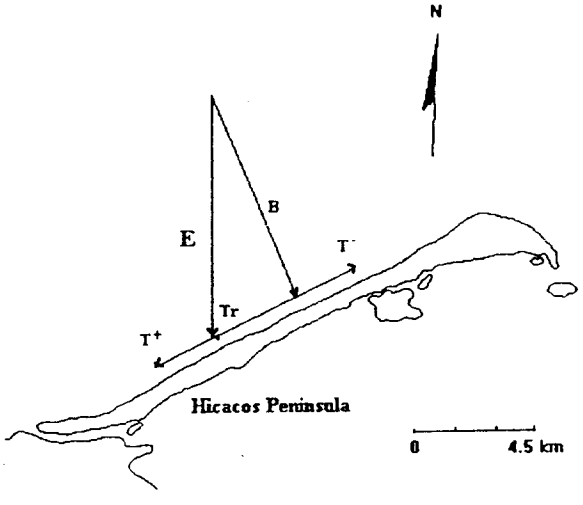


Fig. 3. Erosion trends for three chosen points in Varadero beach (Los Tainos, Las Américas, El Caney).

Fig. 4. Schematic submarine profile in Varadero Beach.





T^+ - Longshore transport index to West

T^- - Longshore transport index to East

$Tr = T^+ + T^-$ (Net longshore transport index)

B - Onshore - offshore transport index

E - Unidimeasional index of energy trasferred by the wind to the sea surface.

Fig. 5. Example of sediment transport trend, based on wind's characteristics, 1978.

Fig. 6. The effect of sea waves on beaches.

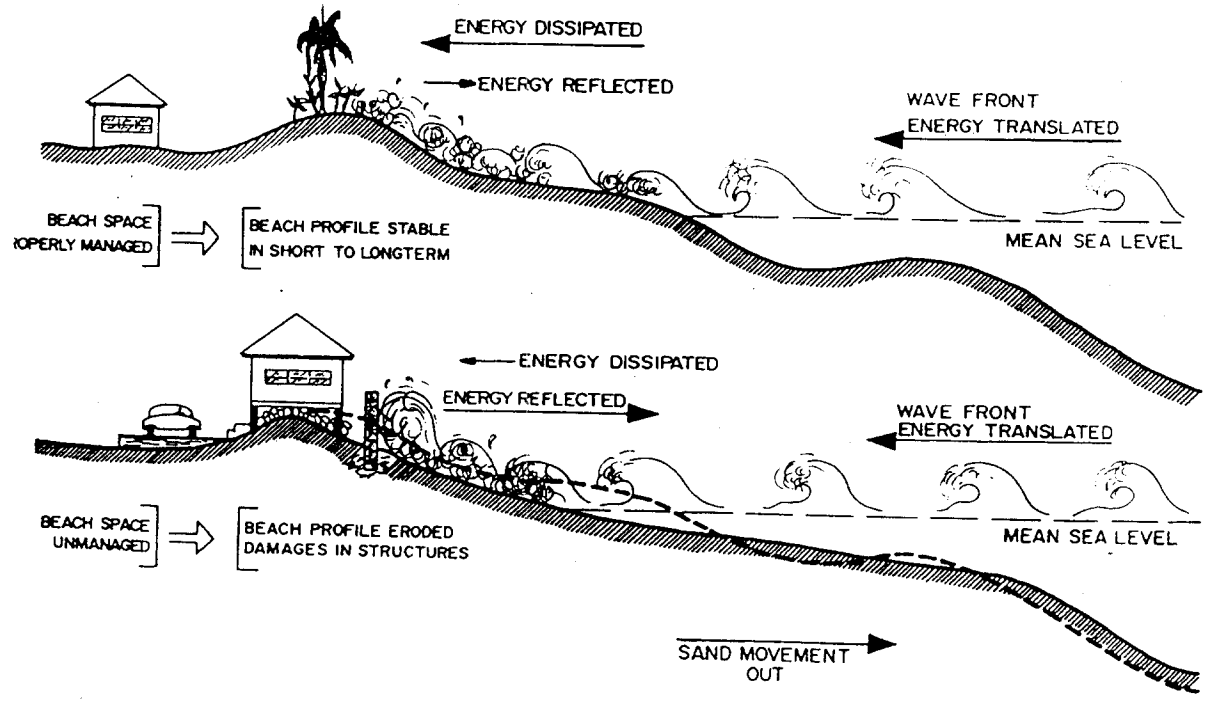


Fig. 7. Before and after the artificial beach nourishment in "El Caney". (a) August 1988; (b) November 1988; (c) October 1991.

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LONG-TERM CHANGES OF A FLOOD TIDAL DELTA ADJACENT CHANNEL, TAURANGA HARBOUR, NEW ZEALAND

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ABSTRACT

Hydrographic surveys of the Tauranga Harbour, New Zealand (Fig. 1) dating from 1852 indicate that the harbour has a history of large scale bathymetric and shoreline changes (Davies-Colley, 1976; Dahm, 1983). Growth of the flood tidal delta by deposition from decelerating flood tidal flow resulted in the diversion of flood and ebb tidal flow, and hence affected sediment transport. Dahm (1983) suggested that growth of the flood tidal delta resulted in the closure of the channel path which originally linked the Upper Western and Otumoetai Channels. This led to the formation of the Lower Western Channel as an ebb discharge route, associated with large scale morphological changes to the ebb- and flood-tidal delta and adjacent shoreline.

Analysis of bathymetric survey between 1962 and 1979 by Dahm (1983) shows large scale bathymetric changes occurred in the Lower Western Channel, effected by deposition from decelerating flood tidal currents entering the harbour. This deposition resulted in the formation of a bank on the west side of the channel and major shoreline changes. Analysis of bathymetric data from 1983 to 1994 show the continued deposition of sediments along the Lower Western Channel until 1990. Since then it has been relatively stable with only minor changes.

There has also been large scale deposition on the flood tide ramp adjacent to the Lower Western Channel. This deposition was up to 7 m during 1983-1991 (Fig. 2). Deposition on the flood tide ramp continued during the 1991 - 1992 period and was maximum (Sm) compared to that of other years. This deposition was predicted by Dahm (1983) and the numerical studies by Bell (1991) and Healy et al. (1991).

A major dredging programme by the Port involving deepening and widening of the shipping channels occurred during 1990 - 1992. This also affected the hydrodynamics and hence the sedimentation pattern within the harbour and on adjacent beaches. Deposition on the flood ramp continued during November 1992 - August 1993, but was less wide spread and was small (up to 3 m) compared to that of the previous years. During August 1993 to April 1994 the deposition continued almost in a similar manner to the previous year but a further southern extension. A change in the orientation of deposition was evident (from north-south to northwest-southeast) indicating a change in the flow direction. Current measurements before and after the major dredging from this region show a change in magnitude and direction of current between 1991 and 1993.

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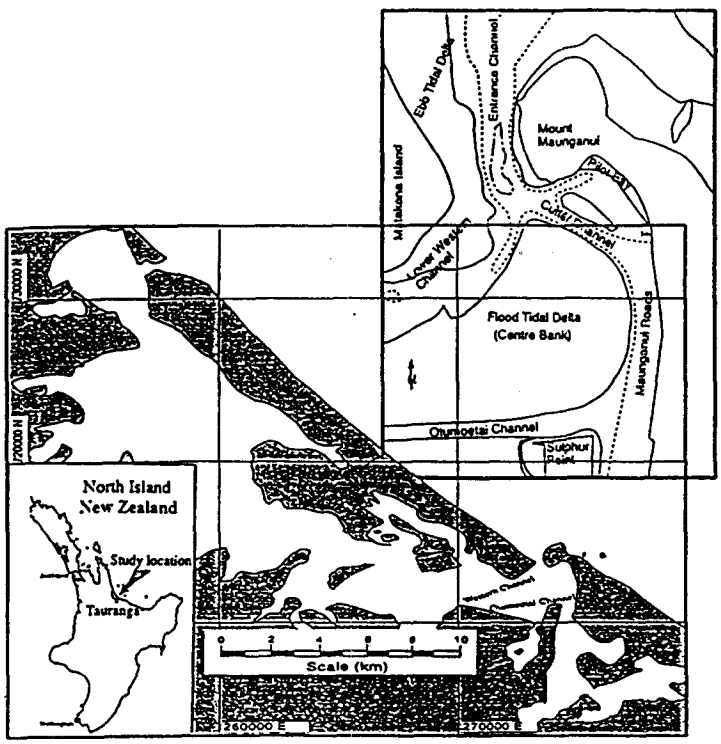
Fig. 1. Location map.



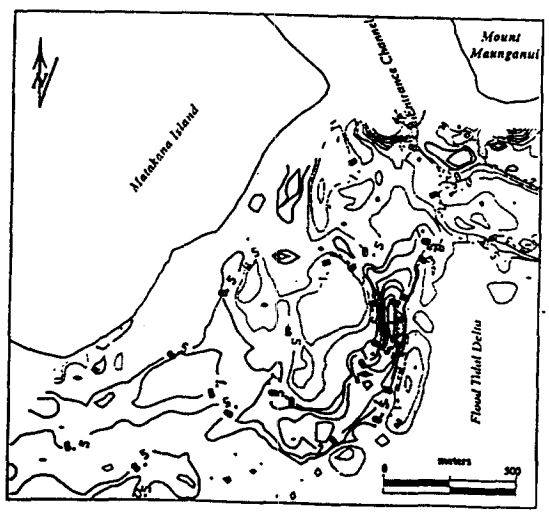


Fig. 2. Comparison of 1983 and 1991 bathymetric contours (— erosion; —— accretion).

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DYNAMICS AND CHANGES IN ESTUARINE SYSTEMS

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KEYWORDS: estuaries; sediments; sediment budget; sea-level rise; wetlands; coastal management; estuarine management

ABSTRACT

Estuarine systems are extremely dynamic portions of the coastal zone. Receiving inputs from the marine environment and from the continent, the estuaries are mixing zones that incorporate a wide range of temperatures and salinities, therefore a natural variety of ecological communities (Kennedy, 1984). Estuaries also have high economic value because they can support many uses and provide for many exploitative opportunities (Kennish, 1992).

Environmental conditions in estuaries are subject to many intrusions because of the surrounding land use and effluent that may be discharged into the waters. Further, continuing development along estuarine margins is driving a physical modification of the system and producing changes which are not easily accommodated.

BACKGROUND

A general goal in estuarine management is to preserve and maintain environmental quality while permitting use of the system and its resources. However, it is necessary to understand the mechanisms of estuarine development and the modern driving forces in order that management strategies can be designed and implemented to function within the natural conditions and their inherent variations. This knowledge is especially important in dealing with a system as dynamic as an estuary because there are natural changes as well as human-induced changes which are occurring as managers attempt to apply controls and regulations (Psuty, 1992). Two important variables that are driving natural changes at the present time are sea-level rise (Warrick and Oerlemans, 1990) and sediment input (Wolaver et al., 1988). These two variables function in tandem to change wetland distributions, to affect bottom conditions and habitats, and to foster equilibrium-disequilibrium environmental conditions throughout the estuary (Wolfe, 1986; Titus et al., 1990, Psuty, 1992).

Estuarine changes are manifested in habitat modification along the wetland margins of the basin, within the aquatic habitat, and at the inlet position. In tidally-dominated inlets, the tidal deltaic formation often undergoes areal pattern changes as flow characteristics and sediment transfers are affected by variations in quantities and directions of input. Whereas some of the changes are the direct product of human intervention, such as agricultural practices releasing nutrients and sediments into the estuary, environmental pollution from commercial, residential and industrial development, and reduction of sediment because of dams and detention systems in the drainage basin, other changes are being driven by natural events. One major change is the reduction in sediments being transported from the nearshore zone into the estuaries. As described early by Meade (1969) and more recently by Clark and Patterson (1985), sediments supplied to the marine margin of the estuary are eroded and transported from the shoreface and from near portions of the continental shelf. Some of the transfer has been created by sea-level rise and some by direct shoreface erosion. The sediment supply derived from this offshore source has a natural volumetric limit and in many areas of the world, this available supply has been exhausted.

From a management perspective, the limits of sediment availability must be considered when attempting to provide for habitat maintenance and environmental protection. Habitats are the product of numerous variables that have been fluctuating during the past several thousand years and they have been subject to natural disruptions during this period of global change. There is no reason to assume that estuaries are spatially static or that the distribution of their natural features, such as wetland communities and aqueous habitats, are fixed. To the contrary, the system dynamics of an estuary is a constant interaction of terrestrial and marine processes and the boundary zones are continuously shifting. It is against the background of variable inputs into the system, variable dominance of sources, and changing quantities of inputs that management goals must be defined and approaches enacted. It is especially important in these times of heightened interest in global change and a concern for its accompanying impacts that a recognition of estuarine dynamics be a basis for estuarine management.

STUDY AREA

A study of changes in an estuarine environment was conducted along the coastal zone of New Jersey, specifically in the Great Egg Harbor estuary (Fig. 1). This estuarine system is part of the general barrier island and embayment association characteristic of the Mid-Atlantic portion of the United States (Walker and Coleman, 1987). It has developed in response to the geological history of sea-level rise and sediment availability during the past several thousand years. The pattern of development, however, has been variable and has even reversed during this time. Within the past several centuries, the pattern has changed again as estuarine systems are responding to accelerated sea-level rise and to modifications of sediment inputs. Measurements and observations from the current century reveal that natural processes are producing changes within the estuaries that are interacting both with human-induced changes and with management attempts to control the changes (Kennish, 1992).

The Great Egg Harbor estuary lies at the mouth of the Great Egg Harbor River. It is bounded by a barrier island on its ocean side. It is flanked by extensive saltmarsh development along its coastwise margin, and has a large, shallow, open water body in its center. The estuary connects with the ocean through the Great Egg Harbor Inlet, a break in the chain of barrier islands in this portion of New Jersey. The Great Egg Harbor Inlet is described as being flood-tide dominated because of the deltaic accumulation at the inland position of the inlet, leading into Great Egg Harbor estuary. The flood-tidal delta is composed of a group of marsh-covered islands and adjacent shoals, separated by tidal channels. Flow measurements and in the inlet and channels during 1993 show that general tidal circulation of the estuary is counter-clockwise, with Ship Channel carrying about 56.4 % of the tidal inflow and the Intracoastal Waterway channel conducting about 34 % of the tidal outflow (Psuty et al., 1994). Short term measurements of the sediment transport during this time suggest that there is a net input of sediment from the marine environment into the estuary. Fine sand and very fine sand are moved as bed load, whereas silt and very fine sand are conveyed as suspended load.
There are few earlier measurements of flow and no earlier measurements of sediment transport in Great Egg Harbor, so that it is impossible to conduct a quantitative comparison of the temporal changes over a long time period. However, there is a photographic record of the islands and estuarine margin (1:20,000 scale) that extends back to 1940. The most recent photographs available were taken in 1991 (1:10,000 scale). These photographs permit an areal and spatial comparison of the shapes and locations of the flood-tidal deltaic islands, and it may be hypothesized that spatial/temporal shifts of the islands individually and in groups are manifestations of the adjustments to changes in flow regimes and to changing sediment inputs during the recent decades.

DATA COLLECTION

A photographic comparison was accomplished by digitizing and registering each of four flights over

the study area. Shoreline position of the features on the relatively large-scale photographs was very good. Standard measurements of error resulted in a spatial resolution of within $\pm$ 2 m when registered to the common base. Numerous comparative tests were run on the spatial data collected from the images (Table 1). Among the results, the data indicate that the centroid of the islands as a group, for the period 1940-1991, had a displacement of about 102 m to the east and about 62 m to the north, or a shift toward the inlet. This measure is a comparison of the position of the geometric center of each of the islands, averaged for the group. Further, the areal extent of the islands has decreased about 5% for this time period, from 2,976,087 m^2 in 1940 to 2,835,535 m^2 in 1991. In one case, an island had disappeared completely during this time, replaced by a subaqueous shoal. The average orientation of the long axes of the islands retained a similar azimuthal bearing during this period, indicating that the general reduction was accompanied by a shift of the centroid of the islands toward the inlet and not by a reorientation of the islands.

Sedimentation patterns in the estuary and among the flood-tidal delta components portray a classic relationship between grain size and channelled flows. The high flow velocity tidal channels are locations of the coarser sediments whereas the interchannel shoals are locations of finer-grained sediments (Fig. 2). The coarsest sediments are found either at the inner margin of the estuary where older Pleistocene gravels are encountered, or in the channels where large quantities of coarse shell fragments accumulate.

The channel bottom sediments tend to be fine sand with some high velocity areas characterized by accumulations of medium sand and shell fragments. Most of the highest velocity channels are lined with a lag of very large clam valves. The interchannel shoals are a mixture of very fine sand and silt with an admixture of fine organic detritus. Generally, the shoal areas have a slightly coarser mean grain size nearer the channels and a slightly finer mean size in mid shoal or to the lee of the saltmarsh islands.

A series of vibracores were taken in the estuary to relate the surface sedimentation characteristics to those found at depth. In places, the cores portrayed a consistent sediment size for many meters, indicating that a similar sedimentation habitat persisted during the accumulation. Others showed variation with depth. One example is selected from a shoal located to the lee of marsh islands where the flows are very low at present (Fig. 3). The surface sediments collected in this have a mean grain size toward the finer margin of the very fine sand category. Viewed through depth, the mean grain size does not change much and stays within very fine sand, although there is a modest coarsening with depth. This location was probably always in a shoal location near to a distributary channel and not exposed to high velocity flows during the accumulation of these sediments. A second core (Fig. 4) shows a considerable coarsening with depth. This is indicative of a change from higher flow velocities in this zone in the past, but becoming more sheltered with time. This might the result of a shifting channel which was closer to the site in the past, or it may be a general spatial expansion of the flood-tidal delta which accumulated fine-grained sediments and extended onto the adjacent shoals, thereby extending the sheltering effects.

A deep core located inland of the inner margin of the flood-tidal delta (Fig. 5) revealed considerable complexity. The deepest portion of the core, 4.05 m below mean sea level (bmsl), contains sediments with a mean grain size in the middle range of the very fine sand category, indicative of open water with flow. It may be near a channel location or in an area with large volumes of water being exchanged in a broad zone. Within the core there is a length of about 1.5 m containing large numbers of oyster valves, *Crassostrea virginica*, intermixed with silt and very fine sand. This portion of the core has both single valves and articulated valves, in place. This part of the estuary was a location of an oyster reef in the past. There are a few oysters present farther upstream in the estuary at present but most of the population has succumbed to a oyster disease and oysters are not available in commercial quantities now. Above the oyster bank, the sedimentation sequence in the core returns to very fine sand and

then coarsens to the coarse boundary of very fine sand, with a large proportion of silt and with whole hard clams, *Mercenaria mercenaria*, in the surface sediment. The grain size variation from depth to the surface suggests that the conditions changed from an open exposed habitat to one of quieter conditions, likely to the lee of a portion of the tidal delta. Importantly, the changes in the benthic organisms suggests that this was accompanied by a change in salinity because the oysters are found at the freshwater margin of the estuary and the hard clams at the saltwater margin. Thus, this core depicts a changing habitat, most likely the product of sea-level rise and marine intrusions which displaced the oyster habitats farther upstream. It is also likely that the tidal-delta islands migrated inland with the sea-level rise and changed this portion of the estuary from open water to an area encroached upon by the inlet-related sedimentation.

The depositional environments in this last core probably represent a time span of several thousand years and probably relate to the Holocene transgression that is reported to have reached stillstand in this area about 2500 years Before Present (B.P.) (Psuty, 1986a). Changes in the estuary, however, are still occurring as a result of sea-level rise. The tidal gage at Atlantic City, New Jersey (Fig. 6), located 15 km to the north, depicts an average annual rise of about 4 mm from 1930 to the present (Lyles et al., 1988). Cores taken in the flood-tidal deltaic wetlands provide yet another piece of evidence documenting modern sea-level rise. The upper portion of a core from one of the older portions of a saltmarsh was subjected to Cesium-137 analysis. ^{137}Cs is deposited from the air and is associated with atmospheric testing of atomic bombs. The peak production of atmospheric ^{137}Cs is regarded to be 1963. Analysis using this isotope usually means determining the depth of the peak concentration in the core. Once found, it is assumed that the sediment accumulation above this peak is post-1963. In the core analyzed in Great Egg Harbor, the ^{137}Cs peak was about 30 mm below the surface, or an average accumulation rate of about 6 mm per year.

ANALYSIS

Combining the data from the photographic survey with the sedimentological data, it is apparent that the estuarine islands are being modified by natural processes related to sea-level rise. One response to this condition is the continued elevation of the saltmarsh surface to maintain its position relative to sea level. However, the volumetric addition of sediment to the island is insufficient to support the elevation of the entire delta so there is a reduction in the areal size of the delta.

This reduction is occurring because of an inadequate natural supply from the offshore. Other scientists report a similar effect because of a reduction of sediment from the continental shelf (Kearney and Stevenson, 1991). Nearly all scientists agree that these changes are the product of an accelerated rise of sea level that began a few centuries ago and whose rate may be increasing. A consensus report was produced by the Intergovernmental Panel on Climatic Change (Warrick and Oerlemans, 1990) that described the several caveats in bringing so many pieces of information together but concluded that the most likely scenario called for a rise of 0.66 m by the year 2100. This is the value caused by an absolute increase in the world's ocean level. Local subsidence and compaction will cause relative sea-level to rise at a higher rate. And all of the world's estuaries will be affected by this rise.

Applying data from Great Egg Harbor, and from other estuarine cores in New Jersey, several scenarios can be developed that relate to management considerations in estuarine settings because of the current sea-level rise rates(Psuty, 1986b). As represented on Figure 7, the natural development of estuaries in New Jersey has progressed through several stages. The earliest stage on the figure represents a time of rapid sea-level rise and an estuarine system which was in constant disequilibrium. Because the rate of sea-level rise was so fast, the rate of infilling in the estuaries was unable to produce broad shoals and extensive wetlands. Indeed, it is likely that only a narrow wetland existed at the margins of the estuaries all during the early Holocene. The wetland would expand and contract in relation to

the perturbations in sea-level-rise rates; expanding during the less rapid rates and contracting during the more rapid rates. In New Jersey, the early period of sea-level rise ended about 2500 yr BP when the rate of rise was substantially reduced. During the rapid rise period, the rate from about 7000 yr BP to 2500 yr BP was about 2 mm/yr (0.2 m/century). This value is an average rate during this time and certainly there were variations about this mean number. However, around 2500 years ago, the rate had fallen to an average value of about 0.75 mm/yr (0.075 m/century). Data from the cores after 2500 BP are interpreted to describe a condition in the estuary of the initiation of extensive wetland development as sedimentation in the estuaries was greater than the rate of sea-level rise and thus the estuaries began to shoal and wetlands extended farther and farther into what was previously an open-water environment behind a string of barrier islands. Ecosystem equilibrium was established in the sense that horizontal accretion dominated within the estuaries as a positive sediment budget prevailed in the embayments. Further, according to this interpretation, it was only in the last several millennia that extensive wetlands became characteristic of the estuaries. Prior to that time, the estuaries were open-water embayments with very little shoal development.

In the past several centuries, there is evidence that the modern rate of sea-level rise is once again disturbing the balance between sediment input and the volumetric accumulation, horizontal as well as vertical extent, in the wetlands (Orson et al., 1985). The documented relative rise of sea-level of 6 mm/yr in Great Egg Harbor and 4 mm/yr in the next estuary to the north, at Atlantic City, point to a return to a disequilibrium condition. Several investigators have suggested that the change is currently in place and the wetlands are disintegrating into smaller units, or there is net erosion at the wetland margins to decrease the wetland areas (Kearney and Stevenson, 1991; Psuty, 1986; Stevenson et al., 1986).

MANAGEMENT IMPLICATIONS

Management and retention of estuarine wetlands is a suitable topic for environmental policies and strategies because the wetlands are a very important component of the productivity of the estuary. But coupled with the driving force of sea-level rise, an inadequate sediment supply, and the anthropogenic effects, the dimensions of the change can be dramatic. Yet, it is important to stress that not all estuarine areas are undergoing similar rates of relative sea-level rise, or similar rates of sediment input. Very basic questions need to be considered regarding the rates at specific places and of the responses to these rates (Hoffman et al., 1983) and how this change is manifested in the geomorphological (Psuty 1986b) and biological components of the estuarine system (Frank et al., 1990; Kennedy, 1990). The questions require an analysis of past events, either the past centuries, or least the changes within this century. However, it is not always easy to separate the changes produced by the natural variations in the system from those caused by human perturbations. This is a challenging component of the riddle. But the issue may not be so dependent upon identifying the reason for the changes as identifying the changes, the trends of the changes, and the consequences of the changes.

Of especial importance is that most of the world's estuaries have a history of sea level rise in the past several centuries, and there is considerable information that can be derived from a study of these environments that will assist in developing models as to what the future sea-level rises will bring. The data are in the charts, maps, aerial photos, in the sediments, in the wetland peats, and in the organisms that have occupied these environments. The record is there, it will have to be sampled, deciphered, and extrapolated to future rates of changes. Equally important, the scientific knowledge that is gained by the realm of investigations into estuarine dynamics associated with sea-level changes will have to be translated clearly and unequivocally to the managers in order that decisions can be made based on this information. The managers and the scientists must have a similar data base so that policies, programs, and strategies can be derived from the

factual information. In this way, the management decisions can be exercised to enhance the desired objectives and can relate the components of the estuarine system to the planned multiplicity of uses in a proactive style.

CONCLUSIONS

In the short term, the major issue of environmental quality will drive most management decisions. Maintenance of those areas that continue to be productive natural systems will be a prime concern, as will the improvements to those locations whose areas are degraded. Economic development will continue to stress the estuaries because of the concentration of industry, commerce, food production, and urbanization. The short-term challenge will be to develop compromises that benefit both the humans in the estuarine settings and the resource itself.

The long-term challenge (a century) is more daunting. Rising sea levels will continue to cause natural stresses in the estuaries. Boundaries and gradients will shift spatially, and natural ecosystems will adjust to new distributions of water levels, salinities, temperatures, water depths, sediment budgets, and nutrient budgets. Barriers such as dikes and walls will partially limit the extent of the changes in the estuaries, but they will probably redirect the changes and cause increases in the magnitudes elsewhere. Of special importance is that the rise will interact with the cultural patterns of infrastructure and land use. It will be impossible to retain the status quo. Management decisions will be required to accommodate the relocation of resources and of land use. Management will mean providing for the multiplicity of uses within a dynamic system. The management practices will have to be equally dynamic and will have to retain a flexible allocation of resources as the zones of the estuary shift inland.

It is against the background of natural variation in estuarine habitats that management practices need to be applied. Recognition of the scales of natural changes and the rates of these natural changes are necessary considerations for management. A general model of rates and scales of equilibrium/disequilibrium development in estuarine systems is presented and implications for management are discussed.

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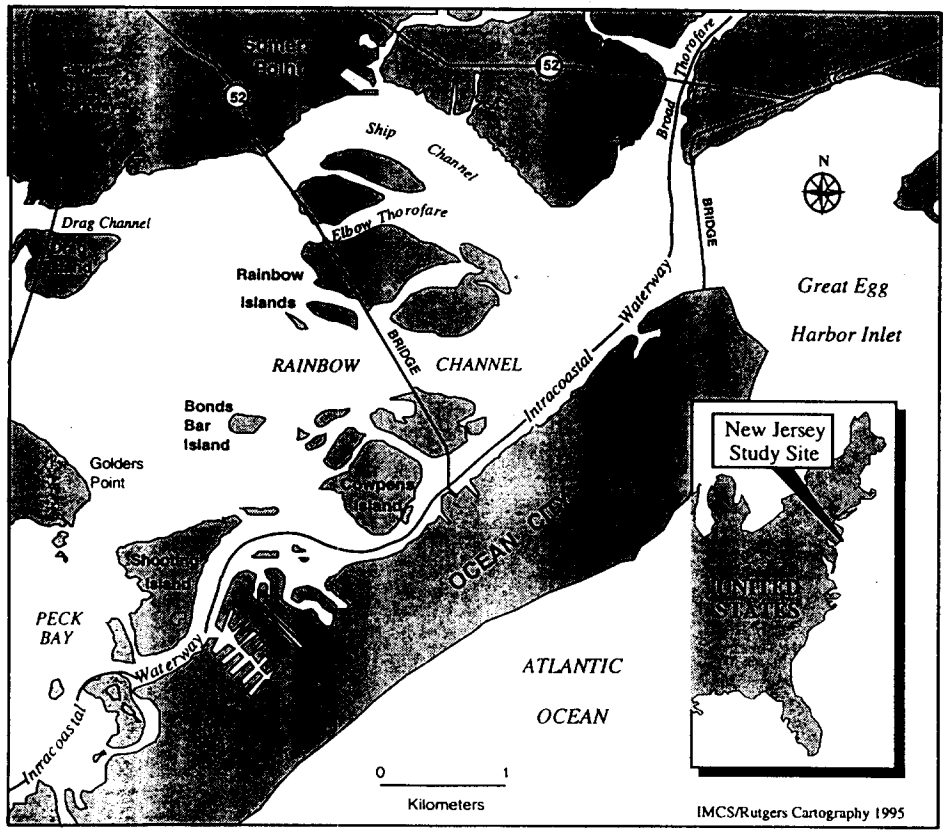
Table 1. Spatial change of islands composing the flood-tidal delta, interpreted from aerial photography.

Period	Change in area (%)	Shift of centroid (in m)		Rotation of long axis (+ is clockwise degree)
		East direction	North direction	
1940-1963	0.177	61.4	13.0	-0.905
1963-1981	-2.836	-0.3	9.0	+0.905
1981-1991	-2.115	40.6	56.6	-0.429
1940-1991	-4.723	131.6	61.7	-1.035

Fig. 1. Great Egg Harbor estuary, flood tidal delta features, and bounding conditions. Location in New Jersey, USA.



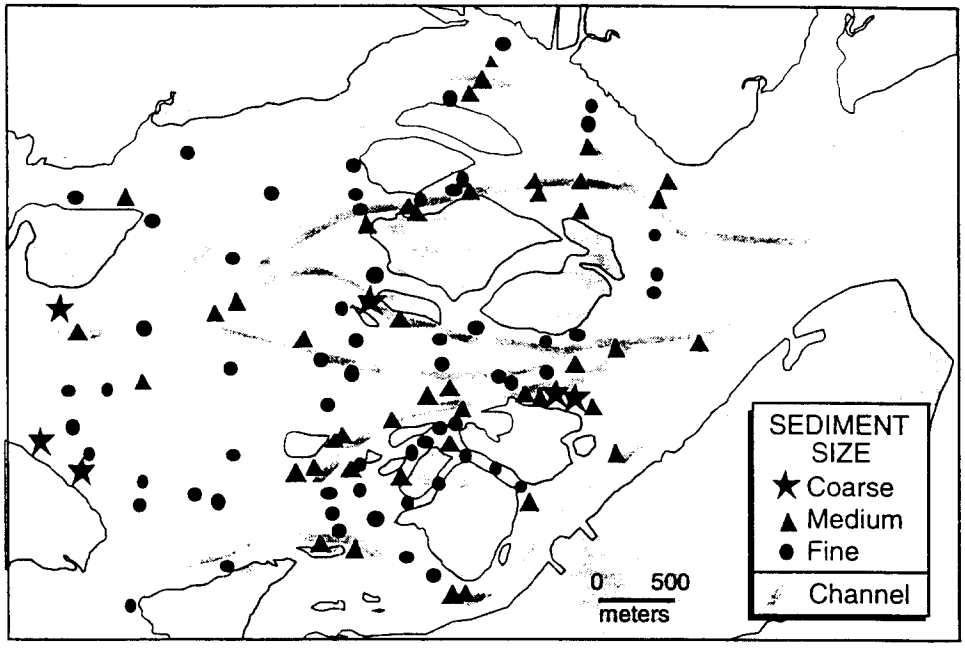
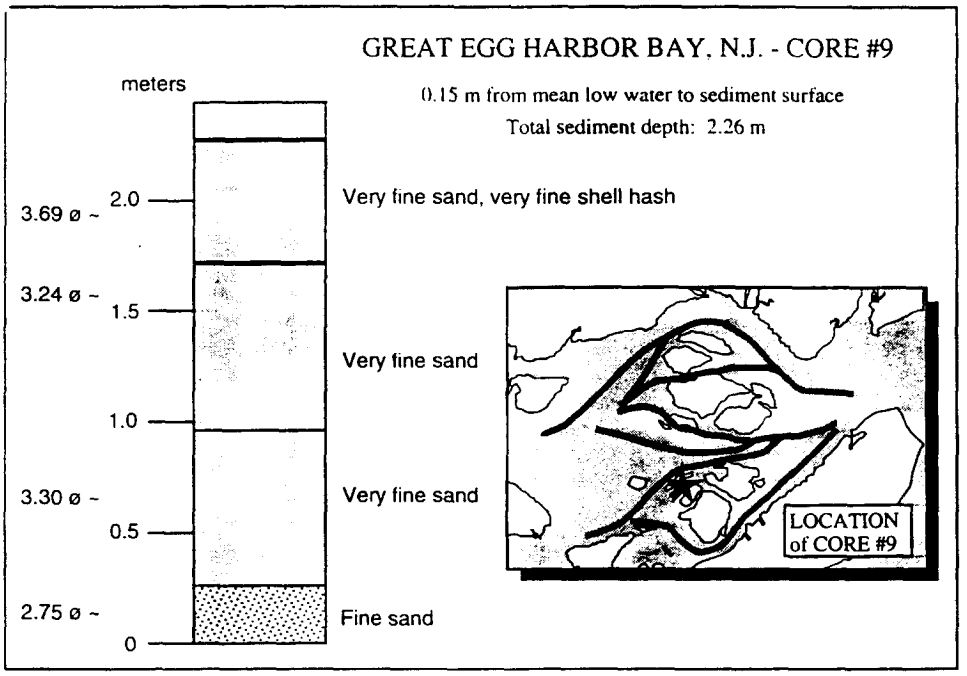


Fig. 2. Location of grab samples within Great Egg Harbor in relation to channels and shoals. Grain size shown in relative ranges.

Fig. 3. Core 9. Relatively consistent grain size with depth, some coarsening. Phi sizes denote the mean values for the partitions in the core. Descriptions apply to the partitions in the core. Dark lines in inset show locations of channels through flood-tide delta.



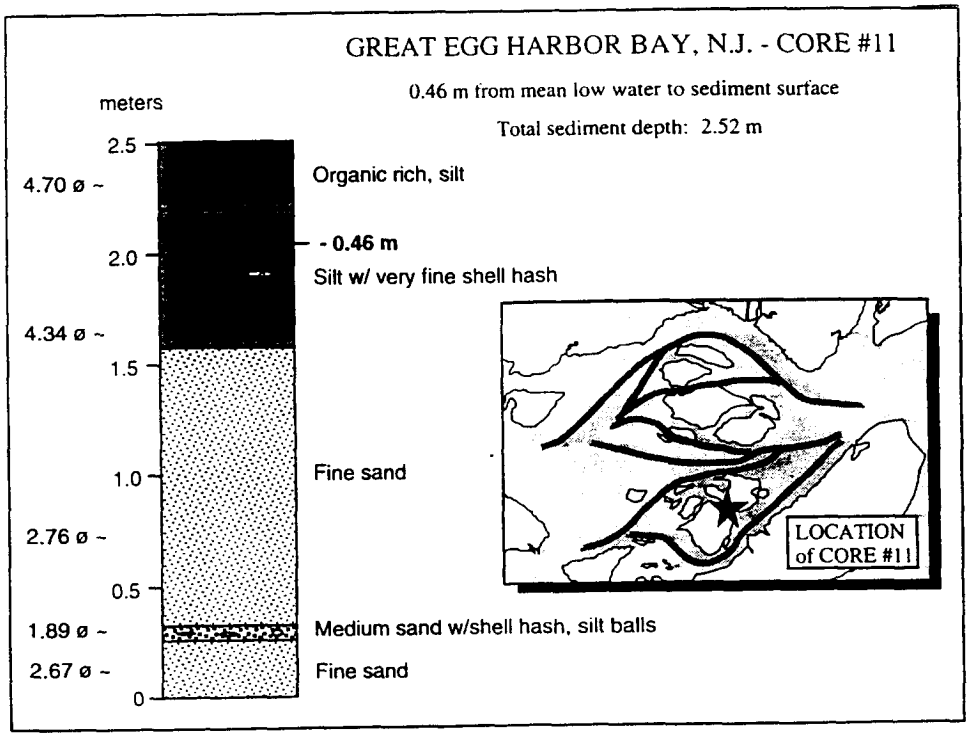


Fig. 4. Core 11. Coarsening of mean grain size with depth, related to changing energy levels in area of deposition. Phi sizes denote the mean values for the partitions in the core. Descriptions apply to the partitions in the core. Dark lines in inset show locations of channels through flood-tide delta.

Fig. 5. Core 1. Change in habitat with depth. Phi sizes denote the mean values for the partitions in the core. Descriptions apply to the partitions in the core. Dark lines in inset show locations of channels through flood-tide delta.

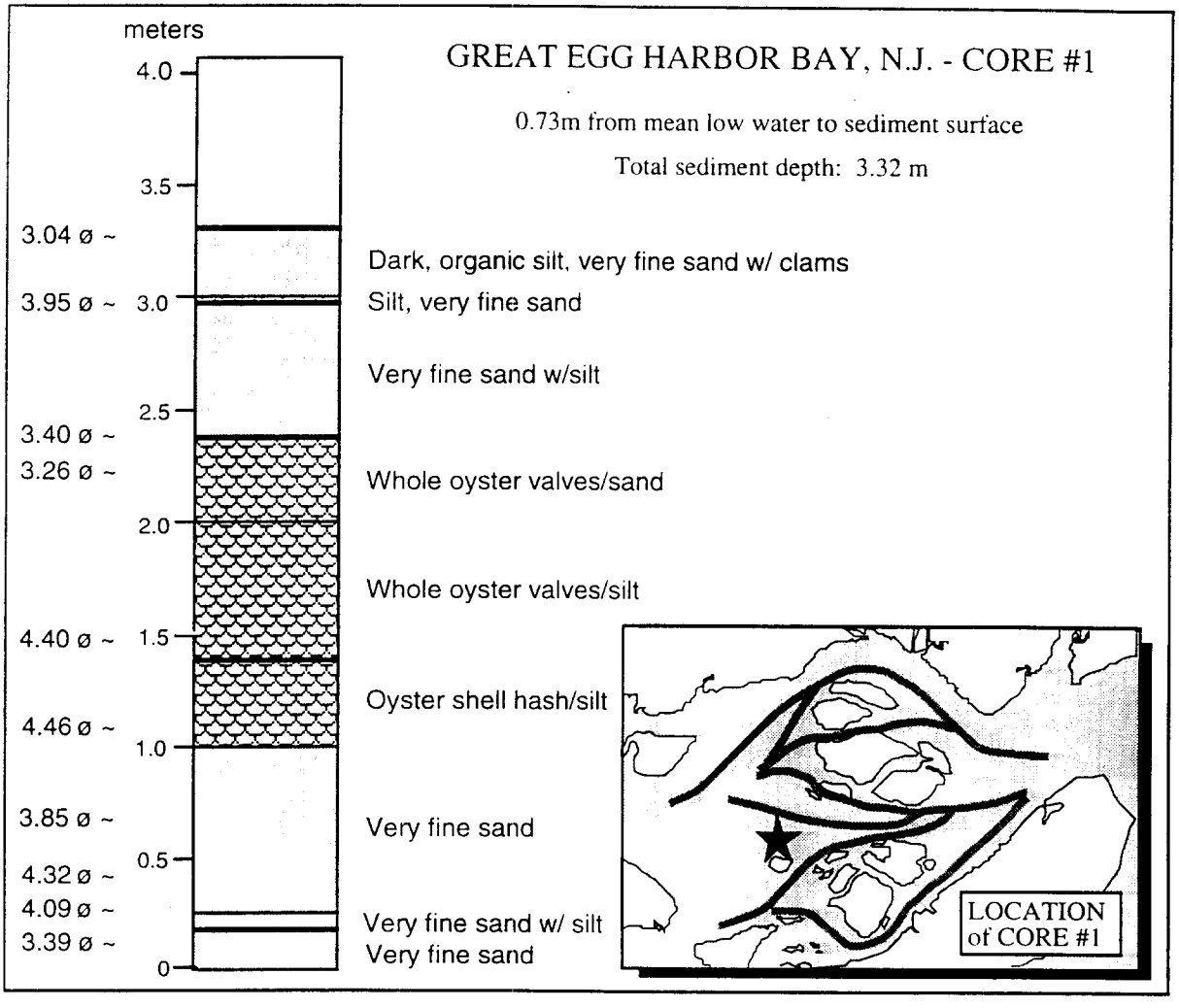
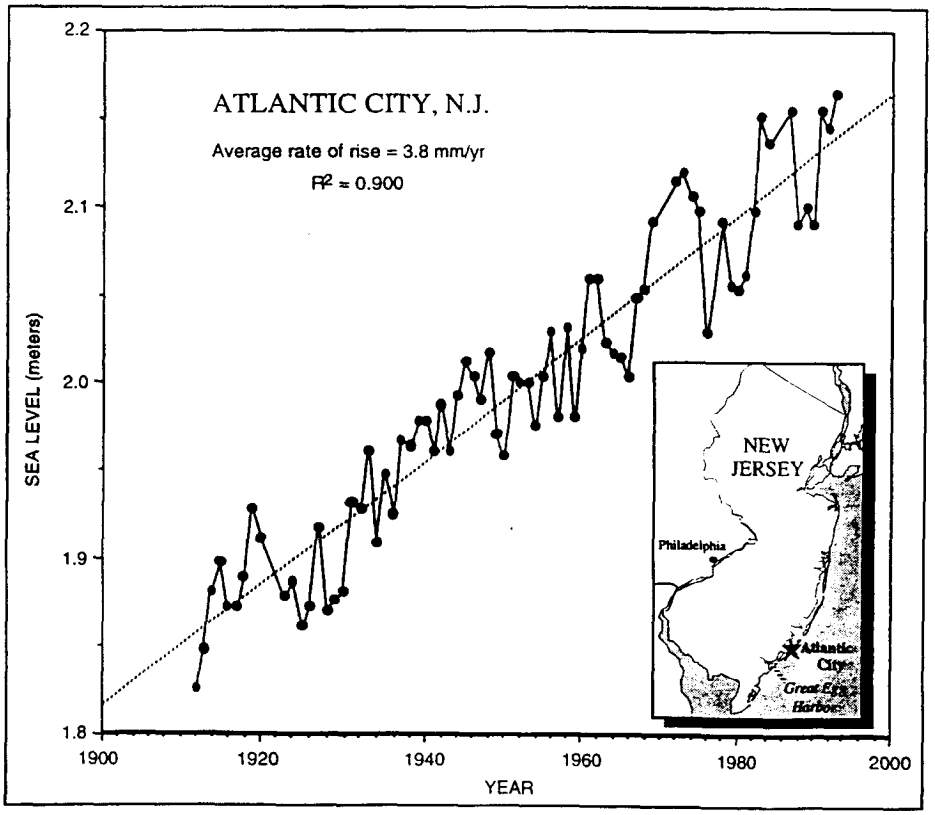


Fig. 6. Trend of relative sea-level rise recorded at tidal gage located at Atlantic City, New Jersey. Linear regression line shows general rate of rise for duration of record.



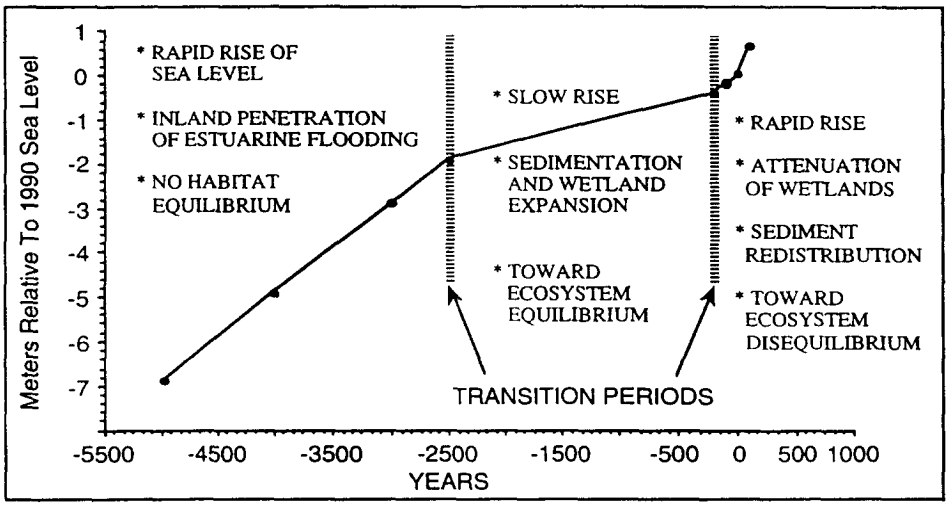


Fig. 7. Portrayal of the rates of sea-level rise and the expansion or attenuation of the estuarine habitats in a temporal context. The changing areal dimensions and the spatial associations are related to the balance between the three-dimensional volumetric rates of inorganic and organic accumulation in the estuaries and the one-dimensional vertical rate of sea-level rise. The rates of rise in the past century, and probably the preceding one as well, exceed the rates of the earlier period when the estuaries were largely aquatic environments.

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STUDY FOR IMPROVEMENT OF HYDRAULIC CONDITIONS OF POLDER AREA IN THE COASTAL REGION OF BANGLADESH BY DEVELOPING A MATHEMATICAL MODEL FOR POLDER AREA OF THIS REGION.

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ABSTRACT

Hydraulic conditions of polder areas in the coastal region of Bangladesh have been changed due to siltation of rivers connected with these polders. A computer based one dimensional mathematical model has been performed to study the improvement of hydraulic conditions of the polder areas. The results show the potential of the mathematical model for evaluating the impacts of human interference and other factors on the flow regime of river system in polder areas. A mathematical model constitutes a useful computational tool for the integrated development, control and utilization of water resources.

INTRODUCTION

Flooding is one of the major problems in Bangladesh. This flooding occurs almost every year mainly due to the drainage congestion in the river network of the coastal region of Bangladesh. The coastal region in Bangladesh is a part of the largest delta in the world. It drains the Ganges, Brahmaputra and Megna rivers into the Bay of Bengal. During the 1960's large areas of land in the coastal region were brought under cultivation by the construction of several polder embankments. Siltation of the tidal channels since that time has been one of the more widely observed responses of nature to man-made alterations in the coastal area. Near the inland limits of tidal intrusion the siltation has been severe and progressive. The results have been a continued deterioration of the drainage capacity of the river system. For this reason water can not move from the polder area, and as a result waterlogging started inside the polders and gradually some polders became stagnant water bodies. Water pollution took place in these stagnant water bodies and consequently the environment became polluted in the coastal region.

Computer based mathematical models are being increasingly used by engineers and planners in the Bangladesh for water resources planning, management and design, as well as to study the impact of various existing and proposed projects. This paper deals with the development, calibration and application of a mathematical model which can be used for the study of improvement of the hydraulic conditions of the polder area of the coastal region of Bangladesh, as well as study of drainage congestion problem.

DESCRIPTION OF MODEL AREA

The model area

The southern limits of the model area have been placed at Mongla on the Pussur River and at Nalianala on the Sibsa River. The northern limits of the model area at Bardia on the Nabaganga River which controls the inflow of the fresh water to the model area from the Ganges-Gorai river system. The western limits coincides with natural or man made drainage basin boundaries (height of land, or road and rail routes) and are practically closed. Along the east side the dominant Rupsa-Kazibacha-Pussur river system forms a soft margin, which is sufficient to deliver correctly the fresh water discharges arriving from the upland as well as to represent correctly the tidal action in the model area.

The river system

Within the model area itself a network of small rivers and tidal channels exists. Upland discharge is generated from rainfall occurring in the model

area. The Harihar, Muketeswari / Hari, Buri Bhadra, Solmari, Salta, Hamkura and Hatia rivers all originate within the model area (Fig. 1) and provide drainage paths to the south. These rivers are also connected to the major Pussar-Sibsa tidal river system (Fig. 1) to the south via a complex arrangement of interconnecting channels. The Pussur and Sibsa rivers are also interconnected via smaller cross channels and the mouth of both rivers are open to the sea, the Bay of Bengal. Major upland discharge into the upper reaches of the Pussur-Sibsa system occurs via the Rupsa and Kazibacha rivers.

Flood control embankments and polders

During the implementation of the Coastal Embankment Project (CEP) embankments were constructed along the tidal rivers in the southern part of the model area to prevent tidal flooding. Many small sluices were built in the embankments to allow drainage from the polders to the tidal channels. Within the polders low-lying areas of land known as 'beels' exist. The beels are separated by road embankments and naturally occurring land formations and hence form separate drainage units. Drainage of the polders takes place during tidal ebb, when sluice gates are opened. The low water levels in the tidal channels create sufficient hydraulic head difference to permit drainage by gravity from the polders. During tidal flood the sluice gates are automatically closed to prevent the intrusion of saline water into the polders.

MATHEMATICAL MODEL

The MIKE11 soft ware of the Danish Hydraulic Institute (MIKE11, 1989; Saint Venant, 1973) was used in the study. The model is based on an implicit finite different solution of the Saint Venant equations.

$$b\frac{\partial h}{\partial t}+\frac{\partial Q}{\partial x}=q$$

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}(\beta Q^2/A)+gA\frac{\partial h}{\partial x}+\frac{gn^2|Q|}{AR^{3/4}}=0$$

where A is the flow area, b is the width of channel, h is the stage, Q is the discharge , R is the hydraulic radius, g is the acceleration due to gravity, n is the Manning's roughness coefficient, ß is the momentum distribution coefficient, q is the lateral inflow rate per unit length.

GEOMETRIC AND HYDRAULIC DISCRETIZATION

Data collection

Most of the channel cross sections used in the model were obtained from the field surveys and have been tied to the PWD (Public Works Dept.) datum through land surveys carried to established benchmarks in the vicinity of the cross sections. The actual surveyed crossings were chosen in the field to be representative sections of channel, without unusual local influences, with relatively straight streamlines, and lying beyond the effect of channel junctions. Positions were estimated or determined by chaining from local land marks and were transferred to maps with the aid of the aerial and satellite images.

Hydrometric data, including water level and discharge were also collected from the field observation. Rainfall runoff data as runoff coefficient and direct precipitation were collected for the year 1990 to provide lateral inflow into the model.

Polder and embankment information like height of the embankment, crest level, width, vent size of the sluice gate, sill level etc. were also collected from the field investigation.

Schematization of river system

The schematization of river system was carried out on the basis of the 1:5000 index maps and the aerial photographs. In this manner a complete hydraulic network was assembled (Fig. 2), which reflects the topographical features of the original system.

The river system is represented in the model by 35 branches, 25 junctions, 1 inflow boundary point

and 2 water level boundaries at the outflow point as shown in Figure 2. Total length of the schematized river is 350 km. Selection of the river branches was based on the following factors: size of the river in terms of width, depth, magnitude of peak discharge, importance of river in relation to other nearby rivers and importance in relation to existing polders.

Schematization of polders (hydrological catchments) and structures

The schematization of hydrological catchments in the modelled area is shown in Fig. 3. The catchment delineation was based on the broad scheme used in the South West Region Model at the Surface Water Modelling Centre (Pilot Calibration Report, 1990). Within the model areas the large scale catchment areas were divided into the subcatchments corresponding to the command areas of the various drainage sluices. Locations of the drainage sluices included in the model are shown in Fig. 4. The naming conversion adopted for these structures and the areas they serve is loosely based on the labels used on Bangladesh Water Development Board (BWDB) index maps. For example the structure located at Salua at the source of the upper Solmari River drains a portion of polder no 25 and is known 25DS-1. In the model both the structure and its associated sub-catchment are labelled as 2501 (Fig. 4). Some sub-catchments and their structures, which have same sill level, vent size etc. and are very close to each other were lumped in favour of model simplicity.

Model boundaries

The external model boundaries, marked on Fig. 2, are located on the Pussur River at Mongla port, Nalianala on the Sibsa River and at Bardia on the Nabaganga River. The first two are the tidal water level boundaries which controls the ebbing and flooding of tide water within the channels and tidal margin areas of the model. The boundary at Bardia is the river discharge boundary which control the inflow of the fresh water to the model area.

Internal zero-flow boundaries were defined for the source points of the main rivers which drain polder areas and the non-embanked upland areas at the north end of the watershed. These rivers noted on Fig. 2 and Fig. 4 are the Harihar, Buri Bhadra, Mukteswari, Hamkura, Solmari and Hatia. The water they contain in the model results from the combination of tidal action and fresh water inflow from adjacent catchments. The rate of production of fresh water from precipitation within the catchments to the point at which the water was considered available for delivery to the main stream was calculated separately using MIKE-11's hydrological rainfall runoff soft ware (NAM).

CALIBRATION OF THE MODEL

The model was calibrated against water level of the month of May 1990 to August 1990 in order to cover both the dry and wet seasons, using time step of 15 minutes which allowed satisfactory resolution and Courant condition (Courant & Friedrichs, 1948) of the tidal nature of flow in the model area. Computed water level was compared with measured values of water level at 4 polders. Calibration yield values of Manning's roughness coefficient (Barnes, 1967) varied from 1/30 to 1/40.

Figs. 5(a), (b), (c) and (d) illustrate the calibration performance for typical polders for which comparable 1990 observations were available.

The multi-vent regulators located at the outlet of the Mukteswari River and upstream at Dhakuria were operated as open culverts after the end of June 1990. Water nevertheless accumulated in the low-lying southern portion of the basin as the wet season continued. As shown in Fig. 5(a), the model reproduced the observed behaviour relatively well. Due to the poor description of the Mukteswari channel above the Hari River, modelled rates of flow out of the storage area could be considerably in error, but the large size of the basin means the local water levels offstream and in the drowned channel remain fairly stable.

Local intervention at the Khapalia sluice, just downstream on the Hari River, was a major factor in determining polder water levels above the structure during 1990. The flap gates were

held open most days from June 1 to June 13, allowing water to enter the polder. For simulation of this period, two-way flow at the sluice was allowed for the thirteen days, and normal flap operation was assumed for the rest of the time.

The northern parts of Polders 25 and 27 are drained by the Hamkura and Solmari rivers, the upper reaches of which are highly constricted by silt accumulations. Recent seasonal, flooding patterns in the two low-lying catchments have been quite different. Being served by several sluices which empty into parts of the two rivers not yet seriously affected by the progressive siltation, Polder 27 maintains a water level well below that of its northern neighbour. The latter's three main outlets are all located near the upper ends of the two rivers. Figs. 5(b) and (c) shows the model simulation results of two basins under 1990 conditions.

Polder 25 (Fig. 5(b)) water levels are relatively closely followed by the model through the 1990 monsoon, indicating that model representation of the drainage constriction is reasonable. Polder 27 (Fig. 5(c)), however, exhibits the expected well drained behaviour in the simulations, but shows an unusual retention of water through June in the observed record. It is conceivable that local intervention to retain some water following the early rains of late May has affected the water level gauge location, which was confirmed by field investigation.

Fig. 5(d) shows the calibration result of Polder's water levels. Computed water levels match reasonably with measured water levels, except in the months of June and August where the model overestimates the water level. This might be due to the model's limitation.

CASE STUDY: IMPROVEMENT OF HYDRAULIC CONDITION OF POLDER AREA (POLDER 25)

Generally the performance of polder drainage capacity depends on the daily variation of water levels in the tidal channels. If for any reason the tidal amplitude reduced in the vicinity of the outlet sluices, the whole drainage system is adversely affected.

Due to siltation of Hamkura and Solmari rivers the upland discharge generated with the Polder 25 is insufficient to provide the required flushing to maintain the drainage capacity of the channels. Siltation severely constricted the conveyance capacity of Hamkura and Solmari rivers by which decreased channel capacity increases and the effective hydraulic friction, which causes the damping of the propagating tidal waves, leads to a reduction in tidal amplitude of the above mentioned rivers. As a result the velocity of the flow in Solmari and Hamkura rivers reduced remarkably, which is the main cause of water-logging in Polder 25.

To improve the hydraulic condition of Polder 25, it is necessary to preserve sufficient velocities in the channels both in flooding and ebbing periods, which are connected with this polder. It has been suggested that Solmari should be dredged from its mouth (0.00 km) to the confluence between Solmari and Salta rivers (Fig. 1) i.e. a total of 14 km from the mouth, because from the field investigation it has been found that the Solmari River is more silted than the Hamkura River and the rate of siltation of the Solmari River is much higher than of the Hamkura River. It has also been suggested that the mouth of the Solmari River which is connected with Polder 25 should be open, i.e. no regulator in the mouth of the river. The channel dimensions for Solmari River are given in Figure 6.

Using the new channel dimensions of Solmari River (Fig. 6), the above described model has been run again for the period of May 1990 to August 1990.

The result is compared with the existing simulation shown in Fig. 7. From the figure it has been seen that the water levels in Polder 25 rise earlier and that the increase in tidal volume is reflected in large increases in both ebb and flood velocities in the Solmari River. This is the indication of the improvement of hydraulic condition of this polder.

CONCLUSIONS

Simulation of water levels in a polder area has been performed by a one-dimensional mathematical model. The result shows the

potential of computer-based simulation models for evaluating the impacts of interferences on the flow regime of rivers and polders. Improvement of the hydraulic conditions of polders can be achieved by dredging the rivers connected with the polders in the coastal region of Bangladesh.

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Fig. 1. Map of the Model Area.

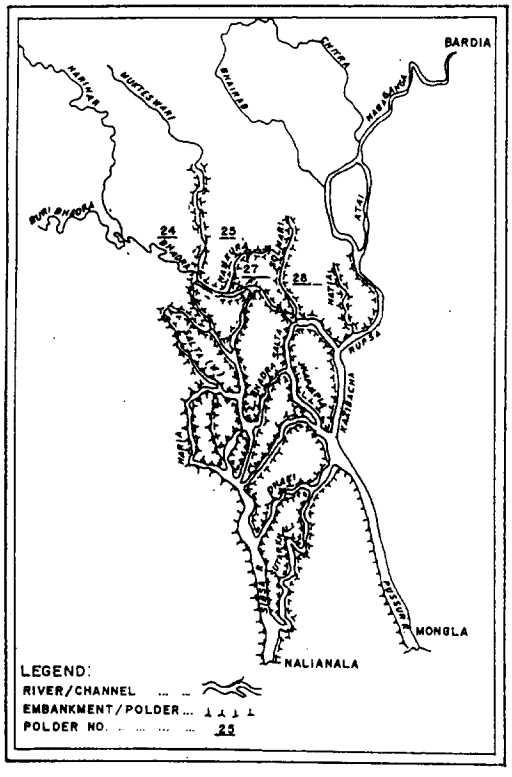


Fig. 2. Schematic representation of the river system for mathematical modelling.

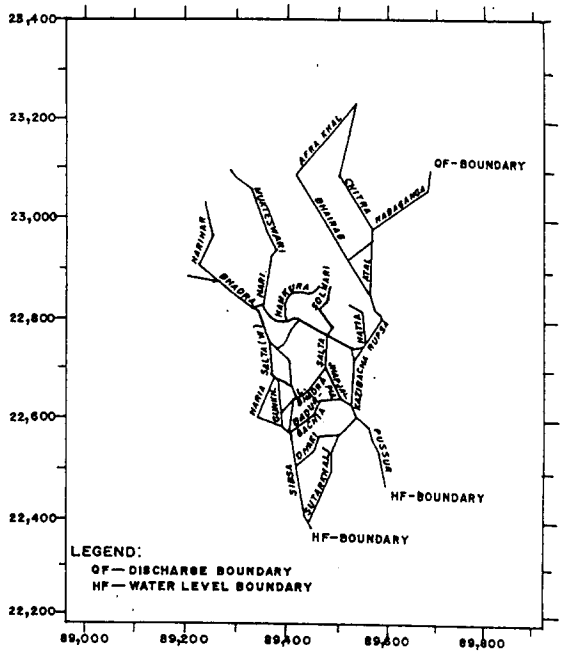


Fig. 3. Hydrological catchment delineation.

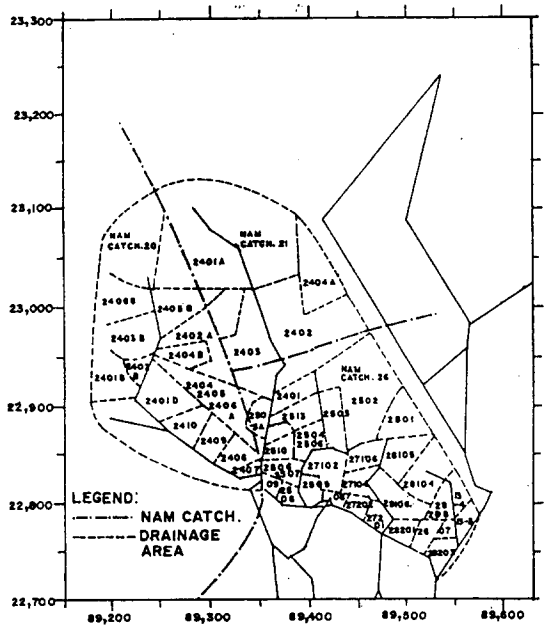
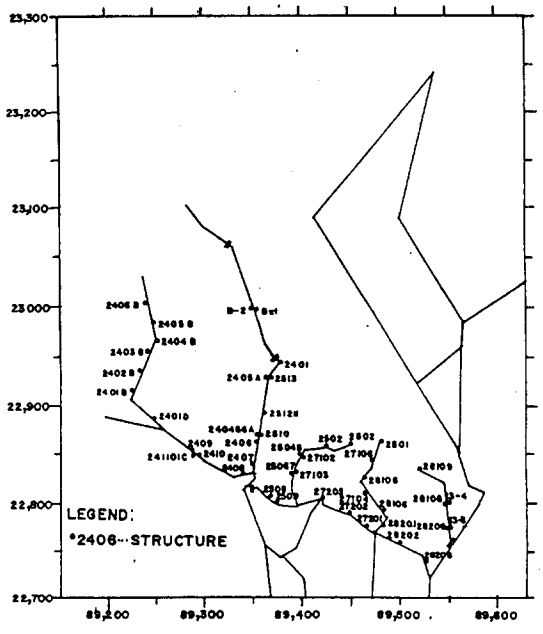


Fig. 4. Location of the structure included in the model.



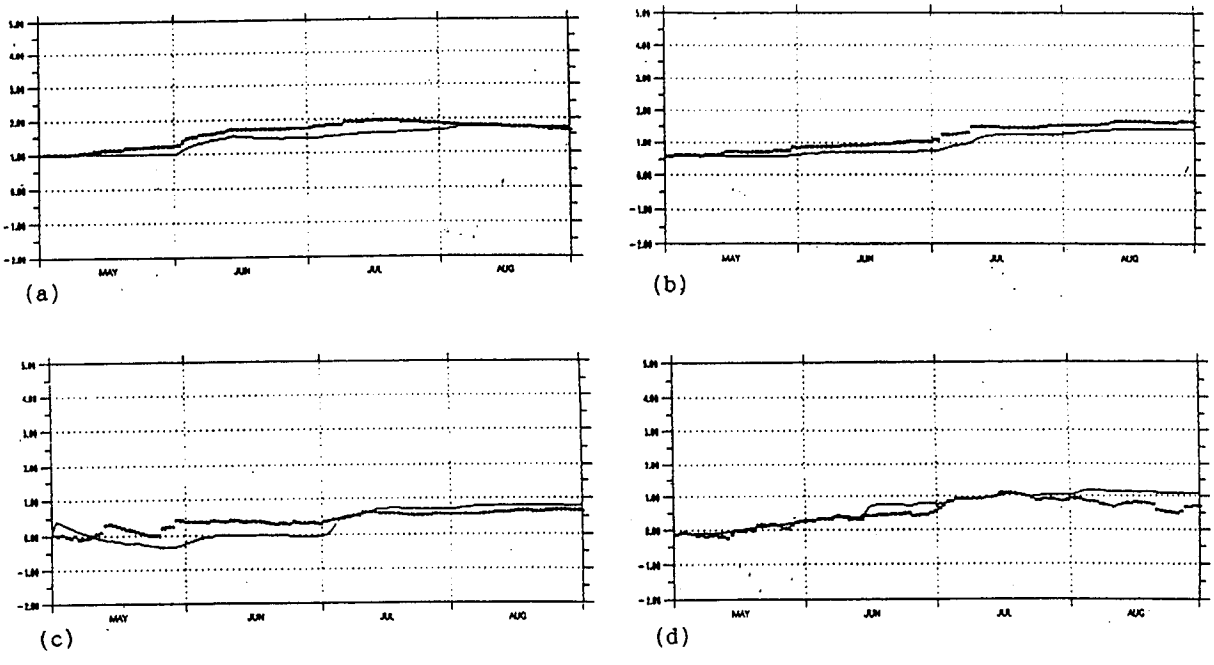
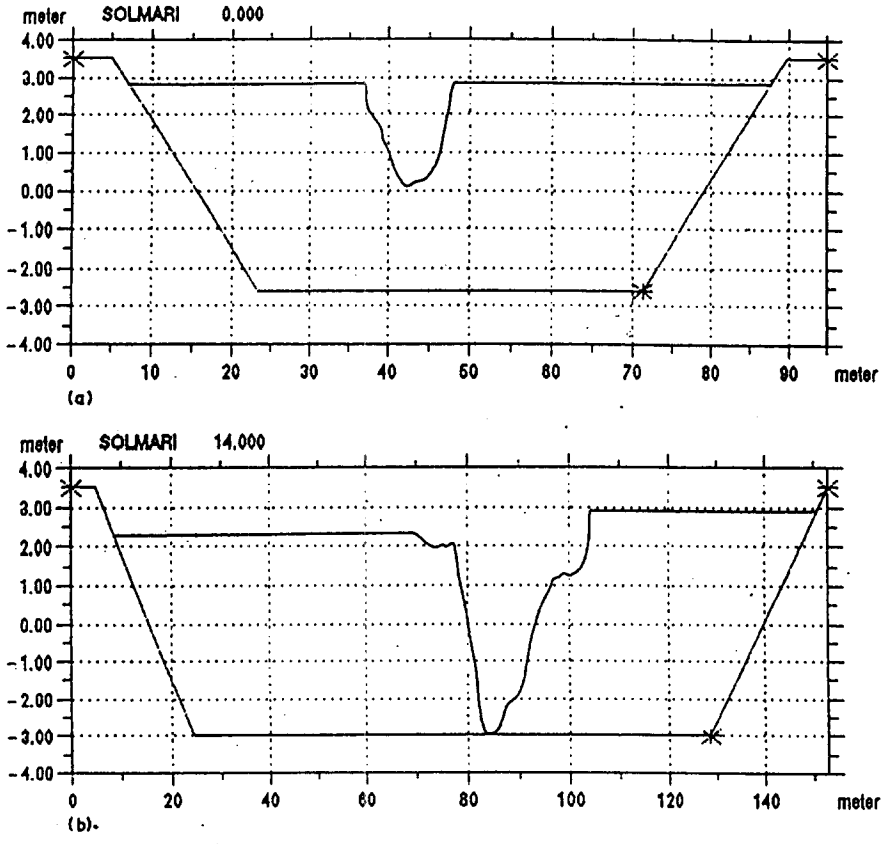


Fig. 5. Comparison of computed and measured water levels for May-August 1990. (a) Polder-24, (b) Polder-25, (c) Polder-27 & (d) Polder-28. ******* measured; ——— computed.

Fig. 6. Modified channel dimension for the Solmari River.



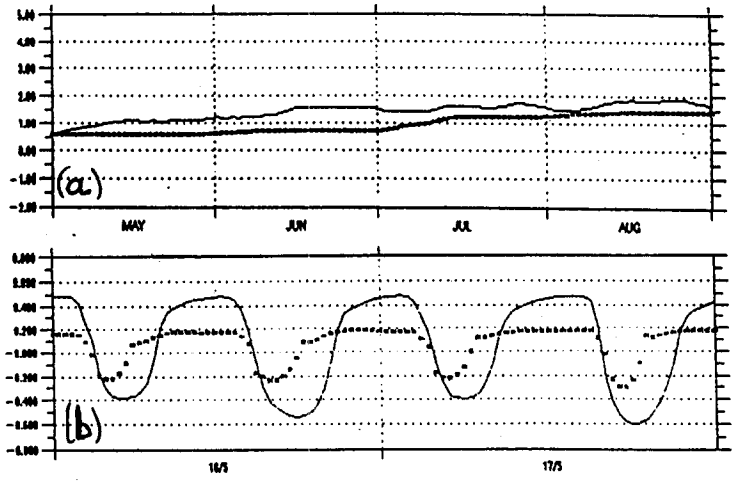


Fig. 7. Effect on polder and channel hydraulics after using modified cross sections of the Solmari River. (a) Water level (m) inside Polder 25, using modified cross sections of the Solmari River. (b) Velocity (m/s) at Solmari River after using modified cross sections. **** existing; ——— after using modified cross sections.

SESSION III

Regional & National Case Studies Africa-Pacific-Caribbean

Chairman: N. Nasu & K. S. Adam
Rapporteurs: J. P. Tastet & N. Nasu

Proc. Int. Conf. 'Coastal Change 95' Bordomer-IOC, Bordeaux, 1995, p. 265 - 267

COASTAL CHANGE: IT'S IMPLICATIONS FOR EASTERN AFRICA

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ABSTRACT
The coastal region of East Africa and the Western Indian Ocean encompasses the coastlines of four mainland countries extending from Somalia in the Horn of Africa through Kenya and Tanzania to Mozambique in the south, as well as five island nations, including the Seychelles, the Comoros, the Mauritius, Reunion and Madagascar (Fig. 1). Together, these countries have 12,000 kilometres of coastline and a rapidly growing population of about 55 million (UNEP, 1988, 1989; Granlund, 1994). The coastline of East Africa is an area of great physical beauty, rich in living resources. Palm-fringed beaches of white coral sand lead down to tranquil lagoons, enclosed by spectacular coral reefs with their wealth of colourful fish, shells and coral. The coastline has vast Mangrove forests, high cliffs, wide stretches of sand dunes and numerous offshore and oceanic islands (UNEP, 1989).

Along the shorelines of East Africa and the Island states of the Western Indian Ocean, however, coastal change is a common problem damaging or threatening tourism and communication infrastructure. Coastal change as it occurs in the region, is usually caused by natural changes in the prevailing condition of sedimentation along the shore, or as a result of human interference with coastal sedimentation systems. The usual causes of coastal change in the region include coastal erosion, sediment accretion and coastal reclamation. The latter is commonly carried out in the Island States where land is at a premium. This usually involves filling of wetlands and other lowlands to create new land area for construction. In the Seychelles, for example, this method was used to reclaim large areas where the airport and Port Victoria are built (Odada, 1993).

In many countries of the region, the rate of coastal erosion, or in the case of Malindi in Kenya, of sediment accretion and the resulting environmental degradation and economic loss is on such a scale alarming. Retreat or recession of coastline causes many problems, including the displacement of settlements, destruction of agricultural and recreational lands and damage to harbours and navigational structures. The problem of coastal erosion is acute in Tanzania, both on the mainland in the vicinity of Dar-es-Salaam and on the island of Zanzibar and Pemba. In Kenya erosion affects resort development both North and South of Mombasa, while in the Seychelles it affects particularly the Islands of Praslin and La Digue (Arthurton, 1992). At Malindi in Kenya, sediment accretion is a major cause of management concern. Beach hotels and dwellings constructed in the coastal trip directly adjoining what was previously the backshore in the northern part of the resort are now distant from the shore by a hundred meters or more and the intervening sands accreted are now vegetated with scrub and immature coconut palms.

Although individual countries in East Africa and the Island States of the Western Indian Ocean have periodically addressed the problem of coastal change within their own territories, the record within the region is one of only modest success. The usual response to coastal change in the region has been the construction of shoreline structures, most commonly seawalls, groins and breakwaters (Odada, 1993).

Seawalls are usually made of thick concrete and are solidly anchored to make sure that they are not destroyed by waves. The thick walls are generally vertical which often has the effect of accelerating erosion at the foot of the wall as a result of the wave reflection. These measures have generally performed poorly in the region, and in several cases, shoreline protection structures have aggravated the very problems they were designed for, resulting in accelerated shoreline change.

The options available to the countries of the region to respond to these common threats to their coastal environment include:

i) Increased public awareness of implications of coastal change through education.

ii) Development of effective planning and management strategies for the protection of the coastal zone, particularly with respect to erosion and sediment accession.

iii) Enforcement of set back lines and conservation easements in order to control inappropriate coastal development.

iv) Enactment of new and sweeping legislation required to reduce coastal change. For example new laws are required to prohibit reef blasting and sand mining, to control dredging operations, to limit mangrove destruction, etc. In already built-up areas of the coastal zone, the emphasis should be on "disengagement" from the coast, where practicable and on the installation of low-cost, low-technology coastal change control measures.

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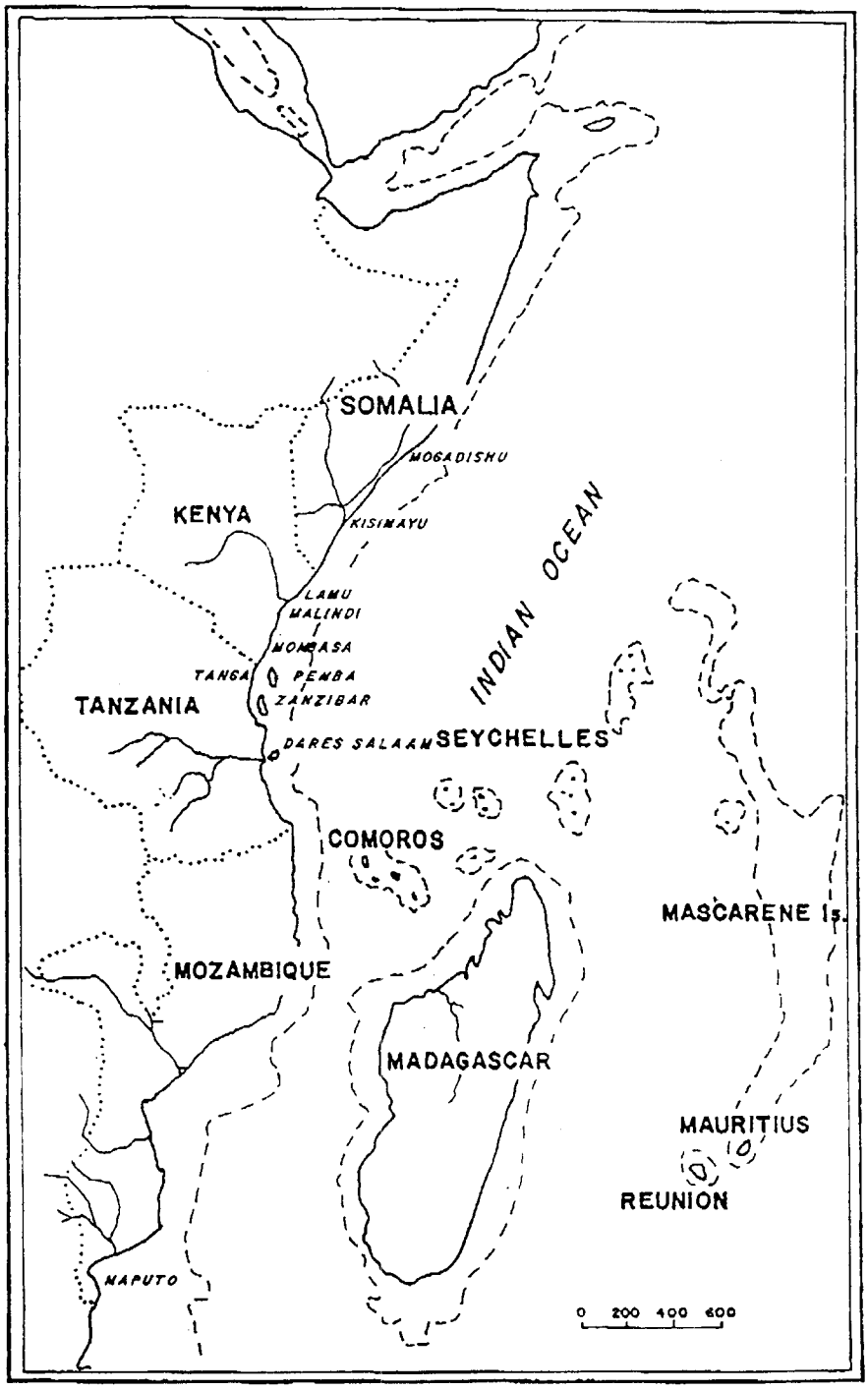
Fig. 1: The East African Region. The dashed line represents the limits of the continental shelves and the major banks in the Western Indian Ocean.



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COASTAL DEVELOPMENT IN THE RED SEA, CASE STUDY

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ABSTRACT

In recent years the Red Sea coast has been getting increased attention for touristic and reconstruction developments. This paper deals with the surveying activities in relation to developing a limited strip on the Egyptian Red Sea coast.

The surveys conducted for this phase of the project were mainly; Bathymetric survey, hydrographic survey and environmental design data collection. Satellite altimetry was utilized to enhance the collected data.

Altimetry data had proved to be useful in providing a regional solution for the Mean Sea Level determination in remote areas. This study has now provided the main baseline data for the case study area in any future development or study such as; planning of site and the choice of the foundation level, environmental impact assessment (which is becoming mandatory by the Egyptian rules), design of a marina or jetty and design of the inlets for the required artificial lagoon and circulation inside the lagoon.

INTRODUCTION

The case study area, namely El-Gouna, is located approximately 25 km north of Hurghada city, the site location is Longitude 33° 41' 08" E and Latitude 27° 23' 12" N. Fig. 1 shows an aerial photograph of El-Gouna. The total area is about 2,600,000 m^2. Development started in the area in 1991 with one five-star hotel, a marina for boats up to 20 m in length and forty villas. The shoreline is approximately 4 km east of the main road Hurghada - Suez. The new area under development overlooks about 1 km of the shoreline to the north of the area already developed.

It is also planned to excavate an artificial lagoon in the low land area. The lagoon is 1.5 km along the shoreline by 1.7 km perpendicular to the shore. The lagoon has two openings to the sea, the distance between them is about 1 km. The water area inside the lagoon is expected to reach 600,000 m^2 planned on three phases. The main cause of water circulation inside the lagoon will be the water level variation due to tidal action and wind effects. Wave action near the lagoon entrances is expected to be negligible, as the area under consideration is totally protected by coral reefs, namely Sh'aab Abu Shaar.

In this paper, results of several field measurements are presented to show:

- The bathymetric and shoreline maps.
- Set a zero datum for the area based upon theoretical calculations and evident by measurements during the survey.
- Inspect the shoreline and analyse shore, bed and water samples to aid in the calculations of the sediment transport, and finally
- Collection and analyses of the available data on tides in the area.

BATHYMETRIC AND SHORELINE SURVEY

The bathymetric survey was made during 7 to 15/4/1993. Data were obtained by a well-known angle and distance measurement technique for horizontal position determination. In addition, an instantaneous depth measurement at these horizontal points was performed. The survey was

conducted using a combination of angle and distance measurements, utilising a theodolite equipped with an electronic distance measurement (EDM), for the horizontal determination of the position of a small boat as it performed depth measurements, as well as accessories such as tapes, chains and reflectors. Time tagged horizontal positions were correlated with offshore depth measurements. In order to overcome the local effect of waves on the depth measurements, the observer on shore made simultaneous measurements to a known bench mark of adjusted elevation; thus, stabilizing the height of collimation (observer's line of sight) for each time a depth measurement was made.

Coral reefs and shoals were identified and bounded during the survey. The density of the depth observations in terms of horizontal spacing were taken in proportion to the bathymetry relief, i.e. the rougher the bathymetry the higher the density of observations. The bathymetry observations were tied and referenced to points of precisely known horizontal coordinates on-land within the study area, as well as to a bench mark of known elevation.

The choice of the method involved in bathymetric mapping had the advantage in providing a precise horizontal position in addition to the height difference between the observation points on the land and the prism; thus eliminating any water level variation during the survey period. Another advantage is the great reduction in the cost of the equipment such as positioning system and sounder.

This survey was tied to traverse stations that were involved in previous planimetric and topographic surveying. The objective of the bathymetric survey was to produce a map for a shoreline of 4 km length by 1.5 km offshore with an overlapping distance to the land area to set a better definition to the shoreline and tidal flat zone. This map may be then used in coastal modelling and sediment budget appraised for the coast if any man-made interference is planned, e.g. jetties and lagoon entrances.

The water depth measurements were performed on an irregular grid with an approximate spacing of 80 m between profiles along the shoreline by 40 m between points along the profile. This grid spacing was chosen in relation to the required 1:4000 scale map of the area. The grid was further densified in areas where coral reefs were detected. The position of the grid corners was determined by angular and distance measurements made from a traverse point on the shore to the location of a light boat with a prism reflector. The basic method for producing the bathymetry map relied on the concept of TIN (Triangulated Irregular Network) where interpolation was based on nonlinear interpolation methods to include the influence on the neighbourhood variations.

One contour map was produced for both land topography and sea bathymetry. The map produced is presented in Fig. 2 which displays the land and the sea topography. This map is presented with respect to the chosen zero level datum for the area. Determination of the zero level will be discussed later in this paper. A three-dimensional view of the land and sea, and a sketch showing the area exposed to high and low tides (tidal flat) are shown in Figs. 3 and 4, respectively.

TIDAL DATA

Various forces act on the sea surface. Some are external, and some are due to the nature of the fluid itself. Forces such as gravity and the tide producing forces due to the sun and the moon are external, as is also the stress of the wind on the surface of the fluid. While a force acting on the fluid element that is due to the fluid itself, is the pressure gradient force, which is the variation in density or due to difference in the elevation of the free surface of the fluid.

The tides are periodic movements which are directly related in amplitude and phases to some periodic geophysical forces. The dominant geophysical forcing function is the variation of the gravitational field on the surface of the earth, caused by the regular movements of the moon-earth and earth-sun systems. The tidal responses of the oceans to the forcing of the moon and sun are very complicated and both the range and the period of the tide vary greatly from one location to another.

In general, the sea level change may be produced by one or more of the following factors:

1. Astronomical Forces (due to moon and sun), these are known as astronomical tides
2. Density Gradients.
3. Storm surges; which are due to the changes in atmospheric pressure, wind stresses or wave action
4. Configuration of the bathymetry of the site.

Mean Sea Level (MSL) as it implies, is the mean level taken up by the sea. It is determined at a tide gauge station from a long period of tide observations. The geoid, which is supposed to be the datum for the heights, is defined as "that equipotential surface which on average coincides with the mean sea level" (Thomson, 1974).

The average of recorded values of all the high and low waters over a period is called the Mean Tide Level (MTL), which is used more often in calculations instead of the MSL. The average throughout the year of highest of high waters during the spring tides is termed Mean High Water Springs (MHWS) and highest of low waters during the spring tides is termed Mean Low Water Springs (MLWS). Mean High Water Neap (MHWN) and Mean Low Water Neap (MLWN) are the average throughout the year of highest of high and low waters during the neap tides, respectively. The highest tide which can be predicted to occur under average meteorological conditions is termed High Astronomical Tide (HAT), while the lowest predictable tide is called the Low Astronomical Tide (LAT).

Generally, a chart datum is defined as a low water level. Ideally, LAT level should be taken as a chart datum, but since one cannot accurately define it, we choose a chart datum arbitrarily as close to LAT as possible such that; (i) Tides will seldom fall below it and (ii) it is not so low as to give unduly shallow depths.

Theoretical studies and tidal observations taken at certain locations along the coast of the Red Sea, suggests that the extreme northern part of the Red Sea exhibits nearly the same amplitude and phase. This is particularly true between Kosier city @ Lat. 26° N, on the Red Sea and Ashrafi Island at the entrance of the Gulf of Suez. The situation in the extreme north at Suez is different for several reasons, but a water rise in the study area is associated by a water fall in the northern part of the Gulf and *vice-versa*. The greatest amplitude (difference between high and low levels) is found at Shedwan Island (facing the case-study area). This level decreases smoothly southwards to Port-Sudan and decreases sharply northwards towards El-Tor (southern tip of Sinai), where minimum tidal range is observed (@ 18 cm).

Generally, the Red Sea is poor in established tidal gauges along the coast. Very few tidal gauges were fixed in the main Harbors along the coast at Perim, Assab, Massawa, Jidda, Port-Sudan and Suez. On the other hand, seven tidal gauges have been fixed for short duration at eleven stations along the Red Sea from one to six months during 1923-1924. From the measurements obtained, harmonic constituents of the tidal component have been calculated, as given in Table 1.

The data of Table 1 suggests that the tides in the area are semi-diurnal (two highs and two lows occur daily), this is calculated from the ratio of the amplitudes, i.e. $(O_1+K_1) / (M_2+S_2) < 0.25$.

The above harmonics were commonly used to predict the water levels due to tidal action for any required period. The basis of this method assumes that the tidal variations can be represented by the sum of the series of harmonic terms whose angular speeds and phases are related to the astronomical conditions.

The height of the tide at any time may be represented harmonically by the formula:

$$h(t) = S_o + \sum_n f_n H_n \cos(\sigma_n t + V_n + U_n - g_n) \quad (1)$$

where

h(t): is the height of the tide at any time t.

S_o: is the mean height of water level above datum used for prediction.

H_n, g_n : are the amplitude and phase of constituent n as found from the harmonic analysis of the tides in the area.

σ_n: the angular speed of constituent n.

f_n, U_n: Are slowly varying astronomical functions.

V_n: is the phase angle at time zero.

In 1984, a tidal gauge had been fixed at the National Institute of Oceanography and Fisheries (NIOF), Hurghada centre, located @ Abu Sh'aar Bay, Lat. 27° 17' N, Long. 33° 46' E. This location is 15 km south of El Gouna area and considered one of the few stations along the Red Sea. The tidal gauge was installed in a well of depth of 1.57 m, the base of the well is considered the zero level for the presented data. Data were recorded for a period of eight months from 3/3 to 13/10/1984 and presented in a graphical form in Fig. 5a.

The high water level recorded was 145.3 cm in September, and the lowest water level recorded was 1.7 cm in March. Moreover, the greatest range observed during 1984 was 93.6 cm in September and the least range was 29.6 cm in May. The difference between the Lowest Low Water level (LLWL) and the Highest High Water level (HHWL) is 1.436 m. Table 2 summarises the spring, neap and maximum ranges during the 1984 survey and compared to the predicted by the computer program results of NIOF for the years 1993 and 1994 (*).

The maximum tidal range recorded was 1.09 m during September and the minimum range was 0.69 m during October. Based on this data, a more rigorous analysis was made to accurately estimate the amplitude and phase of different harmonics (short, medium and long term). The calculated spring range was found to be 1.16 m and the neap range, 0.28 m.

In the present analysis, eq. (1) for height of tide h(t) at study area and at any time t can be expressed as the sum of harmonic terms (Dronkers, 1972):

$$h(t) = S_o + \sum_{k=1}^{\infty} H_k \cos(\omega_k t + \alpha_k) \quad (2)$$

where S_o is the height of mean water level above the datum, ω_k is the constituent frequency, H_k is the amplitude of the constituent k and α_k is the initial phase of the constituent.

Using trigonometric relations for compound angles, eq. (2) is rewritten as

$$h(t) = S_o + \sum_{k=1}^{\infty} A_k \cos\omega_k t + B_k \sin\omega_k t \quad (3)$$

Eq. (3) is a trigonometric polynomial that can predict the observed time series h(t) at time t in the given time interval. Least squares approximation methodology (Vaniçek and Wells, 1972) is used in the current analysis to determine the coefficients S_o, A_k and B_k, k = 1, ...N, and N is a truncation parameter equalling the number of constituents included in the analysis. Eq. (3) is then written as (M) simultaneous equations, where M is the number of recorded points in the tidal chart. The resulting equation is transformed using Vandermonde's design matrix then solved using a standard matrix inversion routine to determine the amplitude and phase of each constituent k.

In the analysis, two tidal records were considered; the first is the hourly water level for a period of two weeks, Fig. (5b), (Saturday 10/3/1984 @ 12:00 pm to Saturday 24/3/1984 @ 1:00 pm, for a total of 338 hours); the second record is the mean daily water level for an eight-month period starting 3/3/1984 till 13/10/1984 (225 days). The first record analysis allows an estimation of the short duration constituents (less than or equal to two weeks period) and the second record, the long duration constituents (more than 24 hours and less than or equal to one year). In digitizing the data for analysis the following were considered; a proper time step was chosen to be compatible with the condition of the folding frequency, and the frequencies considered were taken to satisfy Rayleigh's criterion.

First, a Fast Fourier analysis was made to determine the frequencies at which most energy of the signal is concentrated. Each frequency was then approximated to the nearest actual

constituent frequency (Godin, 1972). Then the Least Squares Harmonic analysis was performed to predict the amplitude and phase of each constituent. Table 3 presents the amplitude and phase of each constituent resulting from the analysis.

The results show that most of the energy is concentrated around the 12:00 hours period wave and this again confirms the type of the tides in the area "SEMI-DIURNAL" tides (i.e. two peaks and two troughs per day).

The summation of the amplitudes obtained from the analysis is about 58 cm, i.e. the maximum tidal range expected within one year period is 0.58 x 2 = 1.16 m. A comparison between the measured and the predicted tides for both records is given in Figs. 6a and 6b.

The water level of the Red Sea is strongly influenced in the long term by the rate of evaporation and the balance between inflowing and outflowing water. In winter, the inflow exceeds the outflow and the loss by evaporation combined in spite of the fact that evaporation is probably higher in winter than in summer. Consequently mean sea level rises over the whole of the Red Sea. In summer, the combined losses are greater and mean sea level falls.

Based on the very few measurements of sea level available it appears that the range is from a maximum depression of 15 cm in June to August, to an elevation of 5 cm in December and January. Superimposed on these large scale variations are changes caused by meteorological factors (essentially wind stresses) which may be short lived and local in character. The prevailing NW winds drive surface water southwards and because of the Earth's rotation, this water tends to move to the right thus raising the level on the African Coast. Changes of water levels due to changes in atmospheric pressure are generally negligible in the Red Sea.

Here it should be noted that the tidal record does include these other tidal effects, such as the pressure and wind surges. The record analysis shows that a wind surge of about 15 cm should be included to predict the maximum and minimum water levels. Superimposed on that are the very long term constituents (periods more than one year). Unfortunately no longer records were available in the area, however a similar analysis was made for the data collected in Port Tewfik (northern tip of the Gulf of Suez) showed that a value of 5 cm should be considered for long term constituents. In our analysis, it is suggested that the global sea rise effects are neglected as the land rises almost by the same rate in the Red Sea area, (Mart and Hall, 1984).

ZERO LEVEL DETERMINATION IN EL GOUNA

The basic concept of satellite altimetry is explained briefly herein and based on Baraka (1991). An altimetry satellite is a geodetic satellite with altimetry measurement capabilities used to study sea and ocean surfaces and its characteristics. Such a satellite is equipped with an altimeter that emits electromagnetic pulses in the direction of the earth surface. These electromagnetic pulses are reflected off water surfaces, such as seas and oceans. The times of transmission and receipt of the pulses are continuously recorded by the altimetry satellite, along with the precise coordinates of the sub-satellite point, latitude and longitude, from which each pulse was reflected.

The precise computation of the satellite motion and coordinates in its orbit, namely the satellite ephemeris, allows for the determination of the satellite's height above the centre of earth. The knowledge of the coordinates of the sub-satellite point, at the time of the pulse emission, allows for the determination of the distance of this point to the centre of the earth. At the same time, the altimetry distance of the satellite above the sea surface is continuously determined and recorded. Hence, a mathematical model is utilized to refine and determine best fitting values for mean sea levels worldwide. Accuracies of mean sea level determination worldwide have reached 5-10 cm (Baraka, 1991).

A bench mark of precisely known elevation was available within the study area. The elevation of this bench mark was determined through an earlier national levelling surveys conducted by the Egyptian Survey Authority (ESA). Conventionally, all bench marks determined by ESA are referenced to the national vertical reference

system of Egypt, namely, the mean sea level as determined from tidal records made in the Port of Alexandria during the years 1906-1922, denoted in short as MSL 1906. MSL 1906 is adopted as the zero level for land elevations nationwide in order to guarantee the consistency of all related topographic maps and subsequent works. Hence, the elevation of the bench mark established by ESA within the study area was referred to the mean sea level of Alexandria for an earlier specific epoch.

The above mentioned situation is conventionally accepted for all land surveys and related applications. However, in the case at hand, the construction of water passage ways and lagoons in the study area overlooking the northwestern seashore of the Red Sea gave arise to concerns about what could be termed as the zero level problem. The main reason for the concerns was the fact that there may exist a significant difference and regional variations in sea surface levels between the Mediterranean Sea and the Red Sea. It should be clear that in engineering activities such as those proposed in the study area one cannot directly use of the known elevation of any bench marks referenced to MSL 1906. Such elevations need to be transformed and adjusted so as to refer to the current status of the mean sea level of the Red Sea.

The transformation and adjustment of the bench marks within the study area were based on data sets derived from satellite altimeter measurements of the whole north and northwestern regions of the Red Sea. Satellite altimetry measurements from two satellite missions, namely SeaSat and Geos-3 (Engelis, 1983 and Rapp, 1982), provided direct measurements of the sea surface variations and deviations from the global mean and eventually from the MSL 1906 of Alexandria.

Based on a regular grid data set of satellite altimetry for the northwestern region of the Red Sea, a contour map was established for sea surface variations (Fig. 7). This contour map was used to determine the deviation of the bench mark within the study area in relation to the MSL 1906. The process involved the transformation from the global ellipsoid GRS80, a best fitting geometric surface representation for the whole world, and the Helmery 1906 ellipsoid, a best fitting surface used in Egypt.

In the study area, a bench mark A (BM A of elevation 1.19 m w.r.t the MSL 1906) was used within the area of the project (during a previous topographic survey). The calculations using the satellite altimetry data for El-Gouna had shown that there is a variation between the MSL 1906 surface and that of the Red Sea Mean Sea Level (MSL) in the project location of a negative 49 cm. Consequently, the BM A elevation has to be initially changed to be 1.19 + 0.49 = 1.68 m.

Furthermore, tidal gauge measurements @ 15 km south of El-Gouna shows a spring range of 1.079 m, and the present harmonic analysis shows that this level should be modified to 1.16 m (difference between MHWS and MLWS). Since the satellite altimetry data refer to the Mean Tidal Level (MTL = MSL), which is defined as the average of recorded values of all the high and low waters of a period. Then half the difference between MHWS and MLWS (tidal amplitude) has to be added to the correction derived from the satellite altimetry data, consequently, the BM A elevation has to be further changed to be 1.19 + 0.49 + 1.16/2 = 2.26 m.

It should be mentioned that these preliminary calculations showed a possible difference between the High Astronomical Tides (HAT) and the Low Astronomical Tides (LAT) of 1.54 m., which implies a possibility of the water level Variation above the MHWS or below the MLWS by a value of 0.19 m. Since the LAT and HAT do not occur within the same day, rather they are the highest and lowest tidal records separated by a span of several years, design precautions should suffice to account for this deviation.

However, these numbers have been verified twice:

1) During the bathymetric survey, Table 4 shows the level of BM (A) as recorded at different times and days.

2) Furthermore, our calculations suggest that the MHWS level is 1.16 above the MLWS level (taken as the zero level for El-Gouna) this number was verified through the shoreline inspection survey; at which an almost constant height between BM (A) and the salt line is recorded (to be 1.10 to 1.12 m).

In conclusion, when BM (A) is used in reference to the Red Sea within El Gouna area, its elevation is now taken as 2.26 m, with the MLWS taken as the zero for the area.
Fig. 8 shows the different levels as deduced from the collected data and analysis.

HYDROGRAPHIC SURVEYS

Two surveys were made in the area, the first was during April 1993 and the second during July 1994. The objective of these surveys was to investigate areas with different exposure to wave energy, to collect soil and water samples at different locations, to describe the sea bottom near the shoreline, and to analyze the samples for the suspended sediment concentration.
A total of 23 soil samples where collected mainly where a change in colour or formation was noticed. The samples were collected in plastic bags, numbered and sent to the lab for analysis. In the lab, the samples were first visually identified, then they were dried at 105°C, a known weight of 200 g was taken from each sample for standard sieve analysis using a mechanical shaker and standard sieves. The accumulated weight on sieve no. 200 (ASTM), equals to 0.074 mm, was then washed, dried and reweighed, if this weight is greater than 20% of the total weight, a hydrometer test was made to determine the grain size distribution of the fine particles. The minimum density was measured for some representative samples using a standard sand cone test. Chemical analysis was made only for some representative samples. Details of the survey are found in Task (1) report, 1993.
During the survey, a total of 4 water samples were collected each in a 10 litre bottle. The first was taken from an open lagoon (old lagoon in the middle of the villas) at depth of 1.5 m and at 0.8 m from the bottom. The second was collected from a newly excavated lagoon to the north of the hotel, but still not connected to the sea @ 0.1 m from the bottom @ 1.0 m water depth. The third was taken near the shoreline at a depth of 1.5 m @ 0.05 m from the bed. The final sample was taken from deep sea at a location 600 m from the shoreline. A vacuum apparatus was set up with a 0.45 μm (0.00045 mm) membrane filter. The membrane was first weighted and then one litre of water was filtered through it. This was repeated using a new membrane for each one litre of water. A total of 4 litres were filtered for each sample. After filtration, membranes were dried and reweighed. The weight of sediment was calculated to determine the average weight of sediment per one litre of sea water. Results for the suspended sediment concentration for each sample are as follow; WS#1 (40.4 ppm), WS#2 (85.9 ppm), WS#3 (86.3 ppm) and WS#4 (35.9 ppm). Suspended particles are defined as fine silt and clay with diameter more than 0.00045 mm.

ENVIRONMENTAL DATA

No measuring devices were used on site, but rather data on wind and waves were collected in the area and in the southern part of the Gulf of Suez (North of El-Gouna).
Generally the wind is prevailing from the NW direction (Edwards and Head, 1987) with an average speed of 6.5 m/s. Significant wave height is 0.6 m with a period of 5 sec (Glenn, 1991). Currents are mainly due to tides with a speed of 0.1-0.2 m/s. Other data were also collected such as; air temperature, relative humidity, rain, thunderstorms and evaporation. During the summer survey a second team collected the biological data in the area, mainly on the terrestrial and marine habitats. Details may be found in the EIA report, 1994.

CONCLUSIONS

The present paper presents the results of a field study in El-Gouna area on the Egyptian Red Sea. The total area for development is 2,600,000 m^2. The development is planned under several phases to include; four five stars hotels, 60 villas a small town, an artificial lagoon, a marina and all infra-structure needed.
Particular attention was paid to the determination of the zero level in the area. A satellite altimeter study was coordinated with the collected data on tides near the site and verified during the bathymetric survey. Bathymetric data were obtained by an economical method and a well known angle and distance measurement technique for horizontal position determination and

instantaneous depth measurement. Determination of the different tidal levels in the area is useful in several aspects e.g.:

- Setting the foundation level for the structures from the shoreline and determination of the minimum required water depth in the lagoon.
- Study of the circulation inside the lagoon.
- Study of the shoreline changes due to any man-made interference.
- Environmental Impact Assessment (EIA) of the project, noting that EIA became mandatory by Egyptian law since 1994.
- In coordination with the topographic and the bathymetric maps, digitized baseline data could be created for several purposes. For example, monitoring the terrestrial or marine habitats, management of the site during or after construction.

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Table 1. Historical tidal data.

Location	Date		M_2	M_4	S_2	K_2	N_2	K_1	P_1	O_1
Ashrafi	15/2 to 17/3/24	Ampl (cm)	13.4	1.2	4.0	1.1	4.3	2.3	0.8	1.6
		Phase (deg)	200	212	212	155	201	201	201	187
Shedwan	March 1924	Ampl (cm)	25.1	1.2	4.0	1.1	8.0	2.3	0.8	0.7
		Phase (deg)	185	280	212	212	155	202	202	212
Hurghada	3/3 to 5/4/84	Ampl (cm)	24.0	0.92	5.9	---	10.9	1.6	---	0.6
		Phase (deg)	210	041	004	---	273	166	---	134

Table 2. Tidal ranges recorded near Hurghada.

level (cm)	J	F	M	A	M	J	J	A	S	O	N	D
Highest Recorded	--	--	109.3	108.3	103.3	89.3	108.3	122.3	145.3	132.3	--	--
Lowest Recorded	--	--	1.7	11.7	18.7	13.7	18.7	32.7	36.7	63.7	--	--
Spring Range Recorded	--	--	92.6	86.6	80.6	69.6	73.6	89.6	93.6	60.6	--	--
Neap Range Recorded	--	--	30.6	33.6	29.6	32.6	32.6	30.6	43.6	41.6	--	--
Max. Range Recorded	--	--	107.6	96.6	96.6	84.6	75.6	89.6	108.6	68.6	--	--
1993*	68.0	69.0	72.0	72.0	70.0	70.0	69.0	68.0	72.0	73.0	76.0	72.0
1994*	71.0	69.0	72.0	77.0	76.0	74.0	71.0	68.0	70.0	74.0	74.0	77.0

Table 3. Amplitude and phase of each constituent as a result of the analysis.

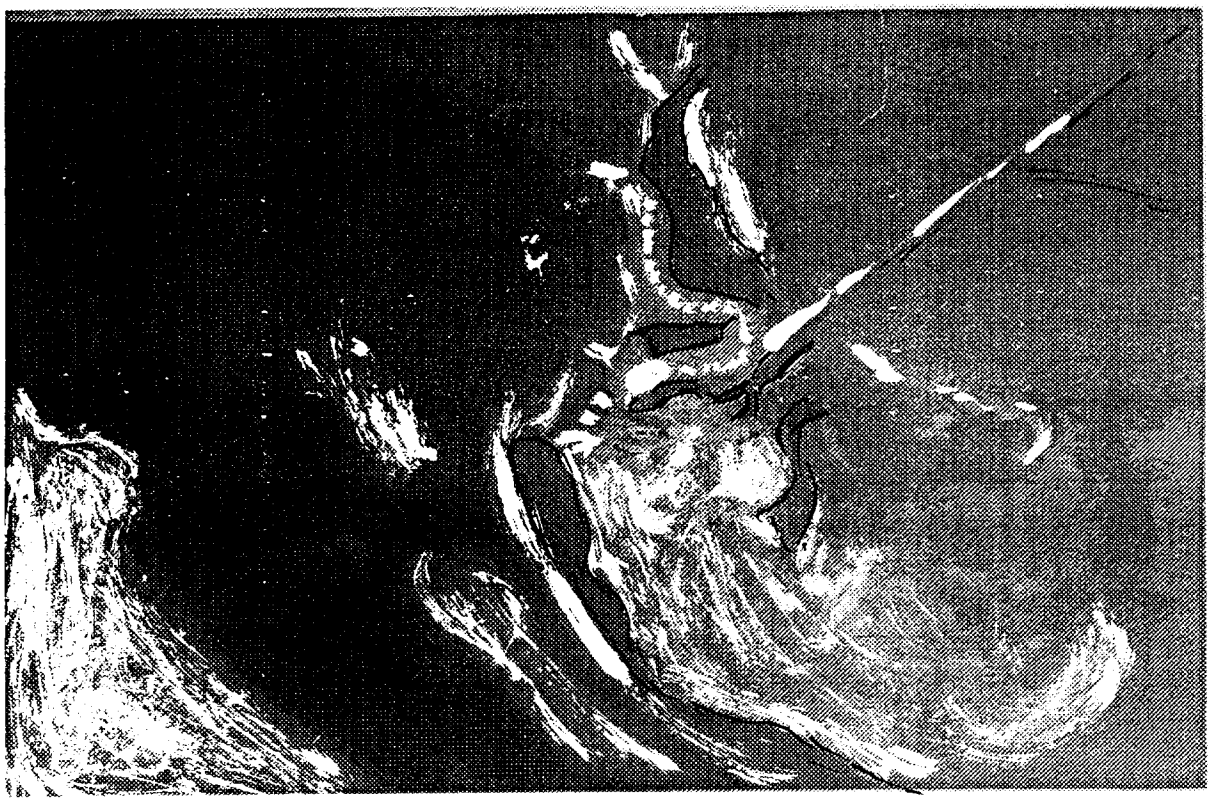
Constituent No.	Name	Period	Amplitude (cm)	Phase (deg.)
1	M_3	8.28040 (hrs)	0.30	54.18
2	η_2	11.75452 (hrs)	4.13	183.34
3	λ_2	12.22178 (hrs)	11.41	137.96
4	ν_2	12.65835 (hrs)	28.15	351.15
5	ϵ_2	13.12727 (hrs)	2.95	177.77
6	ϕ_1	23.80448 (hrs)	2.33	339.15
7		4.79260 (days)	0.60	75.78
8		7.53495 (days)	1.33	66.18
9		13.77728 (days)	0.90	239.27
10		23.94208 (days)	0.20	76.71
11		27.21222 (days)	1.40	84.63
12		32.12822 (days)	1.25	342.07
13		182.64840 (days)	1.10	222.13
14		365.24220 (days)	1.80	116.04
SUMMATION			57.85 cm	

Table 4. Observed levels of BM (A), measured from the instantaneous sea surface.

Date	Time	Level of BM (A) above sea surface
8/4/93	5:00 PM	1.47
9/4/93	5:00 PM	1.68
10/4/93	9:00 AM	1.34
11/4/93	8:30 AM	1.46
12/4/93	12:00 PM	1.73
12/4/93	5:00 PM	1.86
13/4/93	11:00 AM	1.81
13/4/93*	5:00* PM	2.09*

* Calm wind observed

Fig. 1. Areal photo of the El-Gouna area.



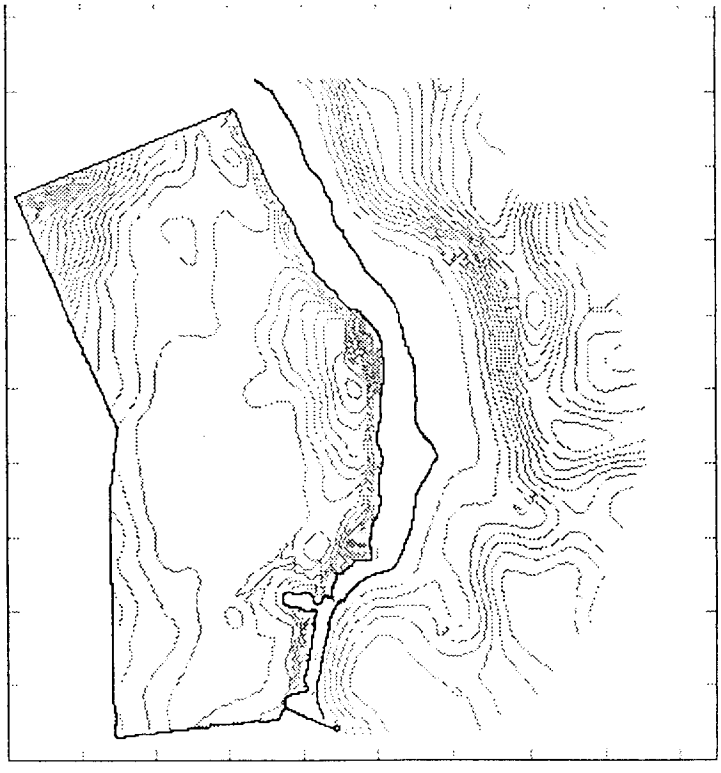
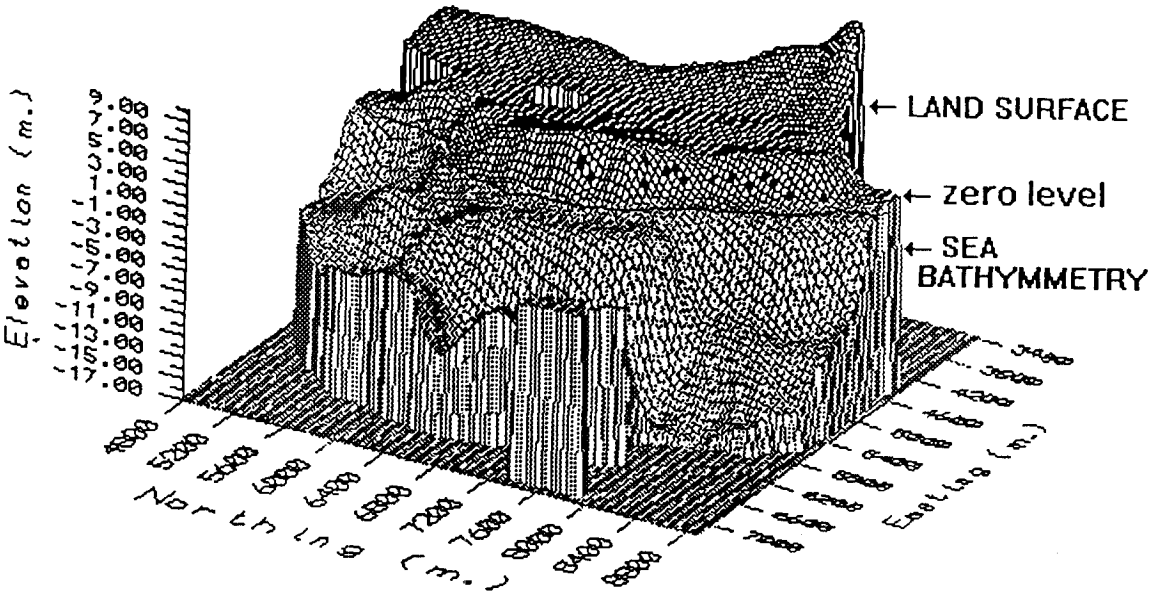


Fig. 2. Land topography and bathymetry.

Fig. 3. 3-D prespective, land and sea, El-Gouna area.



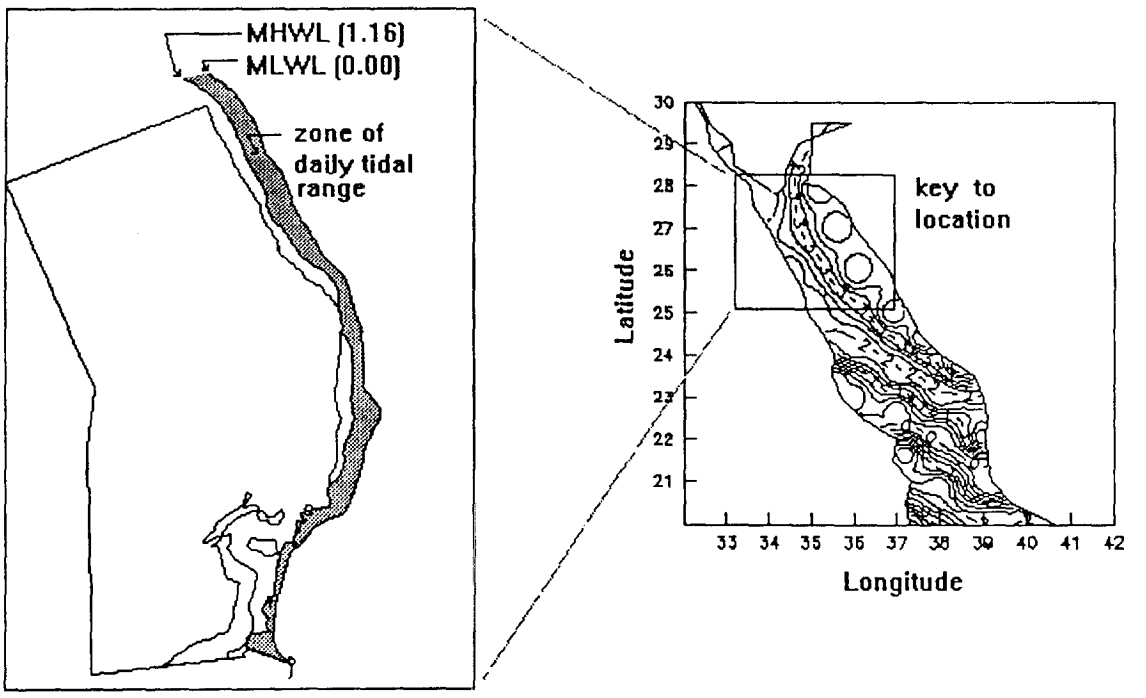


Fig. 4. Tidal flat zone El-Gouna area.

Fig. 5. Recorded tides:
(a) eight months and (b) two weeks

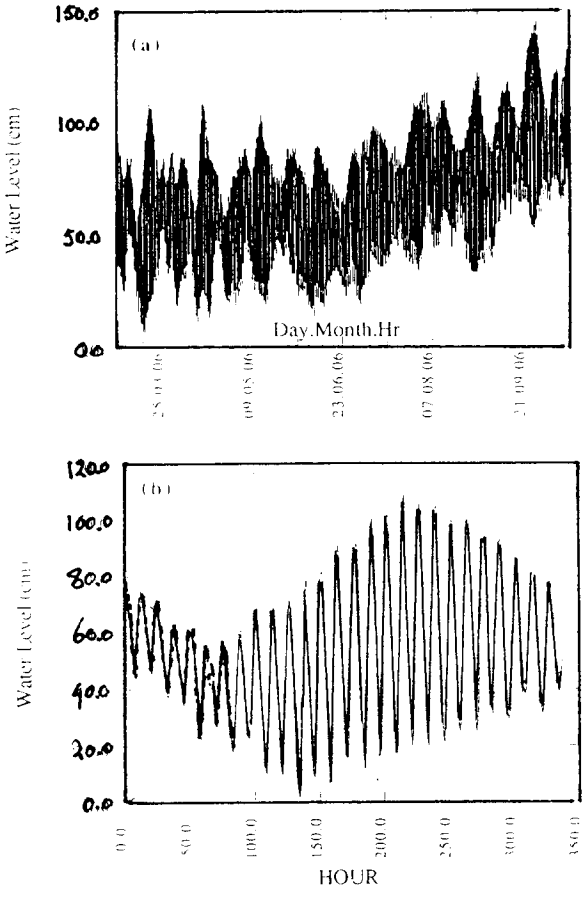


Fig. 6. Measured and predicted water levels:
(a) eight months and (b) two weeks.

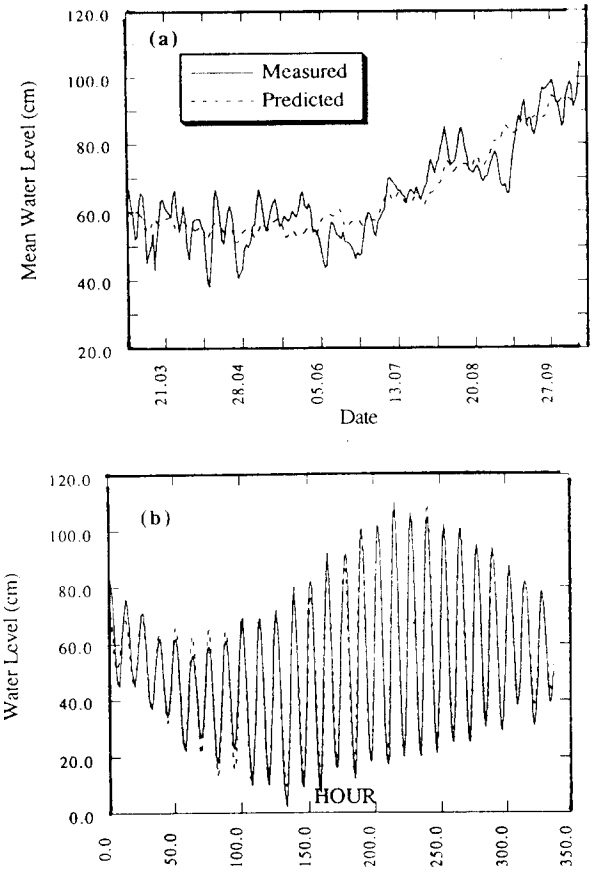
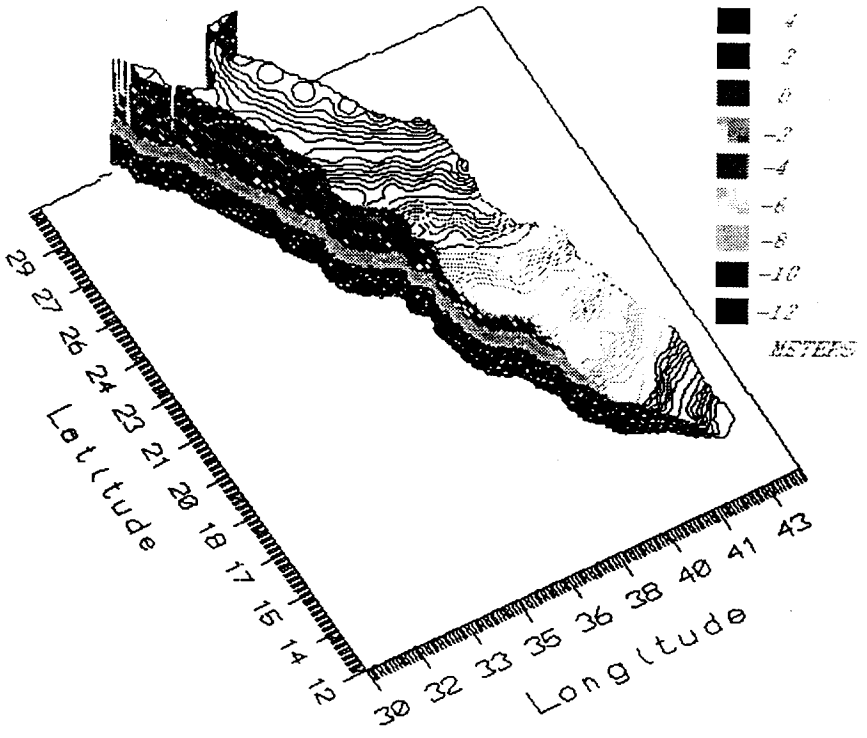


Fig. 7. Red Sea surface topography.



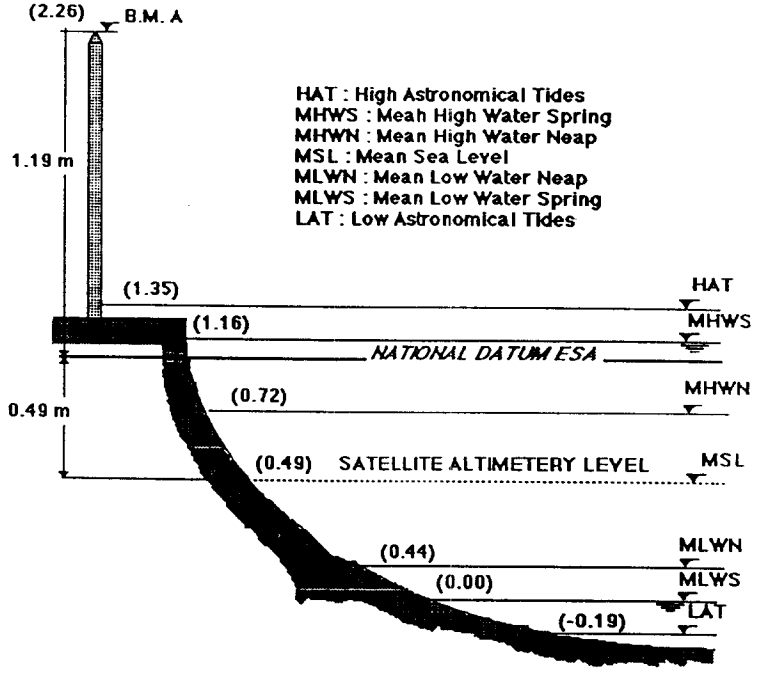


Fig. 8. Sketch showing different levels w.r.t. the National Datum and the Zero Level in the El-Gouna area.

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VULNERABILITY ASSESSMENT AND RESPONSES TO SEA LEVEL RISE IN THE BENIN COASTAL ZONE

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KEYWORDS: Gulf of Benin, Benin, climate change, coastal beaches, coastal erosion, accelerated sea-level rise (ASLR), assessment, impacts, environment, development, management.

ABSTRACT

The Benin coastal zone is especially critical because of its geographical situation and its dynamics. It is an important maritime front, the most densely populated in the country and contains the hub of economic activity. Accelerated sea-level rise due to overall climatic change (global warming) will bring about important natural, socio-economic and cultural disruption in the coastal plain. Data suggests that an ASLR will aggravate the existing ecological problems (increased salinisation of groundwater and soil, greater influx of diverse pollutants) in the Benin coastal zone and result in serious cultural and economic consequences (misery for the population).

Economic conditions, development priorities, attitudes towards coastal land use, as well as low levels of government and public awareness of accelerated sea-level rise bode poorly for the timely implementation of appropriate response strategies. The findings underscore the necessity of addressing current erosion problems and coastal development pressures, as well as the need for coastal management planning in face of ASLR.

INTRODUCTION

Environmental dynamics in Africa are in a state of dangerous degradation. Within the West Africa sub-region, the most vulnerable areas are the coastal zones because of existing erosion but above all due to the impact of sea level rise following overall climatic changes. They are threatened by practices which ignore traditional and ritual rules and uses, and also by sea-level rise and increasing marine dynamics. The coastline of West Africa in general, and the Benin Coastal Zone in particular have witnessed sea level variations of considerable dimensions in the past. The present configuration is the product of the oscillation of sea level that has taken place over the past 20,000 years. For the past century or so, the general trend has been towards a continued rise in sea level. Short-term as well as seasonal oceanic fluctuations (tides, waves, storms waves) linked to atmospheric disturbances are sometimes spectacular on the West African coasts, but the greatest dangers are long-term changes that could result from a change in the world's climate.

Earlier studies have emphasised physical, ecological and technical aspects. A second generation of studies, which take a holistic approach, have focused on physical, socio-economic and political processes. Despite uncertainty in timing and magnitude, a greenhouse-effect with an induced acceleration in the rate of sea-level rise is now widely accepted by the international scientific community and by the Intergovernmental Panel on Climate Change (IPCC). A 1.0 m rise by the year 2100 is increasingly used for planning purposes and coastal nations are encouraged to begin immediate consideration of alternative response options (structural protection, accommodation, retreat) and comprehensive coastal zone management planning to mitigate against accelerated sea-level rise.

This paper is (i) an assessment of the present environment, (ii) a report of the first attempt to quantify SLR impacts, and (iii) a guideline for actions to manage this vulnerable part of the

region. The aim of the research is (1) to examine the present environment and the present management of this coastal zone, (2) to examine the possible effects of global-warming-induced sea-level rise on coastal ecosystems and human activities on the coastal plain, and (3) to provide data that will spur action on the SLR issue in Benin, encourage detailed study of current coastal problems and foster coastal management initiatives. In addition, it is hoped to contribute to knowledge with respect to global warming and sea-level rise at the international scale.

PART I. PRESENT ENVIRONMENT OF THE COASTAL ZONE IN BENIN

The coastal zone of Benin is located in the central part of the Gulf of Benin which stretches from the Cape of the Three Headlands (Takoradi Region in Ghana), to the Niger Delta, in West Africa (Fig. 1). To understand the environmental problems that confront the local authorities of this region, it is necessary to analyse the different environmental components, even if national priorities have favoured the study of only certain aspects.

The coastal geomorphology (Fig. 2)

The littoral as considered in this study can be dated from Inchirian transgression (Ouljian), when the sea-level rose above its present level, partially altering the Continental Terminal deposits and causing a marine cliff to develop. During the marine regression of over 100 metres which followed (Ogolian, parallel to Pre-Flandrian in Europe), and under a drier climate than the present one, the Continental Terminal deposits were further affected by the sea, and spread on emerged areas. This took place from the maximum of Ogolian regression around 18,000 - 17,000 years B.P. (Faure & Elouard, 1967). These clay-sandy glacis end, either in a slope or else in a lagoon or lake (Adam, 1986).

Since the last great Nouackchottian transgression (parallel to Flandrian in Europe), whose maximum is dated between 6,000 and 5,000 years B.P., the sea encroached on the plateau, creating a wide system of rias. Sandy barriers resulting from the long shore drift (W-E) closed the rias and gave rise to lakes, coastal lagoons and marshes. The sandy barriers were formed during glacio-eustatic Holocene marine fluctuations from 5,000 to 2,500 years B.P.

The coastal plain is made of sandy beach ridges. Both the granulometric and morphoscopic characteristics of the ridge sand (medium, fine, blunted and shining sands) point to its marine origin. It was spread under homogeneous hydrodynamic conditions (Blivi, 1985).

Close analysis of sediments along the littoral of the Gulf of Benin shows fine to coarse sands (median diameters between 0.4 and 1 mm) on the shore, down to -4 m; from -4 m to -16 m elevation, the sediments are very fine and well sorted. Despite the homogeneity in the distribution of sediments from the West to the East of the Gulf, there is a strong variation to the East of the mouth of Mono river. These sediments have medium diameters from 3 to 6 mm at depths of -12 m and are composed of coarse sands mixed with gravel.

The coastal climate and the hydrological systems

Climate

The climate of the Gulf of Benin is of a beninian type (subequatorial) with two rainy seasons (mid-March/July and September/November) and two dry seasons. The average rainfall is 1,200 mm per year decreasing towards the West (1,500 mm per year in Seme and 850 mm in Lome); this decrease is due to the configuration of the coast in relation to the marine winds.

The temperature is constantly high (year average is 27°C) with the average maximum in March (33°C) and the average minimum in August (25°C) when temperature can fall to 22°C. The months of January, February and March record high thermal amplitudes (12°C). These variations are reduced during the rainy season.

The predominant direction of the wind is SouthWest with average speeds of 4 to 6 m/s (3 Beaufort). The winds from the South-SouthEast sector are not frequent and they blow in April and May. Because of the relatively even relief, the pattern of winds does not vary much according to seasons. In the dry season, the wind strength is weak to moderate (2 to 5 m/s in the morning. It

is stronger during the day (5 to 7 m/s) and becomes moderate in the evening and in the night (4 to 6 m/s). During the rainy season, a moderate wind blows (4-6 m/s) in the morning which becomes stronger in the afternoon (6 to 8 m/s) and remains constantly moderate-to-strong (5-8 m/s) in the evening and at night. The peak speeds reached during the passage of rain lines (East to West direction) with average speed of 15 m/s, accompanied by harsh rainstorms.

Hydrology

The hydrological systems in Benin are, from West to East, as follows:

(1) The estuary of Mono is a hydrological complex characterised by the courses of the Mono and Couffo rivers and the tidal flows. The dynamic behaviour of this sector is linked with variations in the tides and the flow of the river. During flood time, the flow is at a low level, the salt water contact goes up to Agome-Seva (40 km). This part of the valley, including Athiémé area, is completely under the influence of the tide.

(2) The Delta of Ouémé is the most important hydrological element of this area. It is characterised by the regime of the Ouémé-Sô system which is influenced by the tropical rainfall pattern of the upper basin of Ouémé river and the tidal currents.

(3) The mangrove edges, particularly coastal lagoons and Ahémé lake. It is an edaphic plant formation plainly connected to tidal estuaries. It spreads from Togbin (West of Cotonou) to Aného and to the north of Lake Ahémé, where the wave amplitude determines its existence. Three species are indicators of mangroves, particularly between Cotonou and Aného. They are (a) *Rhizopora racemosa*, (b) *Avicennia africana* and (c) *Acrostichum aureum*.

These hydrological systems are characterised by the freshwater marshy forests which are observable in coastal areas. They are mostly situated along river valleys, specially on the periodically flooded banks of Mono, Couffo and Ouémé rivers. All these inlets have undergone important changes since the nouakchottian transgression that put the different barriers in place. First of all, the construction of successive spits has diverted all the inlets towards the East. Such is the case of the Mono river that used to pour its water into the ocean at Grand-Popo, but currently discharges though the opening at Avlo which became a permanent mouth only two decades ago. The Ouémé river that flowed into the sea at Lagos before the opening of the Cotonou channel (in 1886) is a phenomenon that can be explained only by this progressive migration towards the East over a 5,000 year period.

These inlets are frequently blocked by the construction of different spits, which often provoke catastrophic floods during the rainy season. Such was the case of Cotonou in 1885, which prompted the opening of the channel in 1886; even after this opening, floods were reported in 1907, 1929, 1935, 1942, 1968, and 1987.

Those specific floods made it possible to map out marshy areas which cover more than 35% of the coastal plains of Benin. They are more widespread in the estuaries of the Mono and Ouémé where there are only a few islands whose banks are covered with mangroves. In general, in all of the coastal plain, the depressions between the islands are swamp landscapes which look like littoral meadows.

Coastal oceanography

The coastal oceanography in the Gulf of Benin is governed by a strong swell from SSW (particularly from May to July and on October). Along the Gulf of Benin, one observes a long swell of distant origin, the wavelength of which can vary between 160 and 220 m. This swell unfurls over the bar at a distance of about 150 to 200 m from the shore (characteristics at Cotonou wharf). There are also waves due to local winds whose characteristics are changing but have little importance for morphological phenomena of the coast. Their wavelength is about 50 m. The swell whose primary period is 12 seconds (though it can vary between 10 and 16 seconds) has a relatively regular average height between 1.0 and 2.0 meters (Fig. 3). The average amplitude of swell in Cotonou is shown in Table 1.

These swells generally travel from SouthWest to NorthEast (Port Autonome de Cotonou, 1980) and give the following distribution:
- SE-S 135° to 180° = 10%
- S-SW 180° to 203° = 36%
- S-SSW 203° to 225° = 54%

The two main types of water flow we can distinguish in the Gulf of Benin are (i) the general flow (the equatorial flow from West to East and the equatorial counter-current), and (ii) the coastal flow, composed of (a) the nearshore current which flows towards the East at a speed of 0.5 to 1.5 m/s, (b) the tidal current, and (c) the strong littoral drift which is responsible for the movement of an average of 1,200,000 m^3 of sediment per year (see Fig. 2):

According to the statistics of the Port Autonome of Cotonou, the tide is semi-diurnal with two highs and two lows of nearly equal amplitude that succeed each over at regular intervals. The average level of the sea is 0.90 m, the high water reaches + 1.95 in September, the low tide is 0.20 m in May; the mean sea-level is above the 0 IGN (basis of topographic maps in the region) by 0.40 m.

Human Context of the Benin Coastal Zone

Since the sixteenth century, the littoral of the Gulf of Benin, just like the whole of the West African coast, has been the centre of many human migrations and the magnet attracting intense agricultural and commercial activities (Adam, 1991).

Demography

Although the distribution of the population is uneven, the density of rural population in the coastal plain of Benin is more than 250 inhabitants/sq.km. The urban and demographic dynamism is marked by industrial and related activities in Cotonou and a similar situation exists in Togo in relation to Lome. The combined population of the major cities of Benin and Togo (Lome, Aného, Grand-Popo, Ouidah, Cotonou and Seme) is estimated at about 1,700,000 inhabitants; the population of the entire coastal plain of the two countries is about 2,500,000, over 25% of the combined population. The urban dynamism of Cotonou is a subject of concern, as it is a town in full demographic growth (800,000 persons) where the only open space for expansion is on barrier islands stretching East of the town in areas where coastal erosion is already very important.

Economic Activities

The coastal region is the economic hub of both countries (Benin and Togo) for it harbours the main towns, the ports and, above all, a number of important industries. The role of the port activities in the present economic development of the two countries is unquestionable, in spite of the scarcity of comparative data to demonstrate its importance. Cotonou and Lome ports both play an important role in the import and export trade of landlocked countries of West Africa (Mali, Burkina Faso and Niger). The steady growth in the port activities which was more than 500% from 1968 to 1978, even recorded a sudden increase between 1977 and 1980 because of the onset of certain activities (oil refinery in Lome and the role played by Nigerian imports during the time of oil boom, when Lagos port was "congested").

Agriculture in the region is a function of the climatic and pedologic conditions, which are not good. The coconut trees constitute a well-planned planting which continuously borders the shoreline of the Gulf of Benin. They are specially found on the actual and subactual coastal barriers, and on the old ridges which arise from lagoons and marshes as small islands. Near the coastal lagoons, some grain and root food crops are grown with pulses (maize, cassava, cowpeas) as well as vegetables. These agricultural activities are complemented by the specific female activities of salt extraction and coconut oil processing.

Fishing for many native people was, and still is, a traditional activity (small day-trip fishing) and provides freshwater species (*tilapia* and *crustacea*). Since the construction of Cotonou port, offshore fishing has developed with the massive influx of *Fanti* and *Keta* people from Ghana who introduced gear boats in this activity which became semi-industrial. The economic position of fishing in the region is an average position (66th)

in the world, near Côte d'Ivoire, but far behind Nigeria (28th), Senegal, (33rd) and Ghana (34th). Today, offshore fishing is the most important activity practised by fishermen living on the coast; it provides a considerable quantity of fish (about 50 million tons/year for both countries) consumed by a large part of the population of the capital cities and the coastal towns.

Tourism is often seen today as the best means of obtaining foreign currency, but a large part of this currency is re-exported immediately to Europe and America. Tourism uses the natural potentialities offered by the Benin Coastal Zone (beautiful beaches, tourist villages of Ganvié, Guézin, Avlo, Djêgbadji) and provides an appreciable amount of accommodation (2,000 comfortable rooms in Cotonou and Ouidah).

These tourist assets favour widespread speculation on large areas of land throughout the region (about US$ 8,000 per ha of land), and specially around the city of Cotonou where the cost is over US$ 40,000 per ha. These assets have in any case to be safeguarded in order to stimulate a well organised and coherent tourist sector.

PART II SEA-LEVEL RISE VULNERABILITY ASSESSMENT

Impacts of Accelerated Sea-Level Rise

Rising sea level is always accompanied by flooding and erosion. The coast of Benin will be very sensitive to the projected sea-level rise and catastrophes may result if appropriate precautions are not taken in time. A discussion follows on impacts in the cases of three possible scenarios.

Sea-Level Rise of 50 cm

As Fig. 3 shows, the shore could retreat considerably, particularly between Hillacondji and Grand-Popo. A retreat of about 100 meters is possible under this scenario; the Cotonou-Lome interstate road would be dangerously threatened and would have to be moved inland. Nearly half the beaches and coconut-tree plantations would disappear in this area, although some of the larger planters could avoid serious damage. It is certain that the Grand-Popo and Agoué graveyards would be periodically washed by the waves.

If urbanisation is checked, particularly in the East of Cotonou, the risks would be less, but there is a little hope that this will happen. The swampy areas would increase considerably, especially in the estuary of the Mono river, which would bring about a critical loss of available land. The ecological imbalance caused by the oversalinisation of the coast lagoons would surely be disturbed and the degradation of the mangroves, which is already persistent, would be aggravated.

Protective measures would continue to aggravate the problem downstream (to the East), but they could protect the very sensitive strategic places on the coast. However, such protection will be short-lived and would lead to the other management problems.

Sea-Level Rise of 100 cm

All damage expected in the first scenario would be aggravated. In addition, shoreline retreat would provoke the displacement of all hamlets built on the crest of recently formed barrier islands. Two-thirds of Cotonou would be submerged and the town would be depopulated because there is no adjacent unflooded land suitable for resettlement. The towns of Grand-Popo and Agoué would be seriously threatened and would undoubtedly disappear through erosion as much as flooding. A high salinisation of the coastal plain would render living conditions more precarious. Protective measures would not be feasible and people would, instead, think of planning for migration towards the plateau.

Sea-Level Rise of 200 cm

Because their average elevation is only 3 m, all recently formed barrier islands will come close to being completely submerged; the portions not inundated would almost certainly be eroded (Fig. 3). Only a few small "islets" of lesser importance would remain. All human settlements on the coastal plain would disappear. The Lagos-Cotonou-Lome interstate road would be partly submerged. The settlement patterns in this part of the Gulf of Benin would have to be completely reconsidered. In any case, if this rise of the sea level persisted, people would surely not wait

before considering relocation toward the plateau and new modes of life.

Quantification of Risks to Benin of an Accelerated Sea-Level Rise

Because of the extent to which natural and cultural systems in Benin have evolved in close association with current and past rates of SLR, an accelerated SLR of any magnitude will have serious cultural and economic consequences for the coastal populations and the country as a whole.

Cultural and economic impact

Whereas in strictly numerical terms the totals are quite modest, they represent very serious dislocations for Benin at the national level. Accelerated sea-level rise would seriously threaten the country's largest city (Cotonou) as well as the other coastal towns and nearly all major economic and infrastructure investment. For instance, located within 2 m of high tide are about 25% of the country's total population (1,200,000), 2.5% of rural settlement (150,000), 50% of tourist accommodation, 75% of industrial production capacity, and all airport facilities (Table 2).

Dislocation in Cotonou would be of paramount concern because of the increasingly dominant role the port plays in the economic development of the country, as well as the increasing share of national population living the capital and the surrounding region. In the Cotonou area, 5 km of shoreline is presently fronted by port facilities and 3 km is fronted by industry. Associated with Cotonou are 6,000 of the 6,400 hectares of urban land which is below 2.0 m (Table 2). Without protection, a 0.5 m rise would bring loss of approximately 25% of mainland in the Cotonou area and a 1.0 m rise would inundate nearly two-thirds of the city (Adam, 1991). Mangrove loss, wetland expansion, and erosion are already critical in the Cotonou area, particularly on the barrier islands stretching East of Cotonou, where population is rapidly expanding.

Industry occupies 150 hectares below 2.0 meters and the value of the goods produced (US$ 200 millions) in these areas represents 75% of the country's industrial production (Table 2). Commercial areas occupy 400 hectares below 2.0 m; cultivation on the barrier islands, consisting predominantly of large-scale coconut plantations, is practised on approximately 9,000 hectares below 2.0 m (250 ha in the intertidal zone) and contributes US$ 11.6 million to the economy, approximately 5,8% of the total annual national agricultural product. Half of the area under coconut plantations would be lost by a SLR of 0.5 m.

The development of tourism is a priority in Benin and tourism is the largest single factor in the economic development of the immediate shoreline today. Fifty-percent of the tourist accommodation facilities in the country are located in the area below 2.0 m. (Data sources also identify 10 swimming pools and 3 golf courses in the 0-2 m zone). Presently, tourist areas extend along 75 km of beach and occupy approximately 1,000 hectares. Nearly half of the area of beaches could be lost, if left unprotected, by a SLR of 0.5 m.

Table 2 reveals 135 km of road and 32 km of rail located below 2 meters which would require protection or relocation as sea level rises. Under a sea-level rise of 0.5 m, the main interstate road would be dangerously threatened and would have to be moved inland (Adam, 1991).

Impacts on natural features

Estimation of impact on the natural landscape is much more difficult. The quantification methodology does not lend itself easily to discussion of the intrinsic value of the natural environment or the non-economic importance which natural features may have to the coastal populations.

Dunes are an ubiquitous feature along the entire 125 km barrier shoreline. The role of the dunes in barrier stabilisation under conditions of accelerated SLR is inefficient, considering the wave direction and height. Marshes account for the vast majority of area within the intertidal zone (12,720 ha) and approximately 75% (31,800 ha) of the undeveloped area from 0 to 2 m (Table 2).

Lagoons, occupying 3,120 ha, have attracted artisan fisher people, many from Ghana, and support a vibrant fishing trade. Many of the fish caught in the region, lagoon and offshore, depend

on the coastal wetlands as breeding grounds. It is not known whether the shallow water bodies that would replace the wetlands would have the ability to support fisheries.

Offshore fishing is an important activity, contributing US$ 40 million to the national economy and providing 20,000 tons of fish for a large part of the population in the coastal cities and towns. Table 3 indicates the potential for extensive land loss to estuarine environments under the 0.5, 1.0, and 2.0 m sea-level rise scenarios.

PART III. POSSIBLE RESPONSES TO SEA-LEVEL RISE

The IPCC Coastal Zone Management Subgroup (IPCC RSWG 1992) has urged developing nations to:

(1) identify the coastal areas affected by a one-meter rise in sea level,

(2) identify national response measures, and

(3) develop and implement coastal zone management plans by the year 2000.

In the case of Benin, although identification of areas at risk is underway, it remains a pursuit of a few concerned academics. In order to develop a national response strategy, further attention must be given to coastal problems, quantification of risk must be continued, and the costs, benefits, and the cultural, economic, and institutional barriers to alternative response options must be assessed. Some form of national coastal planning would be necessary in order to carry out initiatives towards effective coastal management and mitigation of SLR impacts. The current experience with coastal management in Benin suggests that a timely and successful response to coastal problems is a distant prospect.

Strategies to protect the coastal zone

The coastal environment is subject to many important modifications (coastal erosion, degradation of vegetation, specially of mangrove trees, destruction of molluscs).

The Benin coastal zone is the economic hub the country, therefore it is a strategic asset to be safeguarded. The different types of coastal defence structures, as expensive as inefficient, must be reconsidered in order to take the environmental assessment into account, particularly the sea-level rise due to global warming resulting from greenhouse gases.

In relation to this situation a double response is needed. First of all, adequate management of short term issues is needed. Secondly, in view of the accelerated rise in sea level, an overall strategy will become essential.

In order to secure an overall policy for the management of the coastal zone of the Gulf of Benin, no fact can be ignored when proposing spatial re-organisation. Two solutions are possible:

(i) protection of the strategic site,

(ii) respect for nature, adapting it in some cases by strategic recession.

Coastal management of short term issues

The means of protection used up to now are the rocky groins.

On the Benin coast, except for a limited number of perturbations at the mouth of the river Mono, the situation is less dangerous to the West of Cotonou. Groins are used for the protection of the harbour and the channel of Cotonou.

However, the situation in the West of Siafato is very worrying for the authorities and the owners of the housing on that part of the city. In fact, it is at present the only viable area for satisfactory urban development and many promoters, unaware of the danger of coastal erosion, have built nice and very expensive houses when compared to the overall poverty prevailing in the country. Some coastal defence structures are under study. These are the rocky groins or "gabbions" used to protect about ten kilometres of the coast. Everywhere else, the coastal populations adopt strategic recession as a response to coastal erosion.

A coastal management policy is seen by everyone to include respect, as far as possible, of the coastal environment. This approach has to be approved when one knows that the sea-level rise is a reality which cannot be avoided. The protection of natural areas is therefore a necessary condition in securing coherent management of the coastal region.

A policy of land use in the coastal zone of the Gulf of Benin is unavoidable and it must be based

on the respect of the natural elements, but also take account of traditional institutions, in particular by associating the groups concerned with each sector of the coast.

Some of the barriers islands in Benin are already experiencing intensive development and erosion. SLR-related erosion and beach profile adjustment will accelerate the narrowing and retreat of the barriers. Even without ASLR, it is urgent that Benin begin the process of adapting to coastal erosion and degradation because opportunities for avoiding severe cultural and economic impacts in the future require immediate action. At present, responsibility for coastal management is with the government survey offices (National Coastal Management Committee) and the Applied Research Laboratory at the National University of Benin. Often, the advice of those responsible for coastal management is ignored by policy makers and decision makers favour proposals of foreign survey offices.

A coastal development plan

The management of the Benin coast is dictated largely by the demands of the national and international economies. The port of Cotonou has witnessed a steady growth of its activities over past decades (e.g., 500% from 1968-78) largely a result of its role in the import and export trade of landlocked West African countries. More recently, mainly as a result of petroleum transport and congestion in the Lagos Port, the Cotonou port has experienced a sudden increase in activity. The construction of a deep water harbour and industrial sites, the construction of piers for the protection of strategic areas, and hydroelectric developments on the Mono River have all added to the sedimentary and ecological imbalance of the coastal zone. The foremost concern of planners and developers is promoting tourist development and the that led to the general consumption of space all along the Gulf of Benin by hotels and various facilities aimed at satisfying the needs of the tourist trade (Adam, 1991). In the face of such priorities and disorderly management, a coastal development plan was proposed in the late 1980's. In summary, the plan consisted of:

- set back requirements for urban settlement and large-scale development;
- identification of prospective strategies where shoreline stabilisation is necessary;
- planning tourist and recreation zones on the basis of mobile facilities.

As yet, no official government position has taken such ideas into consideration. Obviously, to avoid irreversible choices, a new philosophy is necessary for management of the coastal zone. Policy change, with respect to improving coastal management, is only now becoming possible through the pressure of public opinion which is obliging decision makers to enter a dialogue with researchers, planners, and now developers. Even so, few perceive rising sea level as an important factor in coastal management concerns. Additional scientific evidence is necessary to spur government acknowledgement of the problem. Concern for the sensitivity of the coastal zone and the obvious need for a short and medium term scheme to identify strategic areas of the coast has led scientists at the National University of Benin to propose a coastal management strategy based on 4 zones: (1) urban, (2) recreation and tourism, (3) other strategic areas, and (4) ecological.

Options for strategic responses

To date, two strategies have been put forward to address coastal zone problems : (1) coastal defence and (2) a combination of accommodation and retreat measures.

Coastal defence

Shoreline stabilisation in Benin has been practised through the use of rock cladding, seawalls, jetties, and artificial nourishment. Currently, protection of the littoral zone through the use of beach rock is preferred, but the effectiveness of this type of protection will rapidly decrease under any acceleration of SLR. In addition to the technical difficulties, the ecological and economic context of Benin suggest that pressure to adopt the option of structural protection (seawalls, jetties, etc.) will result in irreversible choices in the short-term that will have little applicability in the medium to long term.

As described above, structural protection is already playing a significant role in the ecological instability of the coast. Stabilisation would aggravate downstream problems and encourage further encroachment. Measures may be necessary for temporary, emergency protection of existing strategic areas but would involve very high and recurring costs under accelerated SLR. Approximately 100 km of coast would need to be protected to stabilise the barrier system under a 0.5 m SLR. Even at current levels of development, the costs of protecting the coast from a 0.5 m rise would be exorbitant for a small country like Benin knowing that the GNP of the country is about US$ 502 million (Table 4).

For example, at an estimated cost of US$ 3.5 million per kilometre, seawall protection for the 61.5 km of strategic areas would cost over US$ 215 million. The applicability of structural protection is severely limited under ASLR as no type of protective measure will be feasible in this environment under a 1.0 m rise (Adam, 1991).

Accommodation and retreat

In light of the technical and institutional limitations, ecological implications, and prohibitive costs associated with structural solutions (as well as the lack of available resources in these difficult economic times), coastal management research in Benin has increasingly favoured measures that respect the natural dynamics of the coast. A policy of accommodation would include regulating development, balancing ecosystem preservation and development, and altering land use, as recommended in chapter 17 of Agenda 21. A coastal management scheme has been proposed (see above) that is based on these principles; yet it lies ignored, and port construction, urbanisation, and tourist development continue unabated.

A strategy of retreat could include restrictions such as setbacks requirements for new development; and could encourage ecosystem, settlement, and agricultural retreat to adjacent, higher elevations. Even if the economic, technical and institutional will were found, existing urban, industrial, and agricultural development would not have the possibility of simple inland retreat due to the lack of suitable adjacent land. For example, land constraints have forced recent settlers in Cotonou to occupy ever-lower and more hazardous areas. In fact, a 1.0 m rise scenario would submerge two-thirds of Cotonou and the town would have to be depopulated because of the lack of habitable land for resettlement. In the case of agriculture, the possibility of progressive inland retreat would be extremely limited because of salinisation associated with sea-level rise.

Although accommodation and retreat would be technically feasible in some situations, the state of coastal planning and legislation, as well as the lack of interest from local and national leaders, suggest that, in the future, there will be little opportunity for avoiding decisions that will reduce future vulnerability to SLR. Given the apparent inability to prevent the impending cultural and economic catastrophe related to accelerated SLR, it would seem appropriate to restrict further development on the barrier systems.

Relocation

Although not yet considered, relocation of facilities and settlement from the barrier islands on the inland coastal plateau will be the only option for Benin as sea-level rise progresses. Inland relocation of economic infrastructure and settlements (to a very different environmental setting on the plateau) would involve a massive economic burden and a complete loss of current modes of life for a significant proportion of the Benin's population.

Both structural protection and inland relocation are daunting proposals. A practical approach to the fate of the barrier islands would include a vigorous implementation of accommodation measures in the short-term and a medium-to-long-term goal of transition away from the barrier island-based economy.

CONCLUSION

The fragility of West African coasts in general, and those of Benin in particular, is of great concern. The most important need in the effort to preserve this littoral is better knowledge of its dynamics. Sea level-rise is an inescapable parameter to reckon with any approach of the management of the littoral.

Many studies of coastal processes, carried out in this region for the last ten years, allow us to propose more adequate protective strategies for the coastal areas in order to reconcile environment and development in the Gulf of Benin.

Data, including aerial and linear measurements of natural, cultural, and economic features, now provide a basis for estimating risk to ecosystems, human settlements and economic activity from an accelerated sea-level rise in Benin. The analysis of available data suggests that an ASLR will result in catastrophic impacts on the ecological and cultural systems that have evolved on the fragile barrier islands of Benin. The vast majority of land currently supporting 15% of the national population, 75% of industry, and the majority of economic infrastructure, is located below 2.0 m and would risk widespread dislocation even in the very early stages of ASLR. The data set can be used to emphasise the costs associated with current development patterns and to spur government enactment of coastal planning and policy initiatives as put forward by those currently involved in coastal management studies in Benin. The fragility of the barrier island system to any acceleration in the rise of sea level, combined with rapid progression of ecological degradation and development pressures suggest that an immediate response is needed to avoid catastrophic impacts. However, based on the experience of coastal management to date in Benin, the prospect of an effective response must be seen as extremely dim. Significant, timely progress will depend on the ability of the government to (1) acknowledge existing coastal problems and the threat of ASLR, (2) promote awareness and participation of local populations and officials, (3) redress the cultural and economic forces that underpin the urban coastal bias of investment, (4) enact coastal legislation and empower regulating authorities, (5) assemble the necessary technical and economic resources to implement coastal response strategies as necessary.

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Table 1. Monthly amplitude (in m) of the swell at Cotonou wharf

Year	1954	1955	1966
January	1.10 m	1.15 m	1.00 m
February	1.30 "	1.30 "	0.90 "
March	1.30 "	1.35 "	1.10 "
April	1.30 "	1.45 "	1.10 "
May	1.50 "	1.65 "	1.30 "
June	1.60 "	1.90 "	1.90 "
July	1.80 "	1.70 "	1.70 "
August	1.65 "	1.85 "	1.70 "
September	1.65 "	1.60 "	1.50 "
October	1.15 "	1.40 "	1.60 "
November	1.10 "	1.30 "	1.50 "
December	1.15 "	0.90 "	1.20 "
Year average	1.38 m	1.45 m	1.37 m

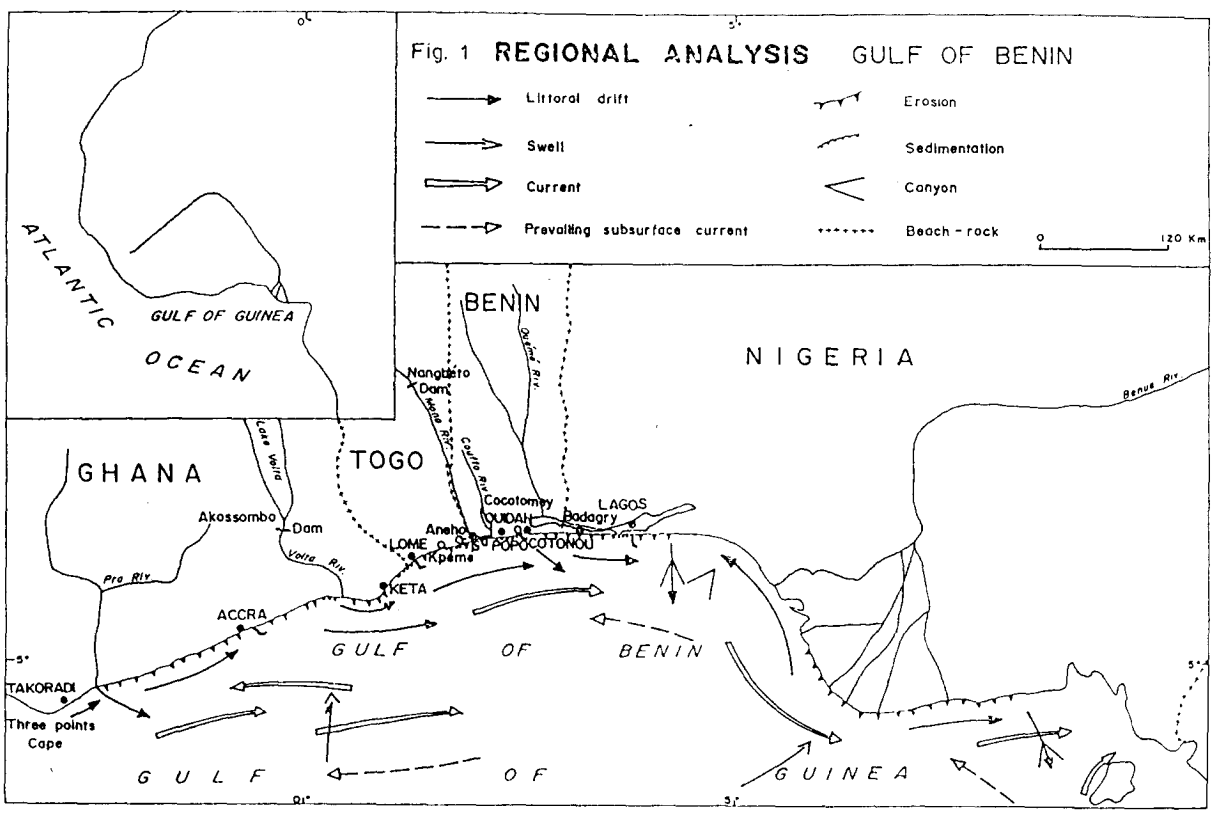


Table 2. Cultural, social and economic features at risk.

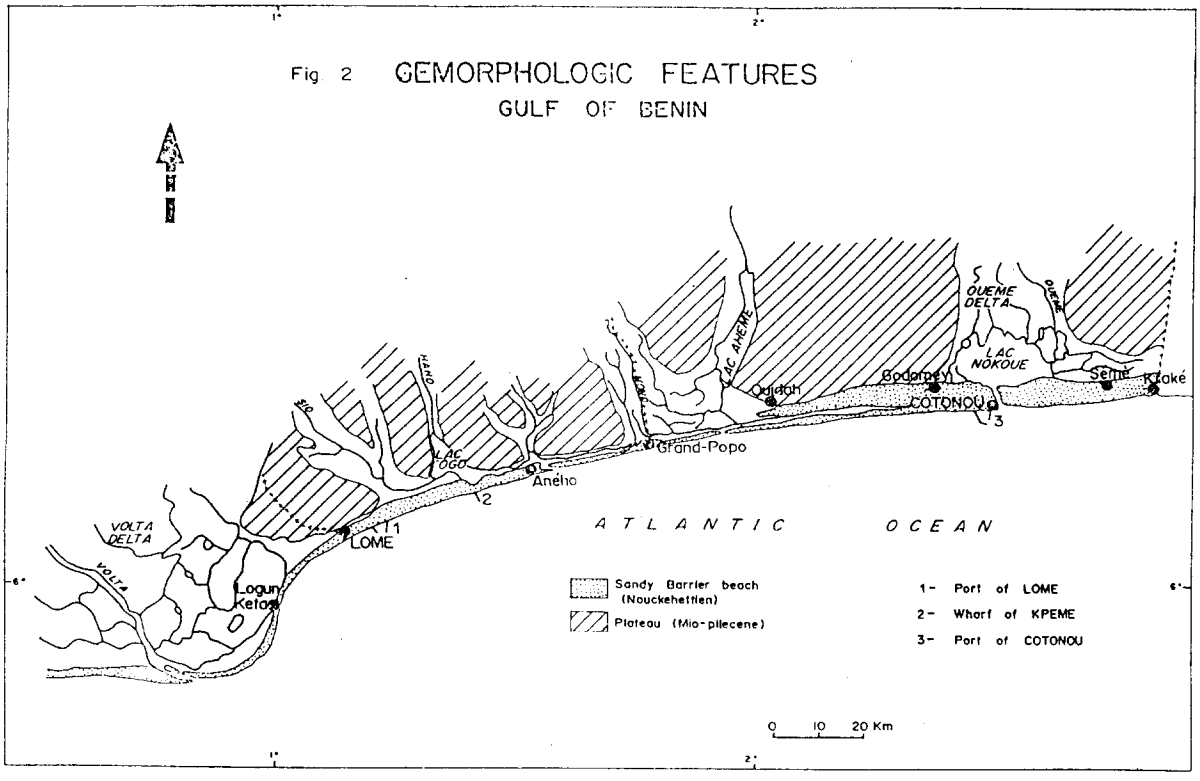
Units	Feature	Zone I intertidal zone	Zone II 0-2 m	Total Zone I + Zone II
	CULTURAL FEATURES			
Nb.	Urban habitat		6,400 ha	6,400 ha
	Rural habitat	10 ha	700 ha	710 ha
	Plantations	240 ha	7,500 ha	7,740 ha
	Cultivated & fallow land		1,250 ha	1,250 ha
	Port		30 ha	30 ha
	Industry		250 ha	150 ha
	Commerce		400 ha	400 ha
	POPULATION			
	Urban population		750,000	750,000 (15% of nat. tot.)
	Rural population		130,000	130,000 (2.55% " ")
	Urban + rural		880,000	880,000 (17,5% " ")
	TOURISM			
	Beds		1,250 beds	625 beds (50% of nat. tot.)
	Rooms		800 rooms	400 rooms (50% " ")
	Other			10 swimming pools, 3 golf courses
	HARBOUR			
	Passenger vessels		1032	1032 (100% of nat. tot.)
	Cargo		1,135,000 tons/yr	1,135,000 tons/yr (100%)
	AIR TRAFFIC			
	Flights		6,300/yr	6,300/yr (100%)
	Passengers		167,840/yr	167,840/yr (100%)
Weight	ECONOMIC FEATURES			
	Agriculture		28,700 tons	28,700 tons (2.8% nat. tot.)
	Fishing	5,000 tons	15,000 tons	20,000 tons (85% " ")
	Industry			
US$	ECONOMIC FEATURES			
	Plantations	$ 3.3 million		$ 3.8 million (3% nat. tot.)
	Agriculture		$ 7.8 million	$ 7.8 million (2.8% " ")
	Fishing	$10 million	$ 30 million	$ 40 million (85% " ")
	Industry		$200 million	$200 million (75% " ")

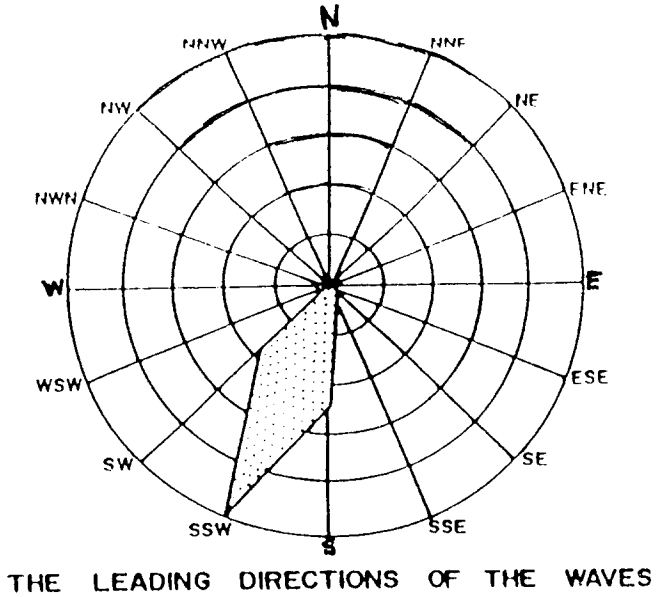
Table 3. Total land loss due to accelerated sea-level rise (km^2), (Adam, 1991).

Increase in mean sea level	Land loss due to erosion	Inundation of deltas / estuaries	Total land loss
0.5 km^2	22.5 km^2	17.5 km^2	40.0 km^2
1.0 "	145.0 "	85.0 "	230.0 "
2.0 "	450.0 "	150.0 "	600.0 "

Table 4. Estimated costs of protection strategies for different types of coastal development.

Type of development	Length	Protection method	US $/0.5 m rise costs
Residential	25.0 km	Seawall	$ 87.5 million
Industrial	2.0 "	Seawall	$ 7.0 "
Tourism	19.5 "	Seawall	$ 68.25 "
Fishing villages	10.0 "	Retreat/relocation	No estimate
Other strategic areas	15.0 "	Seawall	$ 52.5 million
Total	71.5 km		$215.25 million





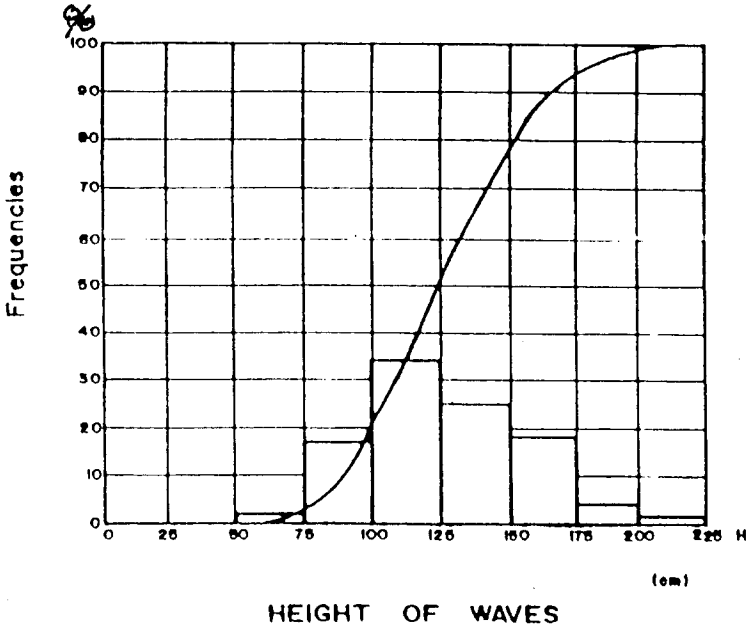


Fig. 3. Wave leading direction and height (cm) frequencies.

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L'UPWELLING LE LONG DU LITTORAL MAURITANIEN: UNE ÉTUDE PRÉLIMINAIRE

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RÉSUMÉ

La variabilité mensuelle et pluriannuelle de l'upwelling a été étudiée dans la zone mauritanienne, en utilisant les données de température de surface collectées par la flotte industrielle pélagique opérant dans la zone de 1986 à 1989, les données des campagnes océanographiques effectuées entre 1972 et 1989 et celles collectées dans la zone de Cooperative Investigation of the Northern part of the Eastern Central Atlantic (CINECA) sur cinq ans de 1971 à 1975. La répartition spatiale et temporelle de l'upwelling en particulier son évolution intra-annuelle dans les quatre dernières années a été déterminée. Les résultats mis en évidence confirment l'existence d'un upwelling permanent au niveau de la zone nord de Cap Timiris. En revanche, le sud de ce Cap, est le siège de passage des eaux froides résurgentes et celles chaudes provenant de la Guinée.

INTRODUCTION

Le phénomène d'Upwelling, est à l'origine de la richesse des eaux mauritaniennes. Schématiquement, il consiste à un transport (Transport d'Ekman) (Roy, 1988; Dobrovine et al., 1991) d'eaux superficielles chaudes vers le large sous l'action du vent (alizés); le vide ainsi créé sera compensé par la remontée des eaux profondes, froides et riches en éléments nutritifs. Au contact de la lumière, un bloom phytoplanctonique se produit constituant ainsi la base d'une chaîne alimentaire.

De nombreux travaux scientifiques ont présenté les caractéristiques physiques, chimiques et biologiques des upwellings ouest-africains (Rossignol et Aboussouan, 1965; Rebert, 1983 et Roy, 1988a et b).

La permanence d'un sous courant s'écoulant en sens inverse du vent vers les pôles est un trait commun à l'ensemble des upwellings mondiaux (Smith, 1968). Les images satellitaires illustrent la complexité des structures spatiales dans un upwelling (Koblinsky et al.,1984; Simpson et al., 1986), constituant dans les limites un front rectiligne qui a autant de structures distinctes qui évoluent dans le temps et dans l'espace sous formes de lentilles d'eaux froides à proximité d'eaux plus chaudes qui favorisent le développement de la production biologique (Haury, 1984).

L'objectif visé par cette note est de décrire les traits majeurs de l'upwelling sur le littoral mauritanien et son évolution mensuelle et pluriannuelle.

ZONE D'ÉTUDE

Les côtes mauritaniennes s'étendent sur le centre Est de l'océan Atlantique, entre 16°04'N -20°36' N sur près de 720 km (Fig. 1). La baie du Lévrier, située à l'est de la presqu'île du Cap Blanc, est l'une des plus vastes de la côte Ouest - Africaine. Au sud du Cap Blanc et de la baie du Lévrier s'étend le grand Banc d'Arguin qui déborde la côte au sud sur une longueur approximative de 80 milles jusqu'aux abords du Cap Timiris (19°20' N - 16°35' W); sa largeur maximale est de 50 milles environ. Le plateau continental au sud du Cap Blanc est large de 40 à 60 milles puis se rétrécit jusqu'au niveau du Cap Timiris où l'isobathe 200 m ne se trouve plus qu'à 10 milles de la côte. Au sud du Cap Timiris, les côtes prend la forme d'un arc de cercle ouvert vers l'ouest. la largeur du plateau continental n'excède pas 30 milles dans cette région.

MATÉRIEL ET MÉTHODE

De 1972 à 1981 les données de température de surface sont collectées par des navires océanographiques. Ces données sont éparses dans le temps. A partir de 1982, avec l'acquisition par le Centre National de Recherches Océano-

graphiques et des Pêches de Nouadhibou, d'un navire océanographique (N/O N'Diago), la qualité des données sest améliorée. De plus, de 1986 à 1989, avec lembarquement des contrôleurs sur les bateaux industriels pélagiques opérant dans la ZEE mauritanienne, la couverture spatio-temporelle se trouve renforcée. Des moyennes mensuelles par carré de 20' de côté, de 1972 à 1989 ont été établies.

"Cooperative Investigation of the Northern Part of the Eastern Central Atlantic" (CINECA), avait collectée des données au large de la Mauritanie sur la longitude 25°W. Les données utilisées concernent la période de 1971 à 1975. La méthodologie développée est la même que celle citée plus haut pour les moyennes mensuelles.

- Pour l'étude intra-annuelle, les données manquantes au niveau des carrés ont été remplacées par les moyennes mensuelles dans les carrés contigus.
- L'indice dupwelling (Norme d'upwelling) a été déterminé par la différence entre la norme mensuelle de température dans les carrés statistiques sur le plateau continental et celles situées au large.

LES RÉSULTATS:

Variations mensuelles pluriannuelles

De novembre à avril le plateau continental mauritanien est envahi par des masses deaux froides (Fig. 2, novembre et avril). Sur les quatre derniers mois de cette période (janvier - avril), l'indice d'upwelling semble homogène (Fig. 2, avril.). La circulation superficielle au dessus du plateau, largement dépendante du régime du vent, est généralement dirigé vers le sud, c'est le courant des Canaries (Binet, 1988a et b). Ce courant froid et côtier engendré par les alizés, du Maroc au Sénégal fait l'unité de cette région; Dans la saison froide, de janvier à mai, les masses d'eaux froides sont présentes le long de ce littoral (Chavance et al., 1988; Dobrovine et al., 1991) (Fig. 2, février). En mai et surtout en juin, un réchauffement est observé dans la zone Sud suite à la progression des eaux guinéennes chaudes (Fig. 2, juin). Tandis que dans la zone nord l'on constate une intensification de l'upwelling. En juillet et août, le réchauffement atteint sa limite la plus septentrionale (Nord Cap Timiris) (Fig. 2, août). Cela vient en accord avec les hypothèses qui confirment la présence des masses d'eaux froides pendant toute l'année dans la zone Nord de la Mauritanie. En septembre et particulièrement en octobre les eaux chaudes sont chassées dans les limites les plus au Sud de la ZEE mauritanienne sous l'effet de l'intensification des eaux froides (Fig. 2, octobre). Aux limites sud, se situé une zone frontale sous l'influence du renforcement ou disparition des champs de vent de directions Nord Est à NNE.

Variations mensuelles au cours des années étudiées

D'une année à l'autre, les variations mensuelles de lupwelling sont importantes à suivre pour caractériser sa dynamique spatiale et temporelle. En 1986, l'upwelling était très intense pendant la majeur partie de l'année sur l'ensemble du littoral. Un retard du réchauffement saisonnier est observé. Au mois de septembre les masses chaudes occupent de manière semblable tout le plateau continental. Au sud de la zone, l'upwelling était plus important de décembre à juillet (Tableau 1).

En 1987, les eaux froides de la résurgence ont dominé pratiquement toute l'année avec un minimum observé en Août, particulièrement nord Timiris. Dans la zone sud, un réchauffement est observé au cours du mois de septembre (Tableau 2).

Au cours de l'année 1988, un ralentissement est observé en saison froide, au mois de mars, mais la saison froide était plus longue. Cela peut s'expliquer par l'absence du signal saisonnier de réchauffement pendant l'inter-saison (froide - chaude) au sud. En août et septembre le plateau est totalement occupé par des masses chaudes jusqu'à Timiris. Le reste de l'année est caractérisé par l'intensification de l'upwelling (Tableau 3).

Durant l'année 1989, d'octobre à juillet, l'upwelling est très intense avec un maximum dans la zone nord en octobre et dans la zone sud en juillet. La saison chaude a pris pratiquement le même rythme que 1988. Il est à signaler que dans

la zone nord du Cap de Timiris, le réchauffement n'est pas mis en évidence (Tableau 4).

DISCUSSION ET CONCLUSIONS

Le long du littoral ouest-africain, les upwellings côtiers constituent un des traits les plus marquant de l'océanographie de cette région. Qu'ils soient permanents ou saisonniers, ces upwellings modifient profondément les structures physiques et biologiques au sein des écosystèmes et sont à l'origine de la forte productivité biologique de ces régions côtières.

Les résultats de ce travail illustrent l'importance de la variabilité d'indice de l'upwelling au cours de la période d'étude. Au nord du Cap Timiris, l'upwelling est permanent avec cependant un maximum d'activité au cours du printemps. Au sud de ce Cap il est plutôt saisonnier. Ces résultats sont en conformité avec des études déjà effectuées relative à la région d'étude. Les études et analyses vont se poursuivre prochainement pour cerner la dynamique de l'upwelling.

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Tableaux 1-4. Indices d'upwelling dans quatre différents carrés (Fig. 1) pour les années 1986, 1987, 1988 et 1989. L'indice d'upwelling = °C (de la côte) - °C (au large 25 °W).

Tableau1 (1986)

	Janv	Fév	Mars	Avril	Mai	Juin	Juil	Août	Sept	Oct.	Nov.	Déc.
(124+134)	-2.7	-3	-2.9	-3.8		-4.6	-2.6	-0.7	0.4	-4.1	-5.1	-2.8
19°-20°N (113+114)	-2.1	-3.2	-3.6	-3.3	-3.6	-4.4	-2	-0.3	1.5	-4.1	-4.3	-1.9
18°-19° (61+71+81+82)	-2.8	-3	-2.8	-3.6	-3.1	-3.5	-2.2		2.87	-2.6	-2.8	-4.3
17°-18° (32+41+51)	-4	-3	-3.4	-3.2	-3	-3.7	-4.7		-0.3		0.3	-3.4
16°-17° (12+22)	-5	-3.5	-3.6	-3.3	-4.2		-5.2					-3.5

Tableau2 (1987)

	Janv	Fév	Mars	Avril	Mai	Juin	Juil	Août	Sept	Oct.	Nov.	Déc.
20°-20°30' (124+134)	-2.1	-3.1	-2.7	-3.3		-2.9	-3	-1.2	-2.4	-3.3	-4	-2.6
19°-20°N (113+114)	-1.6	-2.5	-1.8	-3.1		-2.4	-1.7	-0.1	-1.3	-3.4	-2.6	-2.6
18°-19° (61+71+81+82)	-2.5	-3.2	-2.2	-3.1	-2.9	-0.6	-0.3		0.6		-3.5	-2.3
17°-18° (32+41+51)	-2.4	-2.9	-2.4	-2.2	-2.5	0.25						
16°-17° (12+22)	-3.2	-2.9	-3.2	-1.8	-1.6							

Tableau3 (1988)

	Janv	Fév	Mars	Avril	Mai	Juin	Juil	Août	Sept	Oct.	Nov.	Déc.
20°-20°30' (124+134)	-1.9	-4.1	-1.9	-3	-3.4	-3.5	-3	0.95	-0.1	-5.2	-3.7	-2.6
19°-20°N (113+114)	-1.2		-1.4	-2.3	-3.1	-3.6	-2.6	1.33	0.1	-5.4	-3.9	-3.8
18°-19° (61+71+81+82)	-3.2	-3.7	-1.9	-2.1	-3.1	-2.8		2.5	1.67	-4.5	-3.6	-3.1
17°-18° (32+41+51)	-2.5	-3.4	-1.8	-2.1	-3.1	-2.4		2.88		-4.2	-3.3	-2.7
16°-17° (12+22)	-2.5	-3.2	-1.7	-2.3	-3.1					-3.4		-2.5

Tableau4 (1989)

	Janv	Fév	Mars	Avril	Mai	Juin	Juil	Août	Sept	Oct.	Nov.	Déc.
20°-20°30' (124+134)	-2.2	-3.4	-2.8	-3.3	-3.4	-3.6	-2.9	-0.3	-0.9	-4.2	-4.5	-2.7
19°-20°N (113+114)	-1.6	-2.8	-2.2	-2.9	-3.4	-3.5	-2.1	0.3	0.1	-4.3	-3.6	-2.7
18°-19° (61+71+81+82)	-2.8	-3.3	-2.3	-2.9	-3	-2.3	-1.3	2.5	2.08	-3.8	-3.3	-3.2
17°-18° (32+41+51)	-3.1	-3.1	-2.5	-2.5	-2.9	-1.9	-4.7	2.88	-0.3	-4.2	-2.6	-3
16°-17° (12+22)	-3.6	-3.2	-2.8	-2.5	-2.9		-5.2			-3.4		-3

Fig. 1. Schéma de découpage du plateau continental en carrés statistiques de 20'x20'.

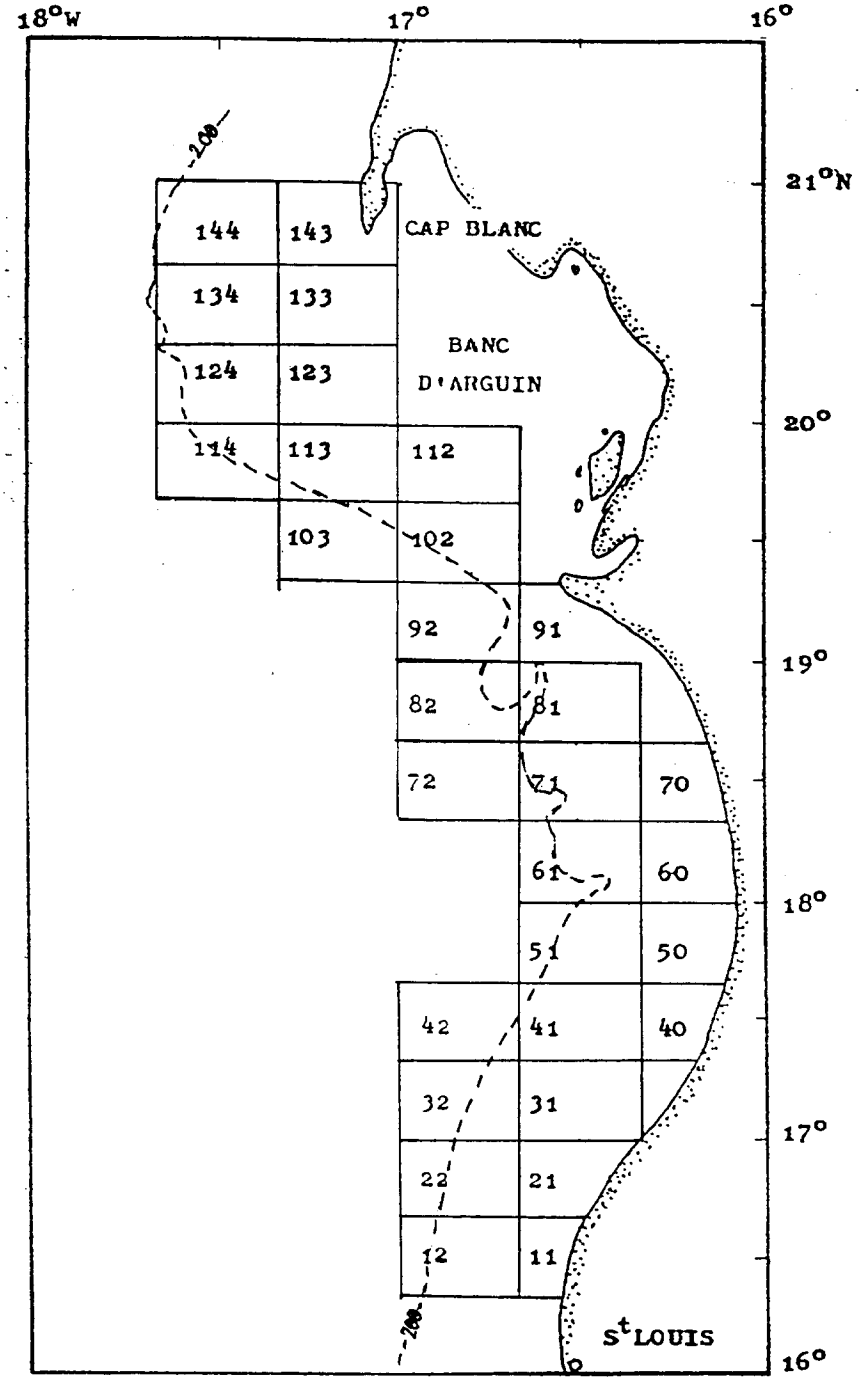
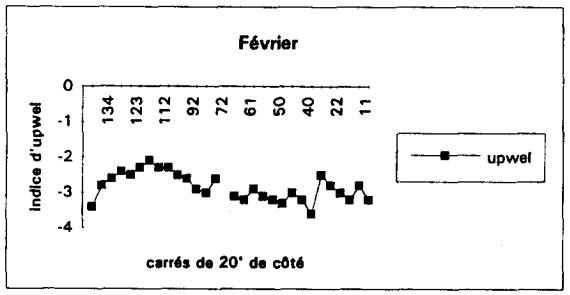
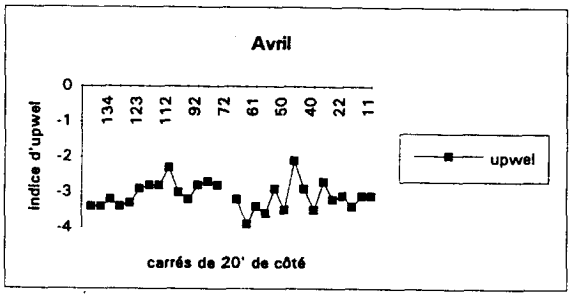
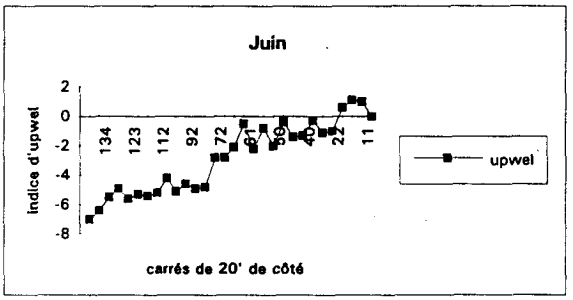
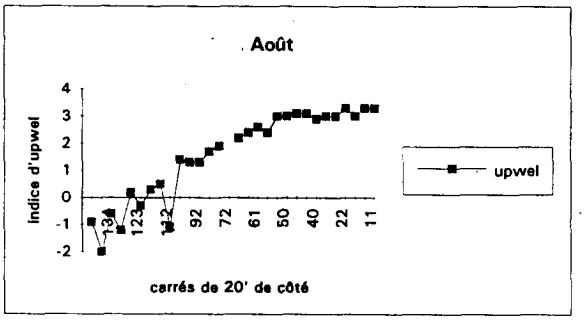


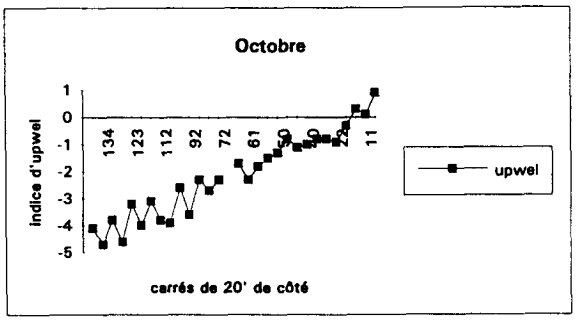
Fig. 2. Indices d'upwelling pour différent mois de l'année et des carrés.

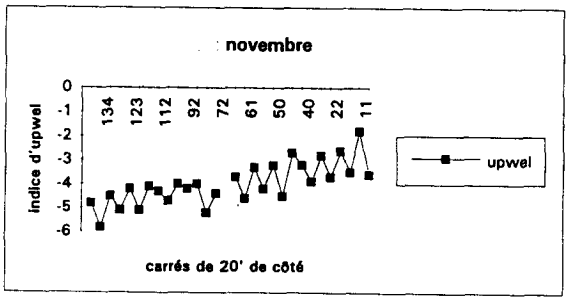












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THE IMPACT OF COASTAL CHANGES ON BIOLOGICAL RESOURCES OF KENYAN COASTAL WATERS

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INTRODUCTION

The coastal zone is essential to marine life and supports a large part of the living marine resources. This zone has the highest biological diversity compared to any part of the sea and it is estimated to contribute about 25% of global biological production and supports most of the world's fisheries as well as their important living resources (Norse, 1993). The coastal zone is also the region of the globe where variations in climate and the effect of a wide range of human activities have the greatest environmental impacts (IGBP Reports, 1992, 1993). The long term coastal ecosystems' capacity to provide people with adequate quality of life and produce renewable resources is being reduced at an alarming rate and the Kenyan situation is no exception. Biological diversity is declining at an accelerated rate as habitats are destroyed or modified either through natural processes or man's undesirable activities.

Kenya's coastal zone is an area of great physical beauty with many different ecosystems and a high biological diversity. Ecosystems consist of communities of individuals of different populations living in a given area together with their non-living physical environment. The individual species depend on each other as well as the non-living physical environment as food source and shelter, hence, taking one component out of the system creates an imbalance within it. Among the important biological resources of the Kenyan coastal zone are the coral reefs, seagrass/seaweed beds, the fisheries and the mangrove forests.

COASTAL BIOLOGICAL RESOURCES

Coral reefs

Coral reefs occur along shallow tropical coastlines where the marine waters are clear and clean. They are a major productive ecosystem of the coast. The type of reef that occurs in Kenya is the "fringing reef" which is continuous with the shore and runs parallel to it at a distance ranging from 500 m to 2 km from the shoreline. The reef is interrupted at various points by mouths of inlets, rivers and small islands (Fig. 1). About 140 different species of both soft and hard corals have been identified within the reef and these exist in a complex relationship with other living organisms such as fish and plants, both micro and macroscopic. Corals are a single most important reef builder. They usually grow from one to ten centimetres per year and their growth rate is very sensitive to changes in water quality (Emery, 1991; Hulm & Pernetta, 1993; Norse, 1993). The coral reef has important ecological as well as economic functions and these include;

(i) Acting as direct fishing grounds for artisanal fisheries which are the major fisheries along the Kenya coast.

(ii) Providing shallow protected coastal waters which are used as breeding and nursery grounds by other marine life.

(iii) High productivity which contributes to fisheries in the deep sea. Studies have documented the importance of reefs to fish population of tropical coastlines. The amount of coral relief and substrate covered by living coral tends to be positively correlated with the diversity and biomass of fishes (Smith, 1978)

iv) Supporting booming tourist industry in Kenya by catering for snorklers, divers, underwater photographers, sightseers etc. who are attracted by the spectacular sights that the corals offer. Thousands of millions of shillings of foreign earnings are realised annually through these activities.

Apart from their ecological/economic roles coral reefs create land and also serve as natural protective barriers against the forces of oceanic waves to coastal areas, thus deterring beach erosion.

Mangrove Forests

The mangrove forests along the coastal zone of Kenya cover an area of approximately 530 km^2 with about 70% of this occurring in Lamu area (Fig. 1). The forests are mainly found in estuaries and creeks where low salinities prevail due either to freshwater seepage from underground or from rivers that drain into the sea. Eight species of mangrove trees have been identified from the Kenya coast. Mangrove forests are a most productive and valuable biomass. Ecologically they have a number of recognised roles in the areas where they occur (Kokwaro, 1985).

(i) They have a prominent role in the production of leaf litter and detrital matter which is exported and used as a source of food by organisms in other parts of the coastal area such as lagoons, coral reefs, seagrass beds and even open sea.

(ii) Mangrove ecosystems provide valuable physical habitats for a variety of coastal species such as waterfowl shore birds, crabs etc. They are an important feeding and breeding ground for most commercial and sportfishes as well as invertebrates.

(iii) The ecosystem is also known to stabilise coastal shorelines that would otherwise be subject to erosion and degradation.

(iv) Mangrove forests help maintain coastal water quality by extracting chemical pollutants from the water that drain past the forest and into the sea. When moving water encounters the forests it is slowed down causing suspended sediment particles to settle thus trapping particles that would otherwise smother benthic species and reduce light penetration and productivity in coastal waters.

In terms of their economic importance, mangrove forests have been used for years to supply poles for the construction of houses and roofing of substantial building in major coastal towns and village communities.

They also provide timber, firewood, charcoal. They are used for boat building and tanning is extracted from the barks of the trees. The social-economic uses of the mangroves are right now threatening their very existence and there is urgent need to ensure that this vital ecosystem is harvested on a sustainable yield basis (Clark, 1992; Kokwaro, 1985)

Seagrass/Seaweed beds

Along the coastal areas of Kenya occur an abundance of seagrass beds and patches of seaweed beds. These grow in quiet protected waters such as estuaries, lagoons and creeks. The habitats are often shallow enough
for light to penetrate and enable photosynthesis to occur. They extend shoreward to the point where wave action prevents them from rooting. Seagrass/seaweed beds intermingle with both mangrove and reef communities at their respective seaward and land boundaries.

Whenever they occur, seagrass/seaweed beds are essential elements of coastal ecosystems. They may not be of much commercial use at present (Oyieke,1993), though they play an important ecological role by;

(i) Providing a substantial amount of nourishment, nutrients and habitats,thus providing shelter, nursery grounds for some of the important valuable species of fish and other marine species.

(ii) Trapping and binding sediments from water, reducing particulate pollutants from the water as well as stabilising the beaches (Clark, 1992).

Fisheries

The bulk of Kenyan fishing is carried out in the shallower regions of the continental shelf between the shore and the outer edge of the fringing reef. This is mainly done by use of traps, hand lines and gillnets by local fishermen, i.e. artisarnal fishery (Nzioka, 1984). There is a wide variety of species being exploited within these shallow waters (Brakel, 1981).

Trawling in the Kenyan waters is severely restricted by the presence of coral reefs, outcrops of rocks, coral and deep fissures. Only one area is suitable for trawling ie the North Kenya Banks. Trawl fishing is also characterised by the presence

of a wide variety of species. Studies from other tropical regions have shown that marine fish abundance, production and marine fisheries yields are closely linked to the productivity of coastal and shoreline habitats such as coral reefs, seagrass beds, mangrove swamps and estuaries, even if the fish populations are exploited a considerable distance from these habitats (Smith, 1978).

Sandy Beach Habitats

Ecologically the beach is an important habitat for some marine organisms. It provides a unique habitat for burrowing species such as crabs and clams. Many important birds, reptiles and other animals breed, feed and rest there. It is noteworthy that sea turtles, which are currently an endangered species, come ashore to lay their eggs in dry beach sand (Clark, 1992),

DISCUSSION

The above discussed coastal biological resources are increasingly subjected to disturbances and destruction due to coastal changes brought about by mans undesirable activities and to a lesser extent, natural processes. The Kenyan coast has witnessed a continuous growth in numbers of tourists (Table 1.) and residents over the last two decades. The natural population growth is estimated to be around 3.8% per year and besides this there is a large number of people migrating to the area. These hundreds of thousands of both Kenyans and tourists at the coast need to eat, drink and find accommodation and transport facilities. Thus pressure on living and non-living resources like land, water, food forests etc. is increasing tremendously.

Increasing population and increased development have meant an increase in effluents discharged into the sea. These include sewage, industrial waters and pesticides which have been reported to have deleterious effects on marine living organisms (Wood and Johannes 1975).

The naturally occurring transport of terrigenous sediments, particularly in the Sabaki River basin (Fig. 1) has been greatly enhanced in the watershed without proper soil conservation. The fine silt may smother bottom dwelling marine organisms and the breathing roots of mangroves. Increased turbidity may reduce light penetration for photosynthetic organisms such as the algae and sea grasses.

Careless exploitation has also taken its toll on coastal resources. This includes artisanal fisheries whereby most reefs show signs of overfishing. The mangrove forests are being clear felled at a rate that surpasses their regeneration capacity. There is pressure on the coral gardens; tourists and the boats bringing them to the reefs physically damage the corals through trampling and anchoring. There is rampant collection of live aquarium fish for export purposes as well as collection of corals and shells.

Development activities along coastal areas has been on the increase, particularly to cater for the tourist industry. Some of these development activities have resulted in the loss of coastal habitats and marine species associated with them. For instance the construction of groins, sea walls and other forms of protection for beach properties has a negative effect on the sandy beaches by deflecting and thus reducing supplies of sand to the beach. The construction of beach properties right up to the high water mark and, occasionally beyond, directly destroys habitats.

CONCLUSIONS

The Kenyan coastal zone is an area of diverse activities most of which depend on the existing marine biological resources. Thus every effort should be made to halt the continued degradation and destruction of the coastal habitats. It is therefore recommended that:

- An active programme on public awareness / education be put in place, targeted at local communities and the tourism industry, focusing on the sensitivity of the coastal environment as it relates to their activities.
- An interagency authority be created to facilitate integrated planning and policy / decision making within coastal areas.
- Coastal research activities be strengthened through funding, manpower development and capacity building. Practical avenues for disseminating research findings to policy / decision makers should be put in place.

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Table 1. Growth of Tourism in Kenya. Breakdown of International Tourist Arrivals, 1980-1989. Source: World Tourism organisation statistics, tourism market report 1987/88 Economic Survey, 1990.

Year	World	Africa	Kenya
1980	284.8 million	7.1 million	362 thousand
1981	288.9 -	8.0 -	352 -
1982	286.8 -	7.8 -	362 -
1983	284.2 -	8.2 -	333 -
1984	312.4 -	8.9 -	453 -
1985	326.5 -	9.9 -	541 -
1986	334.5 -	9.5 -	604 -
1987	361.2 -	10.0 -	662 -
1988	393.2 -	12.7 -	676 -
1989	405.3 million	13.3 million	713 thousand

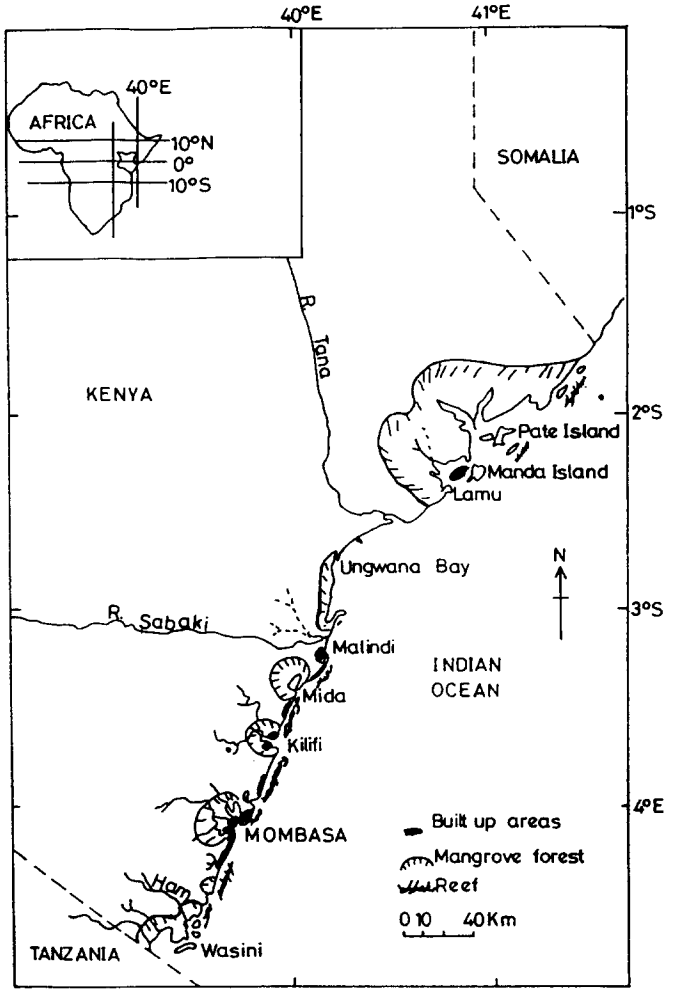

Fig. 1. The Kenya caost. Inset: regional location.

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DU MODÈLE AU RÉEL, LA DIFFICILE GESTION DU LITTORAL DU GOLFE DU BÉNIN

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KEYWORDS: coastal erosion, scale-model, coastal defense, Guinée Gulf

RÉSUMÉ

La côte du Golfe du Bénin, basse et sableuse, soumise à une violente érosion par suite d'une série d'erreurs d'aménagements, a fait l'objet en 1987-1988 d'importants travaux destinés à protéger sur 15 km la ville d'Aného et l'usine de phosphates de Kpémé, principale industrie du pays. La préparation de ces travaux de protection, rendus indispensables par la gravité des enjeux économiques et sociaux, a nécessité des études hydrologiques et sédimentologiques très détaillées, la construction et l'exploitation par un bureau d'étude spécialisé de deux importants modèles physiques (32 x 20 m) et de deux modèles mathématiques destinés à optimiser le dispositif de protection et à déterminer l'évolution du trait de côte sur une période de 25 ans. Dans le même temps, deux études appuyées sur plusieurs modèles mathématiques ont été conduites pour déterminer les impacts de la construction de deux barrages sur le Mono, avec la Volta l'un des deux pôles d'apports en sédiments au littoral.

Un suivi régulier de l'évolution hydrosédimentaire du littoral togolais étant réalisé par l'Université du Bénin depuis 1985, il est possible, aujourd'hui, de faire une première comparaison entre les prévisions des modélisations et l'évolution constatée en milieu naturel. Cette comparaison fait apparaître une bonne correspondance d'ensemble entre les prévisions des modèles et l'évolution en nature du tracé du littoral. Cependant, dans le détail de l'évolution secteur par secteur, se manifestent de sensibles divergences.

Ces divergences sont probablement liées à la relative imprécision quantitative des paramètres hydrosédimentaires observés en nature et utilisés pour le tarage des modèles et, surtout, au fait que la modélisation repose sur l'utilisation de situations moyennes tant du point de vue sédimentologique (débit sédimentaire) qu'hydrologique (cycle de houle) qui ne représentent pas la complexité d'une courte série d'années aux conditions aléatoires. Il est probable que ces simplifications ne puissent pas traduire toutes les finesses de dynamiques aux interactions particulièrement complexes.

ABSTRACT

The low and sandy Togolese coast has undergone violent erosion action, due to a series of development errors. In the years 1987-1988, it was the suject of important protection works, aimed at protecting, along 15 kms, the town of Aneho and the phosphate works of Kpémé, the main industrial activity of the country. The preparation of these works, made vital by the importance of the social and economic stakes involved, required very detailed hydrologic and sedimentologic studies, along with the elaborate building and exploitation by a research consultancy, of two important physical models (32 x 20 m) aimed at optimizing the protection plan, and at defining the evolution of the coastal profile over a 25 year period. The hydrosedimentary evolution of the Togolese coast having been followed through by the University of Benin, since 1985, it is now possible to make a first comparison between the results of this model, and the evolution that has taken place in real life within a four year period.

This comparison shows a good global correspondence between the prediction of built in model, and the real life evolution of the coastal profile within the protection plan scope.
Nevertheless, a detailed study of the evolution area by area shows that rather noticeable differences can be perceived in the sedimentologic behaviour of the compartments, and, above all, of the areas in the downstream drift of the protected zones.
Those differences are probably linked to the relatively imprecise quantitative hydrosedimentary observations in real life. They are probably due above all, to the fact that the model relies on the use of data corresponding to medium situations as far as sedimentology is concerned (sedimentary discharge), and as hydrology is concerned (swell cycle), which do not represent the real complexity of one year, or of a short series of years, the conditions of which are impredictible.
Moreover, it is likely that the reduction to the different scales cannot really express all the details of a complex evolution.

INTRODUCTION

La côte du golfe du Bénin est soumise depuis une vingtaine d'années à une violente érosion, qui est la conséquence d'une série d'aménagements conçus sans prise en compte de leurs impacts. En particulier le port de Lomé, bloquant en totalité l'important transit littoral Ouest-Est (1,2 millions m^3/an en moyenne) a déclenché progressivement sur plus de 40 km un recul de la plage qui a atteint jusqu'à 40 m/an, menaçant toute une série d'infrastructures et surtout l'usine de concentration de phosphates de Kpémé et la ville d'Aného.
La violence de cette érosion et l'importance des sites menacés ont rendu nécessaire la mise en place d'un important programme de protection. Il comporte à Kpémé une batterie de 10 épis de longueur variable et à Aného un brise-lames accompagné de 6 épis. Le système réalisé protège 15 km de littoral. La première phase (brise-lames et 11 épis) a dû être réalisée très rapidement de mai 1987 à mars 1988, parallèlement aux essais sur modèles. La seconde devait être réalisée en 1993, mais les évènements politiques ont renvoyé sa réalisation dans un futur incertain.
L'ensemble des données de ce problème, complexe, a été exposé en détail par ailleurs (Rossi 1988, 1989, 1990) et nous n'en rappelerons ici que l'essentiel. Parmi les études qui ont été menées à cette occasion, deux modèles sédimentologiques et deux modèles mathématiques ont été réalisés à Grenoble par la Sogreah. Le but était d'optimiser le système de protection et aussi de déterminer l'évolution de la côte à échéance de vingt cinq ans. Par ailleurs, nous avons réalisé à l'aide de plusieurs modèles mathématiques pour le compte de la Banque Mondiale et de la société Coyne et Bellier les études d'impact des barrages de Nangbeto et d'Adjarala sur le fleuve Mono, pôle d'apport secondaire en sédiments. Parallèlement, l'Université du Bénin effectuant un suivi régulier du comportement sédimentaire du trait de côte, il est intéressant, de faire sept ans après un point sur l'évolution en milieu naturel et de la comparer aux résultats des modèles.

UNE COTE BASSE ET SABLEUSE LONGEE PAR UNE PUISSANTE DERIVE LITTORALE, ALIMENTEE PAR LA VOLTA ET LE MONO

Sur près de 400 km, du pôle d'apport de la Volta, au Ghana, à celui du Niger, au Nigéria, une série de cordons littoraux W-E ont, depuis 5 000 ans, régularisé une côte qui était échancrée de profondes rias lors du maximum transgressif flandrien. L'altitude de ces cordons ne dépasse pratiquement pas 5 m au dessus de l'actuel zéro hydrographique. Généralement associés à des beach-rocks, ils séparent la mer d'un système de lagunes plus ou moins étendues, parfois colmatées (Fig. 1).

Les paramètres hydrologiques et sédimentologiques

La direction et le régime de l'agitation sont liés à ceux des vents. Ils font apparaître deux saisons: l'une de houles de faible hauteur (0,4 - 0,5 m) de octobre-novembre à mai-juin; l'autre où, durant l'été, les hauteurs atteignent et dépassent 2 m (Fig. 2). Les directions de la houle sont très constantes et montrent une prédominance des

directions S et SSW en hiver et SSW à SW durant l'été; il existe donc une nette corrélation hauteur-direction. Sa période est comprise entre 10 et 15 s avec une fréquence maximale autour de 11 - 12 s. Les mers de vent ont des périodes de l'ordre de 4 à 6 s.

A la côte, l'obliquité de la houle au déferlement varie entre 4° et 9°, avec une valeur moyenne autour de 6° - 7°. Il existe, par ailleurs, de nombreuses zones de concentration d'orthogonales de houle. C'est, en particulier, la présence de telles concentrations autour du wharf d'embarquement des phosphates de Kpémé et face à la partie centrale de la ville d'Aného qui nous a conduit, en 1984, à proposer la protection de ces zones.

De Lomé au Nigéria, la distribution des sédiments est, globalement, homogène:

- sur l'estran et dans la zone de déferlement, les diamètres médians des sables, bien triés, varient entre 0,4 et 1 mm, avec une médiane voisine de 0,6 mm. Cependant, on remarque une nette augmentation des diamètres médians vers l'est à partir de l'embouchure du Mono dont les apports sont évalués, avant constructions des barrages, à 100 000 m^3/an.
- sur les fonds jusqu'à 11-12 m, il s'agit de sables fins, bien classés, dont les diamètres médians sont compris entre 0,2 et 0,3 mm. Là encore, à l'est de l'embouchure du Mono, les diamètres médians varient brutalement, passant à 0,5 - 0,6 mm.
- au-delà des fonds de 12 m, on trouve des sables moyens à grossiers dont les diamètres médians, compris entre 0,4 et 1,5 mm, varient de façon importante d'un échantillon à l'autre sans que l'on puisse identifier une répartition longitudinale ou transversale logique.

Les calculs effectués par le L.C.H.F. (1984) et l'observation des profils bathymétriques montrent que la limite d'action de la houle doit se situer vers 10-11 m. Dans ces conditions, compte tenu de la taille des sables par fonds supérieurs à 12 m, ces dépôts peuvent être considérés comme fossile, ou du moins, subfossiles, si l'on tient compte des variations holocènes du niveau de la mer.

Par suite de l'obliquité de la houle par rapport à la direction de la côte, une puissante dérive littorale longe les plages de cette partie du golfe du Bénin. La capacité de transport a été calculée par NEDECO (1975), par LACKNER (1983) et par le L.C.H.F. (1984). Tous ces calculs ne reposent malheureusement pas sur des campagnes suivies de mesures en nature, ce qui limite la précision. On estime, cependant, que la capacité de transport est comprise entre 1 et 1,5 million de m^3/an, ce qui est énorme et explique l'ampleur et la brutalité des réactions morpho-sédimentaires observées dès que l'on modifie l'équilibre dynamique existant.

Les calculs montrent que la quasi-totalité du transit s'effectue entre + 2 et - 2 m, avec un maximum autour de + 0,30 m ; 75 % de ces mouvements sédimentaires se faisant entre + 0,80 et - 0,50 m, autrement dit dans le déferlement.

Le beach-rock

Le beach-rock est apparu en 1970-1971, à la faveur de l'érosion, à l'est du port de Lomé. En 1980, il affleurait sur 8 km de longueur à l'est de la contré-jetée du port, et l'on remarquait que le trait de côte se stabilisait à une distance de 30 à 60 mètres en arrière du banc de grès. Parallèlement, le maximum de vitesse d'érosion progressait vers l'est en exhumant, au fur et à mesure, le beach-rock des sables du cordon littoral. Ainsi, en 1984, au début de nos travaux, il affleurait sur la quasi-totalité de la côte togolaise.

L'interprétation dynamique de cette évolution semble être que le beach-rock, en dispersant sur sa surface l'énergie du déferlement, ralentit, et peut même bloquer, les transferts sédimentaires dans le profil. Ceci contribue à stabiliser le trait de côte et donc, sous certaines conditions à protéger le littoral. Mais l'arrêt du recul du trait de côte signifie aussi l'arrêt de la fourniture de sables à la dérive, et au fur et à mesure, l'accroissement progressif du déficit sédimentaire en direction de l'est. C'est ce phénomène qui a pu faire penser à une "vague d'érosion" se déplaçant d'ouest en est le long du littoral togolais. Cette interprétation a été confirmée

expérimentalement grâce à deux modèles sédimentologiques.

LES RESULTATS DES MODELISATIONS DE LA COTE TOGOLAISE COMPARAISON AVEC LA NATURE

Deux modèles de la côte togolaise ont été construits successivement afin de ne pas trop réduire les échelles physiques spatiales, l'un pour le site de Kpémé, l'autre pour celui d'Aného, dans une cuve de 32 m x 20 m, les fonds couvrant une superficie de 340 m^2. Ils reproduisent à l'échelle, la topographie et la bathymétrie levée sur le terrain.

Les échelles de similitude ont été les suivantes:

Après réglage, ils reproduisaient convenablement les phénomènes observés en nature sur une période d'un an. Pour l'ensemble des essais, une loi de décroissance du transit sédimentaire dans le temps a été établie à partir des observations en nature sur l'influence du beach-rock et des modèles sédimentologiques réalisés pour tester les conditions de son efficacité. Ces calculs effectués en 1988 montrent que le transit maximal (1,2 m^3) diminue de moitié au bout de cinq ans, et atteint 500 000 m^3/an au bout de 25 ans. La répartition en classe de périodes de cycle annuel de houles utilisé sur le modèle respecte sensiblement celui observé en nature. Les différents éléments du cycle sont indiqués en Fig. 3. Sur ces modèles, ont été réalisés des essais courts (4 ans) destinés à l'optimisation du système de protection et un essai long (25 ans) portant sur l'évolution du trait de côte.

Pour le site de Kpémé, sept ans après l'achèvement des travaux, le système fonctionne correctement et conformément aux prédictions du modèle. (Voir Tableau 1)

A l'est du dernier ouvrage, le recul a atteint dans un premier temps 50 m à 150 de l'ouvrage un an après sa mise en place. Mais un réengraissement de 25 - 30 m s'est alors manifesté et se maintient depuis. A 2 000 m de l'épi, le recul est de 25 - 30 m et reste du même ordre à 3 000 m ; il devient négligeable à 4 500 m (Fig. 4).

A l'est du dernier ouvrage, si la localisation du recul maximal est correcte, de même que l'évolution du recul à 2 100 m de l'épi, des différences sensibles affectent la quantification des autres phénomènes. Le réengraissement derrière l'épi, persistant sur 700 m de long, n'a pas été prévu. L'érosion à 3 000 m de l'épi est fortement sous évaluée. Ces deux derniers phénomènes étant probablement liés, une part significative du transit sortant du système de Kpémé se déposant immédiatement derrière le dernier épi, ce qui paraît, effectivement, contraire à la logique. Cette curiosité pourrait être due à un phénomène de réfraction sur un haut-fond, non repéré.

A Aného, les résultats des essais montrent au bout de 4 ans:

- un recul généralisé d'une dizaine de mètres du trait de côte dans tous les casiers sauf à l'extrémité Est qui reste stable. Ce recul s'accompagne d'un léger basculement;
- le mince cordon littoral qui ferme la lagune s'ouvre naturellement pendant les cinq premières années lorsque le niveau de la crue est supérieur ou égal à + 3,50 m, cette ouverture étant facilitée par les tempêtes;
- à l'est du dernier épi, en direction de la frontière du Bénin, le recul est de l'ordre de 20 m, décroissant régulièrement jusqu'à 10 à 2 000 m de l'épi.

En nature, le recul généralisé et sa décroissance vers l'est sont également observable. Il est même plus important que prévu puisqu'il dépasse 20 m à l'ouest du dispositif. La tendance au basculement se manifeste discrètement.

La loi d'ouverture de la lagune a été respectée. Elle a eu lieu en 1991, en période de fortes houles lorsque le niveau de la crue lagunaire a dépassé + 3,20 m. La forme de l'embouchure, l'évolution dynamique des flèches et le mode de fermeture ont été alors conforme. Depuis la lagune est restée fermée car son niveau de n'a jamais dépassé 2,40 m. La concordance avec les prévisions du modèle est donc excellente.

Par contre, le recul à l'est du dernier ouvrage a été très fortement sous-estimé. Il atteint au maximum 100 m, à 2,50 m de l'épi, et décroît assez régulièrement. Il est encore de 80 m à 2 000 m de l'ouvrage et de 60 m à 2 700 m, à la frontière du Bénin (Fig. 5).

Ce dernier point constitue la distorsion la plus importante observée puisque ces chiffres n'auraient dû être atteints qu'au bout de 17 à 18 ans d'évolution avec un transit littoral à la frontière estimé alors à 900 000 m^3/an.

LES PREVISIONS D'EVOLUTION DE LA COTE BENINOISE ET LE ROLE DES BARRAGES SUR LE MONO

Le système hydrosédimentaire débutant à l'embouchure de la Volta est donc actuellement tronçonné par les ports de Lomé et de Cotonou qui interrompent totalement le transit littoral. Entre ces deux ports, seul le Mono assure une réalimentation en sables évaluée à 100 000 m^3/an.

En 1987 fut mis en service sur ce fleuve le barrage de Nangbetto et la construction, en aval, de celui d'Adjarala, n'a été retardée que par les évènements politiques récents. L'effet de ces barrages va être, à terme, l'interruption de la fourniture de sables à un moment où l'érosion littorale en provenance de l'Ouest va se propager au Bénin du fait de la stabilisation naturelle (beach-rock) ou artificielle du recul de la côte togolaise, et du déficit de saturation croissant dans le temps de la dérive littorale.

Les modèles mathématiques exploités à l'occasion des études d'impact de ces deux barrages ont permis de réaliser un modèle d'évolution à 25 ans du littoral béninois qui tienne compte, à la fois, de l'évolution probable de la décroissance de la valeur du transit littoral à la frontière togolaise et de celle des apports du Mono à la mer après la mise en service des barrages. Afin de tenir compte des incertitudes portant sur l'évaluation du transit littoral actuel à la frontière et sur son évolution dans le temps, différentes hypothèses ont été testées.

Le premier fait qui se dégage des résultats est que pour toutes les hypothèses les deux phénomènes d'intérêt, à savoir la réduction du transit littoral venant de l'Ouest d'une part et les apports solides du Mono d'autre part, peuvent être considérés comme indépendants l'un de l'autre, tout au moins sur la période considérée de 25 ans. Au bout de cette période l'érosion en provenance du Togo n'atteint pas encore l'embouchure du Mono.

Cela étant, le recul de la côte à la frontière togolaise atteint 150 m après 25 ans pour des conditions optimistes d'évolution du transit littoral en provenance de l'Ouest (1,32 à 0,96x10^6 m^3/an en 25 ans). Pour des conditions plus pessimistes (80 et 60 % du transit initial), le recul passe respectivement à 250 et 350 m. Dans tous les cas, la zone de recul ne s'étend pas sur plus de 14 km à partir de la frontière togolaise, toujours au cours d'une période de 25 années à compter de 1987-88. Cela signifie que la ville de Grand-Popo devrait être peu affectée par l'érosion consécutive à la construction des ouvrages de protection à Kpémé et Aného et à l'effet du beach-rock sur la côte togolaise.

Toutefois, deux éléments peuvent influencer ces résultats. D'une part, la loi de décroissance du transit repose sur des hypothèses fondées sur des paramètres qui sont susceptibles de se modifier très sensiblement dans le temps et qui sont, aujourd'hui, imprévisibles. D'autre part un recul de plus de 200 m du trait de côte suppose, après liquidation du stock sédimentaire représenté par les sables du cordon littoral, une attaque par la mer du "plateau", lequel supporte de multiples infrastructures. De ce fait, il est peu vraisemblable que dans la réalité un recul de plus de 200 m soit acceptable économiquement et socialement. Or, si l'on admet qu'au-delà de ce recul des mesures seront prises qui l'empêcheront, cela signifie que la progression de l'érosion vers l'Est sera plus rapide.

Aussi ne peut-on exclure l'hypothèse que l'érosion atteigne Grand-Popo plus rapidement que ne l'indiquent les résultats. Par ailleurs, l'érosion de la flèche littorale, béninoise, fermant la lagune, togolaise, aurait pour effet de reporter la frontière Togo-Bénin 15 km plus à l'Est.

En ce qui concerne la situation future à l'Est du Mono, les situations encadrantes : passage en 25 ans de 100 000 à 0 m^3/an (hypothèse pessimiste) et de 75 000 à 25000 m^3/an (hypothèse optimiste) se traduisent par des reculs de, respectivement, 17 m et 12 m à l'embouchure,

cette érosion s'amortis-sant progressivement pour disparaître 8 km à l'Est.
En valeur absolue ces chiffres sont faibles : ils correspondent à la valeur observée des fluctuations saisonnières du trait de côte. Mais il faut prendre en compte l'étroitesse (parfois à peine 25 m) et la fragilité du cordon sableux qui ferme la lagune et le lac Ahémé. Il n'est pas possible de savoir si le cordon reculera parallèlement à lui-même en s'amaigrissant ou s'il disparaîtra progressivement en élargissant l'embouchure mais il est certain que le défaut d'alimentation le fragilisera un peu plus en provoquant des ruptures saisonnières dans un premier temps, probablement permanentes ensuite.
Les conséquences de cet état de fait pourraient être l'ouverture de la lagune sur la mer, le trait de côte étant reporté progressivement sur la rive nord de celle-ci. Compte tenu de l'importance occupation humaine du milieu lagunaire et, en particulier de la présence de villages construits sur des îlots limono-sableux à très faible altitude au-dessus du plan d'eau, les répercussions de ce recul pourraient être sérieuses.
Par ailleurs le régime d'exploitation des barrages va aboutir à maintenir en permanence des vitesses importantes dans l'embouchure (0,5 m/s) en même temps qu'un débit constant de l'ordre de 40 à 50 m^3/s. Les effets combinés de cette situation sur la dynamique de l'embouchure ainsi que sur la création d'un éventuel effet d'épi hydraulique n'ont pas été modélisés, mais on peut penser qu'ils iront dans le sens d'une instabilité et d'un amaigrissement croissant du cordon littoral à l'Est de Mono.

CONCLUSIONS: Sur la fiabilité des modèles

Lorsque l'on analyse les divergences entre l'évolution constatée sur les modèles et celle observée en nature, on remarque qu'elles concernent principalement le recul du trait de côte à l'aval - dérive des systèmes de protection et, principalement, celui d'Aného.
Les causes de ces écarts peuvent être multiples. Dans ce cas, la surestimation du transit littoral peut avoir deux catégories principales de raisons. En premier lieu, le débit sédimentaire injecté à l'entrée du modèle de Kpémé a été évalué à partir d'une estimation de la décroissance dans le temps du transit en provenance de l'ouest. Cette estimation est fondée essentiellement sur les résultats des deux modèles physiques réalisés pour tester les conditions d'efficacité du beach-rock, ce qui peut-être une première cause d'incertitudes, et sur une estimation de l'érosion de la côte à l'amont - dérive de Kpémé lors d'un cycle annuel de houle "moyen", c'est-à-dire correspondant à des situations théoriques de forte occurrence, mais pas forcément représentatives d'une courte succession naturelle d'années aux conditions hydrologiques aléatoires. Par contre, il est possible qu'à long terme, la succession de situations annuelles singulières tende à se rapprocher du cycle hydrologique "moyen" défini pour les essais. Dans ce cas, on devrait voir les distorsions de résultats s'atténuer. On peut remarquer que c'est cette tendance qui tend à se manifester actuellement. Au-delà de ce problème, peut-être fondamental, d'autres raisons peuvent intervenir.
Le réglage d'un modèle repose sur la reproduction analogique de phénomènes en nature et sur le modèle. Sa fiabilité repose donc sur le nombre, la qualité et la durée des observations. Dans ce cas, le réglage a été effectué essentiellement sur le remplissage des épis et du brise-lames et de quelques éléments secondaires comme la localisation des concentrations d'orthogonales de houle ou la forme de la flèche de l'embouchure de la lagune. Ces observations sont précises, mais elles portent sur une durée très courte (moins d'un an). On peut donc se demander si les éléments disponibles pour le réglage offrent une garantie totale de fiabilité. Il est, certes, souvent difficile de disposer de nombreux éléments sur une longue période, mais il n'est pas douteux que la précision des résultats en est affectée.
Enfin, il convient de ne pas oublier qu'une modélisation repose, par principe, sur une schématisation et des réductions d'échelles. Il serait illusoire de vouloir traduire à travers cette représentation et cette interprétation de phénomènes naturels, la grande complexité de l'évolution hydro-sédimentaire de détail d'un

littoral, fut-il comme celui du Golfe du Bénin, un véritable cas d'école.

En dépit de leur relative précisions, les résultats des modélisations comportent une marge d'erreur croissante dans le temps. S'agissant d'interactions de dynamiques complexes générant des impacts dont les conséquences économiques, sociales, voire politiques, peuvent être importantes, on est conduit à tenter d'imaginer comment gérer cette incertitude. Dans les faits, seul un programme de suivi morpho-sédimentaire est susceptible de préciser les évolutions et de permettre un réajustement périodique des prévisions modélisées.

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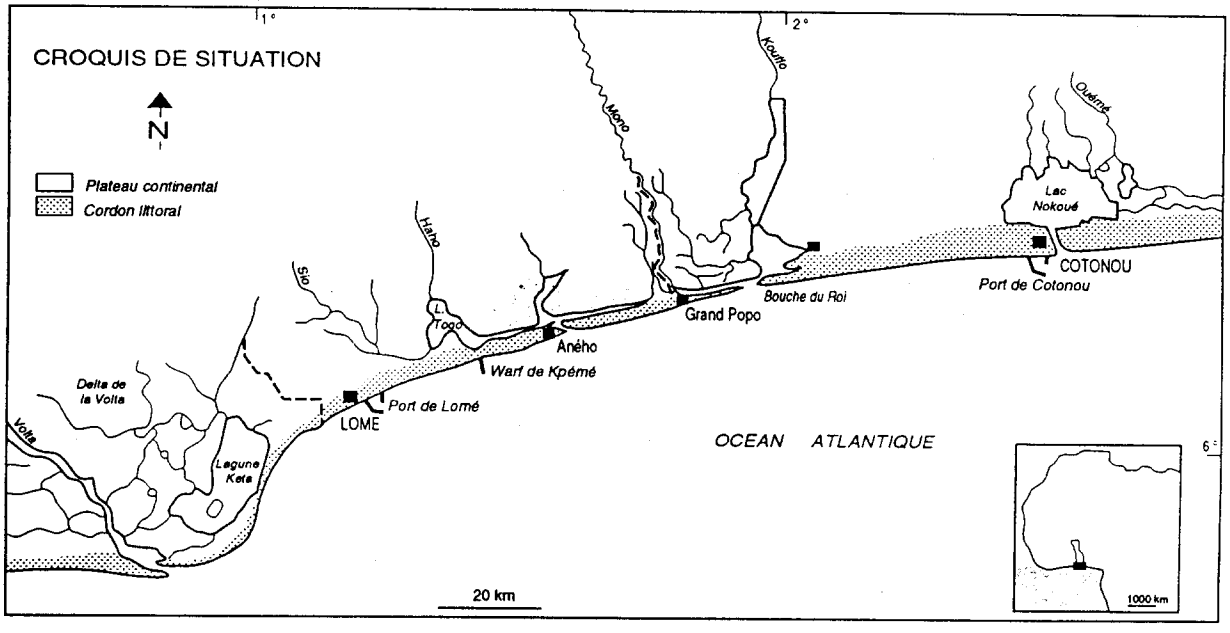
Tableau 1. Fonctionnement du système conformément aux prédictions du modèle, sept ans après l'achèvement des travaux; site de Kpémé.

DESIGNATION	NATURE	MODELE
Marnage moyen vives eaux	1,10 m	1,0 m
Duréee d'une marée	12h25	25,05 mn
Houle:		
- hauteur	0,5 à 3 m	0,45 à 2,73 cm
- période	10 à 14 s	0.95 à 1,33 s
Transit littoral moyen annuel	1200000 m^3	121 litres
Temps sédimentologique	1 an	200 mn

Fig. 1. Croquis de situation.



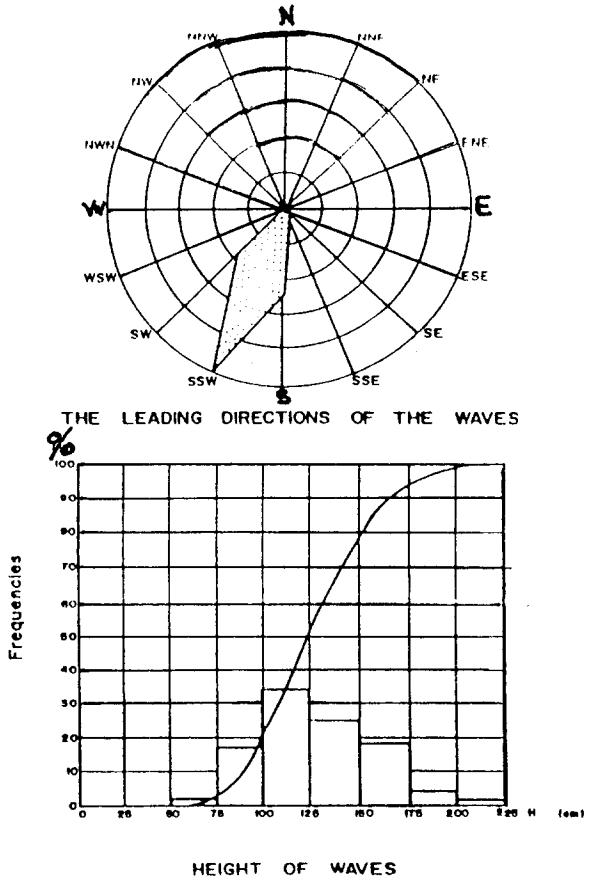


Fig. 2. Directions (en haut) et hauteurs des vagues (en bas) à la côte.

Fig. 3. Kpeme: cycles annuels restitues sure le modèle. Sur le modèle hydrolique annuel a été défini par dix classes de houles, dont les paramètres et la durée variable sont fonction de leur durée en nature. Chauqe classe de houle est caractérisée par sa hauteur, sa pEriode et sa direction. Chaque classe de houle génère un volume de transit littoral. *Source:* SOGREAH.

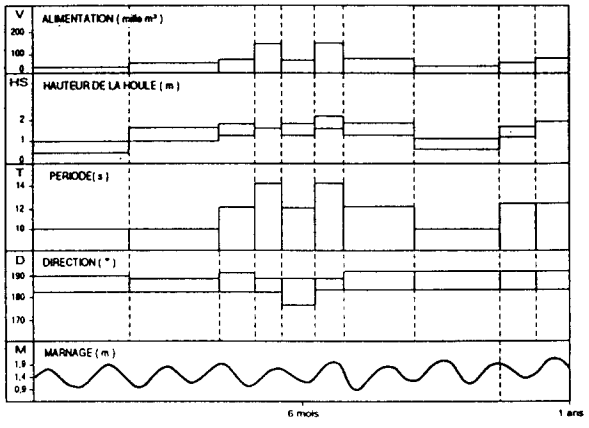
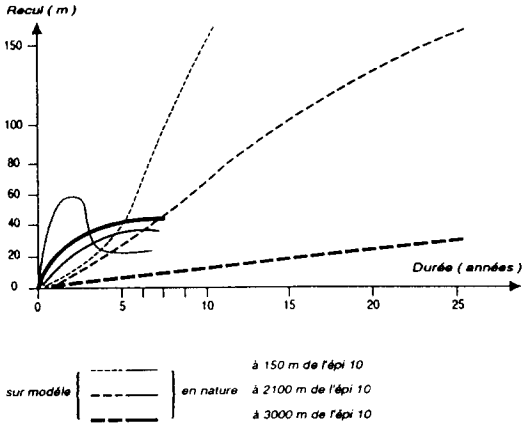


Fig. 4. Recul de la côte à l'est du système de protection de Kpémé, sur modèle et en nature.



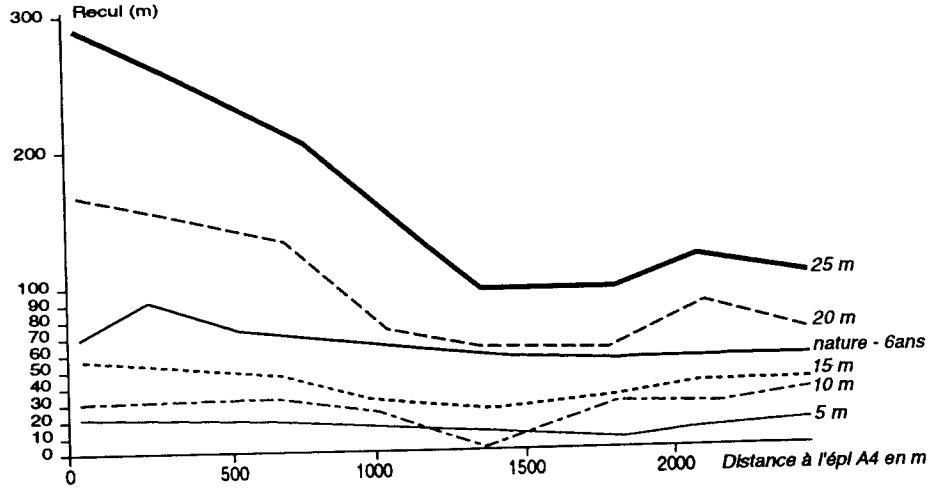


Fig. 5. Evolution du trait de côte à l'est du système de protection d'Aného, en nature et sur modèle.

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LONG-TERM SHORELINE CHANGE IN JAPAN

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KEYWORDS: Beach erosion, comparison of topographical maps, crustal movement, offshore sand drift

ABSTRACT
In Japan, damage due to beach erosion has seriously increased in recent years. Changes in the Japanese coastline were investigated by the comparison of topographical maps. The net loss was 5,059 ha in the 70 year period before 1978, and 2,395 ha in the 15 year period following 1978. An annual net loss rate was determined at 72 ha/yr before 1978, increasin to 160 ha/yr after 1978. Erosion was particularly severe in Hokkaido and along the Japan Sea, both in the former period and the latter one. A comparison of erosion rates and crustal movements shows that the crustal subsidence in Hokkaido was favourable to severe erosion, while the slight uplift on the Japan Sea coast did not support erosion. The primary cause of long-term and overall erosion was considered to be a net offshore sand drift.

1. INTRODUCTION

Japan is an island country, and its people have been deeply involved with the ocean since ancient times. Geographically speaking, Japan is an arc-shaped chain of islands located in the northwestern, monsoon region of the Pacific Ocean. Compared to other places in the world, Japan is very susceptible to the harsh effects of waves. In addition, it has also suffered from countless tidal waves (tsunamies), being located in the circum-Pacific earthquake region.

The surface of Japan is 378,000 km^2, with a coastline as long as 345,000 km. Compared with other countries, this length is relatively large, and this has caused the close involment of the country with the surrounding ocean. The people of Japan have since the beginning of agriculture lived near the sea, and the use of coastal regions has grown along with the development of civilization until the present. However, at the same time, lives and property have been lost countless times due to the destructive energy of the ocean. Then protection from coastal disasters has increased in importance along with a wider use of the ocean.

In recent years, instances of damages due to coastal erosion have gained frequent attention in the mass media. Such treatments of the subject seem to suggest that the cause of the problem lies in the development of river basins since the period of Japan's high economic growth. Actually, however, coastal erosion was a problem in some regions before the beginning of the high economic growth, and the problems involved are very complex. At present, the following can be considered to be the causes of coastal erosion: the construction of large-scale structures on the coast, decrease in the supply of sediment from rivers and sea-cliffs, ground subsidence, and the influence of ocean waves and currents. However, it is not possible at present to identify these precisely.

There is an accumulation of data regarding areas in which erosion is severe, though data of the same preciseness is not available with regard to tendencies and amounts of erosion for the country as a whole. This being so, changes in the coastline between two points of time can be investigated through the following methods: comparison of topographical maps, comparison of aerial photographs, sounding measurements, etc. However, the easiest method of investigating the entire country with the same precision is the use of topographical maps. Regarding sandy beach shorelines, Koike (1977) used maps to investigate the 70 year period following 1890, and Tanaka, et al. (1973,1974) used aerial photographs to investigate major changes in the shoreline in the 20 year period following the World War II.

Since these reports are now more than a decade old, and since losses around the whole country

due to coastal erosion have increased in recent years, there is a need to grasp the situation of coastal erosion for the whole country. For this purpose, the most current maps as of 1992 were compared with those of 1978 to determine the situation of erosion since 1978. In addition, by comparing these results with the situation prior to 1978, it was also possible to investigate trends in the erosion situation.

2. NATIONWIDE SURVEY OF THE CURRENT SITUATION OF COASTAL EROSION

2.1 Method of the Survey

In this study, all of the maps were on a scale of 1:50,000 from the Geographical Survey Institute. The maps of 1978 (hereafter referred to as second edition maps) were compared with those available in 1992 (hereafter referred to as current maps). In all, there were 607 maps that covered the whole country. Also, I compared the earliest, first edition maps with the second edition maps, focusing mainly on sandy beach shorelines. Although, in this comparison only 386 maps were used, it was possible to look at nearly the entire country and to compare differences between the erosion from the Meiji Era to 1978 and that from 1978 to 1992.

In Fig. 1, the areas covered by Koike, or in his compilation of the material taken from Tanaka and others, are shown along with those of the present survey. From this, it can be seen that the present survey covers a larger area than these earlier studies. It should be noted, however, that the legend for that from 1978 to 1992 is not shown, since the entire country has been covered in this case.

The first edition maps were published between 1887 and 1934, and the average date of publication is 1905. On the other hand, second edition maps were published between 1957 and 1978, with the average year being 1973. What are referred to in this study as current maps were published between 1976 and 1992, with the average being 1986.

As to the intervals between publication of first and second edition maps, its average was 67.5 years and its maximum interval was 74 years. So, I regarded these intervals as a 70 year period up to 1978. Similarly, as to the intervals between publication of second edition and current maps, its average was 14.6 years and its maximum was 18 years. I regarded these intervals as 15 year's periods up to 1992.

The method of measurement was as follows. First, the old and new maps were compared precisely and a drawing for measurement was made by sketching coastlines that had changed. Areas of coastal change are roughly divided into cases of erosion, sediment accumulation, reclamation, dredging, and estuaries. In this study, however, cases of estuaries, or river mouths, were excluded since there are large, seasonal, temporary fluctuations in the amount of sediment released from river mouths. Also, cases of dredging were excluded. Next, a digitizer was used to measure the areas as well as lengths and widths of changed parts.

Resolution of the equipment used was 0.1 mm. But there were errors due to such things as the widths of lines in the drawings (0.2-0.3 mm), readings of the maps and orientation, consequently, overall precision of measurements was equivalent to measuring the shoreline changes of about 20 m in the cross-shore direction. Also, the precision for area was approximately one hectare.

2.2 Results and Considerations

(1) Coastal Areas which Changed due to Erosion and Sedimentation

There are 39 prefectures with sea coast in Japan. The areas of erosion, sedimentation and net loss are shown in Table 1 for each prefecture. There are data of the former 70 year period and of last 15 years. Fig. 2 shows each location of prefecture. Though the results regarding Okinawa Prefecture are also shown in the table, these were disregarded in calculating the total since there were regions that diverge greatly from the actual situation. In the 70 year period, the area of erosion for the whole country was 12,539 ha. In contrast to this, the area of sedimentation was 7,480 ha. This indicates a net loss of 5,059 ha. In the 15 year period, in contrast to the area of erosion for the entire country that was 4,605 ha,

the area of sedimentation was 2,210 ha. This indicates a net loss of 2,395 ha. In both periods, erosion exceeded sedimentation, and the tendency toward erosion continues. Looking at the annual average loss, this was 72 ha/year in the 70 year period, while it was 160 ha/year in the 15 year period. It can be seen from this that the rate of loss of national territory is increasing extremely. Looking at prefectures separately, Hokkaido shows the greatest erosion for both the periods, making up 2/5 of the figure for the entire country. Though Hokkaido also had the most sedimentation, since this was not as much as the erosion, the amount of net loss area was large. In fact, its net loss is more than half of that for the country as a whole.

(2) Average Cross-shore Change

Each prefecture has a different length of coast, and there are also differences in the lengths of sandy coasts. For this reason, comparisons of the extensions of sandy coasts were attempted. Table 2 shows the results of dividing the changed areas in Table 1 by lengths of sandy coasts based on a 1975 Geographical Survey Institute survey to get the average cross-shore change. During the 70 year period, there was an average net loss of 5.3 m of coastline. During the 15 year period, there was an average net loss of 2.5 m of coastline. In other words, sandy coasts receded an average of 1 m over a 6 year period in the 15 year period. Also, during the 70 year period, prefectures with over 10 m of sedimentation were Miyagi, Chiba, Shizuoka, Tottori, and Miyazaki Prefectures; but during the 15 year period, with the exception of Shizuoka Prefecture, all of these switched to net losses due to erosion. Even in the case of Shizuoka Prefecture, the average amount of sedimentation decreased from 23.8 m to 1 m; and it is thought that in the future erosion will eclipse sedimentation. During the 15 year period, the prefectures with large average net losses included Chiba, Akita, Tottori, Hokkaido, and Fukui.

(3) Shoreline Length which Changed due to Erosion and Sedimentation

Table 3 shows shoreline length changes due to erosion and sedimentation, and the proportions of these two processes in sandy coastal extension in the 15 year period. Nationwide erosion has accounted for 1,320 km of extension while the sedimentation has only accounted for 640 km, therefore an advance to retreat ratio becomes 0.48. The same ratio also applies to the extent of area. Calculation with the areas and the lengths shows average widths to be 34.9 m for erosion areas and 34.5 m for areas of sedimentation. In addition, 13.9% of all sandy coast in Japan are subject to erosion, while sedimentation is apparent in 6.7% of these areas. In other words, in the last 15 years, 20% of all sandy coastal areas have experienced erosion or sedimentation of 20 m or more. Prefectures with eroded sandy coastal extensions exceeding 20% include Hokkaido, Akita, Yamagata, Ibaraki, Chiba, Fukui and Tottori. Furthermore, in Yamagata, Chiba and Tottori prefectures, the length of coastline changes of 20 m or more caused by erosion or sedimentation exceeded half of the sandy coast.

(4) Rates of Beach Erosion

According to Koike, the ratio between coastlines that grew in comparison with those that receded from 1890 to 1965 is 1.24. The ratio for the 20 years following the war is 1.05. According to the present study, the ratio between sedimentation and erosion for the 70 year period, which nearly corresponds with the earlier period just cited above, is 0.57, while for the 15 year period it is 0.48. Though the results of both studies correspond in showing the tendency towards increased erosion, there is a wide discrepancy in the numbers. The principal reason for this is that Koike measured coastline changes of over 50 m in width for those coastlines that had sandy coast over 500 m in width and over 5 km in length. The accretion/retreat ratio for Koike's Region II is 84 km/36 km = 2.33. In the present study, the total for the Shimokita-Hachinohe Coast, the Sendai Bay Coast and the Kashima-nada Coast is 116 km/122 km = 0.95. This number represents a large difference. However, when the area west of the Shiriyazaki Cape, which is north limit of the Region II, is excluded and only areas with over 50 m of change in width are collected, the result is 96 km/50 km = 1.92. This latter figure is closer

to Koike's. From this fact, it can be said that there is a balance somewhat in favour of accretion in areas of the type which Koike investigated where there is a very long coast.
As can be gleaned from the information obtained comparing topographical maps as described above, it can be seen that in Japan there are obvious topographical changes. In particular, erosion greatly exceeds sedimentation, and is in fact becoming worse.

3. COMPARISON WITH EROSION AND CRUSTAL MOVEMENT

Fig. 3 shows accretion/retreat length ratios for large blocks of Japanese coast. In this figure, the upper is the one for the 70 year period and the lower is for the 15 year period. In all blocks and both periods the ratio is less than 1.0, that is, erosion has exceeded accretion and there has been a net loss. Further, in any blocks, the ratios became lower. This tendency shows that beach erosion in Japan has become severer. Looking at blocks separately, erosion is severe in Hokkaido and the coast along the Japan Sea.
Fig. 4 shows vertical crustal movements in Japan as deduced from tidal records for the period 1951 - 1982 after Kato et al. (1983). The shaded area indicates crustal uplift. It shows rapid subsidence in northeast part of Japan. This fact agrees well with the severe erosion in the north part of Japan. In other parts of Japan there is no good agreement between vertical crustal movements and beach erosion. Especially, on the Japan Sea coasts, though the vertical crustal movement was positive, the beach erosion was rather severe. In addition, on the Japan Sea coasts, because economic growth has been not so high, there are few large-scale structures on the coast nor so much development in river basins. After all, it is concluded that the vertical crustal movement might be one of the causes of severe erosion of Japan, however, the mechanism of erosion is still uncertain.

4. TYPICAL EXAMPLES OF EROSION

Next, let us look at examples of coastal erosion and its major causes. As stated earlier, coastal erosion is a result of the complex interactions of diverse factors. For this reason, careful examination is required in considering possible countermeasures.

4.1 Erosion from Old Days

(1) Kaike Coast

Kaike coast is located in the midwest part of the Japan Sea coast. There are the Kaike hot spring and Yonago city behind it. Between Yonago City and Sakaiminato City in Tottori Prefecture, there is an arc-shaped coastline lined with white sand and pine trees by the name of "Yumigahama", which means arc-shaped beach in Japanese. It is considered that Kaike beach had been formed from the discharged sediment from Hino River whose upstream basin had been famous for iron production from iron sand. As the iron production caused a lot of sediment discharge into the Hino River, the shoreline of Kaike beach progressed, for example, 180 m in 30 years from 1868. However, as the iron production declined around 1920 due to modernization, the beach began to suffer from erosion. In particular, about 300 m of sandy beach has been eroded away due to wave action at the front beach of Kaike hot springs, with losses both of hot spring wells as well as of lodgings (see Photo 1). In view of countermeasures against erosion, this coast was one of the first coasts in Japan at which many countermeasures were carried out. First, jetties were constructed in 1947. In a few years it became unsuccessful. Next, a seawall was applied. However, erosion could not be stopped. Finally, a detached breakwater was introduced in 1971, then a tombolo formed behind the detached breakwater, and beach erosion stopped (Photo 2).

(2) Shimoniikawa Coast

The Shimoniikawa coast is situated along the mouth of the Kurobe River which runs through the eastern part of Toyama Prefecture. In this region, villages are located here and there along the arc of the fan-shaped delta of the Kurobe River at where underground water is plentiful. In this coast, erosion has been a serious problem since ancient times due to sand moving in a westerly direction, and there are records of several times when villages have had to relocate

inland. Further, swells peculiar to Toyama Bay are exceptionally large, and coastal disasters have occurred repeatedly in conjunction with erosion. Still more, the slope of the seabed is very steep, and there is no place for coastal sand to accumulate on the coast. Judging by the above facts, it is thought that sediment is swept away to the deep ocean. So far, a seawall was completed but a detached breakwater has been carried out mainly near villages as an emergent measure against erosion and high waves.

(3) Niigata Coast

Niigata is located in the central part of the Japan Sea coast. The Niigata Plain is one of the biggest alluvial lowlands in Japan and has several sand dune ridges. The Shinano River, which is the longest river in Japan, and the Agano River run into the sea at Niigata city. It is said that Niigata coast has been eroded since the 1890s. A meteorological observatory was constructed 100 m landward from the shoreline in 1928, but it collapsed in the water in 1949 (Photo 3). Major causes of the beach erosion have been thought to be:

1) interruption of sand drift in a westerly direction due to the construction of breakwater of Niigata West Harbour,

2) reduction in the amount of sediment discharge from the Shinano River due to the operation of Ookouzu flood channel and

3) ground subsidence due to extraction of ground water for natural gas. As countermeasures, a seawall was constructed first. The beach could not restore enough until the detached breakwater was introduced. Instead of detached breakwaters, however, an artificial reef method has been recently applied because Niigata city, the major city along the Japan Sea, is famous for sunset scenery.

4.2 Problem of Coastal Structure Interrupting Littoral Sand Drift

The Shimokita-Hachinohe Coast is located in the north Pacific coast of Honshu Island. In this area, a northerly littoral drift is predominant. In Photo 4, while a large advance of the shoreline can be seen on the southern side, there is severe erosion on the northern side. Though seawalls and wave dissipating works have been built, the area of erosion is gradually expanding to the north. In 1987, sediment stretching 3 km in length and 150 m in width accumulated on the southern side of the breakwater. On the other hand, on the northern side there was erosion for 6 km. Uda (1991) shows a diagram shown in Fig. 5 for this kind of situation.

4.3 Erosion near the Lee of Large Offshore Structure

The Oarai Beach is situated on the northern end of the Kashima-nada coast, which is located in the central Pacific coast. There is Oarai harbor next to the beach, and in conjunction with expansion of the harbor, large-scale breakwaters have been built. As a result, however, erosion problems have developed (Photo 5). Uda (1991) also shows a diagram shown in Fig. 6 for this kind of situation. Because waves behind the breakwater become smaller, a difference in wave height occurs between which in the lee side of the offshore breakwater and outside of it. This condition develops a circulating current that flows toward the inside of the harbor near the beach. This current causes littoral drift into the harbor. On the other hand, in the area outside of the lee of offshore breakwater, because littoral drift is induced by incident waves, the direction of littoral drift is out of harbor for this wave condition. Therefore, erosion occurs in the area where the tip of the breakwater projects upon the shore in the direction of the predominant waves, and this area stretches in both directions along the shore. On the harbor side, however, as result of the circulating current and the calming of waves, sand accumulates in the harbor and near the breakwater (Photo 6).

5. CAUSES OF EROSION

As noted previously, though coastal erosion is a phenomenon that has been observed since long ago, its causes are complex and have not yet been clarified. In this regard, let us consider the movement of sand on the coast.

Fig. 7 shows the relations involved in the movement of sand along the coast. The amounts

of sand entering the rectangle in units of time are: R of sediment from rivers, Rc from rocky coasts, B1 of sand blown in from surrounding areas by the wind, L1 of sand carried in by littoral drift, and O1 of sand carried in from offshore by onshore drift. Conversely, amounts of sand carried out of the region in units of time are: B2 by the wind, L2 by littoral drift, and O2 by offshore drift. When the amounts coming in and going out are balanced, there is no change in the amount of sand within the system; but when the amount going out exceeds the amount supplied, then there is a net loss in the system and erosion occurs.

It is supposed that the effect of the imbalance of B1 and B2 is small. From the macro scale point of view the sand moved due to littoral drift L1 and L2 will remain nearshore. The net loss of erosion and sedimentation, like section 4.2 and 4.3 by the imbalance of L1 and L2, is therefore considered to be diminished as a whole while there is local severe erosion and sedimentation here and there. Further, in spite of the sediment discharge from rivers, there were coasts that suffered from erosion from early days such as the Shimoniikawa coast. Additionally, the crustal movement could not give enough explanation of erosion all over Japan. These facts imply that there has been an imbalance of O1 and O2, that is, a net offshore sand drift, and this has played important role in sand budget of littoral zone.

Therefore it must be noted that the hydraulic mechanism in shallow water under waves and currents should be investigated further in order to understand the mechanism of the net offshore sand drift and to cope with it.

6. CONCLUSION

In Japan, beach erosion has become severe in recent years. Investigation by comparison of topographical maps shows that the net loss was 5,059 ha in the 70 year period before 1978 but 2,395 ha in the 15 year period after 1978. It indicates that an annual net loss rate had been 72 ha per year before 1978 while it grew to 160 ha per year after 1978. The length ratio of the sedimentation to erosion for the 70 year period is 0.57, while for the 15 year period it is 0.48. While Japanese high economic growth began around 1960, beach erosion was severe here and there long before that. Further, although the river basins facing the Pacific Ocean were developed higher than those of the Japan Sea, the Japan Sea coast has suffered from severer erosion than the Pacific Ocean coast. Erosion was severe in Hokkaido and along the Japan Sea in both the former period and the latter one. A comparison of the erosion rates and crustal movements shows that the crustal movement could not give a good explanation to the overall characteristic of erosion. Considerations from a macro scale point of view imply that net offshore drift is suspected as the cause of net losses in topographical maps. All these results suggest the necessity of further investigation on the hydraulic mechanism in shallow water.

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Table 1 Shoreline Change in Area

(Unit:ha)

	1905 - 1978			1978 - 1992		
	Erosion	Accretion	Net Loss	Erosion	Accretion	Net Loss
Total	12,539	7,480	5,059	4,605	2,210	2,395
Hokkaido	4,534	1,869	2,665	1,921	631	1,290
Aomori	676	60	616	182	94	88
Akita	447	123	324	153	43	110
Yamagata	84	53	31	65	43	22
Iwate	21	13	8	8	9	-1
Miyagi	68	292	-224	79	52	27
Niigata	847	444	403	221	121	100
Fukushima	259	68	191	65	73	-8
Ibaraki	300	306	-6	114	176	-62
Chiba	315	658	-343	249	127	122
Tokyo	0	0	0	36	79	-43
Kanagawa	62	127	-65	37	26	11
Shizuoka	327	867	-540	21	43	-22
Toyama	305	36	269	26	16	10
Ishikawa	384	31	353	38	26	12
Fukui	56	28	28	100	19	81
Aichi	298	198	100	40	25	15
Mie	196	200	-4	51	26	25
Wakayama	38	20	18	16	20	-4
Kyoto	49	9	40	10	12	-2
Osaka	20	17	3	1	17	-16
Hyogo	635	148	487	36	89	-53
Tottori	137	346	-209	106	42	64
Shimane	51	118	-67	89	19	70
Okayama	165	105	60	31	5	26
Hiroshima	40	30	10	79	3	76
Yamaguchi	191	37	154	55	10	45
Ehime	296	97	199	53	24	29
Kagawa	61	102	-41	21	20	1
Tokushima	233	157	76	28	11	17
Kochi	114	123	-9	78	75	3
Fukuoka	189	64	125	3	10	-7
Saga	39	1	38	3	1	2
Nagasaki	85	3	82	134	22	112
Kumamoto	17	1	16	7	3	4
Oita	356	97	259	90	8	82
Miyazaki	170	366	-196	95	46	49
Kagosima	474	266	208	264	144	120
Okinawa	341	332	9	1,117	597	520

Table 2 Shoreline Change Considering Extention of Sandy Coast

	Sandy Beach Length (km)	1905 - 1978			1978 - 1992		
		Erosion (m)	Accretion (m)	Net Loss (m)	Erosion (m)	Accretion (m)	Net Loss (m)
Total	9,499.1	13.2	7.9	5.3	4.8	2.3	2.5
Hokkaido	1,993.1	22.7	9.4	13.4	9.6	3.2	6.5
Aomori	366.7	18.4	1.6	16.8	5.0	2.6	2.4
Akita	146.7	30.5	8.4	22.1	10.4	2.9	7.5
Yamagata	49.3	17.0	10.7	6.3	13.2	8.7	4.5
Iwate	100.6	2.1	1.3	0.8	0.8	0.9	-0.1
Miyagi	167.6	4.1	17.4	-13.4	4.7	3.1	1.6
Niigata	290.1	29.2	15.3	13.9	7.6	4.2	3.4
Fukushima	114.7	22.6	5.9	16.6	5.7	6.4	-0.7
Ibaraki	123.3	24.3	24.8	-0.5	9.2	14.3	-5.0
Chiba	138.9	22.7	47.4	-24.7	17.9	9.1	8.8
Tokyo	113.8	0.0	0.0	0.0	3.2	6.9	-3.8
Kanagawa	89.9	6.9	14.1	-7.2	4.1	2.9	1.2
Shizuoka	227.0	14.4	38.2	-23.8	0.9	1.9	-1.0
Toyama	65.7	46.4	5.5	40.9	4.0	2.4	1.5
Ishikawa	188.8	20.3	1.6	18.7	2.0	1.4	0.6
Fukui	135.3	4.1	2.1	2.1	7.4	1.4	6.0
Aichi	111.7	26.7	17.7	9.0	3.6	2.2	1.3
Mie	426.4	4.6	4.7	-0.1	1.2	0.6	0.6
Wakayama	135.0	2.8	1.5	1.3	1.2	1.5	-0.3
Kyoto	81.8	6.0	1.1	4.9	1.2	1.5	-0.2
Osaka	21.5	9.3	7.9	1.4	0.5	7.9	-7.4
Hyogo	202.6	31.4	7.3	24.0	1.8	4.4	-2.6
Tottori	93.1	14.7	37.2	-22.5	11.4	4.5	6.9
Shimane	269.5	1.9	4.4	-2.5	3.3	0.7	2.6
Okayama	157.5	10.5	6.7	3.8	2.0	0.3	1.7
Hiroshima	187.3	2.1	1.6	0.5	4.2	0.2	4.1
Yamaguchi	414.5	4.6	0.9	3.7	1.3	0.2	1.1
Ehime	303.3	9.8	3.2	6.6	1.7	0.8	1.0
Kagawa	196.4	3.1	5.2	-2.1	1.1	1.0	0.1
Tokushima	115.3	20.2	13.6	6.6	2.4	1.0	1.5
Kochi	180.0	6.3	6.8	-0.5	4.3	4.2	0.2
Fukuoka	189.7	10.0	3.4	6.6	0.2	0.5	-0.4
Saga	54.6	7.1	0.2	7.0	0.5	0.2	0.4
Nagasaki	787.1	1.1	0.0	1.0	1.7	0.3	1.4
Kumamoto	141.8	1.2	0.1	1.1	0.5	0.2	0.3
Oita	190.8	18.7	5.1	13.6	4.7	0.4	4.3
Miyazaki	173.0	9.8	21.2	-11.3	5.5	2.7	2.8
Kagosima	754.8	6.3	3.5	2.8	3.5	1.9	1.6
Okinawa	732.9	4.7	4.5	0.1	15.2	8.1	7.1

Table 3 Shoreline Change in Length for 1978 - 1992

	Changed Length			Proportion to Sandy Beach		
	Erosion (km)	Accretion (km)	Total (km)	Erosion (%)	Accretion (%)	Total (%)
Total	1,320.4	640.0	1,960.4	13.9	6.7	20.6
Hokkaido	521.7	198.8	720.5	26.2	10.0	36.2
Aomori	64.5	26.6	91.1	17.6	7.3	24.8
Akita	38.9	12.5	51.4	26.5	8.5	35.0
Yamagata	16.0	14.2	30.2	32.4	28.8	61.2
Iwate	3.1	2.9	6.0	3.1	2.9	6.0
Miyagi	27.2	16.3	43.5	16.2	9.7	26.0
Niigata	56.2	37.0	93.2	19.4	12.8	32.1
Fukushima	19.3	18.0	37.3	16.8	15.7	32.5
Ibaraki	25.7	26.1	51.8	20.8	21.2	42.0
Chiba	53.5	32.8	86.3	38.5	23.6	62.1
Tokyo	7.9	14.3	22.2	6.9	12.6	19.5
Kanagawa	14.8	10.8	25.6	16.5	12.0	28.5
Shizuoka	7.7	9.2	16.9	3.4	4.1	7.4
Toyama	8.7	5.6	14.3	13.2	8.5	21.8
Ishikawa	15.2	8.0	23.2	8.1	4.2	12.3
Fukui	31.1	7.3	38.4	23.0	5.4	28.4
Aichi	11.3	8.2	19.5	10.1	7.3	17.5
Mie	14.8	9.7	24.5	3.5	2.3	5.7
Wakayama	4.6	4.9	9.5	3.4	3.6	7.0
Kyoto	4.9	4.3	9.2	6.0	5.3	11.2
Osaka	0.2	5.9	6.1	0.9	27.4	28.3
Hyogo	13.0	25.4	38.4	6.4	12.5	19.0
Tottori	34.6	13.1	47.7	37.2	14.1	51.2
Shimane	26.8	5.4	32.2	9.9	2.0	11.9
Okayama	13.6	2.9	16.5	8.6	1.8	10.5
Hiroshima	25.4	1.0	26.4	13.6	0.5	14.1
Yamaguchi	14.9	4.1	19.0	3.6	1.0	4.6
Ehime	21.3	10.3	31.6	7.0	3.4	10.4
Kagawa	9.1	6.3	15.4	4.6	3.2	7.8
Tokushima	9.8	4.2	14.0	8.5	3.6	12.1
Kochi	26.3	20.4	46.7	14.6	11.3	25.9
Fukuoka	1.2	3.4	4.6	0.6	1.8	2.4
Saga	0.9	0.3	1.2	1.6	0.5	2.2
Nagasaki	43.4	8.9	52.3	5.5	1.1	6.6
Kumamoto	2.6	0.7	3.3	1.8	0.5	2.3
Oita	32.9	3.7	36.6	17.2	1.9	19.2
Miyazaki	26.0	11.3	37.3	15.0	6.5	21.6
Kagosima	71.3	45.2	116.5	9.4	6.0	15.4
Okinawa	250.8	131.7	382.5	34.2	18.0	52.2

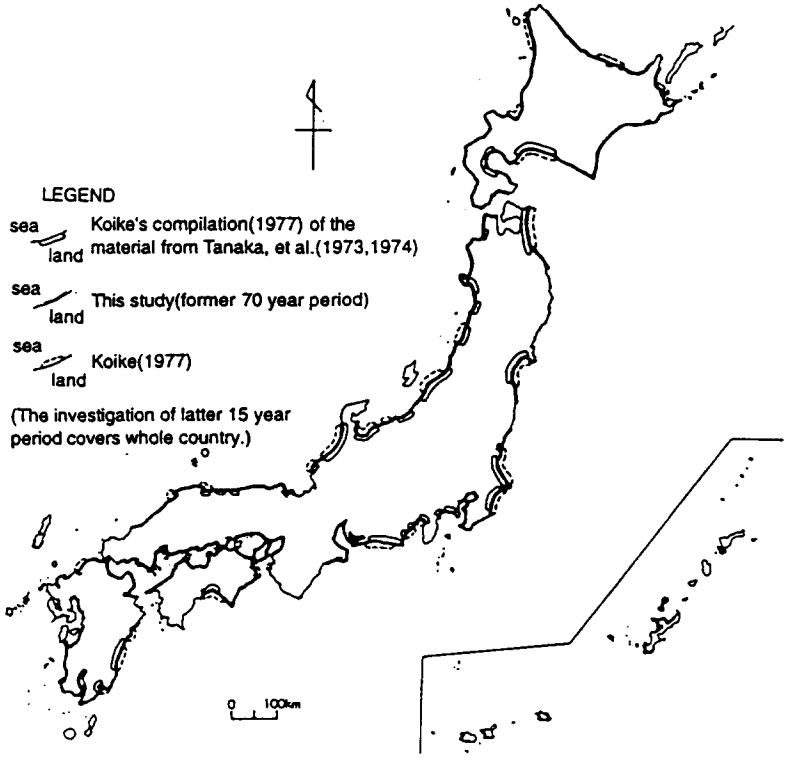

Fig. 1 Extention of Investigation Area

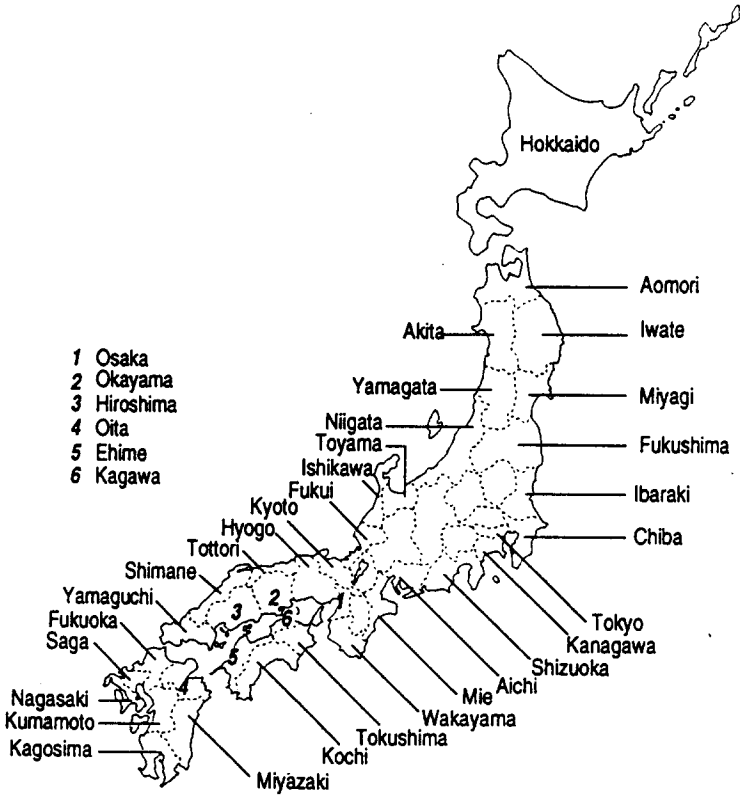

Fig. 2 Location of Prefecture

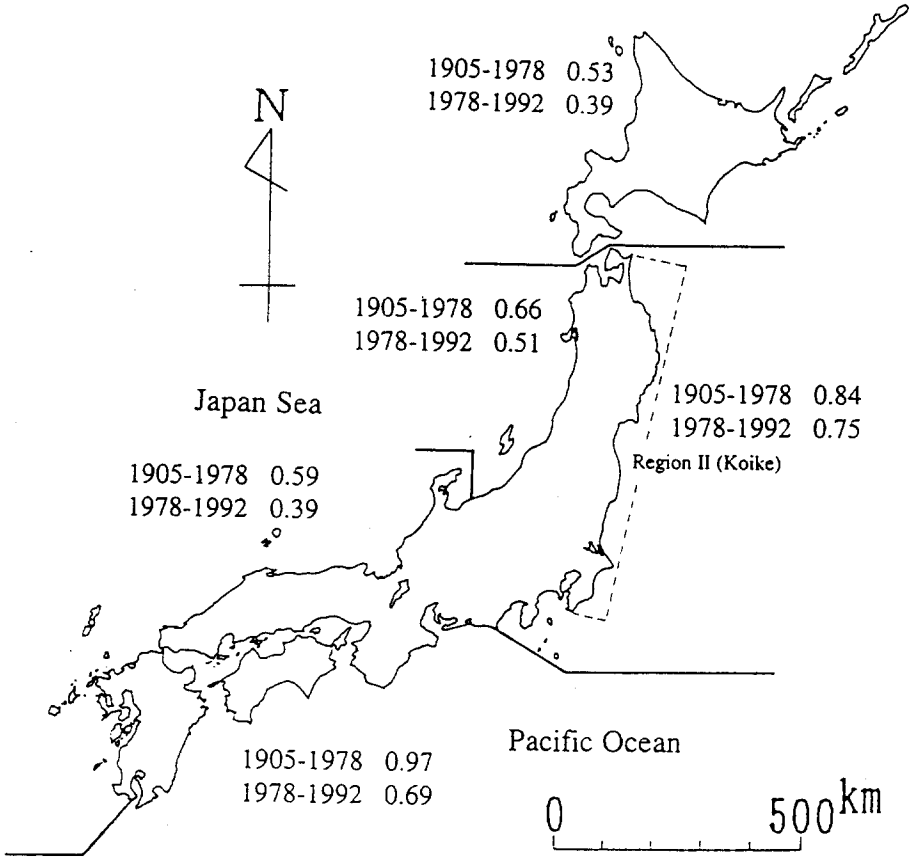

Fig. 3 Advance/Retreat Ratio of Length

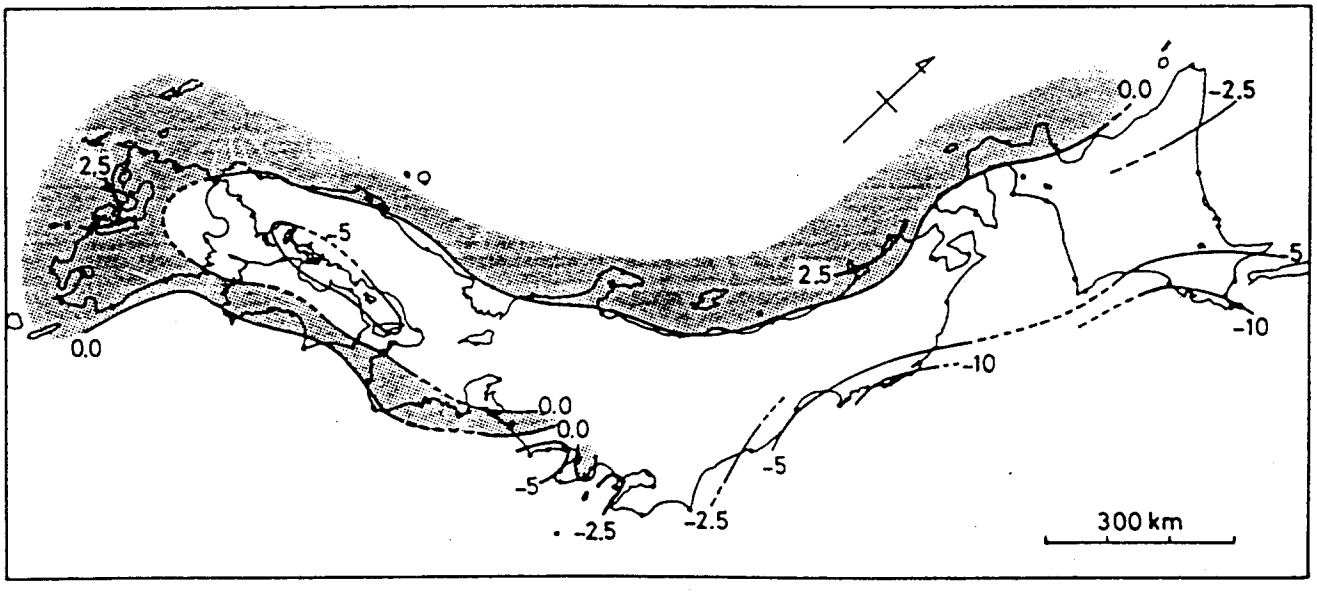

Fig. 4 Vertical Crustal Movements in Japan for 1951 - 1982(after Kato, et al.)

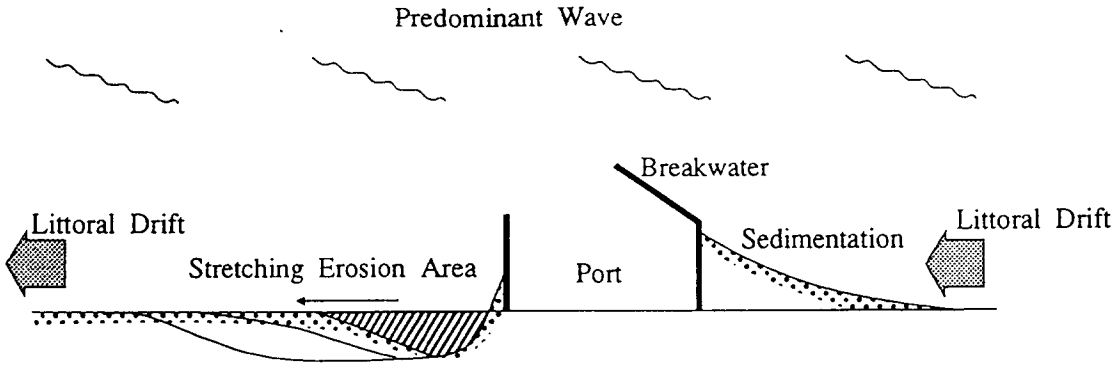

Fig. 5 Beach Changes around the Port Interrupting Littoral Drift

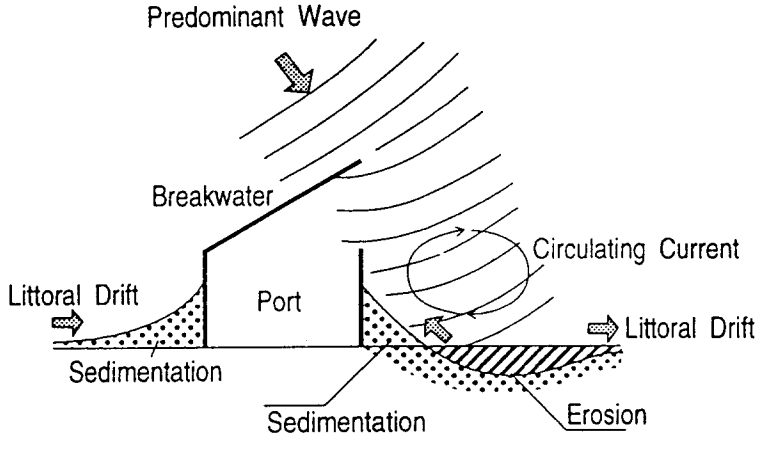

Fig. 6 Beach Changes in the Lee of Offshore Breakwater

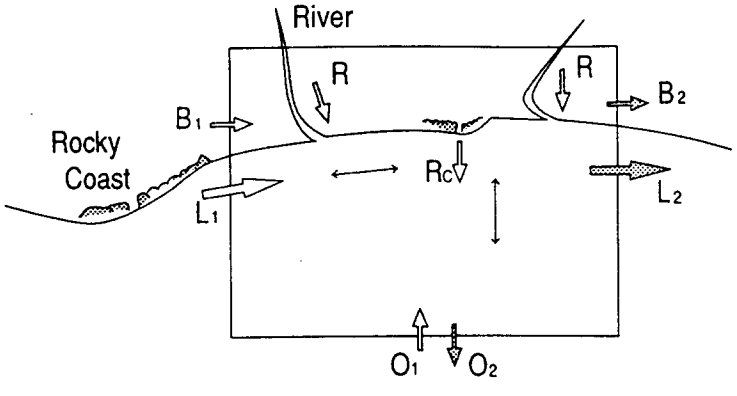

Fig. 7 Sand Movement along Coast

Photo 1 Hotel is about to collapse

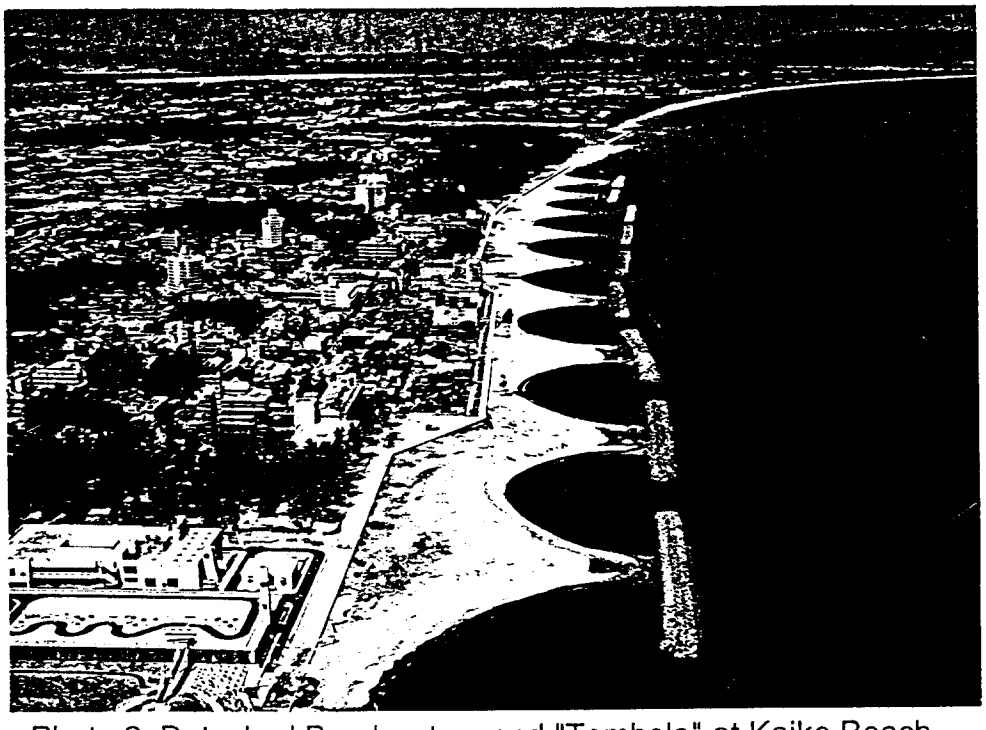

Photo 2 Detached Breakwaters and "Tombolo" at Kaike Beach

Photo 3 Collapsed Meteorological Observatory at Niigata Coast

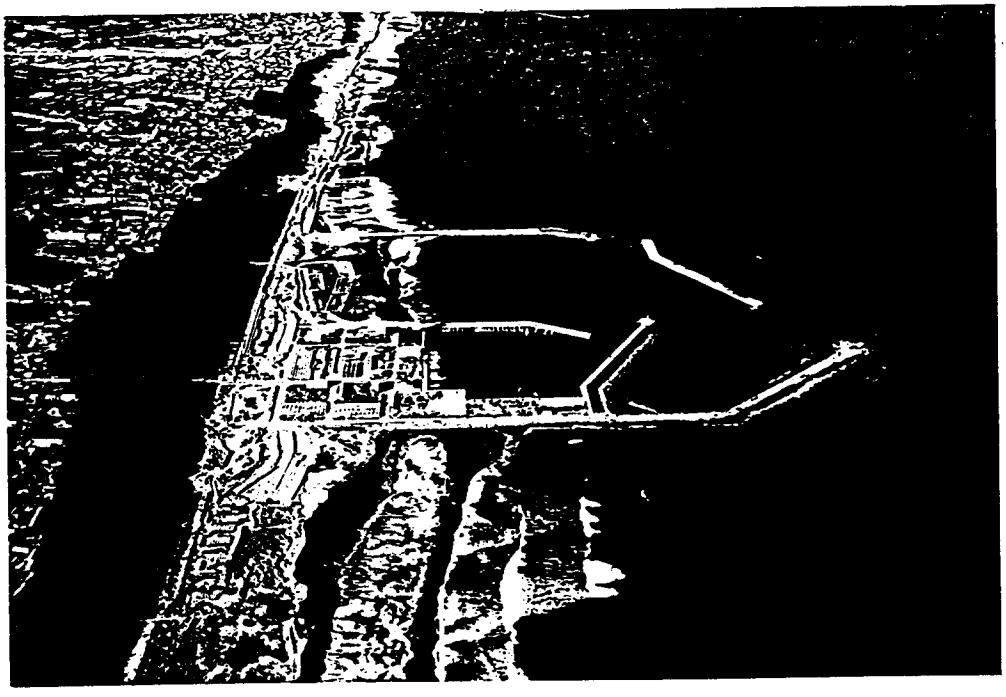

Photo 4 Severe Erosion and Sedimentation around Misawa Fishery Port

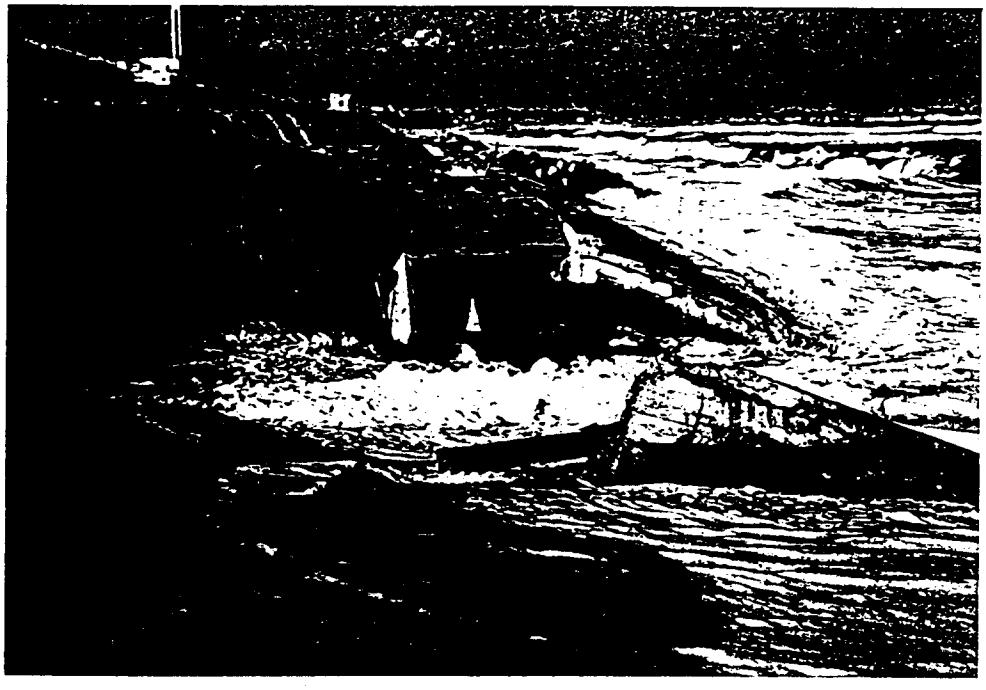

Photo 5 Seawall Damage by Erosion at Oarai Beach

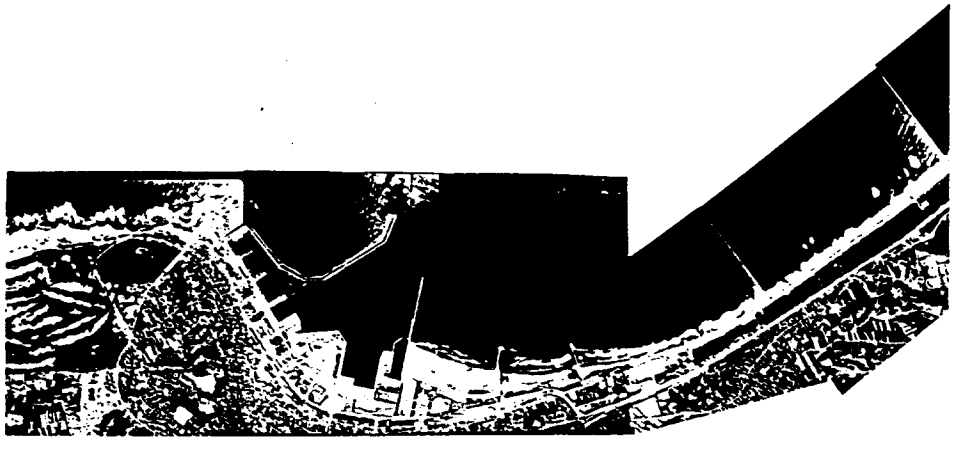

Photo 6 Beach Changes in the Lee of Oarai Harbor

SESSION IV

Low Tropical Coasts

Session IV-a
Africa-Asia

Chairmen: J.K. Patterson-Edward & J. Abe
Rapporteur: J.L.J. Marti

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INTEGRATED MANAGEMENT PLAN (IMP); THE CASE OF RIAU PROVINCE, DISTRICT OF BENGKALIS

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SOCIO ECONOMIC CONDITION

The district of Bengkalis has Dumai as its capital. The economic activities include oil production, agriculture, and tourism. Dumai is not only the center of development activities, but also functions as the center of oil production and commerce. Improvements of Dumai harbour will allow it to handle not only petroleum, but other export products as well.

The district of Bengkalis is located in the coastal zone of the eastern part of Riau Province. This district covers several islands which spread out to the Malacca Strait.

The population density of Riau is 35 people/km^2, which is much lower than the national statistic of 93 people/km^2. As a result the Riau Province has accepted a large number of immigrants from other parts of Indonesia. In 1989 the number of inhabitants of Bengkalis District was 903,919 people, while the per capita regional GDP including petroleum, gas, agriculture and other economic activities was Rp. 4,076,000. However, if gas and petroleum were excluded from this figure, the regional GDP was Rp. 834,000 for the same year. This is representative for farmers and small scale fishermen, living near the shore front of Riau province. Crucial for the Riau Province are conflicts among user groups, degradation of water quality (because of pollution from offshore drilling and paper-pulp-plywood industries along the river) and deterioration of sanctuary areas and natural resources (mangrove cutting and pollution). All of these issues are important for policy makers, either at the National or Regional level and are discussed in "The Development of Coastal Villages with Integrated Management Plans".

Transportation occurs by:

(i) Small airplanes from Pekanbaru to Dumai

(ii) Paved roads running from Pekanbaru - Dumai, in Meskom, in Bengkalis District and in Bengkalis island, not in others.

(iii) Inter-island boats as a means of transport between islands. The relative importance of water transport is high.

Fishermen conduct fishing activities in motorized boats, using long lines, drift gillnets catching big fish like the Bombay Duct, Giant Sea Perch, and Banana shrimp. Gombang gave more profits compared with other gear.

The population of the District comprises several ethnics such as Sumatereses, Javaneses and Chineses. In some islands, Chinese dominate the population.

THE INTEGRATED COASTAL ZONES MANAGEMENT PLAN

Objectives

The government intends to build model areas of coastal villages, but also wants to protect, preserve and restore the coastal ecosystem from degradation of water quality, destruction of natural resources and sanctuary areas which are conflicting with many user groups. This can be done through collaboration and coordination efforts among different government agencies and local communities.

Issues

- Define the baseline data and specify the problem & issues at the SAM (special area management). Basically, to identify special issue & problems in particular areas of management.
- Suppose the issues were:

(a). Coastal area degradation, especially in enclosed bays and estuaries because of conflicts

among user groups and unplanned development growth.
(b). Water quality degradation (pollution and erosion in the coastal water from industrial discharge), because of over-dependence upon oil production, mangrove cutting and fishing.
(c). Lack of coordination between subsectors of industry.
(d). The need of hatcheries to meet the increasing demand of seed production for aquaculture activities.

Solution

Develop an integrated estuary management plan that diversifies economic development & protects the natural resources for sustainable development.

Steps

- Baseline studies by the Universities & Research Institutions (Social, economic and natural resources)
- Identify Long & Short Term Goals & Objectives:

(a) Identity Long & Short Term Goals and Objectives:

- Identify the priority used among the economic commercial activities (whether SAM will be provided for agriculture, energy, fishery, industry, marketing, tourism, etc);
- Provide zoning for the above economic activities.
- Obtain Land use Planning (RUTR) through Bappeda and Governor Regulation in order to avoid conflict among the user groups.

(b) Develop the master plan:

-Prepare a Master Development Plan (SAM) for the Bengkalis district.
- Determine the cost and funding sources for the Integrated Coastal Management Plan.
- Formulate a sustainable development program.

Other steps that needed to prepare are as follows:

(a) Checklist of stakeholders and Government Agencies that are involved in the Integrated Coastal Management Zone Program:

- Determine the institutional structures and strategies and mobilize the involved communities and agencies.
- Establish an Advisory Committee at SAM to determine the boundaries of the problems that emerge from unplanned development; the Advisory Committee is possibly composed of the NSC (National Steering Committee) at National level, and the RSC (Regional Steering Committee) at the regional level.

-Create a work plan for the Advisory Committee in the SAM.

- The Advisory Committee should provide the possibility for consultation and coordination among Governmental agencies and local communities (private industry, fishermen, Non-formal leaders, NGO, etc);

(b) Establish the regulation (monitor the problems, controlling and enforcement programs)

- Suppose the solutions were:

(i) Regulate the zoning among the user group, or
(ii) Close areas of fishing at the sanctuary areas;
(iii) Restrict total fishing effort at point where the MSY occurs, or fishing is only permitted with selective gear.
(iv) Along the river, the various on paper, pulp/rayon and plywood industries should implant water treatment plants.
(v) Develop a 'green belt' for the mangrove forest along the coastal areas, or
(vi) Develop fish culture either in ponds or i floating cages, in order to supplement the method of fishing.
(vii) Develop a coastal fishing port and landing places in the "village model". Prepare, additional to marketing, processing facilities for the fish products, so that fishermen can obtain higher prices in Singapore and Malaysia.
(viii) Public awareness, education and training and extension: Information, paper, post, brochures, bulletin, radios, while volunteering action by local communities and NGOs should be encouraged.
(ix) Encourage the development process of the four Coastal Village Models in the Bengkalis district.

IMPLEMENTATION AND EVALUATION OF THE ACTIVITIES OF INTEGRATED MANAGEMENT PLAN (IMP)

- The concept of Agribisnis in coastal management zones have to focus on the "Profit Margin" of the producer. This will improve income and then alleviate the poverty of the farmers and fishermen in the coastal villages.

Since the profit margin is a function of price, quantity and cost, it is very important to produce:
(1) An increasing production by providing new technology, infrastructure and law enforcement,
(2) High price in the market through providing facilities of transportation, market fish-auction, information, promotion, diversification of the products and markets, and through a study of the needs of consumers.
(3) Low Cost of Production through IMP, small holder credit schemes (KIK/KMKP), PIR schemes, "Dana Menggulir", Zonation/RUTR and deregulation in the business climate etc.
- It is important to mention that when the result of IMP projects at the four coastal villages show feasibility, we can offer this Master Plan to the donor country for the implementation of a final study.
- Later, if the development of the pilot project provides to be successful for the sustainable development of coastal villages, we can use those activities as a model of IMP to other provinces in Indonesia.

In the case of the Integrated Management Plan at Bengkalis district, the stakeholders comprise the NSC, RSC and other institutions that have to be consulted and coordinated. The activities in achieving the main goal of sustainable development are explained in Table 1.
The roles of the research institutions and Universities are shown in Table 2.
Integration among subsectors within the SAM areas is shown in Table 3.
The concept of the development schemes in the coastal villages is shown in Table 4.
The idea of regulation and enforcement programs, step by step are explained in Table 5 & 6.

THE ROLE OF SCIENCE

Objectives:
To involve Universities and Research Institutes
Provides:
- Knowledge & understanding of social & environmental issues
- Information of data bases
- Analysis of the data
- Define the issues and problems at SAM

Define solution step by step trough:
- Coordination and collaboration between government agencies & local communities
- Education & training of local communities
- Information

Sustainable development among user groups:
- By regulation & enforcement we can let private industry and communities develop the natural resources in a sustainable way.

The success of any regulation acts may depend upon many thing such as:
- Coordination & collaboration between many governmental agencies and local communities.
- Constant consultation & coordination between many government agencies & local communities led by the Governor / Bappeda at the Regional level, and Ministers at National level.
- Education of the communities for the consequences of well planned & responsible development.
- Information, leaflets, brochures, pamphlets, etc.
- Implementation & evaluation of CZM activities.
- Enforcement program

THE CHOICE OF THE DESA (village) PANTAI (MODEL COASTAL VILLAGE) BY THE NSC, RSC, AND SSC-JICA

The study provides a matrix which shows the relationship between each location, socio-economic condition, fisheries activities, mangroves existence etc. (Table 7).
System Science Consultant (SSC) provides data and maps from the results of study phase one. All information from those are as will be scanned and selected according to some constraints, in order to get the required Desa Model.
From the study of Coastal Resources Inventory Management and Enhancement (CRME) in Kabupaten Bengkalis, sixty (60) sample coastal villages were chosen. With the characteristics of "Income per capita < $ 160 / year" (under the poverty line according to FAO standards), and "villages that have at least thirty (30) fishermen/desa", the SSC chose twenty eight (28) villages that fall under those conditions. Later SSC develops criteria of fishing villages according to the constraints of fishing activities in five 5 types, A1, A2, B1, B2, B3.

The last step, from several candidates for each type, the NSC, RSC, JICA and SSC choose as follows:
(1) Desa Muntai in Kecamatan Bengkalis as model type A1,
(2) Desa Sungai Cingam in Kecamatan Rupat as model type A2,
(3) Desa Pelantai in Kecamatan Merbau as model of type B3 (for model of aquaculture pond village area)
(4) Desa Teluk Ketapang in Kecamatan Merbau as model of type B3 (for model of fish processing village area), type A1 according to the SSC study is a fishing village with functions of a fish marketing center; Type A2 is a fishing village without such a function of fish marketing center. Both types (A1 and A2) mainly using gill net, and/or bottom long line for exporting fresh fish. Type B2 mainly using gombang, sero, set net gear for catching shrimp those desa type are potentially enabled to develop them by themselves. The economic activities and income per capita in both desas are relatively higher than other type of fishing villages.
Therefore, desa types B1 and B2 were not chosen as models for the fishing village. Type B3 is a fishing village without the function of a fish marketing center and mainly catching fish. Type B3 might be possible as a model for an aquaculture village area (i.e.: Desa Pelantai), and as a model fish processing village area (i.e.: Desa Teluk Ketapang).
It is important to understand that zoning between coastal fisheries village development and industrial, plantation, agricultural, forest and mangrove preservation areas should be provided firmly by the BAPPEDA Tk. I Propinsi Riau. Therefore, zoning (land use plan) is possibly very important in the process of selection.
In order to choose the B3 model (w\criteria 2), some consideration would be important, such as:
a) Study of soil for ponds to contain clay and acid soil in Desa Pelantai
b) The availability of milkfish fry, kakap fry, or shrimp fry captured from natural resources.
c) How to solve the problems caused by lack of management culture techniques, capital investment, and training of aquaculture techniques.

Lastly, for the preparation of the 2nd phase study of CRME, the Consultants of SSC should prepare "The Work Plan" that contains:
(1) description of the study phase two,
(2) detailed activities,
(3) financial (expenses for the activities) and,
(4) who will carry out these activities.
The NSC and RSC require that those activities should concern a Transfer of Technology between the JICA and the local Indonesians.

CONCLUSIONS

a) In developing countries (i.e: Indonesia) initiatives for coastal zone management come from the government and NGOs, but usually never come from the local communities. Local communities, not seeing the direct benefit, will usually not be involved to these programs. Perhaps due to knowledge, skills and capability of their limited investments, so that they are more interested in improving their income to the family rather than participating the development voluntarily. NGO groups and students, who are concerned with the environment, and are economically independent, sometimes participate through the activity of KKN (Student Field Exercises), boycott, and other activities.
b) Since the integrated management plan in the Coastal Zone Management should be developed and watched by many government agencies, coordination, consultation and collaboration are needed for all activities, in order to achieve the main goals of sustainable development. The stakeholders in the previous checklist are needed for coordination, consultation, and collaboration.
c) Explanation by the public school teachers will help to build "Public Awareness" to the local communities. Public education and training, distribution of information, leaflets, posters, etc. will help a lot in order to achieve the main goal of the IMP.
d) In the case of IMP in Riau Province, the zoning among all economic activities, and the RUTR should be provided firmly by the Governor / Bappeda Tk.I - Riau in order to avoid conflicts among user groups.
e) The greenbelt which is spreading 200 m from the coastline should be maintained and preserved

in order to conserve the sanctuaries area from deterioration and the coastline from erosion.

f) The use of water treatment for plywood industry, pulp/rayon industry, and paper industry which operate "up the river" must be done in order to avoid pollution to the local people "down the river". On the other hand, the richness of the natural resources along the river and in the estuary bays should not be destroyed.

g) The activity of monitoring, controlling, and enforcement by the regional government are necessary for proper execution, so that the sustainability of resources can be kept for the future generations.

h) However, for all those activities funds should be budgeted, which possibly should be collected by the government through tax revenues, licence fees, loan and grants.

Furthermore, the government budget will be obtained through Bappenas, if the project activities are agreed.

Table 1. Checklist of stakeholders involved in CZM issues in Riau Province, district of Bengkalis

No.	Name of the Agencies	d	o	
1	Dept. of Agriculture, DGF	v	d	-
2	Dept. of Forestry, DG of INTAG	v	d	-
3	Dept. of Tourism	-	-	o
4	Tourism Agency	-	-	o
5	Regional Fisheries Service	v	d	-
6	Regional Forestry Serves	v	d	-
7	Commercial Fisheries	-	d	o
8	Hotel Owner	-	-	o
9	District of Bengkalis/Bupati	v	d	-
10	District Fish. Serv. Bengkalis	v	d	-
11	UNRI	v	d	-
12	Other University	-	d	-
13	Bappenas	v	d	-
14	Bappeda	v	d	-
15	Governor/KDH Tk I	-	d	-
16	Vill. S.Cingam, Tel. Ketapang, Pelantai & Muntai	-	d	-
17	Public School Teachers	-	d	o
18	Non Formal Leader	v	d	o
19	Pertamina/Caltex Offshore Drilling	-	d	o
20	ALRI, AIRUD, AD, Bakosurtanal	-	d	-
21	Transportation	-	-	o
22	Kanwil Pertanian	-	d	-
23	Small Scale Petanel (Marine Fishing)	-	d	o
24	KLH / LIPI	v	d	o
25	NGO and Environmental groups	v	d	o
26	Regional Revenues	-	-	o
27	Marketing	-	-	o
28	Aquaculture Farmer	-	-	o
29	Dept. of Public Works	-	d	-
30	BPN (Agraria)	-	d	-

Note Table 1: v = Advisory Committees, including the NSC, RSC and NGO's.
d = Need consultation & collaboration in terms of coordination of all activities to achieve the main goal of the CZM
o = affected by the CZM activities, including NSC, RSC and NGO's

Table 2. The role of sciences

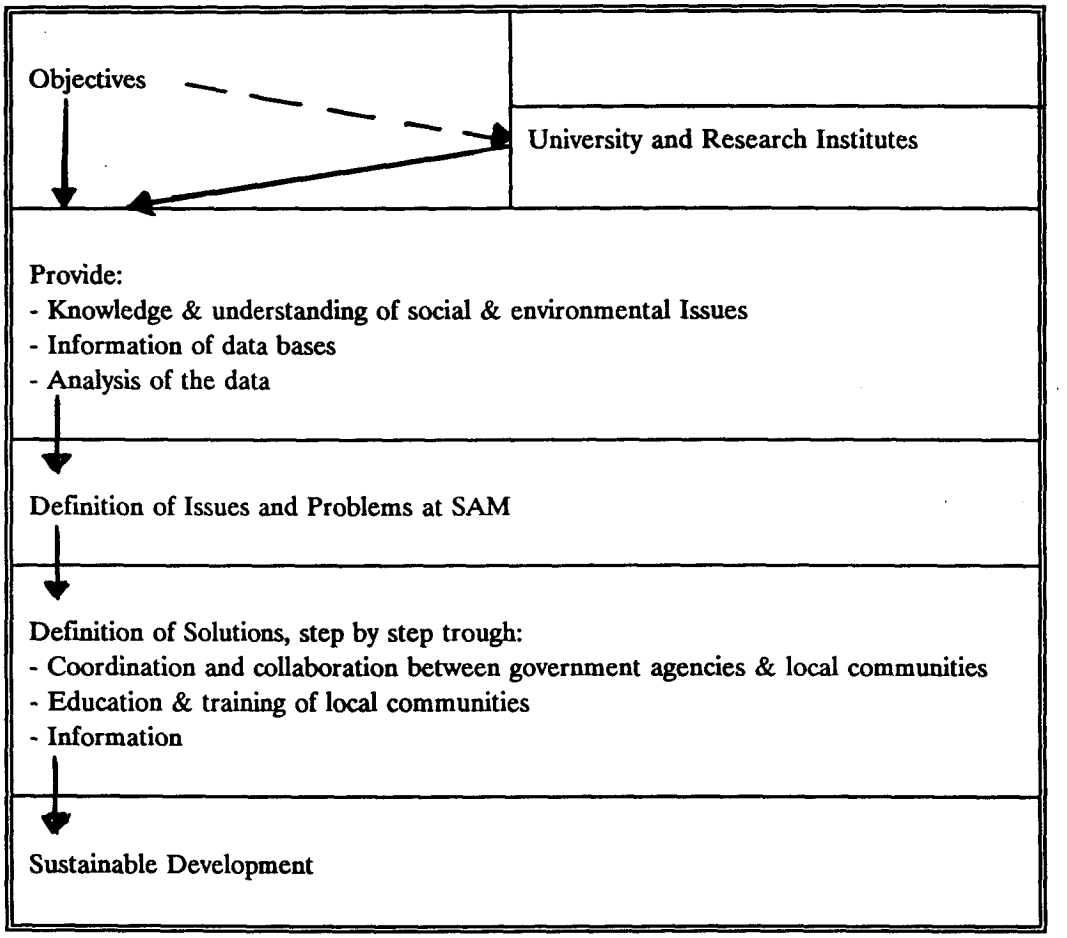

Table 3. Integration among sub sectors within developing areas

Coastal villages are usually isolated and under poverty line	Coordination to be arranged by Local Government (Governor/Bupati)	
High Potential Resources (Natural Resources)	Leading Sector within Sectors of Development	Other Sectors to be built to support the leading sector - Transportation - Electricity - Market & Fish Auctions - Fish Processing - Jetties - PIR schemes - Law enforcement - Zonation, PERDA - Survey of Fishery Potential - Water Treatment
	- Centre of development for developing other sectors - Increasing local government income and income per capita - Supporting other economy activities -Opportunity of works *) Perhaps the other sector (supporting sector) to become leading sector in the future, after the first leading sector can stand alone without the help of other sectors	

Table 4. Regulation and enforcement programs

		Govt. Revenues (through license fees)	
Policies markers: - National Level - Regional level Governor/Bappeda	Planning & Permitting programs for commercial uses of the natural resources	Regulation Acts - Zonation of economic activities - Restriction of fishing efforts - Water treatment - Closing of sanctuary areas	Enforcing programs
Data: Information & analysis by the Universities		Penalty & fines for violation of regulations	By doing you will preserve & restore natural resources from: - deterioration & degradation of the values of the natural resources - conflicts among user groups

Table 5. Sustainable development in fisheries

	Poverty alleviation		
	Income generation	Production (Q)	- Infrastructure (fishing port, landing places) - Education and training - Research and Information of Resource Potential (fishing ground, gears and methods) - New Technology - Fisheries Management (NCS & E); Restriction Effort to NSY, Closing sanctuary areas etc.; Mesh size regulation - Agro wisata activities
	Profit margin Profit = f(Q,P,Cost)	Marketing (P)	- Marketing Facilities (Fish Auction etc.) - Processing and Quality Control - Ice Plant and Cold Storage - Transportation - Efficiency in Marketing Chain
	Capital investment (Fishery activities)	Government policy for reducing the cost of production (Cost)	- Interest Rates of $\leq 12\%$ - Fishery management (sustainable development) - Diversification of Market and Products - Small Scale Credit Schemes (KIK/KMKP) - 'Dana Henggulir' Under Property Alleviation Project - IDT (Special Aid to Reduce Poverty in the Village)
NCS and enhan-cement activities			
	Long term fishery development		

Table 6. Agro-business concepts in open water and lake fishery

Poverty alleviation		
Income generation	Marketing (P)	- Processing - Transportation - Production of Fish according to Market Demand and Consumer Preferences - Production Sites Close to Market and Labour Sources - Promotion, Information and Market Survey - Diversification of Products and Market - Socio-economic Training of workers and Farmers
Profit margin Profit = f(Q,P,Cost)	Production (Q)	- Restocking and Reservation - New Technology (Floating Cages with Economically Valuable Fishes) - Seed Hatchery - Infra Structures (Jetties, Processing, Fish Market) - Research and Information on Resource Potentials - Education and Training
Capital investment in open water and lake fishery	Government policy for reducing the cost of production (Cost)	- Interest Rates of $\leq 12\%$ - Small Scale Credit Schemes (KIK/KMKP) - Zonation (RUTR) - Integrated Intersectoral Devt. Plan (i.e. Fishery, agriculture, Animal Husbandry, Tourism) - PIR, 'Dana Menggulir' Under Property Alleviation Project - IDT (Special Aid to Reduce poverty in villages)
Long term fishery development		

Table 7. Relationship between locations, socio-economics, fisheries activities, mangroves existences, etc.

Item/location	Rupat region	Merbau & Bengkalis	P. Rangsang & Tebing Tinggi (P. = Pulau/island)
1	2	3	4
1. Fishery Communities:			
a) RTP > 30 household/ Fishery village	Rupat all Rupat	Bengkalis & Merbau	P. Rangsang & small Tebing Tinggi
b) Income/capita <$160/yr (FAO standard	all Rupat	11 from 26 desa (villages)	Income & economic activity better than others
c) Residence areas	Dumai (southern part of Rupat)	western part of Bengkalis	western part of P. Rangsang & Tebing Tinggi
d) Chinese population	>50% in the norther part	21.4%	>50% in the north east
e) Number of desa nelyan	15 desa	26 desa	12 desa
2. Fishery Activities			
a) Aquaculture potential	not suitable (too acid) in some places	very suitable (= tanah tanah liat)	suitable (= tanah liat)
Benur from natural resources (available or not)	few	shrimp fry, kakap fry	milkfish & shrimp, kakap fry
Existing tambaks (fish ponds) (tradition Semi intensive, Intensive)	<10 ha	<10 ha	<10 ha (ada dempond) (ada = present)
b) Marine capture			
- Fishing gear	- gill net & bottom long line	gill net & bottom long line	gombong, ambai & set net
- Production	big fish	big fish	white shrimp & 50% trash fish
c) Marketing Centres	in two locations (northern park)	4 locations north east Bengkalis	2 locations (northern park P. Ransang)

d) Fish processing (cold storage, salt & dry, fish meat?)	fresh fish with ice - average pabrik (production) 5 ton	small cold storage - average pabrik 3-5 ton	fresh shrimp with ice sell to tanjung Balai Karimun - average pabrik 3-5 ton
3. Mangrove existence	northern part of Rupat are still good	north & north east Bengkalis & Merbau are still good	north of P. Rangsang need conservation (restoration replan-ting); north of Tebing Tinggi are still good
4. BAPPEDA development plan for Fisheries activities	in norther part of Rupat	Western part of Bengkalis & Merbau	Northern part of P. Rangsang (?)
- Program kemiskinan perahu motor (3GT)	unit	unit	... unit
- Pembangunan TPI/PPI	1	1	1
- Pembangunan desa nelayan	2	2	3
- Aquaculture (tambak = fish ponds)	4 ha	10 ha	15 ha
- Mangrove replanting / conservation	none	none	none
5. Constraints if any (?)	- aquaculture pond surrender, because of domestic market low, management culture not enough & lack of capital investment	- same information with Rupat	- same information with Rupat *)
6. Possible pollution from offshore drilling Caltex/Pertamina	?	?	?
7. Possible conflicts between user groups	yes	yes	yes*)

*) *Conflicts occur if zoning is not firmly developed by the Bappeda/Governor KDH-Riau Province*

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ÉTUDE COMPARATIVE DE LA DYNAMIQUE SÉDIMENTAIRE AUX EMBOUCHURES DES FLEUVES DU LITTORAL IVOIRIEN

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MOTS CLÉS: morphologie, sédimentologie, hydrologie, passe, Grand-Lahou, Grand-Bassam, Assinie, lagune, Côte d'Ivoire

KEY-WORDS: morphology, sedimentology, hydrology, inlet, Grand-Lahou, Grand-Bassam, Assinie, lagoon, Cote d'Ivoire

RESUME

La morphologie récente de l'embouchure du fleuve Bandama à Grand-Lahou connaît une dynamique particulière au cours de ces dernières années (de 1965 à 1993) avec migration significative de l'embouchure vers l'ouest de l'ordre de 1,10 mètres par mois. Son débouché en mer situé au point de changement d'orientation de la côte a nécessité des travaux de protection contre l'ensablement. Il s'en est suivi une profonde modification de la morphologie de la plage sous marine dans cette zone. A l'est du canal la côte subit dans le même temps une sévère érosion évaluée par endroits à 1,5 mètres par an.

La réouverture du canal naturel du fleuve Comoé en vue de l'élimination des plantes flottantes envahissantes a modifié considérablement l'environnement hydro-sédimentaire du domaine lagunaire à Grand-Bassam. Ce système demeure fragile par le colmatage saisonnier du canal en étiage.

De 1989 à 1991 de la passe d'Assinie, suivies de relevés de profils d'estran et de mesures hydrologiques ont permis de mettre en évidence les relations entre les régimes hydrologiques et l'ouverture de la passe. Les échanges lagune-mer sont régis principalement par les apports des rivières. Les diffractions de la houle au niveau du delta de Jusant gouvernent les différentes positions des bancs sableux des rives Ouest et Est.

ABSTRACT

Topographic surveys conducted from 1965 to 1993 show significant migration of the river mouth form east to west. The average migration rate is about 1,1 meter per month. On the other hand, the dredging of the access chanel to the port and protection structures result in trapping sediments coming from littoral drift.

The Bassam inlet was opened in order to revacuate offshore invasive aquatic plants. This has considerably modified the hydro-sedimentary environment of the lagoonal domain at Grand-Bassam. This new system remains fragile, with the seasonal (low river flow) clogging.

From 1989 to 1991 together with beach profiles and hydrological measurements have evidenced the relationships between hydrological regimes and the morphological aspects of the inlet. Hence, the exchange between the lagoon and the ocean only occurs on the surface layers which are mainly fed by the water of continental origin (tanoe and bia rivers). The sediments of the inlet are mainly composed of coarse, fine and very fine sands. These constitute sand banks playing an important role in the stretching of the inlet. Wave diffractions on ebb delta are responsible of the positions and the morphology of sand banks.

INTRODUCTION

Les zones estuariennes du littoral ivoirien, d'importance économique effective et potentielle, ont fait l'objet de plusieurs investigations. Ces études ont généralement porté sur la morphologie, l'hydrologie et les paramètres physico-chimiques de ces milieux. L'ensemble du

système lagunaire ivoirien doit son existence aux variations du niveau de la mer lors des dernières glaciations (Tastet, 1974; 1979). Selon Tastet et Guiral (1993) et Arfi *et al.* (1993), les lagunes ivoiriennes sont d'anciennes vallées orientées Est-Ouest par la tectonique locale et ennoyées lors de la transgression Holocène. L'on assiste aujourd'hui à un comblement de ces lagunes par des matériaux issus du continental terminal. Les travaux sur leur régime hydrosédimentaire sont ceux de Lenoir et Monnet (1968 et 1972); Lecolle, (1971). Parmi ces nombreuses recherches, il apparaît que les études géologiques et sédimentologiques de ces milieux sont relativement peu abondantes. Or il est important de noter que seule l'approche géologique est en mesure d'appréhender les multiples variations historiques et de reconstituer les étapes d'évolution naturelle et provoquée de ces systèmes lagunaires (Vigneaux *et al.*, 1982).

Les interactions entre les continents et les océans constituent un des volets majeurs de l'étude de la zone côtière qui s'inscrit dans les activités du Programme International sur la Biosphère et la Géosphère. La compréhension de ces phénomènes d'échanges entre les continents et les océans passe par l'étude des milieux saumâtres et de leurs communications avec l'océan. Ces derniers qui constituent les passages obligés de la plus grande partie des apports continentaux méritent des recherches approfondies susceptibles d'éclairer le fonctionnement de ces écosystèmes. Car de la nature des fonds et des apports d'origine terrigène ou marine dépend la productivité des lagunes. En effet, les évaluations de stocks halieutiques semblent être en relation avec les variations morphologiques des passes lagunaires insuffisamment connues. En dehors de l'exploitation des ressources animales des plans d'eaux lagunaires, l'homme utilise la zone des passes en tant que lieux privilégiés de peuplement et d'installations urbaines, portuaires, industrielles et balnéaires. Ceci nécessite une bonne connaissance des problèmes de circulation, tant dans le domaine lagunaire qu'entre celui-ci et le domaine marin. Et c'est ce dernier secteur - les zones de passe du littoral ivoirien - qui retiendra notre attention dans cette étude; car toute intervention hâtive sans étude d'impact préalable peut entraîner des préjudices graves, voire irréversibles de l'environnement. En l'occurence, l'éventuelle fermeture de ces différentes passes aurait des conséquences à la fois sédimentologiques (comblement, envasement), chimiques (confinement, dessalure), biologiques et économiques (pêche, tourisme) considérables. Trois grands thèmes seront successivement présentés dans cette étude: le contexte morphologique avec l'influence du transit sédimentaire, la circulation gouvernée par la marée et les apports des rivières et enfin les sédiments, témoins des énergies en présence. La conclusion mettra en relation ces trois thèmes et devra permettre d'énoncer des hypothèses sur le fonctionnement spatio-temporel des passes, afin de prévoir d'éventuelles situations critiques dommageables pour les populations riveraines.

I. GENERALITES

Les fleuves et le système lagunaire débouchent en mer par des exutoires qui sont soit des estuaires permanentes, soit des grau et passes lagunaires. Sur l'ensemble des lagunes du système lagunaire ivoirien, la lagune Aby, présente une morphologie différente. Cette disposition Nord-Sud est en discordance avec la disposition générale Est-Ouest du système lagunaire ivoirien. Cette orientation serait liée à la tectonique (Rougerie, 1951; Tastet, 1979). La partie sud, à l'instar des lagunes Ebrié et de Grand-Lahou est parallèle au trait de côte. Ces communications au niveau du littoral ivoirien sont au nombre de quatre. D'Est en Ouest, on rencontre la passe d'Assinie, le grau de Grand-Bassam, le canal de Vridi et de l'embouchure du Bandama à Grand-Lahou (Fig. 1).

I.1. La passe d'Assinie

La lagune Aby constitue avec la lagune Ebrié les deux plus grandes lagunes du système lagunaire ivoirien. La lagune Aby reçoit deux principales rivières qui sont des rivières côtières: la Bia, en territoire ivoirien, qui se jette au Nord de la lagune et draine une superficie d'environ 10 000 km^2, elle est entrecoupée par deux barrages

hydroélectriques (Ayamé I et Ayamé II); la Tanoé située en territoire ghanéen, communique avec la lagune à l'Est. Elle draine une superficie de l'ordre de 16 000 km^2. Plusieurs petites rivières alimentent la lagune Aby, surtout dans sa partie septentrionale, leurs superficies est de l'ordre de 1.524 km^2. La lagune Aby s'étire sur 56 km dans le sens Est-Ouest et sur 25 km dans le sens Nord-Sud, elle est soumise à un climat de type "équatorial de transition" avec deux crues, une première en Juin - Juillet et une seconde en Octobre - Novembre avec un étiage qui va de Janvier à Mars. Ces deux saisons sont séparées par une "intercrue" qui va d'août à septembre. La superficie de la lagune est d'environ 450 km^2, sa profondeur varie entre 3,8 et 17 m et son volume moyen est de l'ordre 1.6 10^9 m^3 (Chantraine, 1980).

Elle est entièrement contenue dans le bassin sédimentaire traversé par l'accident majeur des lagunes et constitué par une bande de cordons sableux Quaternaires en contact avec la mer, relayée plus au nord par les formations du continental terminal (Néogène) qui représentent l'essentiel des sédiments du bassin. Elles comprennent les sables argileux, les grès ferrugineux et les conglomérats. Au Sud-Est, dans la région d'Eboinda, sur la rive Nord de la lagune Tendo et sur la rive Est de la lagune Aby, affleurent des schistes bitumineux (Bagarre et Tagini, 1965). La nature des fonds selon Gerlotto 1975 correspond à la zonation définie par la bathymétrie (Chantraine, 1980). On y observe des sables et des sables vaseux coquilliers entre 2 et 5 m de profondeur, des vases et vases silteuses au-delà de 5 m et dans certaines baies.

A l'instar de l'ensemble du système lagunaire ivoirien, la zone deltaïque de la lagune Aby subit un comblement progressif, ainsi que l'indique les travaux de comparaison bathymétriques effectués par Charles-Dominique en 1993.

L'on note en lagune Aby (Métongo, 1989), une faible influence marine et une absence d'hydrodynamisme caractérisée (Chantraine, 1980) par la stratification des eaux en toutes saisons dans la cuvette centrale (eaux de 10 à 20 ‰ totalement désoxygénées au-delà de 5 à 6 m de profondeur); d'où l'état anoxyque quasi permanent des eaux de fond observé par Métongo en 1985. L'influence des eaux continentales y est prédominante en toutes saisons. Les eaux sont oligohalines en surface (0,5-5 ‰) avec un gradient de salinité du Nord au Sud (Cantrelle *et al.*, 1983). La température en lagune Aby varie très peu. Elle se situe entre 26 °C et 29 °C (N'goran, 1988). Ces paramètres physico-chimiques conditionnent la vie.

La pêche artisanale qui fournit une quantité importante de protéines animales dans la région Sud, connaît depuis quelques années des perturbations profondes du régime d'exploitation et de la production. L'étude de l'évolution des stocks a montré que l'effort de pêche critique (au delà duquel le renouvellement des stocks devient problématique) a été dépassé en 1980, une baisse des rendements ainsi que la production pour plusieurs espèces (Cantrelle *et al.*, 1983).

Depuis 1658, les positions successives de la passe de la lagune Aby étaient l'objet de percements du cordon dunaire pour évacuer les surcôtes d'eau consécutives aux fortes précipitations (Bouet, 1949; Rougerie, 1951; Iobet, 1701). Ces ouvertures étaient faites par les populations riveraines qui résolvaient ainsi les problèmes d'inondation des terres arables. La passe actuelle est mise en place depuis 1942 (Charles-Dominique, 1993) par les eaux de la lagune, à la suite d'une crue exceptionnelle et soudaine.

I.2. Le grau de Grand-Bassam et le canal de Vridi

Le canal de Vridi représente la voie d'accès au port de la ville d'Abidjan. Son débouché en mer situé au point de changement d'orientation de la côte a nécessité des travaux de protection contre l'ensablement. Le musoir Ouest et l'épi d'arrêt des sables dont les constructions datent respectivement de 1943 et 1972 ont eu pour effet de bloquer l'important transit sédimentaire évalué à 800 000 m^3/an, à l'origine de l'engraissement observé à l'Ouest du canal. La côte Est subit dans le même temps une sévère érosion évaluée par endroits à 1.5 m/an. Le dit canal a été creusé en face du canyon du Trou Sans Fond sur le plateau continental ivoirien, où l'on espérait alors piéger les sables provenant de la dérive littorale. Une partie de ces sédiments

accumulée en tête du canyon, constitue un talus instable qui peut glisser dans ce canyon à l'occasion de fortes houles ou d'ébranlements sismiques.

Le domaine du Grau du Comoé se localise dans la zone centrale du bassin sédimentaire où on observe du Nord au Sud les formations miopliocène à Quaternaire (Tastet, 1979) :

- Les plateaux sablo-argileux mio-pliocène du Continental Terminal au Nord, dominent les sables argileux des bas-plateaux antéholocène qui sont relayés au Sud par les vases et sables lessivés fluviolagunaires. Le cordon littoral Quaternaire plus au Sud est formé de cordons marins sableux successifs. On observe à l'Est de ces cordons et rides de sables marins moyens à grossiers-roux, une génération de cordons de sables moyen à fin blanc jaunâtre (Mondoukou-Assinie).

Les divagations de l'embouchure de Bassam, observées sur environ un siècle portent sur plus de 11 km de côte entre le village d'Azureti à l'Ouest et le bras mort du Comoé à Mondoukou (Varlet, 1958 ; Tricart, 1957). Il faut souligner dans cette historique du grau, l'épisode actuel (1951-1987) après le percement du Canal de Vridi (1951), où la baisse consécutive des courants de chasses dans l'estuaire et le détournement des eaux depuis Moossou en direction des passes de Vridi ont favorisé le colmatage, l'ensablement quasi-permanent des passes et le confinement du milieu. Le Comoé et la lagune Ebrié confluent à Grand-Bassam pour former le plus vaste estuaire du littoral Ivoirien peu profond (2 à 3 m) à travers le mince cordon quaternaire. Cet estuaire bifide, assez singulier est alimenté par le Comoé qui draine du Nord au Sud, 78.000 km², selon un régime tropical de transition (débit moyen annuel 156.8 m^3s^{-1}, 1987) à crue unique (Septembre-Octobre) et par le système lagunaire Ebrié et les rivières forestières à crue dédoublées (Juin-Juillet et Octobre-Novembre).

L'envahissement saisonnier (crue du Comoé) des plans d'eau des secteurs Central et Oriental de la lagune Ebrié par les végétations flottantes (Echinocloea, Salvinia, Pistia) ces dernières années en constitue un aspect à la fois spectaculaire et gênant. La situation actuelle créée par la réouverture du grau du Comoé à Bassam (septembre 1987) décidée par la Commission Nationale de l'Environnement, en vue de l'évacuation en mer de ces plantes par le grau de Bassam. L'évolution de cet estuaire se résume en deux états transitoires, la période avant le percement du canal de Vridi (1950-1951) où seul le grau "temporaire" du Comoé à Bassam évacuait en mer et la période après l'ouverture du dit canal qui a entraîné de profondes modifications hydrologiques.

I.2.1. L'hydrologie ancienne avant l'ouverture du Canal de Vridi

La pénétration de l'onde de marée par l'unique exutoire du Comoé, se caractérisait par d'énormes pertes de charges dans le cours inférieur du fleuve avec un fort amortissement 6 à 10 (rapport des marnages en mer et dans l'estuaire), dès la confluence Ouladine jusqu'à Moossou presqu'équivalent en zone centrale lagunaire Ebrié-Abidjan. La dynamique de l'intrusion saline conférait trois secteurs distincts qui étaient respectivement un domaine sous influence marine, sans dilution (salinité supérieure à 30 °/$_{oo}$), à la confluence Ouladine, un domaine saumâtre, 10 à 13 °/$_{oo}$ du cours inférieur du Comoé à la confluence des lagunes Potou et le domaine à salinité inférieure à 10 °/$_{oo}$ dans la zone Centrale Ebrié (Abidjan) à caractère plus lacustre à l'Ouest.

Les essais de bilan hydrique (Varlet, 1978) avec un grau aux dimensions moyennes, largeur 300 m, profondeur 3,5 m, soulignaient une contribution égale du Comoé et de la lagune Ebrié, avec 12.10^6 m^3 d'eau évacuée au jusant et représentant le double des entrées au flot.

I.2.2. L'hydrologie de l'estuaire après l'ouverture du Canal de Vridi

L'estuaire dès lors bifide a maintenu un flux principal en direction du canal de Vridi. Cette situation favorisée par le caractère temporaire du grau et les dimensions du canal artificiel (longueur 2,7 km, largeur 230 m, profondeur moyenne 12 m, section mouillée 2760 m²) a provoqué le déplacement du secteur estuarien

sous forte influence marine (salinité supérieure à 20 °/$_{oo}$) dans la zone centrale de part et d'autre de Vridi (Tastet, 1979).
L'onde de marée depuis Vridi induit dans le secteur de l'embouchure naturelle du Comoé (confluence Ouladine - Moossou - Iles Vitré) un marnage faible sensiblement équivalent à celui occasionné par le flux du grau de Bassam, 17 à 33 cm pour 100 cm d'amplitude au large de Vridi. Toutefois, il faut mentionner la réduction sensible du retard de propagation de la marée et l'apparition d'un front salé à la confluence Ouladine lorsque les 2 exutoires sont fonctionnels. Le bilan estimé au niveau du Canal de Vridi (Mai-Octobre) le grau fermé, confirme des flux nets plus importants de 18,6.10^6 m^3 évacué par cycle de marée pour un flux de jusant de près de 46,7.10^6 m^3 (Tastet, 1974). Les écoulements résiduels estimés depuis Moossou traduisaient un flux préférentiel en direction du canal de Vridi.

I.3. L'embouchure de Grand-Lahou

L'estuaire de Grand-Lahou est l'exutoire en mer d'un des plus importants fleuves de Côte d'Ivoire. Situé à l'extrémité orientale de la lagune de Grand-Lahou, il est compris entre les latitudes 5° 9' et 5° 12' Nord et les longitudes 4° 56' et 5° 20 Ouest. La partie occidentale de l'estuaire est représentée par un système lagunaire qui s'étire sur environ 30 km pour une superficie de 190 km^2 (lagunes Tadio, Niouzoumou et Mackey-Tagba séparées de la mer par un cordon sableux d'origine marine).
Le bassin du Bandama, de forme allongée dans le sens NNW-SSE, est situé dans la zone de balancement du front intertropical caractérisée par trois types de régimes hydrologiques, un régime tropical de transition dans la partie septentrionale, un régime équatorial de transition atténué dans la partie centrale et un régime équatorial de transition dans la partie méridionale. Son bassin versant couvre une superficie de 97500 Km^2. Son régime hydrologique est de type tropical au Nord et équatorial de transition atténué dans le Sud. Monnet, (1972) situe les crues en Septembre (environ 400 m^{3}s^{-1}) et les étiages en Janvier-Février(60 m^{3}s^{-1}). La charge particulaire moyenne d'environ 400 mgl^{-1} (Koffi *et al.*, 1987). Le Bandama exporte peu de matériel détritique et sa charge annuelle est de l'ordre de 7 à 16 t km^{-2}an^{-1}, malgré le manteau d'altération important qui recouvre son vaste bassin versant.
Ces exutoires de la côte ivoirienne sont instables. Leur migration dans le cordon qui est liée à l'équilibre dynamique entre le transit sédimentaire littoral et les processus estuariens (marée, courant de chasse et vidange de crue) a provoqué des épisodes successifs de colmatage et d'ouverture. L'instabilité relative observée aujourd'hui, trouvera son explication dans les études hydrologiques et sédimentologiques qui suivent.

II. MORPHOLOGIE

La lagune Aby est séparée de son débouché en mer par un ensemble de huit îlots qui occupent une surface d'environ 15 km^2 et qui délimitent un chenal rectiligne de 5,5 km situé entre l'île Esso et le continent. Ce chenal constitue la zone véritablement estuarienne directement soumise à une forte influence de la marée. La carte bathymétrique réalisée en 1991 (Fig. 2) indique que les profondeurs maximales n'y excèdent pas 6 mètres. Le profil en long réalisé dans l'axe du chenal principal fait apparaître, à la confluence avec les lagunes d'Assinie et d'Assinie Mafia, un seuil qui avoisine 3 mètres. Au sud de ce dernier, la passe se resserrant, les profondeurs croissent régulièrement vers le milieu marin. Dans la zone Nord, le chenal se maintient régulièrement à 6 mètres de profondeur. A l'Est et à l'Ouest on observe l'amorce des chenaux secondaires des bras de lagune, témoins de la complexité de la circulation à cet endroit. L'observation des coupes (Fig. 3) indique une dissymétrie morphologique caractérisée par une pente ouest très prononcée; la façade orientale observe une pente beaucoup plus douce. Cette configuration définit un chenal plaqué contre le rebord occidental de la lagune. A la confluence avec la mer on observe un chenal en V bien individualisé. Le suivi des migrations actuelles de l'embouchure a été effectué depuis 1987 par des levés topographiques réguliers et par l'observation de photographies aériennes (Fig. 4). Pendant

les saisons d'étiage, au moment où les rivières observent leurs minima de débit, les sédiments du transit littoral pénètrent dans la passe et engraissent les berges pour constituer des bancs de sables qui réduisent l'ouverture de l'embouchure. Il est important de noter un recul important des estrans à l'Est et à l'Ouest de la passe, au cours des mois de Juin, Juillet et Août. Les sédiments érodés participent à la constitution du delta de jusant. C'est le cas des bancs de sable de la berge Ouest qui disparaissent et se reconstituent selon les saisons hydrologiques marines. La plus petite ouverture de la passe mesurée à la fin de l'étiage des rivières est de 200 m. Sa largeur maximale (environ 500 m) s'observe à la fin des périodes d'agitations maximales (tempêtes épisodiques). Le recul de l'estran à l'Ouest de la passe, pendant ces périodes atteint 150 mètres. La morphologie des bancs de sable orientée vers le milieu lagunaire (exemple du 29/04/89) est un reflet de la prédominance de la marée sur le débit des rivières pendant cette saison. L'exutoire couvre une surface de 4 Km^2 dont seulement 2% d'îlots colonisés par la végétation. Cette aire présente au Nord le site de Lahou Kpanda et au Sud le cordon littoral interrompu par la passe. A l'Ouest, ce cordon plus large (250 m) abrite l'ancienne ville de Grand-Lahou avec les vestiges de ses bâtiments coloniaux. A l'Est Brafedon est plus étroit (120 m) et couvert par des cocotiers; son extrémité à l'embouchure forme une flèche de sable.

Les profondeurs observées n'excèdent pas 3 mètres sur 90% de la surface de l'embouchure. Sur les 10% restants, on note néanmoins l'existence de chenaux qui atteignent 8 m de profondeur. Ils sont au nombre de trois (Fig. 5):

-Le chenal lagunaire au Sud-Ouest (Figs. 6a et 6b) d'une profondeur maximum de 5 mètres est plaqué contre la presqu'île de l'ancienne ville de Grand-lahou. Il vient se heurter à un haut fond de 3 m aux environs de la passe.

-Le chenal fluvial à l'Est qui longe la flèche de sable de Brafedon présente des profondeurs qui excèdent par endroits 7 mètres. Il forme le chenal d'écoulement du fleuve Bandama. Sa profondeur varie selon les saisons (Lecolle, 1971). A l'instar du chenal lagunaire, le chenal fluvial montre un profil transversal irrégulier (Figs. 6b et 6c) avec des flancs abruptes. De façon générale, la rive septentrionale est plus pentue que la rive méridionale. Ces deux chenaux Sud se rejoignent au niveau de la passe pour constituer un chenal unique de 8 mètres.

-Le chenal du Nord qui longe les berges de Lahou Kpanda atteint 6 mètres de profondeur (Fig. 5). Il est très localisé et se heurte à des hauts fonds dans ses prolongements oriental
et occidental. Son profil transversal en forme de V est assez symétrique (Fig. 6e).

Ces chenaux sont séparés par un alignement d'îles couvertes par la végétation. Les hauts fonds situés entre ces îles assurent leurs jonctions. La disposition Est-Ouest des îles suggère une alimentation en sédiments par les apports du Bandama.

II. LES PARAMÈTRES OCÉANIQUES

III.1. La marée

Elle est de type semi-diurne avec de fortes inégalités journalières. L'onde de marée qui y pénètre est amortie par la présence des îles barrières à Assinie, des delta de marée (Grand-Lahou et Grand-Bassam). L'onde dynamique de marée décrite pour les différents états entraîne un très faible marnage, dû à l'influence des courants de chasse des fleuves, variable environ 16 cm à Grand-Lahou, 30 cm à Grand-Bassam et 50 cm à Assinie.

III.2. La houle, de direction Sud-Sud-Ouest, subit des diffractions sur le delta de jusant lors des grandes crues des fleuves. Sa hauteur moyenne est de 1,20 mètres et de période moyenne comprise entre 7 et 11 secondes. Sa hauteur peut atteindre 3 à 4 mètres lors des tempêtes exceptionnelles des mois de Juillet et Août. Au moment des fortes tempêtes levées par les vents du secteur Sud, l'influence de la houle devient très importante. Elle est à l'origine de l'érosion des estrans adjacents à la passe. Les basses côtes de ces régions font l'objet de washovers assez fréquents. Les courants induits par la houle sont responsables du transit littoral Ouest-Est sur l'ensemble de la côte ivoirienne.

III. APERCU HYDROLOGIQUE ACTUEL

III.1. La passe d'Assinie

Stations S1 (Fig. 7)

Elle est située sur une marge peu profonde et comporte un seul point de mesure à 1 m de profondeur. La vitesse de courant la plus élevée reste inférieure à celle mesurée dans le même temps dans le chenal. Elle est de 0,729 m/s au maximum de jusant. L'évolution de la salinité a subit le schéma classique; elle est de 33 °/$_{oo}$ au maximum de flot et 5 °/$_{oo}$ à l'étale de jusant. La direction moyenne des courants au niveau de la section S_1-S_2 est de 187° Sud au jusant et de 22° Nord au flot. Dans la passe d'Assinie elle est de 334° Nord au flot pour 166° Sud au jusant. Cette différence dans la direction au flot est due au changement correspondant d'orientation du chenal de la passe.

Stations S2 (Fig. 8)

Le jusant l'emporte sur le flot avec une vitesse maximum de 0,978 m/s en surface. Les courants de marée sont alternatifs. Les directions moyennes enregistrées sont de 22° Nord en flot et de 190° Sud au jusant. Selon les observations faites dans ce chenal le jusant a une durée nettement plus longue (8h 10mn) que le flot. Les salinités augmentent progressivement au cours du flot et atteignent leur maxima à l'étale du courant. Elles diminuent de nouveau au cours du jusant et atteignent leur minima à l'étale suivante où elles avoisinent 5 °/$_{oo}$ en surface. En profondeur les salinités sont plus fortes et les valeurs à l'étale de flot atteignent 33 °/$_{oo}$. La variation de la salinité est plus sensible en surface qu'en profondeur.

Station S3 (Fig. 9)

La vitesse la plus élevée a été observée au jusant (0,923 m/s); cette vitesse est sensiblement égale à celle observée au flot où elle a atteint 0,900 m/s. Sur toute la tranche d'eau, le jusant l'emporte sur le flot avec des vitesses résiduelles de 0,098 m/s à 1 m et 0,016 m/s à 3 m de profondeur. Le débit calculé est de l'ordre de 72,848 m^3/s. La salinité est de 34 °/$_{oo}$ au maximum de flot et de 8 °/$_{oo}$ à l'étale de jusant. Pour cette période, le courant de marée a une orientation de 334° Nord au flot et 166° Sud au jusant.

III.2. Grand-Bassam et Vridi

Des essais de relevé de vitesses de courant de marée ont été effectués sur 2 états post-ouverture (Station Moossou-S2; Station Embouchure-S1) (Fig. 10) comparés à l'état "zéro". Ce dernier état nous présente deux zones dynamiques distinctes:

- Une zone interne confinée II, saumâtre des environs de l'île Bouet jusqu'à la confluence ouladine sans courant de marée effectif, (Anonyme, 1987).
- Une zone interne, fluviale I, drainée en permanence par le jeu des courants de chasses du fleuve et de la marée depuis Vridi. La circulation résiduelle correspond en surface à 6,3 cms^{-1} direction jusant et au fond 3,4 cms^{-1} direction flot caractérisant la répartition classique dans les estuaires.

Les 2 états post-ouverture, réalisés les 17 Août 1988 et 7-8 Janvier 1989, nous permettent de déterminer trois zones dynamiques comme suit:

- L'apparition d'une zone externe III, sous forte influence marine à salinité supérieure à 30 °/$_{oo}$ plus ou moins réduite à la confluence Ouladine-grau avec des vitesses instantanées supérieures à 0,400 ms^{-1}.
- La zone interne II, de la confluence Ouladine à l'Ile Bouet soumise à l'action de courants de marée faibles à modérés selon la section du grau. Les vitesses maximales relevées à la station embouchure sont comprises entre 0,18 ms^{-1} le 17 Août 1988, le Grau très ensablé avec une section de moins d'une centaine de mètres, et 0,50 ms^{-1} le 7 Janvier 1989 avec l'embouchure largement dégagée (Fig. 3). Les écoulements résiduels de la surface de direction jusant et ceux du fond de direction jusant (Vr = 0,08 cms^{-1}) sont équivalents. La salinité de cette zone intermédiaire varie entre 30 °/$_{oo}$ et 5 °/$_{oo}$ avec une stratification des eaux (Fig. 10).
- La zone interne "fluviale" I, à la confluence Comoé - lagune Ebrié Moossou est drainée par un écoulement plus important. La vitesse maximale à la station Moossou varie entre

0,68 ms^{-1} (17 Août 1988) et 0,55 ms^{-1} (7 Janvier 1989). Les courants alternatifs donnent respectivement un écoulement résiduel de 0,04 ms^{-1} direction jusant en surface et 0,08 ms^{-1} et 0,11 ms^{-1} direction flot à 3 m et 5 m de la surface. La salinité traduit la plus forte dilution de l'intrusion saline (5-15 °/$_{oo}$) et l'écoulement en surface des eaux du Comoé (Avril 1988). L'eau de mer remonte en profondeur (4-5 m) jusque dans cette zone en étiage 7 Janvier 1989 (Fig. 10).

III.3. L'exutoire de Grand-Lahou

Des mesures de vitesses de courants et de salinité ont été effectuées toutes les heures, pendant un cycle de marée, dans les principaux chenaux, aux stations hydrologiques mentionnées sur la Fig. 2. Située plus à l'Est, la station sur le Bandama comporte deux radiales pour tenir compte de la dispersion latérale, tandis que les trois premières n'en comportent qu'une.

La représentation graphique des vitesses en fonction de la marée et de la tranche d'eau (surface, milieu, fond) présente les caractéristiques suivantes:

Station Grand-Lahou

Il apparaît au flot, des vitesses généralement plus élevées en surface (114,2 cms^{-1}) et à mi-profondeur (Fig. 11a). Dans la première moitié de la renverse, elles deviennent plus importantes au fond où elles atteignent 53,4 cms^{-1}. Le débit à cette station atteint 227,5 m^3s^{-1}. Les salinités quasi constantes (23 ‰) dans cette partie de l'estuaire dénotent la faible influence des eaux du Bandama (Fig. 12a).

Station Bandama

Au niveau de la section mouillée Bandama sud (Fig. 11b), la vitesse résiduelle est nulle entre 3 m et 6 m de profondeur. Ce qui traduit l'existence d'une couche d'eau saumâtre (23 ‰) permanente, oscillante, sur laquelle glisserait l'eau douce du Bandama. Dans le chenal Nord (Fig. 11c), presque toute la colonne d'eau suit le mouvement de la marée, à l'exception de la couche en dessous de 2 mètres qui est très peu diluée par l'eau du fleuve. la salinité moyenne est d'environ 22 °/$_{oo}$ (Fig. 12c).

Station Embouchure Est

Le flux et le reflux des eaux entre lagune et mer se produit sur toute la hauteur de la nappe (Fig. 11d). Néanmoins, au delà de 3 m de profondeur les valeurs de la salinité permettent d'isoler la couche d'eau saumâtre permanente. Quoique très rapprochée du milieu marin, l'influence des eaux du fleuve reste très marquée en surface, avec des salinités voisines de 5 °/$_{oo}$ au maximum de jusant (Fig. 12d).

Station Embouchure Ouest

A cette station lagunaire les vitesses de surface restent supérieures à celles du fond au maximum de flot (Fig. 11e). Cette situation s'inverse au maximum de jusant. Il faut toutefois noter que cette partie de l'embouchure est très peu soumise à l'influence des eaux du Bandama; ceci explique la constance des salinités qui oscillent entre 20 à 23 °/$_{oo}$ (Fig. 12e).

Les différents volumes ayant transités dans la zone de l'embouchure, pendant un cycle de marée sont:

Station Embouchure Ouest 83.19 10^5 m^3 (flot)

Station Embouchure Est 157.47 10^5 m^3 (jusant)

IV. REPARTITION SEDIMENTOLOGIQUE

IV.1. Dans la passe Assinie

Deux grands types de faciès sédimentaires caractérisent le secteur. Ce sont:

- Les sables qui couvrent la presque totalité du site étudié. Ce sont des sédiments moyens à fins, de couleur blanchâtre, caractéristiques du cordon de la zone d'Assinie.

-Les sables vaseux qu' on retrouve généralement sur la berge Est du chenal, dans les zones colonisées par les végétations de mangroves et dans le chenal. Ils sont parfois très coquilliers avec de nombreux débris végétaux. La portion d'arénite est constituée de sables fins à très fins. Les analyses granulométriques effectuées font ressortir deux grandes catégories de sables, représentées par les faisceaux de courbes cumulatives, caractéristiques de zones sédimentaires différentes (Fig. 13). Il s'agit de la zone située entre la confluence des bras lagunaires jusqu'aux îles barrières où l'on ne rencontre que des sables fins à très fins, caractéristiques des sables lagunaires.

Depuis le milieu océanique jusqu'à la confluence des bras lagunaires, l'on se trouve en présence d'un mélange de populations de sables fins à très fins et de sables moyens, témoignant ainsi de la forte énergie relative de ce milieu. Les sédiments des estrans avoisinants étant constitués par le même cortège de sables, on peut en déduire que ceux-ci participent à l'engraissement de la passe d'Assinie.

IV.2. Dans l'embouchure de Grand-Bassam

La répartition des faciès superficiels dans le domaine de l'embouchure en relation avec le niveau d'énergie et la dynamique des fonds trace parfaitement les différentes zones dynamiques définies dans l'aperçu hydrologique.

- La zone interne I de Moossou, sous forte influence fluviale, est caractérisée par les faciès les plus grossiers: sables grossiers roux à sables moyens fluvio-lagunaires (Martin, 1977 - Tastet, 1979). Leur répartition trace parfaitement la confluence du fleuve en lagune Ebrié. Les vases sont localisées sur les berges fortement colonisées par les plantes flottantes. Les abords de l'Ile Morin au Nord sont tapissés de sables fins.
- La zone interne II du Nord de l'Ile Bouët à la confluence Ouladine au Sud, où le confinement du milieu a favorisé la décantation des eaux lagunaires et des crues du Comoé. Les fonds sont formés de vase jusqu'à la confluence Ouladine où sont observés les sables fins à très fins lagunaires. Les affleurements de sables (moyens et fins) dans cette zone forment les bancs et hauts fonds.

Le bras lagunaire à l'opposé de la lagune Ouladine est très confiné avec des dépôts de vases fluides noires à forte odeur de H_2S.

La répartition des faciès superficiels comparativement à l'état initial ci-dessus présenté traduit une amorce d'érosion des fonds avec l'apparition d'une zone externe sous influence marine (houle et swash).

- La zone interne I de Moossou: Les sables moyens occupent une superficie plus importante à la faveur du lessivage des vases localisées aux berges orientales du Comoé et de la lagune Ebrié.
- La zone interne II du Nord de l'Ile Bouët au Nord de la confluence Ouladine: L'érosion des fonds des berges Nord de l'Ile Bouët provoque la découverte des sables moyens. Les fonds restent vaseux dans le secteur de l'île. Les vases remobilisées sont évacuées en suspension (permanente) vers le large (Rivière, 1977, Migniot, 1968, Allen, 1977).
- La zone externe III, du Grau à la confluence Ouladine: on observe la progradation des sables marins moyens sur les sables fins lagunaires à la faveur des courants de marée de flot . Le bras lagunaire oriental n'a pas évolué. Les fonds y demeurent vaseux.

L'étude granulométrique de ces différents faciès sédimentaires est la suivante:

- Les sables grossiers ($\phi > 500\ \mu m$) du domaine fluvial, jaune-roux généralement azoïque: ce faciès se caractérise par une forte occurrence de gravillons. Les populations sont relativement homogènes, modérément classées ($0,55 < \sigma < 0,93$). La teneur en carbonate faible est inférieure à 5%.
- Les sables moyens ($250\ \mu m < \phi < 500\ \mu m$): Ces sables jaune-roux à grisâtre contiennent quelques débris coquilliers. Ils sont peu homogènes, multimodaux avec un écart-type compris entre 0,51 et 1,17 pour des populations modérément classées à mal classées. La teneur en carbonate est modérée avec quelques exceptions à plus de 30%.
- Les sables fins à très fins ($63\ \mu m < \phi < 250\ \mu m$): Les sables fins à très fins sont blancs à grisâtres. Ils constituent une population assez hétérogène, modérément classée à mal classée ($0,51 < \sigma < 1,32$). On y observe les plus fortes teneurs en carbonate pour les sables fins vaseux (40%).
- Les vases et silt ($\phi < 63\ \mu m$). Ce sont:
- les vases molles gris-verdâtres, bio-turbées, assez riches en matière organique provenant en grande partie de la décomposition des plantes flottantes;
- les vases fluides, noires, à forte odeur de H_2S et très riches en matière organique.

L'analyse granulométrique de la fraction inférieure à 63 μm n'ayant pu être faite, le faciès des vases couvre ici les silts et argiles.

- Les faciès de mélange (sables vaseux et vases sableuses): Il s'agit du mélange des faciès sableux et vaseux susmentionnés en des proportions variables. La coupure entre vases et sables est située à 50% de particules inférieures ou supérieures à 63 μm.

IV.3. Dans le canal de Vridi

De l'étude granulométrique, il résulte que les cordons sableux qui séparent les lagunes de la mer ont été mis en place par la dérive littorale il y a environ 5000 ans; ce qui indique que ceux-ci ont été constitués bien avant l'ouverture du canal. Dès lors, le matériel détritique qui le compose est partout le même. Il est composé pour l'essentiel par des grains de quartz dans la proportion de 80%; le reste, 20%, regroupe quelques grains de feldspath et de nombreux minéraux lourds tels que ilménite, rutile, grenat.

Depuis la construction du canal portuaire, si la composition minéralogique des sédiments reste inchangée, la morphologie des grains de silice par contre se différencie quelque peu, selon que l'on se situe à l'Ouest ou à l'Est du canal.

En effet, depuis Grand-Lahou jusqu'aux structures de protection à l'Ouest du canal, les grains de quartz sont de plus en plus arrondis, tandis que dans la baie de Port-Bouet voisine, ils sont plus anguleux. Cette coupure au niveau du canal est encore plus franche si l'on considère la granulométrie des sédiments. Ceux-ci s'avèrent plus grossiers dans la baie de Port-Bouet qu'à l'Ouest du canal où ils ne sont au plus que des sables moyens.

IV.4. Dans l'exutoire de Grand-Lahou

Les dispositions des sédiments correspondent aux différentes unités morphologiques. Ainsi, les hauts fonds et les bancs sont constitués de sables fins à très fins (189 μm < d < 208 μm) multimodaux et modérément bien classés.

Dans les chenaux, on rencontre des sables moyens multimodaux avec des diamètres compris entre 0,261 et 0,326 μm. Ces faciès sont différents de ceux de la passe qui sont composés de sables moyens, roux à tendance grossière (0,311 μm < d < 0,483 μm). L'écart-type compris entre 0,47 et 0,56 μm indique leur homogénéité. Ces caractéristiques sont similaires à celles des sédiments marins. En 1971, ces formations étaient essentiellement vaseuses (d < 10 μm) recouvrant les sables fins à très fins (Lecolle, 1972). Il résulte de ce constat que les vases qui jadis tapissaient ces hauts fonds ont été emportées par les courants de marée pour laisser apparaître les sables fins à très fins. D'autre part, les sables de la dérive littorale contribuent au comblement de la zone de l'embouchure.

V. L'OUVERTURE DES EMBOUCHURES DANS LE CORDON

La position des passes et leur existence même dépendent de la crue des différents fleuves et lagunes, de l'équilibre qui se crée entre les houles océaniques qui tendent à l'obstruer et les courants de marée qui, par leur va et vient périodique, entretiennent un passage pour les eaux (Bidet *et al.*, 1977). La Fig. 14 indique les mouvements respectifs de la flèche libre de Brafedon à l'Est et du cordon à l'Ouest de l'embouchure de Grand-Lahou. A cela, il faut ajouter la dynamique des sédiments dans l'axe de l'embouchure qui correspond à une pénétration des sables moyens marins remaniés à la côte sous l'action de la houle en déferlement (Swash) et des courants de marée. L'importance de cet apport de sable est favorisée par la diminution de l'énergie des chasses du fleuve en étiage et par l'érosion des plages dans le cas de Grand-Bassam.

CONCLUSION

L'essentiel des échanges se produisant dans les couches superficielles des masses d'eau. Par ailleurs, la morphologie du chenal d'accès en mer n'est pas favorable à une circulation des eaux profondes plus denses qui parviennent en lagune pendant le flot, car ces dernières se heurtent à deux obstacles constitués par les îles barrières et le seuil situé à la confluence des bras lagunaires d'Assinie. Le schéma d'évolution de la passe montre que pendant les périodes d'étiage, les quantités d'eaux évacuées pour l'entretien de l'ouverture ne sont plus suffisantes; on observe alors une prédominance des courants de flot sur ceux du jusant. Les apports sédimentaires

d'origine marine, très importants, concourent au comblement partiel de la passe en constituant des bancs sableux. Ceux-ci sont beaucoup plus importants dès lors que l'étiage des rivières coïncide avec les saisons d'engraissement (de Novembre à Février) des estrans. La passe est alors à son maximum d'obstruction. Les sédiments marins, qui alors colonisent toute la zone de la passe, concourent à la formation du haut-fond de la confluence des bras de lagunes. Les échanges mer-lagune étant réduits par cette obstruction de la passe, la migration de certaines espèces faunistiques qui pourrait être sérieusement perturbée, devrait faire l'objet d'une étude plus approfondie qui tienne compte des variations bathymétriques saisonnières.

La réouverture artificielle du Grau du Comoé à Grand-Bassam, le 17 Septembre 1987, a entraîné de profondes modifications de l'environnement hydro-sédimentaire du secteur lagunaire avec un flux dominant maintenu en direction du canal de Vridi. La pénétration d'une onde de marée à moins de 4 km de la confluence du Comoé en lagune Ebrié bien qu'amortie (très faible marnage) a induit un caractère estuarien dans un domaine lagunaire antérieurement confiné, malgré les crues annuelles du Comoé. La dynamique de l'intrusion saline après la pénétration des premières marées suivant la coupure du cordon, détermine la création de trois zones distinctes : la zone externe II, la zone interne II et la zone interne I. La modification des fonds est significative avec le lessivage des fonds confinés qui fait découvrir des faciès plus grossiers: sables fins à très fins lagunaires dans la zone interne II, confluence Ouladine - Ile Bouët; sables moyens à grossiers, dans la zone interne I, confluence Comoé à Moossou. Le domaine particulier du grau de Grand-Bassam, très instable traduit une progradation des sables moyens marins vers le domaine interne sur les sables fins lagunaires sous la forme de hauts fonds et flèches libres.

La construction du canal et de ses structures de protection influencent le comportement dynamique des sédiments dans la zone Vridi Port-Bouet. Il en résulte un déséquilibre dynamique qui se traduit par une accumulation de sable à l'Ouest de l'épi et une érosion en quantité équivalente à l'Est. Lors de la saturation de l'épi de protection, les sables de la dérive littorale contournent celui-ci et migrent vers l'Est. Cette interruption se traduit par la différence de la morphologie des grains de quartz qui sont plus anguleux à l'Est du canal qu'à l'Ouest. Le rétablissement de l'équilibre de la zone nécessite un apport sédimentaire (beach nourrishment) par 'by passing' à l'Est du canal. Mais cette solution s'avère onéreuse dans la conjoncture économique actuelle.

L'étude au niveau de l'embouchure de Grand-Lahou fait ressortir les caractéristiques morphologiques de la passe constituée de hauts fonds et de chenaux. L'on note que l'ensemble du domaine est très peu profond (3 m) à l'exception des chenaux qui atteignent 8 m. L'entretien de l'ouverture de la passe est dû à l'équilibre qui se crée entre les courants de marée auxquels participent les débits du fleuve et la houle. Les mesures hydrologiques font apparaître une dominance des courants de chasse sur ceux du jusant avec des vitesses atteignant parfois 1,2 ms^{-1}. Si le régime du Bandama n'a pas une influence majeure sur les dimensions de la passe, il faut noter que lors des grandes sécheresses matérialisées par un débit minimum, elle se ferme totalement au passage des eaux. Les sédiments transportés par la dérive littorale contribuent au comblement des fonds lagunaires et à l'obstruction de l'embouchure pendant les périodes d'engraissement des plages qui s'étendent de Décembre à Avril. La vitesse de déplacement de l'embouchure vers l'Ouest (1,1 m par mois) doit être prise en compte dans les plans d'aménagement futurs de cette partie du littoral.

Ainsi, les changements morphologiques des embouchures reflètent les énergies mises en jeu par les facteurs hydrologiques. Ceux-ci participent à la construction de deltas de marée sous l'influence de la dérive littorale. Les différents aménagements dans les zones des passes doivent tenir compte des migrations morphologiques saisonnières, parfois irréversibles, du trait de côte des environs immédiats et des washovers épisodiques engendrés par les houles exceptionnelles.

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Fig. 1. Localisation du site d'étude/ Site of study

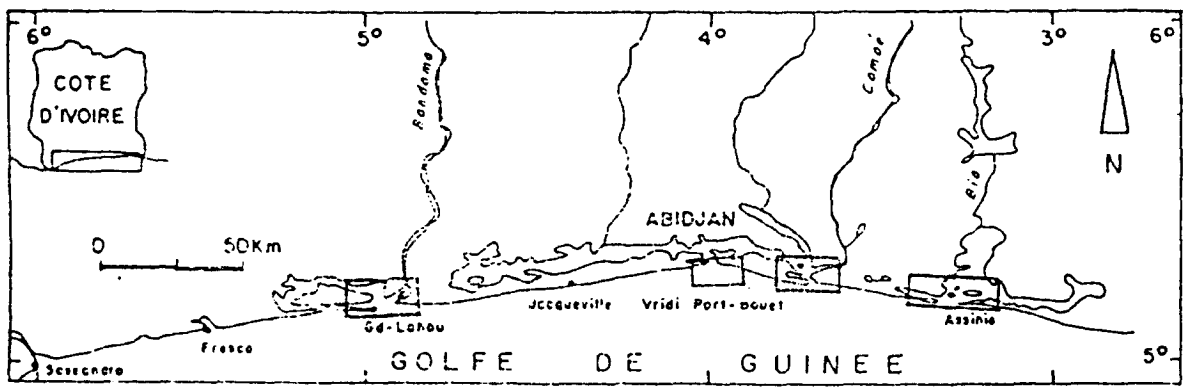


Fig. 2. Carte bathymétrique de la zone de passe d'Assinie.

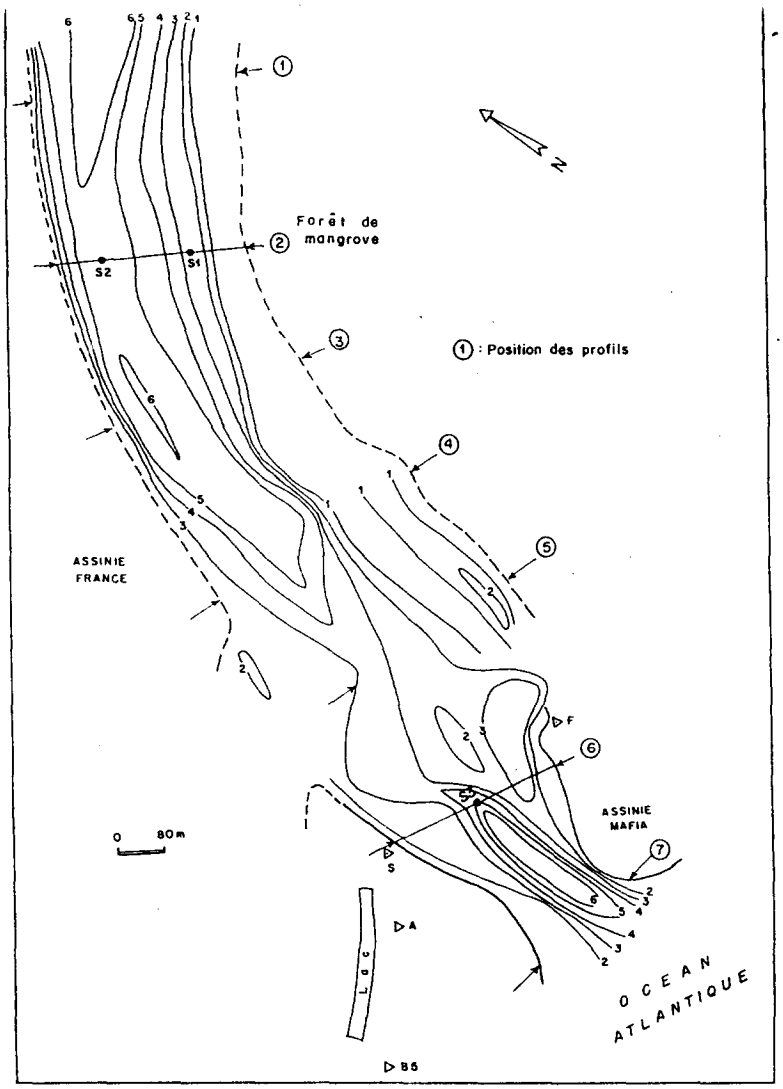


Fig. 3. Configuration du chenal de la passe à Assinie.

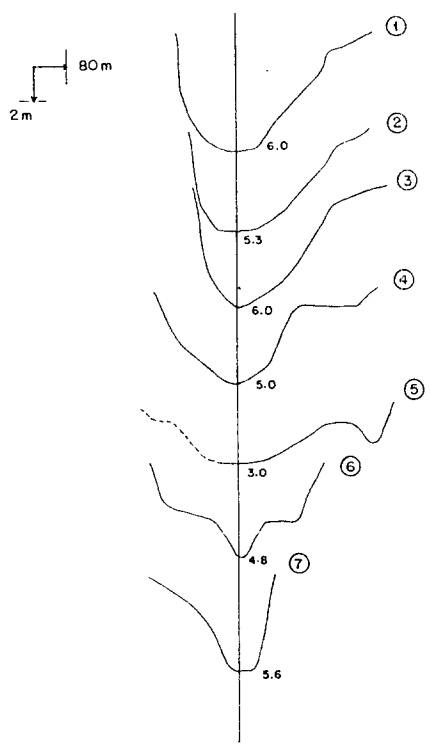
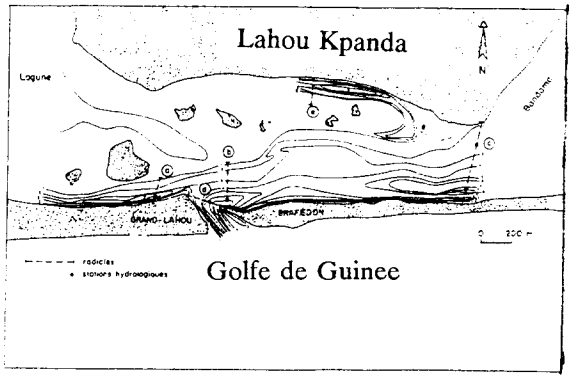


Fig. 5. Carte bathymetrique de l'embouchure du fleuve Bandama à Grand-Lahou



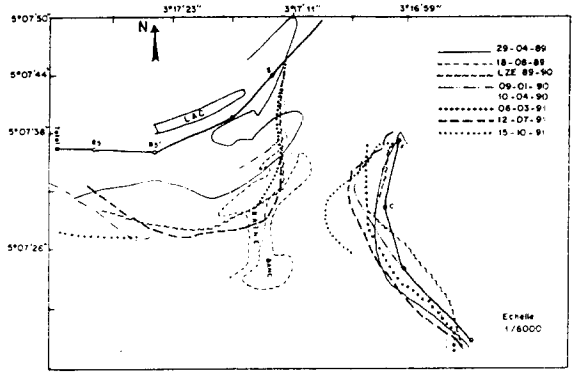


Fig. 4. Migrations actuelles de la passe d'Assinie (1980-1991).

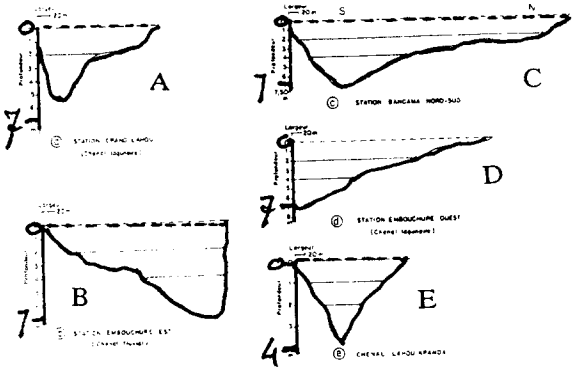


Fig. 6. Configuration des chenaux. A: Station Grand-Lahou (Chenal lagunaire); B: Station Embouchure est (Chenal fluvial); C: Station Bandama nord-sud; D: Station Embouchure ouest (Chenal lagunaire); E: Chenal Lahou Kpanda. Echelle verticale: profondeur en m.

Fig. 7. Evolution des vitesses de courants et de la salinité à l'embouchure d'Assinie, Station S_1.

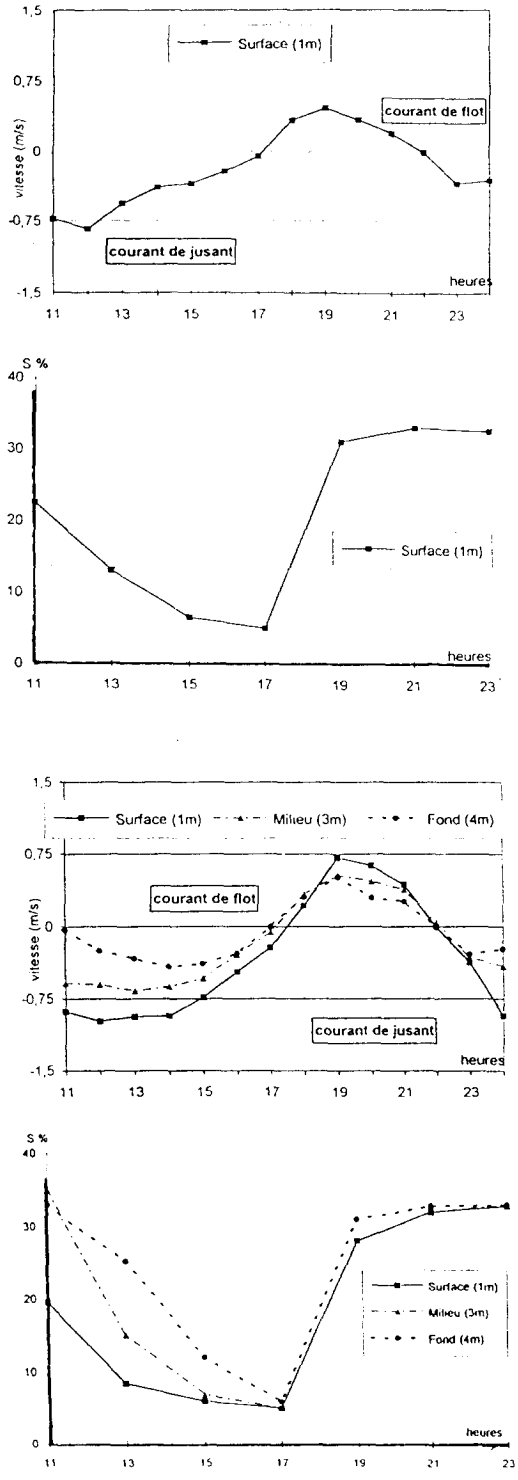


Fig. 8. Evolution des vitesses de courants et de la salinité à l'embouchure d'Assinie, Station S_2

Fig. 9. Evolution des vitesses de courants et de la salinité à l'embouchure d'Assinie, Station S_3.

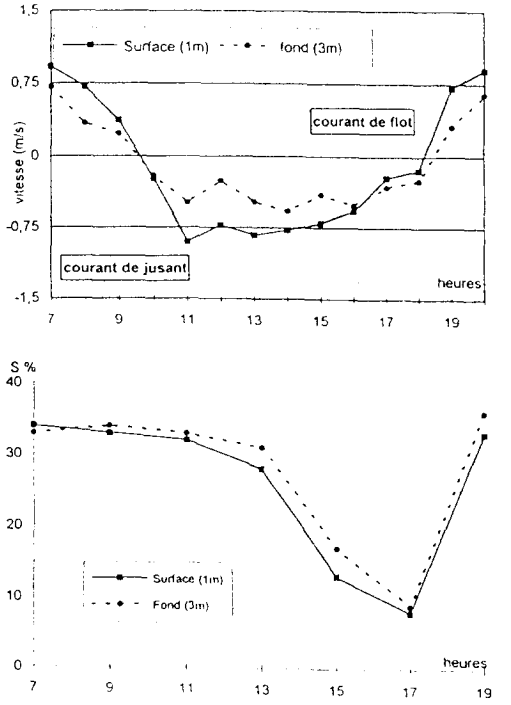


Fig. 10. Coupe de salinité dans l'estuaire du fleuve Comoé. Zone de Grand Bassam.

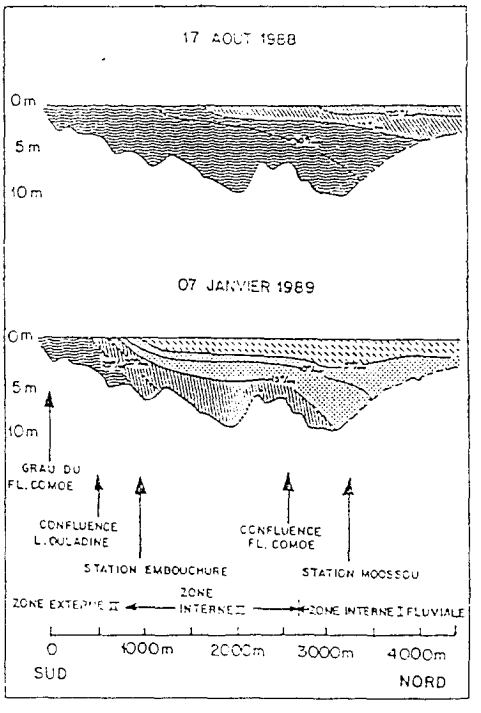


Fig. 11. Evolution des vitesses de courants à l'embouchure du Bandama à Grand-Lahou

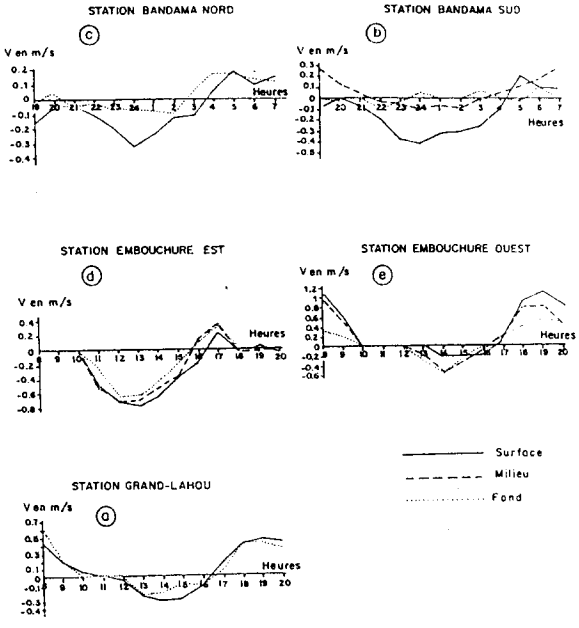
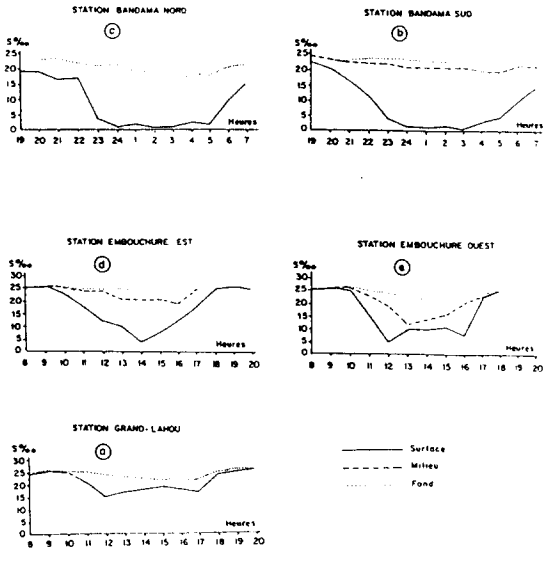


Fig. 12. Evolution de la salinité à l'embouchure du Bandama à Grand-Lahou.



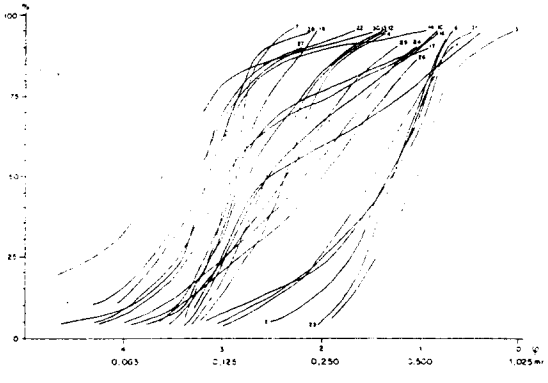


Fig. 13. Fausceau de courbes cumulatives des sables de la passe d'Assinie.

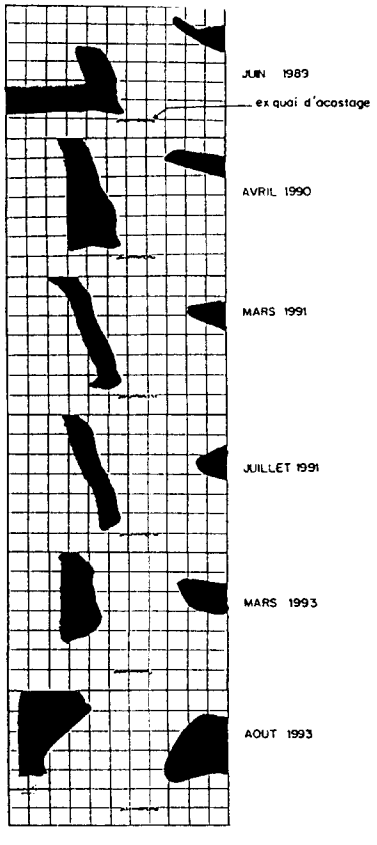


Fig. 14. Evolution morphologique de la passe.

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EFFECTS OF DEVELOPMENT PRESSURE ON THE COASTAL ZONE; EXAMPLES FROM KENYA

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Keywords: Kenya coastal zone, development pressure, human impacts, accelerated erosion, coastal zone management system

ABSTRACT

The object of this paper is to provide information of the effects of the development pressure on the Kenyan coastal zone. Human impacts on the Kenyan coast result in degradation of the shoreline and thus in accelerated erosion. Effects of land-based activities on the beaches include constructions beyond the high-tide mark, and sweeping and playing games on the beaches. Adapted management strategies concern the construction of stabilizing structure such as seawalls, revetments and breakwaters. There is an urgent need for a coastal zone management system and to enact a legislation which would protect coastal resources and environment for their sustainability.

GENERAL INTRODUCTION

The study area is situated on the Kenyan coast (Fig. 1). It stretches over 70 km between latitudes 3° 53' south and 4° 26' south. Major physiographic features of the study area include islands, bays, estuaries, reefs, beaches and cliffs. The cliffs are near vertical with pronounced wave cut notches at 4 m above sea level (Ase, 1978). A narrow strip of land, alternately being exposed and covered by tides or waves, constitutes the present day shoreline in the study area. The coastlines north and south of Mombasa are characterized by coral rocks and sandy beaches protected from the open Western Indian Ocean by the fringing reefs. Except for the interruption of the reefs at the creeks by the outflow of fresh water from rivers, the reefs run parallel to the entire shoreline at a distance of approximately 2 km in the study area. Huge sand dunes and offshore bars are characteristic features of the northern part of Malindi (Fig. 1). South of Mombasa, the reefs are found mostly close to the shore and the shore platform is characterized by small stacks and cavities, because the waves generally break on it and is therefore most of the time under strong wave action.

Due to the equatorial position of the study area, seasonal variations in air temperature are small. The annual mean maximum temperature averages about 30° C while the annual mean minimum temperature is 22° C (Abuodha, 1992). The rainy season occurs during April/May with long periods of rain. Shorter periods of rains occur from October to November. Minimum precipitation occurs in the dry warm season of January and February. The precipitation in this area is usually concentrated during short heavy showers. There are four distinct wind regimes in the coastal region (Turyahikayo, 1987). These are conveniently referred to as;

1. NE monsoon regime (December - February)
2. transition regime (March/April),
3. SE monsoon regime (May-October) and
4. transition regime (November).

The NE monsoons represent the shorter and the warmer of the two monsoon seasons. Mombasa area is subject to an irregular semi-diurnal mesotidal to macrotidal regime in a lunar day. The tidal period is 12 h 25 min. The average tidal range is about 2-3 m. The results of the measured parameters of coastal processes have been summarized in Table 1. Wind intensity and direction have considerable influence on currents. The wind-induced currents are important in the

open shallow waters, the bays and the estuaries, while they occur as longshore currents along the beaches north and south of Mombasa. Off the coast of Mombasa the currents flow to the northeast most of the SE monsoon period but south of Mombasa, current close to the reef reverse into a southerly flow (Norconsult, 1977).
The coastal belt of Kenya comprises of the following main topographic features which are closely related to the geological characteristics of the area:
1. Coastal Plain,
2. Foot Plateau,
3. Coastal Range and
4. The Nyika.
The width of the coastal plain varies between 8 km in the north and 15 km in the south but is absent on Mombasa Island (Fig. 2) and its altitude is generally less than 45 m above sea level.

METHODS

A look at the status of the beaches in Kenya was done by actually walking on the beach and observing the effects of development on the coastal zone. During the field work photographs of prominent coastal features were also taken and are used in this paper for more clarity.

RESULTS

Coastal Zone Management (CZM) is necessary for sustainable development and utilization of coastal resources. Man has turned to the beach as a break from the hectic pressures of modern life. The beaches are without doubt, the most important tourist attractions of the Kenyan coast as whole. The beach provides a restful setting for picnics, walks along the shore, sun bathing and also encourages more vigorous sports including swimming, jogging, surf casting, and surfboard riding. The cool sea breeze and nearby water make the beach an alternative place to enjoy a seaside vacation.
The coastal problems in the study area were identified to be (Abuodha, 1994):
1. Lack of coastal zone management system,
2. coastal erosion and
3. degradation of beaches.

Human interferences are having major impacts on the coastal zone. For this reason, an increasing acceptance to protect the marine environment and its resources is required. Erosion is a prevalent phenomenon along the Kenyan coast. In many places, the rate of coastline retreat and the resulting environmental degradation and economic loss is on such a scale as to be alarming (Plate 1). Apparently, the erosion is so widespread that it also affects the undeveloped coasts, which are beyond the direct influence of man. It seems therefore, that the main factor causing this erosion is the global sea level rise.
From Kikambala to Mtwapa (Fig. 3) several beach hotels, cottages and private houses have been built along the shoreline or just a few meters landward. At Kikambala, a private residential area has been deserted due to cliff erosion. At Shelly beach (Fig. 4), multiple seawalls are now detached from the shoreline (Plate 2). Approaching Mtwapa, more private houses have been constructed on eroding cliff tops. Beach hotels have been constructed at the edge of retreating cliffs at Shanzu and caves are already forming beneath these beach hotels and the sand on the beach has been completely eroded. Along Bamburi and Kenyatta, beach hotels have been constructed only 20 m from the shoreline and during high tide, most of these hotels get flooded.
In some areas along Nyali beach (Fig. 3), development has been extended beyond the shoreline by sand infilling into a structure, built on the beach (Plate 3). The sand is obtained from the adjacent beach or the dunes along the shore. After sand infilling, the structure is stabilized by a pavement on seaward side. The outcome of this project is the acceleration of beach erosion due to no exchange of sand between dunes and the beach.
A private house built along the shoreline on a retreating cliff at Nyali is being reinforced using pillars as erosion has caused undercutting below it. However, it was surprising to note that this house is still inhabited. This was evident from the garbage at the foot of the pillar and a dry carton that must have been dropped onto the beach after water receded during low tide. A few meters southward of this location, a private house stands

at the edge of a retreating cliff. At Leven, a manifestation of intense cliff erosion has resulted in a slab failure which has formed a crack on the wall above. It can be clearly seen that when finally this slab falls due to hydrostatic pressure of waves, it will move with part of the house (Plate 4). A residence built beyond the high tide mark at Tiwi (Fig. 4) has splash water marks above its door (Plate 5). This is probably a new house or it was recently renovated. Despite the splash water marks, no damage can be detected on the house. In general, the coastline is subject to natural fluctuations due to variations in sediment transport, both in terms of quantities and direction. The construction of buildings, very close to the shoreline, often interferes with these natural fluctuations. This leads to a decreased sediment supply to the shore and consequently the erosion is either induced or accelerated. Thus, the present problems are therefore primarily caused by man through construction on the beaches.

SWEEPING OF THE BEACHES

Beach erosion is accelerated by the property owners themselves who employ workers to sweep and bury seaweeds (Plate 6). Sweeping of the seaweeds off the beaches has two serious effects on the beach;

1. By sweeping off the seaweeds from the beach with a rake, sand is not only exposed but also loosened. During high tide, therefore, more sediments are likely to be eroded and
2. by loosening the sand, the waves easily erode the loosened sand from the beach into the lagoons or onto the shore platforms.

Playing games on the beaches like volley ball (Plate 6) and the building of castles, which are a common practice on all the beaches in Kenya, also enhances beach erosion in the same manner in which sweeping of the beaches does, as explained above.

The beach hotels in the study area, utilize sand from the shoreface in ash trays for use by the visitors. This sand extraction, although small in quantity, causes in the long run enhances beach erosion. The extraction of sand from the shore for this purpose is a common practice and is done regularly in all the beach hotels, cottages and private homes, which deprive beaches of sediment and thus likely to cause disequilibrium.

Pollution is another adverse effect of coastal development along the shoreline. Nearly all the beach hotels within the study area dispose of their wastes, especially from the swimming pools, directly into the sea (Plate 7). This results in volumes of sand being eroded from the beach, which has formed 50-100 cm depressions into the beaches. The eroded sediments finally reach the coral reefs which they smother and thus the growth of the coral reefs is hindered, which in turn enhances beach erosion as the waves will now be breaking on the shore. These liquid wastes, not only affect the marine life, but is also dangerous to the health of swimmers along the beaches, not to mention the children who play on them.

DISCUSSION

The generally poor performance of engineering structures to stabilize beaches emanates from the non-cognizance of the distinct peculiarities of beaches such as their morphology, surf zone dynamics, as well as wave-current interactions. It is emphasized that construction activities in the coastal zone should only be undertaken after the consideration of these distinct peculiarities. In order to institute realistic research and management of coastal areas, it is important to understand the biophysical processes operating within the littoral environment. For instance, the movement and supply of sediments along the shoreline is an important phenomenon in coastal geomorphology.

A brief reconnaissance of other places outside study area revealed that coastal protection measures is a common practice along the Kenyan coast as a whole. To protect an eroding coastline, the following corrective measures, sub-divided according to their operating principles, have been used in Kenya:

1. Structures, to prevent waves from reaching erodible materials, such as seawall and revetments are constructed parallel to the shoreline.
2. Structures to slow down the rate of littoral transport such as groins (trapping the sediment)

are set up. These structures are built perpendicular to the shoreline.

Seawall and revetments are present in almost every highly developed coastal area within the Kenyan coast such as Kikambala, Shanzu, Bamburi (Fig. 3 and Plate 8) and Diani (Fig. 4), just to mention a few. Groins have been used only at Shanzu to protect the coast and the main aim in this case is to enable accumulation of sand on the shore.

The groins have been formed by piling 3 rows of rocks to 1 m height, length about 15 m separated by a distance of 30 and 40 m respectively. At kikambala, used tyres and coconut poles have been used for shoreline protection. This method of coastal protection is cheap and rather successful. There is no scour in front of the tyres as the wave-front can easily penetrate between the tyres to the backshore area. At Shanzu a new seawall has been built behind a failed one (Plate 9). The strength of the ocean waves can be understood from the thickness of the failed wall. Still further south, along the same beach limestone boulders, placed against coconut poles, are held in place by a wire mesh and are being used for coastal protection. The coconut poles have been cemented onto the beach, which is already undergoing scour beneath. Erosion on the adjacent areas has resulted into shore moving landward by approximately 10 m. At Kenyatta beach, severe erosion has formed wide notches beneath low seawalls, that has been constructed to protect the property behind (Plate 10).

At Mtwapa, gabions have been put on the fence to stop the creek from eroding residential areas during flood tide, while along Bamburi, limestone boulders measuring 1-2 m in diameter have been placed against an old seawall. In some areas along this beach, boulders have been cemented in front of seawall in an attempt to protect the coast. The tilt, and surface of wall makes it slightly more stable and therefore effective. Further south along this beach, protection using sandstone boulders, wire mesh and coconut poles has failed displacing certain stairs used for access to the beach. Along Likoni, boulders have been placed at the base of cliff to mitigate further cliff erosion.

To restore an eroding coastal area, artificial supply of sand (beach nourishment) and stabilization of the dunes and backshore areas by planting vegetation is practised in some parts of the study area such as Shanzu and Nyali. Along Shanzu, beach nourishment is used in combination with groins. At Nyali, a certain volume of sand is introduced to the beach system to serve as sediment source for littoral drift (and consequently benefit the down drift beaches).

At Kikambala, failure of seawall against wave erosion is already evident (Plate 8). The wall is currently slanted and held in position by mangrove poles but part of it has already crumbled. Trees in front of the seawall have been uprooted and others have their roots exposed. At Kanamai, the failure of a seawall which occurred finally in 1982 resulted in extensive erosion in the backshore area (Plate 1) forming a 1.5 m beach scarp. A coconut tree was observed slanted dangerously as a resulted of this erosion.

Along Bamburi beach, seawalls are undergoing scour at the base, which has resulted in failure of some of the walls. A seawall along Nyali beach is threatened by wave action which has undercut and subsequently cracks have developed on, the wall. More intense cliff erosion has occurred adjacent to this seawall. The crack is a precursor to the seawall failure. In Likoni, at Shelly beach, remnants of former seawall have been left 22 m seaward of the present seawall (Plate 2). Another seawall is currently being constructed at Likoni. Apart from failure of seawalls, which are the most common in the investigated area, other forms of protection also show deterioration. The groins placed at Shanzu have also started showing signs of failure as the piles of rocks are falling.

SUMMARY AND RECOMMENDATIONS

Coastal erosion was identified as one of the major problems within the study area. There are 3 basic options in response to this erosion problem:

1. no action,
2. relocation of endangered structures and
3. positive corrective measures.

No action should be taken particularly if no houses are threatened and only undeveloped land or inexpensive structures are in danger. No action

should be taken at Kanamai (Plate 1) where the seawall has fallen and the structure built beyond the high tide mark should be left to fall when its time comes. Diani area is advantaged in that it has wide beaches and a raised shore platform acting as a natural breakwater. Therefore the seawall in some parts of this beach should be pulled down in order not to induce erosion.

Relocation of endangered structures should be done at Kikambala. It may be less expensive to relocate the beach hotel than to invest in shore protection which costs approximately one million Kenya shillings yearly. The required setback must be carefully evaluated, in order to avoid further relocation of the same structure in the near future.

Positive corrective measures should only be taken for a highly developed beach such as Bamburi (Plate 8). Instead of seawalls which directly amour the shore, breakwaters which intercept and dissipate wave energy should be used in this area. The breakwater should be constructed on a regional basis all the way from the southern tip of Mtwapa Creek entrance to northern tip of Tudor creek (Fig. 3). This corrective measure would thus include Shanzu, Bamburi, Kenyatta and Nyali beaches. Any engineering scheme for beach protection should only be accepted as a last resort and then, only for highly developed areas as Kilindini harbour. This is because once beach protection is started it cannot be stopped and the cost-benefit ratio of saving beach property through shoreline engineering is usually greater than the value of the property to be saved. Moreover, shoreline engineering protects the interests of very few people, as such, decisions affecting coastal development should be based on the welfare of the public rather than the minority or shorefront property owners. Whichever option(s) is chosen between the three, the present and future sea level rises should be taken into account. Thus it is necessary to take into account, this future sea level rise factor in any study of the protection, development and planning of coastal zones. For the immediate future, all but the people living in low lying areas seem to have little to fear from sea level rise. As for the future, no more new settlements should be established too close to the shoreline. All permanent structures should be laid beyond the 50 m contour or at least 1 km from the shoreline within Mombasa-Diani area.

Over development along the beach and building of stabilizing structures along some parts of the beaches were identified as one of the coastal zone management problems. Building such structures causes very drastic changes on the beach, harming the environment in the following ways (Kaufman et al, 1979):

1. They deflect wave energy, ultimately moving the beach and steepening the offshore profile.
2. They increase the intensity of longshore currents, hastening removal of the beach.
3. They prevent the exchange of sand between dunes and beach.
4. They concentrate wave and current energy at the ends of the wall, increasing erosion at these points.

In conclusion, coastal protection plans in the study area more often than not disturb the beach drift system and thus affects the sedimentary balance of the coast as is the case at Kenyatta beach and Kanamai.

Coastal Zone Management (CZM) is necessary for sustainable development and utilization of the coastal resources. Lack of coastal management system was found to be the major coastal problem within the study area. Public awareness can easily eradicate problems such as sweeping of the beaches, games on the beaches and mining of materials from the shore platform which are common practices in the study areas. There is an urgent need to have legislative capability to safeguard the optimal use of coastal zone resources. There is also need to have a long term program on the environmental impact assessment of the coastal zone. This would protect the marine environment and its resources.

While the scientific community should be willing to accept its responsibilities, it is the politicians and the law-makers who should take action, and they should take the responsibility for introducing the necessary modifications in the behaviour of society to counteract the undesirable effects. The plans and actions must be based on local conditions and should include considerations such

as local way of life, social structure, cultural heritage, financial resources and political institutions. Advisers should have all these things in mind as they proceed to advise the coastal community, who do not necessarily understand the technical details regarding coastal protection.

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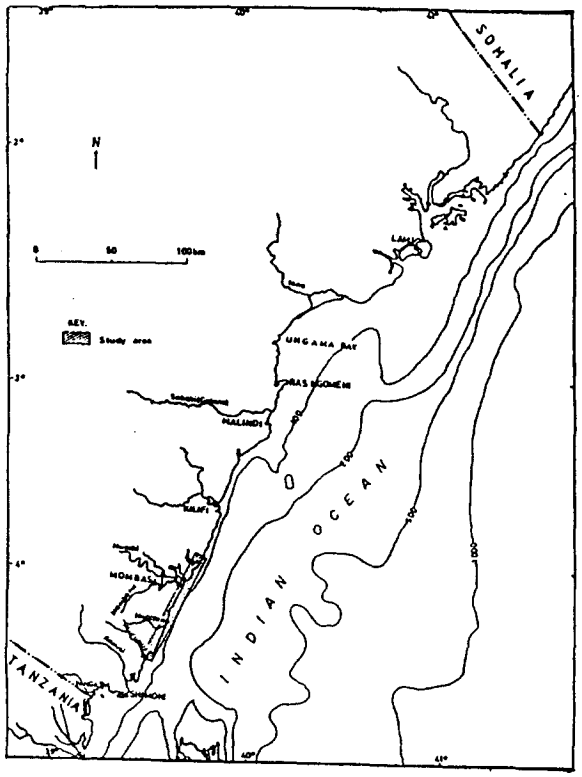
Table 1. Summary of the coastal processes measured in the Mombasa-Diana area, Source Abuodha (1992)

Parameter		Mean	Range
Breaker type spilling % plunging %		 47 53	40-55 45-60
Wave period	(s)	14.2	7.4-20.2
Wave heighet	(m)	1-3 m during south-east monsoon < 1 m during north-east monsoon	
Longshore current	(m/s)	Variable but with slight NNE dominance	
Breaker angle		From SE during south-east monsoon From NE during north-east monsoon	
Tide height	(m)		2-3
Springs:	High water	3.4	
	Low water	0.3	
Neaps:	High water	2.4	
	Low water	1.3	

Fig. 1. Map of Kenyan coast; study area shaded.



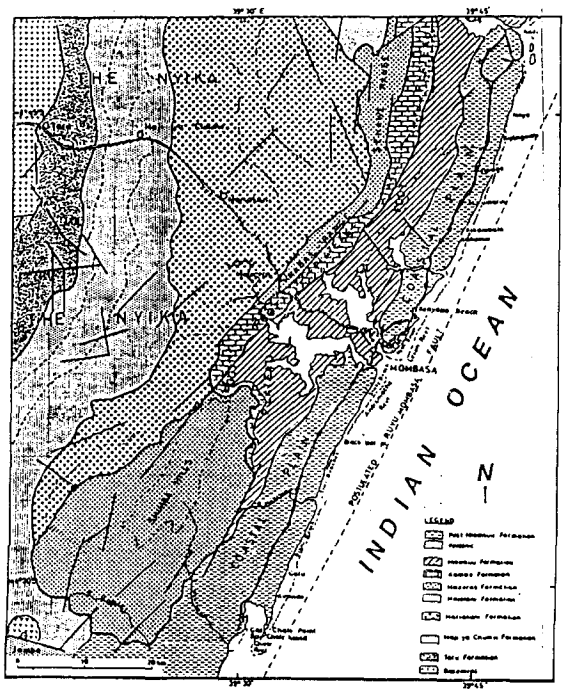


Fig. 2. Generalised geological map of the southern portion of the Kenya Coastal Belt, showing main topographic features; modified after Rais-Assa (1988).

Fig. 3. Geomorphology of Mombasa coastline; from Abuodha (1992).

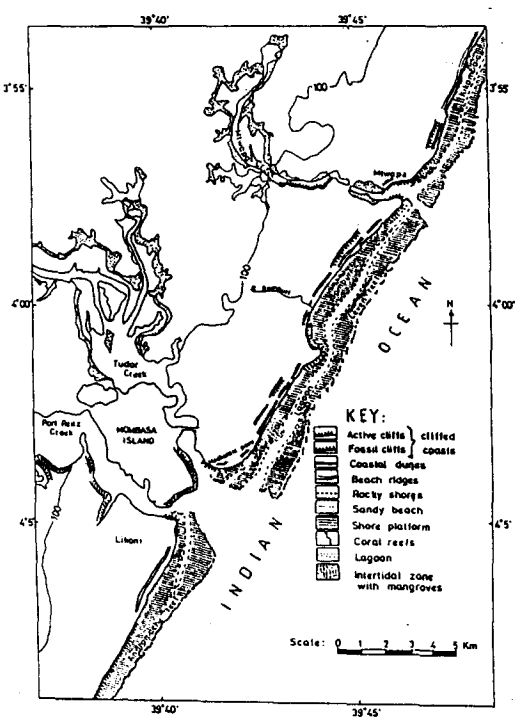


Fig. 4. Geomorphology of Diani coastline; from Abuodha (1992).

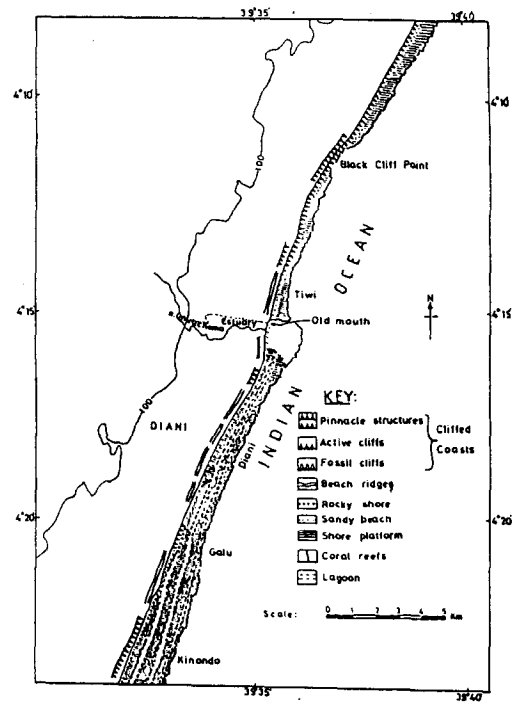


Plate 1. Kanamai beach on Kenya coast showing massive destruction, the results of erosion due to development on the beach.

Plate 2. The multiple seawalls now detached from the shoreline at Shelly beach near Mombasa, Kenya.

Plate 3. Nyali beach on Kenya coast with sand in-filling from the lower beach to build a protection structure against erosion.

Plate 4. Leven beach on Kenya coast with slab failure leading to a crack on the house wall.

Plate 5. Tiwi beach on Kenya coast with splash water marks above a house door.

Plate 6. Diani beach on Kenya coast with swept seaweeds collected for burial. Note also games in the background.

Plate 7. Kikambala beach on Kenya coast with liquid waste disposal on the beach from swimming pool.

Plate 8. Bamburi beach on Kenya coast lined with massive seawall which is already deteriorating for protection against erosion.

Plate 9. Shanzu beach on Kenya coast lined with massive seawalls which are already deteriorating for protection against erosion.

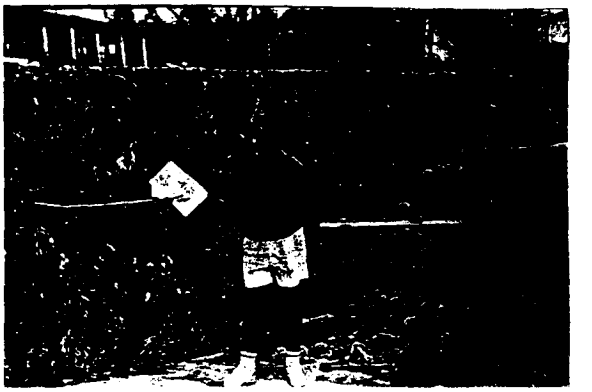


Plate 10. Kenyatta beach on Kenya coast lined with seawall which is already deteriorating beneath for protection against erosion.

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THE ROLE OF NATURAL COASTAL PROCESSES AT A TROPICAL TIDAL INLET IN HINTERLAND DEVELOPMENT

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KEYWORDS: Coast, Tropical tidal inlet, Hinterland development, Coastal Zone Management

ABSTRACT

The management of hinterland areas is often a necessary prerequisite to prevent deterioration of adjacent coastal resources and ensure sustainable development without considerable changes to the regional set up. The study in this respect at a tropical tidal inlet where natural coastal processes continue to dominate while inland area is susceptible to engineered structural modifications. Anthakaranazhi, a location on the south west coast of India and its adjoining coastal zone have been the recent target of large scale developmental activities, a potential site with respect to the influence from natural coastal processes which lead to destabilising conditions. Longshore sediment transport associated with the refracted high energy waves leads to the deposition of beach sands at this tidal inlet during pre-summer months resulting in a seasonal coastal morphological feature, magnitude of which do changes from year to year. This temporal coastal change has resulted in large scale excavation of sand for hinterland development and as well as raw material for quartz industry. However this beneficial utilization, crossing conservative limits have posed a threat to the protection and development of the region and management of the ongoing programmes. Major issues pertain to the erosion of the adjoining beaches, the shoreline modification, salt water intrusion into the low lying (paddy) fields and wave action on coastal protective structures all of which are of adverse nature. Subsequently, this situation may manifest to curtail the proposed port construction, navigational facilities and expansion in fisheries. The paper highlights comprehensive planning and scientific management for this coastal zone which draws a genuine interest towards the right utilization of the coastal resources, especially for a developing country like India, where high percentages of human agglomerations have concentrated on a narrow belt of the coastal zone.

INTRODUCTION

The world's major percentage of human settlement and activities are concentrated on the coastal zone and the management and utilization of the resources from these regions ensure sustainable development of hinterland areas. Vice versa the development of hinterland is a prerequisite to prevent deterioration of the adjacent coastal resources. The tropical coast lands are ecologically complex system with tidal inlets, estuaries, lagoon, swamps, mudflats, sand bars and barrier beaches (Knox and Miyabara, 1984). Since human activities mainly concentrate on the coastal zone by way of human settlements and agriculture, the development of hinterland requires proper attention as far as its utilization is concerned. The increased cost of terrigenous sands and sediments for land reclamation purposes diverted developers attraction to beach deposited sands for hinterland development. This is of significance both to coastal zone and hinterland.

The intrinsic depositional and dispersal features of sand bars at tropical tidal inlets have wide implications on hinterland development, the topic covered in this paper. On excavation of sand, the coastal regions must be depleted by way of increased misuse of available resources from the depositional environments at tidal inlets. Studies in this regard are available in published literatures

by Klein (1976), Fitzgerald and Hayes (1980), Komar (1983), Mengshu (1988), Malikides et.al. (1989). Of importance is the fact that beach sand mining decreases the total volume of sand at the beach, thereby reducing its effectiveness as buffer between ocean waves and coastal protection (Komar,1983). However when the optimum utilization of the sand resources cross the permissible limits, this possess a great threat to the stabilized coast, though this can accentuate then navigational requirements in the channel at the barrier beach. The present study brings out the role of coastal processes at a tidal inlet in the formation of a seasonal barrier beach and its contribution to hinterland development.

ENVIRONMENTAL SETTING OF THE REGION

The tropical regions mainly feature perennial rivers and freshwater discharges into adjacent coastal systems is influenced by the rainfall pattern which in turn carry heavy load of terrestrial borne suspended solids. The tropical tidal inlets which connect estuaries to the adjacent seas play a dominant role in the transport of these terrestrial borne material into the nearshore regions as well as behaves as a pathway for return of marine borne material back into the bay region. This feature exhibits characteristic variations in relation to coastal processes. This study also concentrates on above aspect at the tropical tidal inlet where natural coastal processes continue to dominate while inland area is susceptible to engineered structural modifications. The area under investigation is on the south west coast of India (9° 45' N and 76° 17' E) which features a seasonal barrier beach and a tidal inlet, namely, Anthakaranazhi, which connects the Vembanattu lake, through two streams, mainly from north and south of the opening into the Arabian sea (Figure 1). It also serves as an outlet for the flood waters from the vast paddy fields during Monsoon (June - September). The inlet mouth and the lagoon inside the barrier beach is shallow (2 m) and the tidal prism was calculated as 17.19×10^6 m^3 during monsoon. The inlet remains open only for 6 to 8 months a year, mostly during the south west monsoon and up to January; the inlet then gets closed as a result of less discharge of water and high deposition of littoral drift material resulting from wave action. There are two regulators close to the inlet inside the bay on either sides for preventing the saline water intrusion into the paddy fields. The hinterland of this region is constituted by five major villages, of an area approximately 71.7 km^2. About 80% of the farmers from this region depend on the deposited sand materials for land reclamation and wasteland management. The utilization of fertile soils deposited in the streams is also practised by sand mining activities for agricultural lands as part of their livelihood.

ROLE OF COASTAL PROCESSES

Results and Discussion

Figure 2 shows the geographical location map of the study area investigated from June 1993 to August 1994 covering a full cycle of events. The inlet at Anthakaranazhi is completely open during the south west monsoon with shallow depths across the entrance, the waves are very strong of periods 5-8 s. The commencement of south west monsoon brings about changes in the environmental setting and the combined influence of tides and south westerly waves and run-off from the hinterland drives the water exchange between the bay and the nearshore regions. The dominant waterflow was directed offshore during the rainy season facilitating navigation at the tidal inlet channel of depth approximately 2 m. The adjacent catchment area are low lying plains which flood during monsoon and the run-off is directed to the inlet area through the two sluice gates north and south of the opening. The tidal range at this region is 1.2 m. The boundary banks of the inlet are protected by sea walls and the bay within occupies an area of approximately of 0.12 km^2. The sluice gates are opened only during the monsoon period (June - September) to drain inland waters while helping to regulate the flood levels in hinterland areas. The two regulators are closed during the postmonsoon and premonsoon season (October-May) to prevent entry of sea water during the intervening periods.

The investigation during June 1993 helped to explain the hydrographic features of the inlet. The

wave periods varied from 6-8 s and the wave approach was south westerly (210°-230°). The depth of the tidal inlet varied from 1.5 m to 5 m and the deeper portions are located towards the north of the inlet entrance. Waves of period 8 s break 30 m offshore from the inlet gorge and the circulation pattern is so set that there is no scope for any terrestrial material transport offshore to settle within the bay area, at or on either sides of the inlet. As the rainy season retreats, the interactive forces give rise to the development of a bar at the tidal inlet, commencing first from the southern end and gradually extending northward across the entire opening. The prevailing wave climate during this season is between 240°-280° of periods 8-10 s. The longshore current velocity was observed to vary from 0.16-0.37 m/s and medium to fine sand dominated at the southern side of the bar whereas fine sand was observed at the northern side. The longshore transport of sediments by obliquely incident waves which influence the deposition of littoral sand material at tidal inlet mouths was reported by (Bruun & Gerritsen, 1978). The wave directions gradually altered from west south west to north west at the near shore regions with periods increasing from 8 s to 12 s. The average breaker height was 1.2 m during this season. Similar breaker characteristics at this region was explained by Shenoi and Prasannakumar (1982). The longshore sediment transport rate has computed by using the equation of Walton and Bruno (1989) and was found to be 0.971×10^6 m^3/yr. Investigations on the longshore sediment transport conducted by Chandramohan (1988) had documented similar values at this site. The variation in the quantity of material deposited at this inlet mouth is due to the formation of tidal deltas formed within the bay by flood currents for the subsequent build up of a barrier beach (Ajith Joseph and Balchand, 1995). The effects of tidal currents on the development of sand bar was highlighted by Schmeitz et al., (1982). The beach profile studies conducted at this barrier beach signifies the variation in the depositional feature of the sand bar during different months at the site The monthly depositional rate gives an indication on the development of sand bar at the tidal entrance. The sweep zone graph studies indicated the relatively stable condition of the barrier beach. The near-stable nature of the beach at Anthakaranazhi region during the period of premonsoon has been reported by Sajeev (1993). The regions which are unstable and showing high fluctuation in depositional and erosional behaviour were on both sides of the inlet banks.

IMPACTS ON HINTERLAND DEVELOPMENT

The nearshore wave climate has been recognized to be one of the factors in the development of the sand bar. The sand bar formation is related mainly to the longshore transport of beach material and the wave climate. This process has effectively influenced the sand mining to the order of 1500 m^3/day for hinterland development. Based on these studies, the percentage of sand excavated from the inlet mouth for hinterland development is approximately 56% of the total volume of the material deposited at this region. The optimum use of beach sand now remains within the conservational limits and any environmental issues as far as the coastal management is concerned has not taken dominance. However this beneficial utilization is likely to cross conservational limits. The cyclic deposition and dispersal feature of sand bar coupled with regular excavation of sand could give rise to a serious conflict between optimum use and exploitation with regard to the protective coastal measures. The mining of beach sand and its consequence to the coastline has been reported from many other coastal regions of the world by Inman & Brush (1973). Gagliano and Van Beek (1975) reported that the Mississippi delta system has become the site of a serious conflict between optimum use and actual use of natural resources. In this context human activities can seriously alter the balance of the beach dimensions which control the shore line under consideration.

CONCLUSION

The present scenario of acceptable levels of sand mining could offset plans to establish a fisheries harbour at this inlet and would likely lead to multidimensional management issues (Ajith Joseph and Balchand, 1995). Any conflict can then be resolved by a multi-use management plan in

which environmental management and land use guidelines are closely integrated. The natural barrier beach incidentally act as a sand barrier to protect saline water intrusion into the paddy fields and thereby maintain the freshwater quality of the region. The practice should be the continuance on optimum use of depositional sand for hinterland development, without causing any disturbance to the coastal readjustments. It is suggested to evolve a comprehensive coastal zone management plan based on careful analysis of the natural processes operating in this area, with an inventory of all natural features and resources and an acceptable approach towards multi-use when development of hinterland can be compatible with geomorphic integrity, which must protect the important ecological system and respond to the demands of urbanization and industrialization.

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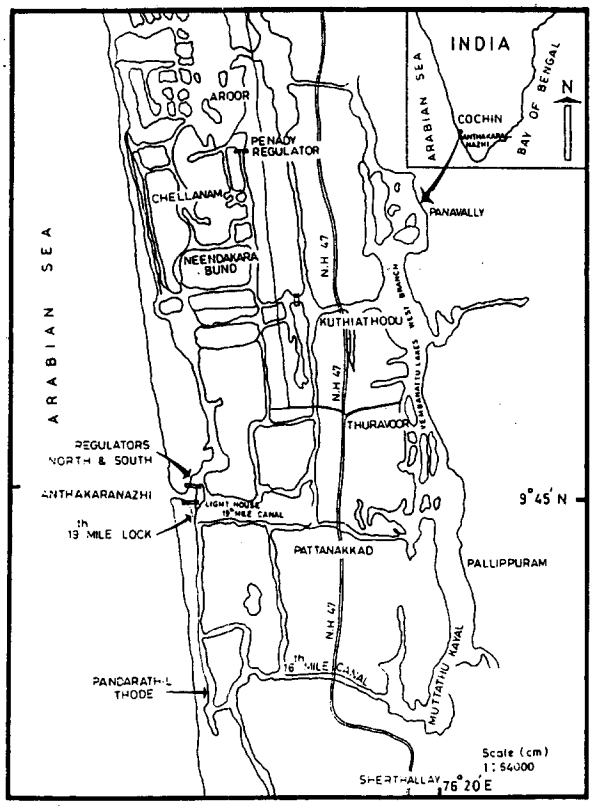
Fig. 1. Map showing tidal inlet at Anthakaranazhi and surrounding hinterland.



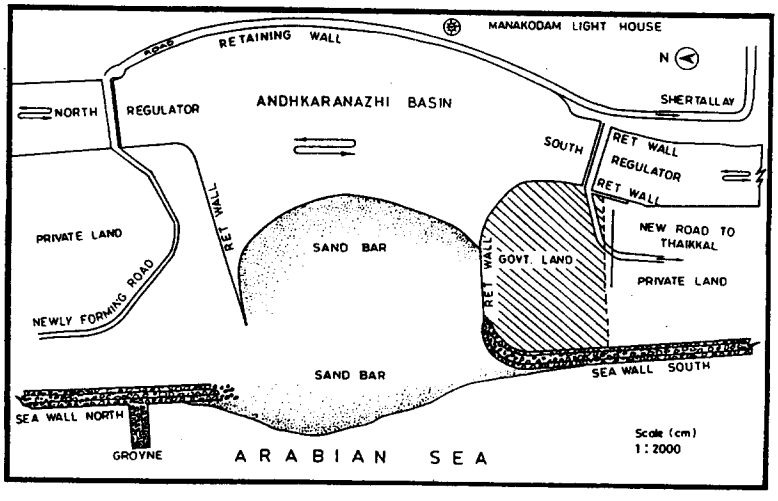


Fig. 2. Tidal inlet at Anthakaranazhi and the sand bar features.

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COASTAL CHANGES IN WESTERN AFRICA - A CASE STUDY

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ABSTRACT

The West African coastal zone with variable width lies predominantly north of latitude 3° N and between longitudes 14° W and 10° E comprising of 13 coastal states. Geomorphologically, this coastal zone consists of low-lying sandy barrier systems, pockets of rocky, cliffed or low-lying muddy coastline, mangroves, wetlands, lagoons, estuaries, and narrow inner continental shelf. This coastal zone include resources like fishery, oil and gas, non fuel minerals like sand, heavy minerals, several species of fauna, floral and wildlife. Conflicting exploitation methods of these resources have exerted pressure on coastal resources, resulting in changes in the morphology, ecology and socio-economy of this area. Coastal erosion, sedimentation, construction of harbour protecting structures, deforestation, salinisation of groundwater have resulted in changes coastal systems in the region. Increasing demands for fisheries and irregular exploitation methods have led to a drastic decline in the fisheries in the coastal areas. Changes in weather patterns along the coastal zone have also been observed. These adverse changes have led the degradation of coastal areas and quality of living standard of the coastal population. A regional approach to Integrated Coastal Zone Management will ensure the sustainability of coastal resources.

INTRODUCTION

The West African coastal zone which consists of low-lying plains of variable width lies predominantly north of latitude 3° N and between longitudes 14° W and 10° E. The states within this coastal zone are Mauritania, Cape Verde, Senegal, Gambia, Guinea, Guinea Bissau, Sierra Leone, Liberia, Côte d'Ivoire, Togo, Benin, Nigeria and Cameroon (Fig. 1). Table 1 shows coastal lengths, marine and mangrove areas for each country in the region.

The coastline bordering these coastal basins consist of:

(1) Sandy, low-lying barrier-lagoon systems prominent between Côte d'Ivoire and the Niger Delta in Nigeria. The barrier systems are backed by lagoons and creeks.

(2) Mangrove and Deltaic coast: These are found along the deltas of major rivers like the Niger in Nigeria. Mangroves also flourish in coastal areas of Côte d'Ivoire, Guinea Bissau, Senegal and in Ghana (Table 1). The Niger delta is then largest delta in the region and is rimmed by about 20 sandy, low-lying barrier-bar islands (Allen. 1965a).

(3) Muddy coastline: This type of coastline is again low-lying with wide inter-tidal zones consisting predominantly of mud. The Mahin mud coast in the north western flank of the Niger Delta is a classic example. Other areas where such muddy coastline exist are along east of Ghana, Senegal, and in some parts of Guinea.

(4) Rocky and cliffed coastline: This type of coastline are coastal extensions of the West African craton or volcanic remnants and are exposed especially along Cape of Biches, Maze and Fann in Senegal, along the western part of Côte d'Ivoire, Cape Three Points in Ghana and in Cameroun. Other areas of isolated rocky coastline occur at Cape Mount Mesurado near Monrovia and Palmas in Ghana. The rocky coastline are usually found alternating with narrow sandy beaches.

Resources within this coastal zone include a wide variety of fisheries, oil and gas, non fuel minerals like sand, heavy minerals etc, several species of fauna, floral and wildlife. These resources constitute the backbone of the economy of several countries in the region. For example, oil and gas mined in the coastal zone constitute over 90% of Nigeria's source of income. Most of the industries

in this region are also concentrated along the coastal zone and the rush to live close to the sea, resulted in the concentration of population along the coastal zone. For example, about 20 million Nigerians (22.5% of the national population) live within the Nigerian coastal zone while about 4.5 million Senegalese (78% of the national population) live in the Dakar coastal area alone (Table 2).

COASTAL CHANGES

Exploitation of many of the coastal resources have exerted pressure on coastal areas resulting in changes in the morphology, ecology and socio-economy of the coastal zone.

Coastline configuration:

Coastal erosion which is very prevalent along the entire west African coastline has led to changes in coastal morphology. This is destabilising the socio-economic activities of this area. Construction of harbour protecting structures in Lagos resulted in rapid erosion in Victoria beach where the beach retreated by 1.5 km between 1900 and 1958 with an accretion of about 600 m on the updrift Lighthouse beach between the same period (Ibe et al., 1984). The Rufisque beach in Senegal receded by about 29 m between 1959 and 1980, while the Sangomar spit in Senegal evolved southwards with the opening between the northern and the southern spits widening to 3500 m between 1958 and 1991. In Côte d'Ivoire coastal erosion has damaged the tourism and local communities in the Grand Bassam area. Rapid erosion along the Jamestown development area in Cotonou has led to destruction of buildings, tourist infrastructure with over 500 m of beach been lost between 1985 and 1993. In the Gambia, erosion has caused extensive damage to coastal structures, tourist facilities and historic monuments. All along the entire west African coast, erosion has changed coastline configuration and causing extensive flooding of coastline that was once hundreds of metres wide.

Several activities in the hinterland have also caused adverse changes in the configuration of the coastal zone. The need to generate cheap and abundant electricity, water for irrigating dry land and development of inland fisheries led to the damming of many of the major rivers in the region. The construction of the Akossombo dam on the Volta in Ghana has led to a 60% reduction in the sediment load reaching the coastline. Several dams built on the Niger river in Nigeria have also led to the drastic reduction in sediments reaching the coastline. The Mono river in Togo with a pre-dam sediment discharge of about 21,000 cubic meters of sand now has a post-dam discharge of close to zero. Trapping of sediments behind the dams is depriving the coastal areas of sand. Such deprivation of sediments along the coastline is exacerbating coastal erosion. In some areas, excessive sediments are being generated as a result of anthropogenic activities. Building of offshore breakwaters result in trapping of sediments on the updrift side leading to excessive siltation. Excessive generation of sediments from upland also causes sedimentation downstream. The silting up of Korlee lagoon in Ghana is a classic example. The Koba coastal rice field in Guinea is also suffering from excessive siltation by sediments generated from the upland areas.

Many wetlands along the coastal areas have been reclaimed for residential and commercial centres. This has led to the loss of wetland flora and fauna. The massive land reclamation along the Lekki barrier in Lagos Nigeria is a classical example.

Deforestation:

Cutting down of mangroves for firewood and construction of houses have been blamed for the depletion of about 50% (World Resources 1990-91) of the mangroves in Nigeria. The same reason has been implicated for the loss of 60% of the mangroves in Guinea and 60% in Côte d'Ivoire. Coastal vegetation in the region has been decimated both by natural and anthropogenic activities that a large percentage of the once primeval vegetation has now been replaced with new species of vegetation. For example, a large part of the mangroves along the Mahin mud coast in Nigeria, Guinea, Côte d'Ivoire have been replaced by the hardy grass *Paspalum vaginatum*. The once flourishing coconut and palm groves along many beaches have either been cut down or uprooted by erosion, leaving the beaches bear of any vegetation.

Fishery resources:

Over the past decade, fish landings from the coastal zone in the region have shown a steady decline (Table 3). This decline could be attributed to over fishing, wrong fishing methods and pollution of coastal waters. It has been estimated that annual marine catch in Nigeria declined by about 38% between 1975 and 1977. In Côte d'Ivoire, demersal species in the 0-50 m stratum are close to been fully over-exploited. Many of the coastal lagoons that used to provide fish to the people hardly support any fishery today. A classic example is the Korle lagoon in Accra, which is now almost devoid of fish due to pollution and siltation. Fish landings in the Lagos lagoon have also dropped significantly in the past 25 years due to overfishing and pollution.

Salinisation of groundwater:

The lack of abundant fresh surface water in the coastal zone makes ground-water the main source for potable water in the region. However, increased salinity of ground-water resulting from excessive flooding and sea level rise is polluting ground- water and rendering this resource unavailable any more.

Meteorological changes:

Meteorologic data in the coastal zone have shown some changes in the weather patterns along the coast. The general trend is a southward progradation of the predominantly dry and dust laden north east trade winds (harmattan) which previously hardly get to the coastal areas between the months of November to March.

Socio-economic changes:

The above said changes have led to a degradation of the coastal zone as well as to a decline in the quality of living standard of the coastal population. Misery levels and infant mortality are on the increase as result of low income and pressures on limited coastal resources. The pressures will undoubtedly result in further increase in coastal changes, which are detrimental to the sustainability of coastal resources.

CONCLUSION

The above-mentioned points are the major factors for coastal changes in Western Africa, that have adverse effects on people and environment. Global climate change and sea level rise will aggravate the already bad situation arising from coastal changes.

The present downturn in the economy of the countries in western Africa will make response measures to coastal problems almost unbearable. For example, total protection of the coastal areas of Senegal from the adverse effects of 1 meter sea level rise could cost the country about US$ 973-2,156 million (Nicholls et al., 1993). Similarly, the cost of total protection of the coastal areas of Nigeria could range from US$1,424-1,766 million (Awosika et al., 1992).

A regional inventory of coastal resources and the changes, that have occurred in the past, is necessary in order to provide the coastal States the necessary ingredients for a workable regional integrated coastal zone management plan for the sustainable development and exploitation of coastal resources.

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Table 1. Coastal length, marine and mangrove areas for West African States.

COUNTRY	COASTAL LENGTH (km)	MARINE AREA (n.mile^2)	MANGROVE AREA (km^2)
Benin	111	7,900	30
Cape Verde	Island	230,200	X
Côte d'Ivoire	515	30,500	640
Gambia	510	5,700	510
Ghana	539	63,600	630
Guinea	346	20,700	120
Guinea Bissau	274	43,900	3,150
Liberia	579	67,000	360
Mauritania	735	45,000	X
Nigeria	853	61,500	12,200
Senegal	531	60,000	420
Sierra Leone	402	45,400	3,400
Togo	50	600	X

X - no data.

Table 2. Estimates of total mid-year population and percentage of Urban population in large coastal cities of West Africa.

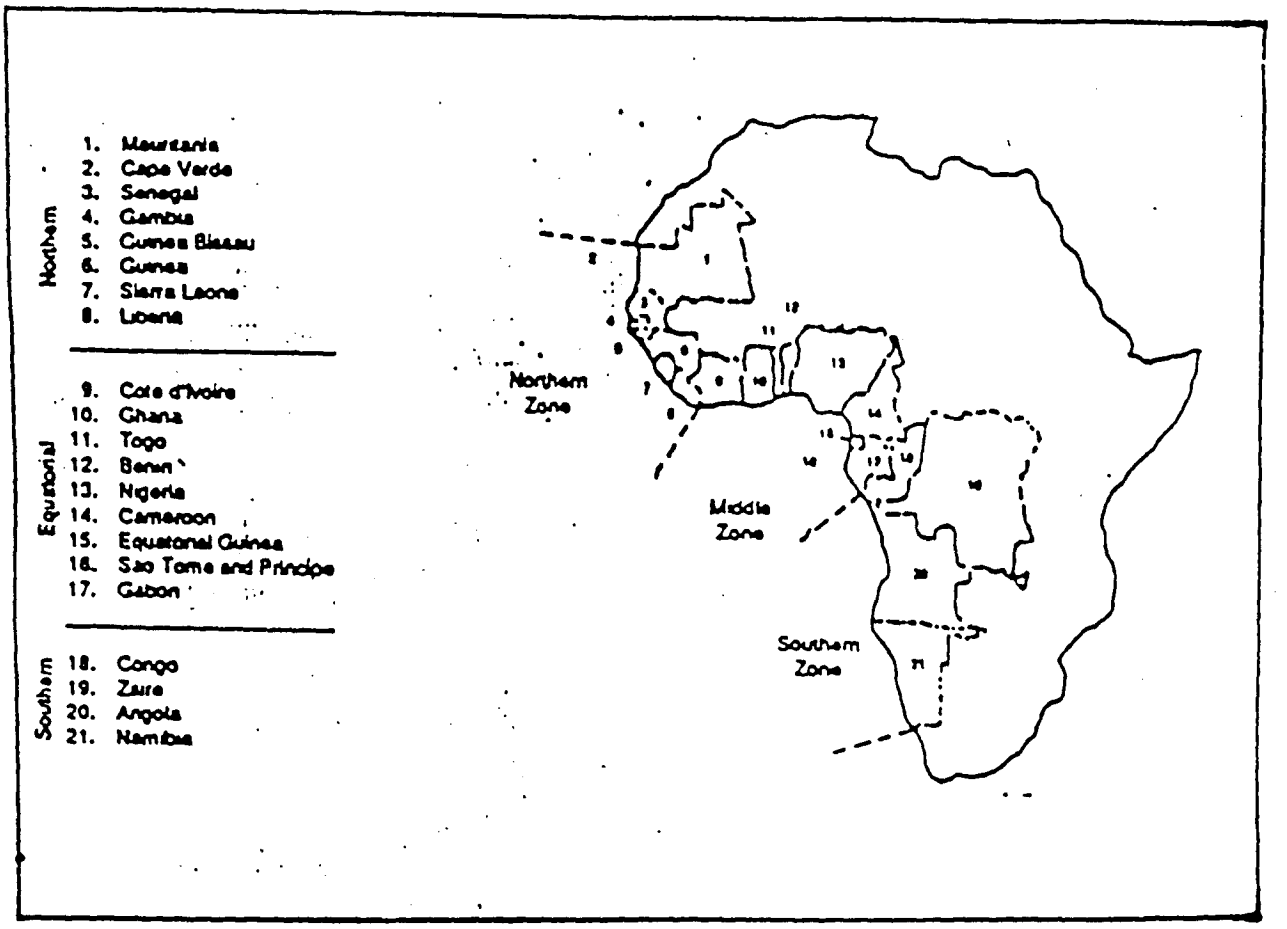
Country	Mid-year population 1980 ('000)	Mid-year population 1985 ('000)	Mid-year population 1990 ('000)	Mid-year population 1991 ('000)	% Urban pop.in large coastal cities+
Ecowas*	122,024	143,129	167,954	173,450	-
Benin	3,459	3,985	4,630	4,776	100
Burkina- Faso**	6,957	7,877	8,996	9,252	-
Cape Verde	289	324	370	382	0
Côte d'Ivoire	8,194	9,933	11,997	12,464	84
Gambia	641	745	861	884	100
Ghana	10,736	12,736	15,028	15,509	72
Guinea	4,461	4,987	5,755	5,931	100
Guinea- Bissau	795	875	964	984	100
Liberia	1,876	2,199	2,575	2,659	100
Mali**	6,863	7,915	9,214	9,507	-
Mauritania	1,551	1,766	2,024	2,082	100
Niger**	5,586	6,608	7,731	7,984	-
Nigeria	61,193.5	75,372.4	85,593.5	88,514.5	20
Senegal	5,538	6,375	7,327	7,533	78
Sierra-Leone	3,263	3,665	4,151	4,260	100
Togo	2,615	3,028	3,531	3,643	100

* ECOWAS - Economic Community of West African States.
** Land locked countries.
+ Compiled from World Resources (1990-91).

Table 3. Average marine catch and percent change of coastal states in Western Africa (World Resources 1989)

COUNTRY	AVERAGE MARINE CATCH	
	1983-85 ('000MT)	CHANGE OVER 1974-75
Benin	4	-38
Cameroun	32	-14
Cape Verde	11	248
Côte d'Ivoire	67	2
Equatorial Guinea	3	-2
Gambia	9	-13
Ghana	212	6
Guinea	26	143
Guinea Bissau	3	30
Liberia	10	61
Mauritania	44	97
Nigeria	214	-10
Senegal	235	-3
Sierra Leone	36	-42
Togo	14	47

Fig. 1. Map of Western Africa - a case study.



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IMPLICATIONS OF COASTAL CHANGES ON COASTAL AQUACULTURE IN NIGERIA.

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KEYWORDS: Coastal aquaculture, Pollution, Ecology, Fisheries.

ABSTRACT
Coastal aquaculture in Nigeria is plagued by a number of problems, of which source of fish seed, pollution and lack of potential sites are a few. These problems can be related to various changes witnessed along the Nigerian coastal region in the past decades, with their attendant alterations on the entire ecology. These changes include sea level rise, sediment loading, dewatering, wet land loss, storms, urbanization, sand mining and sand filling, which are either man made or natural. The impact of these on aquaculture, are not only limited to pollution, inadequate utilization of lagoons and head waters but also to extensive depletion of wet lands and intertidal flats. Decline in fishery is a consequence of this, which normally entails poor fish production.
This paper deals with area and scope of coastal aquaculture in Nigeria and the implications of coastal changes on it.

INTRODUCTION:

The coastal environment is the area between land and sea which forms the limit of coastal influence on the marine environment. It is a zone of varying width which in the landward direction delineates the limit of the continental shelf by the shelf break (Nwangwu, 1990). The coastal environment of Nigeria stretches from Badagry on the West point and includes much of Lagos, Ondo, Delta, Rivers, Akwa Ibom to Cross River States. The Niger delta is also inclusive in this area.
Coastal aquaculture in Nigeria is developing just only recently. It was previously practised on the traditional and subsistence level in tidal ponds of not more than 0.001-1.0 ha (Anyanwu & Alegbeleye, 1993). Coastal ponds were introduced into Nigeria in the early 1940's as experimental ponds (Longhurst, 1961). However traditional coastal aquaculture is an age long practice in Nigeria. The relevance of aquaculture to the Nigerian socio-economic growth cannot be over emphasised. Ling (1974) enumerated four major roles the industry can play as follows:
1). Increasing the production of animal proteins to meet the needs of the fast growing populations.
2). Producing high priced commodities for export and consequently for earning foreign exchange.
3). Creating employment opportunities.
4). Utilizing huge areas of unproductive idle land and water bodies for food production.
Thus the enormous potential of coastal aquaculture in Nigeria should be improved by the introduction of new techniques to ensure better yield.

COASTAL CHANGE

In order to understand the changes in coastal regions, it is necessary to examine briefly some of the major factors both natural and man-induced that influence the dynamics of the coastal areas. Coleman and Roberts (1989) grouped the factors into four viz:
1). Geological
2). Catastrophic
3). Biological
4). Man-induced.
Geological factors include sea level rise, and there are theories suggesting that the sea level will rise at 3.3 mm/yr by the year 2005. Other geological factors include localized sediment loading, dewatering and physical/chemical compaction of recently deposited sediments (younger than 6000 years) of the coastal plain which have added to sinking of the land resulting in wetland loss.

There are no hurricanes on the Nigerian coast but there are heavy storms. The effect of these on the shoreline is controlled largely by the size, speed of movement and path of the storm, slope of the continental shelf and orientation of the shoreline. The role of living organisms in the Nigerian coastline has never been quantitatively documented or studied. However the role of certain organisms in the degradation of the coastal environment has been observed thus:- Deforestation in the watershed area either by overgrazing has resulted in high sediment yield in the coastal area. Tunnelling activities by coastal wetland animals such as the crabs *Cardiosoma sp* and *Uca tangeri*, resulted in the loosening of soil, enhancing erosion albeit on a small scale. Activities of some vertebrates like *Thryonomus swinderianus* (Cane rat) on the vegetation enhancing erosive activities on the coastline. Man induced changes include canal dredging and levees, urbanization, sand mining and sand filling which alter the natural flow of water and sediment across wet lands. This can contribute to land loss, intrusion of salt water into parts of the coastal plain and changes the plant community.

IMPACT ON AQUACULTURE

1) Man made

a) Urbanization

The Nigerian coastal communities have witnessed rapid urbanization over the last decade. This results in degradation of coastal amenities and disturbance of the coastal ecosystem. The degree and disturbance is heightened by increased capital intensive coastal development and close proximity of communities to the water. Sand filling (sand mining), dredging, building of industries and residential quarters have totally changed the face and ecology of the coast. The Lekki peninsular near Lagos was once a very suitable site for coastal aquaculture and artisinal fisheries. It is however now inundated with commercial and residential quarters after a lot of sand mining, filling and dredging. These activities not only make potential sites unavailable, but also destroy nursery/breeding grounds for fin and shell fish. Dead juveniles of fish and shell fish are actually observed after an exercise of dredging and sandfilling (Amadi, 1993). Tidal fish farms that once had direct access to the lagoon as a source of water have been cut off due to urbanization, and household wastes are dumped indiscriminately, thus polluting the very water that feeds the farms. A typical example is the Nigerian Institute for Oceanography and Marine Research (NIOMR) experimental fish farm that was until January 1995 located at Ikoyi, South West of Lagos. Another effect of urbanization is the cost of land and landed property in the coastal areas. A piece of land near the lagoon, the estuaries and sea if it is still available is very expensive. It can cost between 0.35-10m Naira ($15,909-$0.5m). Land owners therefore prefer to sell land to industrialists or property developers rather than to fish farmers. Other available land belongs to the government and the process for acquisition is very tedious and time consuming.

b) Mangrove belt destruction

Mangroves used to form the predominantly intertidal community along the Nigerian coast. Mangroves typically flourish along sheltered coasts and estuaries where ever there is dilution of coastal waters by fresh waters and where ever alluvial sediments accumulate to form mud banks on which mangrove seedlings can flourish. Coastal aquaculture in Nigeria still depend heavily on estuarine and coastal wetlands for searching fingerlings to stock existing ponds. Degradation of this environment goes on at an estimated annual rate of 5% through human activity and this is detrimental to the coastal aquaculture industry. Vast areas of mangrove are cleared and drained to build coastal installations in Nigeria, such as harbour, power stations and refineries. Most of the oil companies in Nigeria have their operational headquarters built on vast mangrove sites for easy access to a channel and hence the water ways for easy movement of drilling equipment offshore. These are mostly in the Niger delta. Whatever mangrove is left is gradually being destroyed by pollution especially from the oil industries.

Traditional fisheries in the mangroves is very important. Many fishes as well as shell fish are associated with mangroves. Construction of ponds

in the mangrove flats to grow fish after trapping them developed from traditional coastal fisheries (Mcintosh, 1980). Mangroves are inherently productive environments and they are able to support major fisheries and aquaculture activities. The mangroves has always constituted grazing grounds for the larvae and juvenile of various species of shell and fin fish. They also find refuge from predators in this environment. Many species of fish and shell fish enter the mangrove water ways to feed, especially the juvenile stages which also find refuge predators. Ezenwa et al. (1985 & 1989), carried out surveys on the fish seed abundance in the Nigerian coastal waters, exploring breeding grounds, schooling areas and nurseries. Analysis of their data showed a drastic reduction of an estimated 100 million fish seed to 51.7 million at the end of 1989. Equally, anthropogenic activities in the form of deforestation, sand mining and nourishment, channelization, dredging, oil and gas exploration and exploitation, and rapid urbanization are currently reducing the mangrove ecosystem in Nigeria (Isebor, 1993). This is therefore having a detrimental effect on the coastal aquaculture industry that depend to a large extent on the mangrove ecosystem.

2) Natural Factors

a) Sea level rise

Ibe (1990) reported an average annual rise in sea level of 4-6 mm based on the 1989 figures from IPCC working group 1. He also observed that the Nigerian coastal zone is part of an actively subsiding geosyncline. The Niger Delta is most affected and the sudden flood and frequency of land loss have lead to sudden and drastic alteration of biotope consequent of conversion of wet lands to marine due to sea level rise. Coastal vulnerability to sea level rise would have implications for fishing settlement stability and residence of fishermen. Some coastal communities have already run out of land (Ajayi, 1990). This inadvertently affects aquaculturists. Sea level rise and loss of land also means loss of potential sites for aquaculture, loss of culture systems already on the ground i.e. cages, pens, coastal ponds which are usually very close to their residence. For some communities the situation is very bad. The lagoons around Lagos and most Nigerian brackish water ways are seasonally inundated with water hyacinth *Eichhornia crassipes* due to influx of salt water. Sea level rise not only increases the salinity of these waters but also of the soils, and this can become a serious problem to fish with low salinity tolerance (Stenohaline species). As sea level rise raises the water table, construction of ponds will become more and more expensive and laborious. Inundation of low lying coastal areas, otherwise potential sites for aquaculture especially in the Niger delta, may become unsuitable.

b. Erosion

Three major types of erosion have been recognised in the Nigerian coastal area viz: bank, gully, and sheet (Bell-Gam, 1988). Unchecked coastal erosion can be manifested by the widening of creeks, rivers, estuaries and the recession of coastlines as evidenced by the recession of western coastline of Nigeria over the last decade which according to Ibe (1988) retreats at an alarming rate of 3 mm/yr. Receding coastlines and erosion has a detrimental effect on aquaculture. Apart from the loss of fishing villages as in Delta and Rivers States,infrastructure on ground like cages, pens, ponds and buildings, the water quality is affected. Water turbidity will be high due to suspended solids. Sediments accumulated later undergo both aerobic and anaerobic decomposition resulting in reduction of dissolved oxygen (Fillos, 1977). This ultimately affects the quality, variety and quantity of life within the ecosystem (Imevbore, 1988).

EFFECTS

Implications of coastal changes are evidenced by a decline in the coastal artisanal fisheries. (Tables 1 & 2). Presently the number of fishing boats has increased thus the unit effort is increasing and catch per unit effort decreasing. This also applies to the Nigerian coastal aquaculture where in spite of increased number of ponds, production has declined (Tables 1 & 2). Observations by Ezenwa et al. (1985, 1989.), related the decline in culturable fish fingerlings population to coastal changes. This phenomenon implies a short fall in

fingerling supply to fish farms. Urbanization and other human activities have converted some potential sites into prime lands thereby causing termination or complete relocation of farms. Oil exploration and exploitation has resulted in the outright destruction of some existing ponds ruination of potential sites either by seismic activities or pollution. The effect of sea level rise on aquaculture is considered by the change in ecology of potential sites and its long term vulnerability to flooding potential sites. Coastal retreat has the effect of reducing the extent of potential sites as indicated in Ondo and Delta States where erosive activities are most marked (Ibe and Antia, 1983).

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Table 1: Coastal and brackish water small scale Fisheries and aquaculture production (thousand tonnes) in Nigeria 1980-1989

Sector	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Small scale coastal and brackish water fisheries	274.2	324.0	377.7	377.0	246.8	140.9	160.2	145.8	185.2	171.3
Aquaculture	-	-	-	20.5	22.0	15.0	14.9	15.2	15.8	25.8

Source: Federal Department of Fisheries Nigeria 1990.

Table 2. Coastal and brackish water small scale Fisheries and aquaculture production (thousand tonnes) in Nigeria 1988-1993

Sector	1988	1989	1990	1991	1992	1993
Small scale coastal and brackish water fisheries	195.2	171.3	170.5	168.2	184.4	90.9
Aquaculture	15.8	25.6	7.3	15.8	19.8	8.5

Source: Federal Department of Fisheries Nigeria 1990.

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KENYAN EXPERIENCES IN COASTAL CHANGE

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INTRODUCTION

Kenya

Kenya, often described as the "land of contrasts" is situated on the East Coast of Africa. It covers an area of 500,000 km^2 and straddles the equator. It rises from sea level to an altitude of 5,199 m on Mount Kenya which explains the hot and humid climate of the Coast, the damp moorland climate of the highlands, the bone chilling snow of Mt. Kenya and the scorching desert climate of North Eastern - all in one country.

The changes in altitude create habitats and ecosystems that support a diversity of flora and fauna and unsurpassed elsewhere in Africa.

The Kenyan Coast is approximately 600 km long beginning from Kiunga in the north to Vanga in the south. About 10% of the Kenyan population is residing along the Coastal region.

Coastal zone use in Kenya

The Coastal zone of Kenya is among the most heavily exploited areas in Kenya and even along the East African Coast. This is because of its diverse and unique natural endowments.

Like any other Coastal zone in the world, the Kenyan Coast provides sites for a wide range of activities such as:

-Fisheries / aquaculture
-Agriculture
-Human settlement / habitation
-Forestry
-Manufacturing / extracting industries (e.g. sand mining, minerals, etc.)
-Waste disposal / dumping
-Transportation
-Water control and supply projects
-Tourism
-Recreation.

As a result of its importance and high level of multiple use, Kenya's coastal zone is a critical area with a sharp conflict between natural resource use and the need to conserve for the sake of posterity.

DRIVING FORCES

The driving forces behind the rapid devastation and consequent change in Kenyan Coastal areas include:

-High rates of population growth
-Poverty (exacerbated by dwindling resources and lack of alternative livelihoods
-Lack of awareness on the importance and hence economic contribution of Coastal resources to Society (among local communities and even policy makers)
-Inadequate legislation on coastal zone management (and lack of government follow up in support of programmes that enhance better management of coastal areas).

CURRENT COASTAL ZONE PROBLEMS

Kenyan coastal problems can be divided into two broad categories viz; environment and management.

(i) Environment

(a) Over-population:

The exponential growth in human populations in the recent past has further increased the pressure on Kenyan Coastal areas and her resources. Kenyan population growth rate of 3.4% per annum is one of the highest in the world. The subsequent concentration of people at the coast has resulted in increasing human sewage disposal in the sea. Recent trends of people immigrating to the coastal region further compounds the problem.

(b) Pollution

One of the most serious indirect impacts of coastal developments is that of a decline in water quality. Pollutants/effluents are often a common source of adverse effects on Coastal zones.

Domestic Waste

Untreated sewage is often discharged into the coastal environment especially in urban centres which have their sewers discharging directly into the sea e.g. Mombasa, Lamu, etc. The Coastal zone has also become dumping ground for garbage.

Agricultural and industrial wastes penetrate into Coastal ecosystem mostly through run off consequently contributing to marked changes in the primary and secondary productivity of the Coastal zone.

Oil spills

Accidental spills especially from ships are increasingly becoming common as sea traffic increases. Spills affect aquatic life, damage beaches and permanently destroy wetlands.

(c) Fishery grounds depletion

Fisheries management has been a major national concern. There has been wide spread depletion of sea food resources as a result of over fishing, coastal pollution and critical habitat destruction.

(d) Tourism

Tourism is Kenya's leading foreign exchange earner. In 1993, the country earned about Kshs. 24 billion through tourism related activities. Nevertheless, it is a potential area of conflict. One of the impacts from tourism development is decline in water quality. Sewage discharges are common source of adverse effects on biota.

Biodiversity reduction, resource depletion and human health problems are also resulted from the accumulated environmental effects of tourism. Coastal construction particularly of beach hotels and associated infrastructure place a heavy toll on the Coastal environment. Motor boating and game fishing for instance destroy the once prestine habitats. A successful tourism strategy should therefore seek to maximize the total benefits to development, while preserving the natural environment and improving the cultural milieu upon which it depends.

(e) Climate change

It is acknowledged that global climate change has its potential impact on Coastal zones. Sea level rise for instance, results in increased Coastal erosion and recession. However, the extent of impact varies from site to site depending on a wide range of specific site processes including rates of vertical movement of the land, rates of erosion in a water shed, present and future patterns of long shore sedimentation and the intensity of other human activity.

Coastal embankments surrounded by low lying wetland areas in extent will consequently affect the available habitats for substantial communities such as sea grass.

The currently projected rates of sea level rise pose no major threat in themselves to the continued survival of the coastal ecosystems except changes associated with physical parameters. Increased air temperatures for instance will lead to increased sea surface temperatures which will affect the growth and productivity of marine organisms particularly those that are currently growing at or near their limits of thermal tolerance.

This is the case for many coral reef communities. The increased frequency of coral bleaching in recent years, coupled with known sea surface temperature anomalies suggest that surface water temperature increase may pose a real and immediate threat to coral reef growth and survival than potential changes in sea level.

(ii) Management

The Kenyan Coastal Zone is an extremely important ecological heritage. There has been a rising concern for its future particularly regarding the status of its natural resources which provide life support and economic development opportunities.

It is becoming increasingly difficult to conserve the Coastal region and her resources in the absence of a comprehensive, integrated frame work for policy, planning and management.

Managing the problems outlined is impaired by the complexity of human interests in the Coastal zone. Wide range of agencies have diverse interests to control the Coastal region, e.g. the Kenya Wildlife Service (KWS) and the Fisheries Department of the Ministry of Environmental and Natural Resources.

If Coastal zones and their resources are to be maintained and remain productive, there is an urgent need for their planned use, their management require a holistic and comprehensive approach.

This points to the need for designing and implementing integrated management programmes like the ICZM (Integrated Coastal Zone Management). The overriding goal of such programmes would be to provide for the best long term and sustainable use of coastal natural resources and for perpetual maintenance of the most beneficial natural environment. In essence, the purpose of ICZM programmes is to maximize the benefits provided by the Coastal region while at the same time minimizing the conflicts and harmful effects of such activities.

In the light of these, the Kenyan Government formed, through an act of parliament, the Coast Development Authority (CDA) to be the leading and coordinating agency of all development programmes along the Kenyan Coast.

CDA has been particularly useful in coordinating the activities of various sectors of conflicting interest like fisheries and tourism. Inadequate finances and integration of multiple interests have been obstacles to this upcoming institution.

OPTIONS

(i) International Cooperation

The future of Coastal areas depends upon an approach that includes everyone, all levels of governments, the private sector and coastal communities. There is need as well for international cooperation in managing coastal areas.

The governments of Eastern Africa realized this and organized the "Workshop and Policy Conference on Integrated Coastal Zone Management in Eastern Africa including the Island States". As an outcome of the Arusha meeting, participating governments signed the Arusha Resolution on Coastal Zone Management in Eastern Africa. The resolution provides a useful tool in the management of Coastal Resources in the Region.

(ii) Research

To ensure better management of Coastal zones, it is vital to undertake research with a view to:

(a) Understanding ocean and Coastal processes, their relationship and impact upon resource endowment.

(b) Establish and evaluate conservation requirements in marine areas.

(c) Develop approaches for multiple uses and identity / resolve potential and current conflicts between various users of Coastal resources.

(d) Develop a framework for coordination and implementation of national ICZM programmes.

The Kenyan government acknowledges the importance of research and has commissioned some research projects. Two reports on the impact of sea level rise on low lying Coastal areas have been prepared through the support of UNEP.

(iii) Environmental Assessment

Environmental Assessment (EIA) studies which should be made mandatory to all development activities in the Coastal region. This is being done through the National Environmental Action Plan (NEAP) process. NEAP has launched the National Environmental Impact Assessment Programme (NEIAP) whose objective is to develop a set of guidelines and procedures to be followed when proposing development projects and to have EIA accepted as a vital practical tool for ensuring sustainability of development programmes.

(iv) Training

Training is important especially in the field of ICZM where so many activities / technologies are involved and need to be integrated, for researchers, managers and policy maker to enhance their perception of Coastal Zone management.

This is an area that the developed world should give priority. International assistance should be

made available to the third world for capacity building.

(v) Education and Awareness programmes

Public education is a prerequisite for successful management of Coastal resources. The goal is to enlighten particularly local communities in coastal zones as well as policy makers on the value and importance of protecting Coastal zone resources. Such education provides the community with both information and ethics so as to make informed decision on the use of their resources. The East African Wild Life Society for instance, is undertaking an intensive awareness campaign in the Tana River Delta fund along the Kenyan Coast with a view to sensitizing and preparing the local communities for the preparation of a management plan for the area.

THE TANA DELTA WETLANDS (CASE STUDY)

The Tana River Delta is the biggest delta ecosystem in Kenya found at the lower reaches of the river Tana, along the East African Coast yet to be impacted by human developments.

The delta is a unique ecosystem which encompasses a large number of habitats incontiguity and rich in biodiversity. These include riverine forests which are habitats of two endangered and endemic sub-species of primates, the Tana River Red Colobus (*Colobus badius rufomitratus*) and the Tana River Crested Mangabey (*Cercocebus galeritus galeritus*) grasslands, woodlands, bushlands, lakes, swamps, mangroves, sand dunes and coastal waters. The delta has the largest concentration of crocodiles in East Africa.

The delta functions as single ecological unit. It maintains high levels of productivity in a dynamic balance which revolves around and is strongly influenced by timing, extent and duration of flooding. Vertical and horizontal water circulation transports nutrients, influences a wide variety of habitat types, flushes away waste, controls salinity and disperses and nurtures larval stages of aquatic organism.

Traditional land use practices of small scale agriculture by the Pokomo, pastoralism by the Orma and fishing by the Bajuni have maintained the ecological balance of the delta for thousands of years. In fact there is a silent agreement between these communities on the utilization of the delta's natural resources.

Like many other critical coastal ecosystems, the Tana Delta has been threatened by large scale and inappropriate unsustainable projects. The government had allocated the area to private developers, yet the area had been earmarked for conservation.

In view of these a prorated conflict of interest ensued between environmentalists, with the East African Wildlife Society (EAWLS) taking a leading role and private developers. The local communities were torn between the two worlds. It took a Presidential decree to put the row to an end. The President of Kenya directed that the area be protected as a wetland of international importance. He also ordered that this should be precluded by environmental assessment studies to be followed by the development of a management plan for the area in close collaboration with the local people.

A multi sectoral steering committee was formed to oversee the implementation of the directive. Recognizing that community involvement in the planning for the delta is important, EAWLS was nominated to implement an environmental awareness programme tailored to prepare the delta communities for genuine participation in the management planning processes for the Tana Delta. This programme will provide a framework for local input into the master plan for the area as it is acknowledged that the local communities have their own unique and valuable traditional knowledge and methods of conserving and utilizing the natural resources of the delta.

Due to both human and natural influences, this unique delta is prone to misuse and resultant environmental disasters as well as drastic evolution over time. This calls for its planned use and management through an integrated approach.

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CHANCING SHORE LINE DURING PAST 20,000 YEARS, AS ILLUSTRATED BY PALEO-KUJI RIVER IN JAPAN

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ABSTRACT

The postglacial age covers approximately the past 20,000 yrs. The eustatic sea-level of 20,000 yrs ago was situated at a depth between 120 and 140 m below of the present sea-level. After this period, the sea-level started to rise with small fluctuations to the present sea-level until about 5,000 to 6,000 yrs ago. Since then, the sea-level has been rather stable at the present level. According to postglacial eustatic sea-level changes, the shoreline has migrated on the present day continental shelf.

The Paleo-Kuji River in Japan well reflects such a kind of eustatic sea-level change. The channel of this river extends towards east of the continental shelf area and is now completely filled with alluvial deposits. The channel is wide at the present depth of 40-50 m. It might correspond to a sea-level which existed for a long duration during the Würm glacial age, which was the last glacial period. The width of channel is narrower in the bottom layer between the present depths of 40-50 m and 120-140 m. This might reflect a short period during the last stage of the Würm glacial age.

THE GREAT ICE AGE

The surface of the earth has been extensively covered by continental glaciers for every 500 million yrs (my) approximately. The last Great Ice Age started around 1.7 my ago and is supposed to be still continuing. The last Great Ice Age consisted of several glacial ages alternating with interglacial periods.

EUSTATIC SEA-LEVEL CHANGES

At a global scale, the sea-level has risen during the interglacial age because of the partial melting effect of the continental glaciers. On the other hand sea-levels also dropped temporarily during glacial age.

Such kind of sea-level changes have been defined as eustatic sea-level changes.

THE WÜRM GLACIAL PERIOD

The last glacial age is called the Würm glacial age. It started around 70,000 yrs ago and terminated 20,000 yrs before present (BP). Fig. 1 illustrates an example of a speculated eustatic sea-level change during the Würm glacial period. The original data used in this figure were collected by Masao Minato in the Tsugaru Strait between the main island and Hokkaido island, north of Japan.

These results were first simplified by Takahiro Sato and additionally by the present author (Nasu 1992).

The sea-level started to drop around 70,000 yrs ago and fluctuated at the level between 40 and 70 m below the present sea-level.

Around 31,000 yrs BP, the sea-level started to drop steeply and reached a depth of 110 m at about 28,000 yrs ago. Then sea-level slightly rose for a short period and descended furthermore to the depth of about 140 m around 20,000 yrs BP. This was the local event, so that it might have been modified by local crustal movements. But, it might also be illustrative for a world-wide tendency of eustatic sea-level changes during Würm glacial age. The level of the sea at the end of Würm glacial age has been suggested to be between -120 and -140 m by many researchers. It was a world-wide event.

POSTGLACIAL AGE

Curray and Shepard (1959) indicated that the eustatic sea-level rise occurred with some small fluctuations from -90 m at 17,000 yrs BP and reached to the present sea-level at around 5,000 to 6,000 yrs BP. Since then, the sea-level remained rather stable with small fluctuations of a few meters (Curray and Shepard 1959).

Curray and Shepard continued their research and found that the sea-level reached its lowest point around 20,000 yrs BP (Fig. 2; Shepard, 1963). Since this discovery, the postglacial age was defined as that of the past 20,000 yrs, and the end of the Würm age took place 20,000 yrs ago. This indicates that the sediments, being deposited during approximately the past 20,000 yrs, are alluvial deposits.

In the field of climatology the postglacial period is interpreted to last 11,500 yrs. Thus there is about 8,500 yrs difference between the results sediment research and that of climatology on the interpretation concerning the duration of the postglacial period.

The author speculates this difference to be derived by a sublimation effect. The higher portion of continental glaciers might be affected since 20,000 yrs ago by an increase of sun-irradiation and, instead of melting, sublimation of ice might have taken place on the slopes facing the sun. The increase of melting of glaciers might have started only around 11,500 yrs BP, because of an increase of atmospheric temperature (Nasu 1994a; 1994b).

4. THE DEVELOPMENT OF HUMAN CIVILIZATION DURING PAST 5,000-6,000 YEARS

It is well known that human civilization started to develop about 5,000-6,000 yrs ago. The author suggests that this might have been stimulated by the stability of the eustatic sea-level during past 5,000-6,000 yrs. Otherwise mankind might not have been able to develop so many cities along the coastlines all over the world (Nasu 1994a; 1994b).

The reason why the eustatic sea-level has kept its present level during past 5,000-6,000 yrs has not been clarified. It is urgent item to be solved by scientific research. If solved, we might be able to create some technology to maintain the present sea-level. Otherwise, mankind will suffer by the rise or drop of the eustatic sea-level in future. The maintenance of this stability of sea-level during past 5,000-6,000 yrs is one of the miracles in nature.

SHELF SEDIMENTS OFF THE COAST OF TOKAI MURA IN JAPAN

Tokai Mura is the area located about 110 km north-east from Tokyo and faces directly to the Pacific Ocean.

Fig. 3 presents the surface distribution of sediments and exposed rocks on the continental shelf (Nasu 1963; 1964; 1976). The shore zone mainly consists of sandy sediment until a depth of 15-20 m, thus forming a long beach. The deeper portion is covered by various kind of sediments while some narrow areas show exposed rocks.

Basement rock, close to the surface of the continental shelf of this area, consists of Neogene Tertiary sedimentary hard rock. Unconsolidated sediment thinly covers this hard rock. This is clearly obvious from continuous sonic profiler records.

Thus, a thin sediment layer covers the shelf, which can be accounted for as relict sediments, deposited during the eustatic sea-level changes in this area. Sandy sediment deposited in the vicinity of surf zone may be composed of deposits having migrated back and forth during the past 5,0000-6,000 yrs, during this rather stabilized eustatic sea-level period. The boundary line between such kind of modern sand and relicts of offshore sediment on the shelf is at the depth of 15 to 20 m, which may correspond to the wave base of this area.

Sediments are sorted into gravel, sand and mud (silt and clay) during the common process of transportation in water, owing to hydrodynamic reasons (Nasu, 1956). Because of the wave-caused turbulence and drifting by longshore currents, sand including some gravel might be separated and be concentrated along the beach line, shallower than 15 to 20 m during the past 5,000-6,000 yrs. Muddy sediment might be separated and resuspended in the water column for long

periods due to its low rate of settling. It is transported and scattered toward the offshore area. This should be the reason why only sandy sediment is present in the neighbourhood along the beach.

PALEO-KUJI RIVER

The Tokai Mura area is situated at the north-eastern extremity of the broad Kanto Plains. The area further north is occupied by the Abukuma Mountain Range. The Kuji River flows eastward, marking the boundary between the Kanto Plains and the Abukuma Mountain Range at its downstream region. Namely, the Kuji River flows at the north-eastern extremity of the Kanto Plains. There are several facilities for atomic energy development in the Tokai Mura region. Prior to the construction of nuclear facilities, a great number of drillings were made to investigate the geology of this area in order to secure the safety of these atomic facilities.

Fig. 4 presents the depth contour map of the surface of the Neogene hard rock of this area (Nasu, 1963; 1964; 1976). This surface is almost completely covered by alluvial deposits. Pleistocene sediments only occupy the hilly area. Therefore, just beneath the strand line of the shore, alluvial deposits overlay directly the Neogene Tertiary sedimentary rock. It is similar to the offshore area of the continental shelf.

Black spots on Fig. 4 present the drilling sites. Fig. 5 presents the geological section along A-A' line of Fig. 4. By comparing those two figures, it can be recognized that there exists a broad ancient river channel, a little south of the present Kuji River. This paleo-river channel is now completely filled by alluvial deposits. These alluvial deposits should have been deposited in accordance with the eustatic sea-level rise and the following stabilized period during the postglacial age of the past 20,000 yrs.

The author named this paleo-river the Paleo-Kuji River (Nasu, 1963; 1964). The broad bottom of this old river channel is situated between about 50 to 60 m below the present shoreline. This old river channel, shown in Figs. 4 and 5 indicates the presence of several river terraces. Evidently one is located about 15 m below the present shoreline. This terrace is regarded as being formed during the Pleistocene, prior to the formation of the broad bottom of the channel. Therefore a thin gravel bed, occurring over this -15 m terrace, may possibly belong to the Pleistocene deposits.

Figs. 4 & 5 indicate also the existence of another ancient river bed, just south of the Shin River, which was named as Paleo-Shin River. Later it was found by a continuous subbottom sonic profiling survey, that this paleo-river is a branch of the Paleo-Kuji River.

In 1963 a sonic profiling survey was carried over the whole area of the continental shelf, off the coast of Tokai Mura (Kagami & Nasu, 1964). The result is shown in Fig. 6. Rather straight lines in the figure indicate the surveyed sonic lines. It clearly indicates the eastern extension of the Paleo-Kuji River and the Paleo-Shin River.

At present, those old channels have been completely filled by alluvial deposits. Although it is not shown in the figures, there are several river terraces along these old river channels. The width of Paleo-Kuji River channel suddenly becomes narrower at the present depth of about 40 to 50 m, and keeps its form downstream, until it expands toward the old final river mouth. The author interprets this phenomenon as follows (Nasu 1992; 1994b; Fig. 7).

During a long period during the Würm glacial age, the shoreline might have migrated slightly around the present depth of 40 to 50 m, as is shown in Fig. 1 and by zone 2 of Fig. 7. The wide river channel at the depth of 40-50 m might have been the old rivermouth at the time of about 31,000 yrs ago. Then the eustatic sea-level started to drop quickly at 20,000 yrs ago. The river mouth also quickly retreated toward the level of 120-140 m deep, as indicated by the line-3 in Fig. 7.

Steep slopes of the river bed might have been formed at the depth range between 40-50 m and 120-140 m. This formed the rather narrow river channel. Then eustatic sea-level started to rise from 20,000 yrs ago and the lower narrow river channel was submerged beneath the sea surface, without having enough time to expand the width of the channel.

All over the world at 20,000 yrs ago, many rivers might have flowed slowly to the present depth of 40-50 m with wide channels, and later rush into the ocean with rather narrow channels. The wide river mouths of many present rivers the world over, may be the result of this phenomenon during the stable eustatic sea-level of the past 5,000-6,00O yrs. Thus, during the last Great Ice Age, the width of river channels at the middle and downstream regions might have been affected strongly by the eustatic sea-level changes. It means that the erosion of river channels might in many cases creep up from the sea-level. Therefore many buried ancient river channels vary their width along with their course.

Finally, the author also wishes to suggest the following (Nasu 1992; 1994b). As is shown in Fig. 5, the axis of the bed of the Paleo-Kuji River is located a little south of the present Kuji River. Here the river flows from west to east. This area is situated at middle latitude of the northern hemisphere of the Earth. The filling of the Paleo-Kuji River channel by alluvial deposits during the postglacial age of the past 20,000 yrs might result in a continuous decrease of the steepness of river bed. The effect of Coriolis Force on the river water becomes obvious, which shifts the axis of river bed toward the left. If this is true, the effect should be the reverse at middle and high latitudes of the southern hemisphere, while the effect should not be evident close to the equator. This understanding might be applied to the construction of buildings at the edges of such kinds of ancient buried river channels from the economic aspect.

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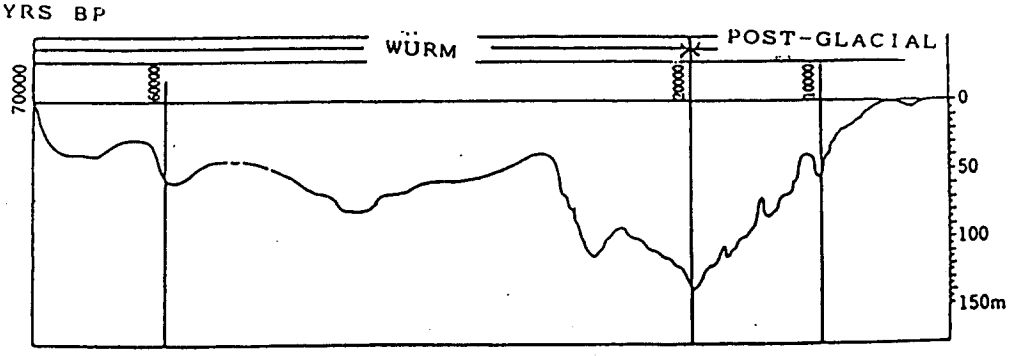
Fig. 1. Eustatic sea-level changes during Würm glacial age and postglacial age (after Minato, Sato and Nasu, see Nasu 1992; 1994).



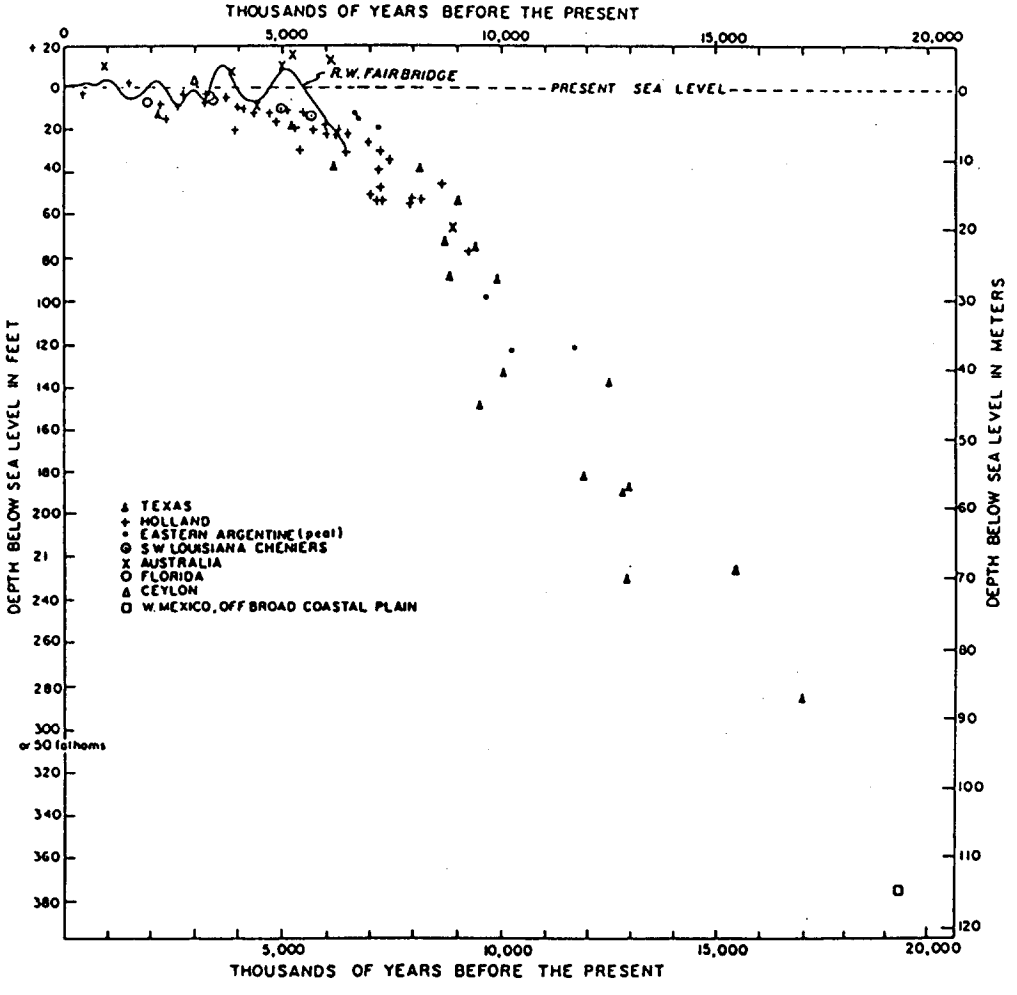
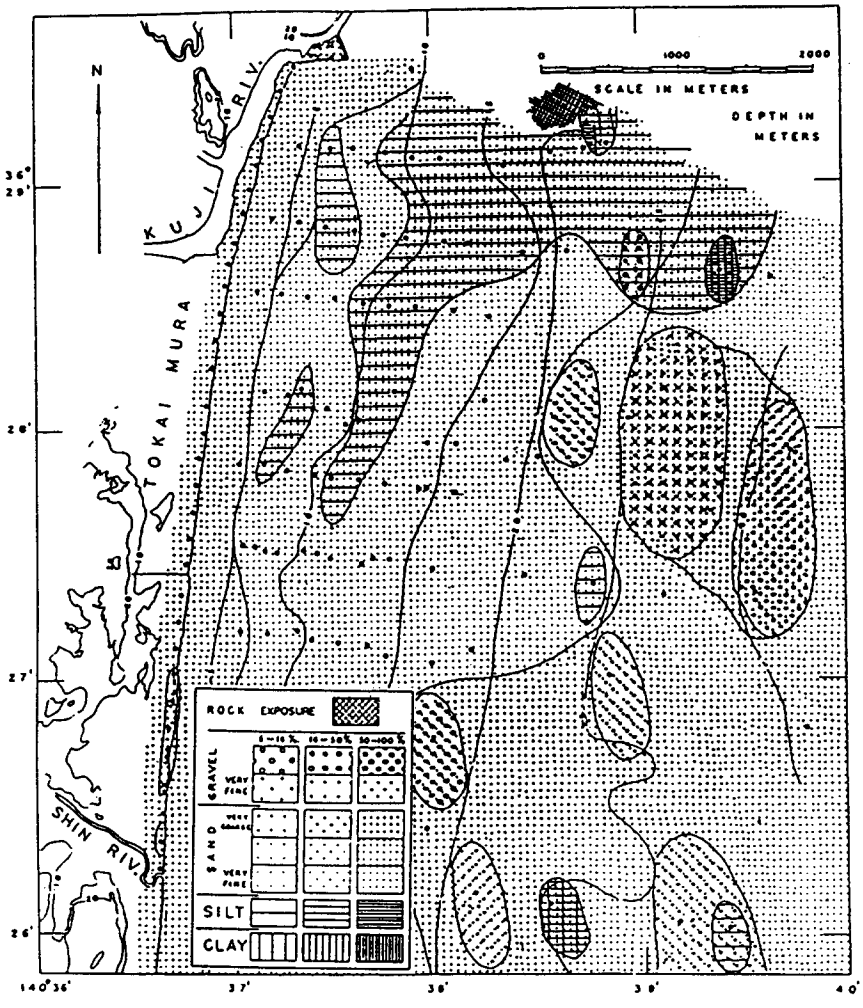


Fig. 2. Sea-level rise during past 20,000 years (after Shepard 1963).

Fig. 3. Grain-size pattern of the shelf sediments off Tokai Mura (Nasu 1963; 1964; 1976).



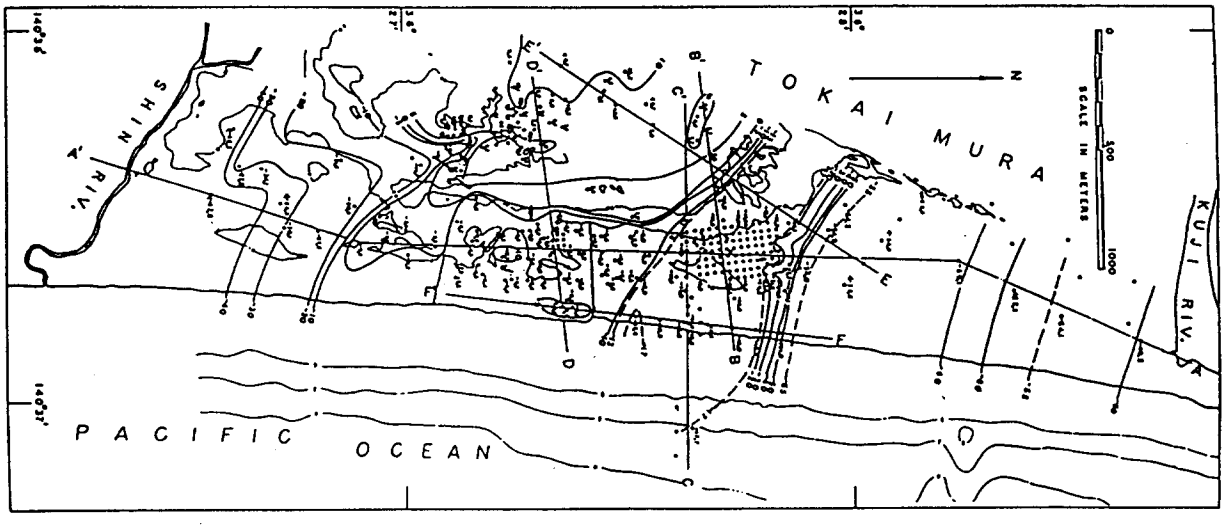
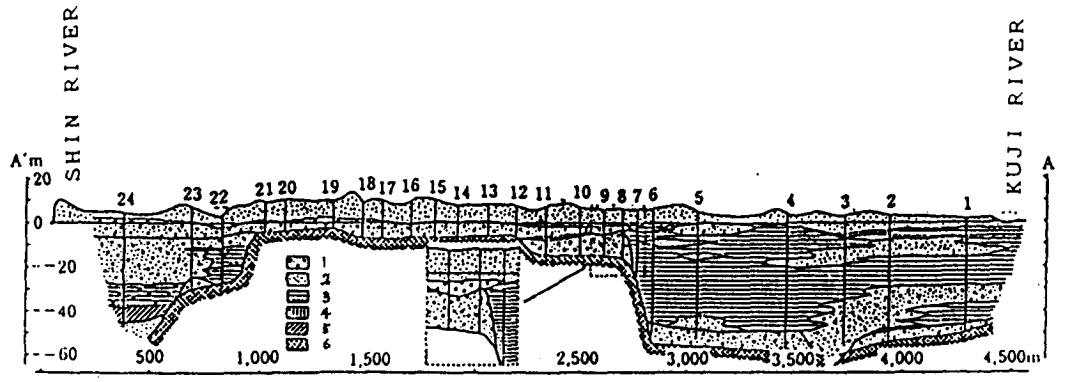


Fig. 4. Depth contour map of the surface of Neogene Tertiary hard sedimentary rock in reference to the present sea-level at Tokai Mura (Nasu 1963; 1964; 1976).

Fig. 5. Geological section along A-A line (close to shore line) of Fig. 4 at Tokai Mura. 1. sandy gravel, 2. sand, 3. silt, 4. clay, 5. so-called Kanto loam 6. Neogene Tertiary hard sedimentary basement rock (Nasu 1963; 1964; 1976)



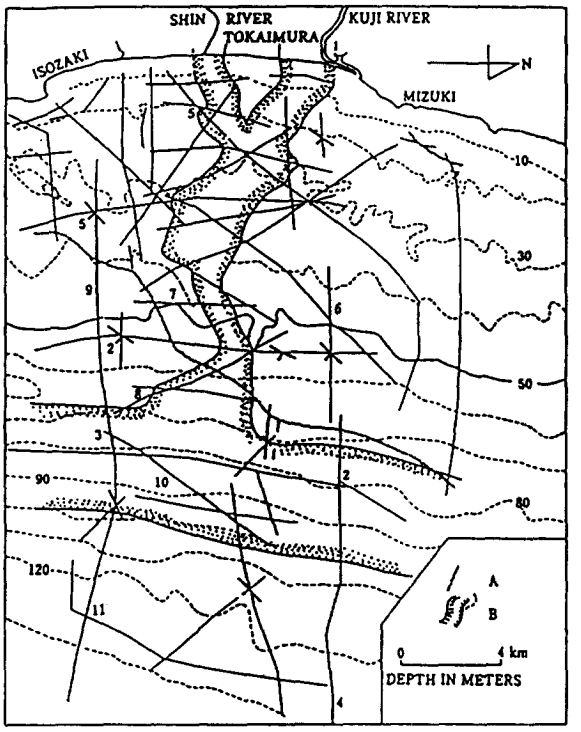


Fig. 6. Paleo-Kuji River channel buried beneath the surface of the continental shelf off Tokai Mura. Straight lines indicate the sonic survey lines (Kagami & Nasu 1964; Nasu 1976).

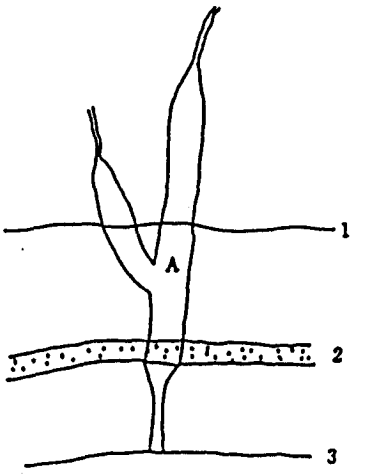


Fig. 7. Schematic plan of Paleo-Kuji River. A. river channel, 1. present shoreline 2. shore zone prior to 31,000 years ago during Würm glacial age, 3. shoreline around 20,000 years ago, just at beginning of post-glacial age (Nasu 1992; 1994a,b).

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CHANGES IN NATURAL COASTAL SYSTEMS IN THE GULF OF MANNAR AND THE PALK BAY, SOUTHEASTERN COAST OF INDIA WITH PARTICULAR EMPHASIS ON CORAL REEF ECOSYSTEM

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KEYWORDS: Corals, Gulf of Mannar, Palk Bay.

ABSTRACT
A coral reef ecosystem is a habitat extremely conducive to different species, with abundance of economically important biological resources like finfishes, shell fishes, seaweeds etc. Coral acts as a natural barrier against sea erosion. There are about 20 coral islands in Gulf of Mannar region of Southeast coast of India, covering about 683 hectares from Mandapam to Tuticorin. This fragile ecosystem is under severe threat due to the indiscriminate anthropogenic effects such as Pollution, Mining, Aquaculture, Fishing and Tourism. Efforts to conserve this ecosystem for proper utilization have already been initiated by various Government and research organizations.

INTRODUCTION

Coral reefs, the most conspicuous of marine habitats, are important in terms of productivity and diversity. It cannot be denied that coral reef habitats are the marine ecosystem richest in species and are responsible for creating a part of the coastal ecosystem. Though coral reef ecosystems are found in different places in the southeastern coast of India, the ecologically and economically valuable coral reefs are found in the Palk Bay and the Gulf of Mannar region. The region between Rameswaram and Kanyakumari along the mainland coast to a distance of about 170 nautical miles is included in the Gulf of Mannar region. This Gulf is part of the southward extension of the Bay of Bengal as it meets the Indian Ocean. It consists of 20 small islands situated between lat. 8° 46' and 9° 14' N and long. 78° 9' and 79° 41' E, each about 5 km^2 in area Fig. 1 (Lalmohan, 1986). The present day patch reefs are a secondary formation, resulting in the emergence of contemporary reefs and islands (Pillai, 1977). The corals of the Gulf of Mannar are more diverse and abundant than those of the Palk Bay (Pillai, 1971). The Palk Bay has lagoons of depth ranging from 1.0 to 2.0 m but they are generally devoid of coral except for a single reef. The seas are turbulent in the Palk Bay. Turbid waters from September to May and the siltation have a greater effect on the corals in the inshore areas of Palk Bay than in the Gulf of Mannar.

There are 120 species (33 genera) of the fringing and patch coral reefs in the Gulf of Mannar and Palk Bay region. Of these, 110 species are hermatypic and 10 ahermatypic corals (Pillai, 1971). The conspicuous species of the corals belong to the family Acroporidae (*Acropora*, *Astreopora* and *Montipora*). *Montipora* and *Acropora* put together constitute 39% of the total species recorded. Species belonging to Poritidae and Faviidae constitute the dominant reef builders here (Pillai, 1971).

There is scope for sustained income through the exploitation of natural resources in any ecosystem in order to fulfil our requirements, it is essential that attention should be focused on any particular ecosystem with a view of its utilization for a longer time without destroying it. Looking the Palk Bay and Gulf of Mannar coral reef ecosystem, one can understand the ruthless destruction of that habitat by human activity. Coral is commonly used to construct homes, seawalls, road and in the carbide factory and hence from time immemorial huge quantities of corals are removed from the Palk Bay and the Gulf of Mannar. Exploitation of some coral

associated living resources are also increasing day by day.

It should be mentioned that these reefs also get damaged occasionally by cyclones. For example, a cyclone in December 1964 severely damaged *Acropora* sp., the typically highly branched and fragile corals. In addition to this, some associated fauna like boring sponges and boring bivalves cause great damage to corals. The Palk Bay and the Gulf of Mannar have 20 species of coral boring sponges and the common one is *Cliona celata* (Thomas, 1972). There are also 18 boring bivalves and the commonest boring bivalve molluscs are *Lithophaga nigra*, *Petricola lithophaga* and *Gastrochaena gigantea* (Appukkuttan, 1972).

It is difficult to prevent the impact of nature on any coral reef ecosystem but we can control or at least minimise, the indiscriminate anthropogenic effects on the ecosystem of the coral reef. In the regions of the Palk Bay and Gulf of Mannar due to human activity the coral reefs are being fastly depleted in the following ways.

POLLUTION

The Gulf of Mannar particularly Tuticorin coast is under severe threat due to various pollutants, like domestic and industrial effluents. Besides the untreated sewage discharged into the bay, the effluents from a number of Government owned and some private industries are also being discharged into the sea. Heavy discharge of such untreated sewage silted the sea in some places along Tuticorin coast. The sea near the discharge point is heavily loaded with a hydrogen sulphide smell and the entire beach area is slushy and black. In addition to this, the sewage pollution leads into the enrichment of nutrients, particularly phosphorous and nitrogen. The enrichment of such nutrients in the sea may lead to eutrophication along the coast and will alter the biodiversity of this ecosystem. Fish mortality also is reported due to obnoxious gases, emanating from particles which get settled at the bottom of the sea for longer durations.

MINING

As corals are being utilized for making lime, in the construction of road and in the carbide industry, they are quarried from May to September in the Palk Bay and from October to May in the Gulf of Mannar. About 250 m^3 of coral reef is removed daily during the peak period of activity. At present, there are four private companies/parties actively involved in lime making using corals. They are mostly collecting corals from the shallow water region and reefs off Tuticorin, and amounted to an annual removal of about 15,000 tonnes of boulders and about 10,000 tonnes of coral debris. As a result of the continuous and unrestricted excavation over many years, corals in and around the islands and its associated fauna and flora get destroyed. This damage is much pronounced in the island of Manauli, Sally Theevu and Upputhanni Theevu in the Gulf of Mannar region and already 40 percent of the coral is gone.

Further, truck loads of red coral are being smuggled from the coast in Andaman Nicobar islands. Exploitation of red corals, which is very slow growing, would seriously disrupt this ecosystem. Some of these reefs, particularly in Andaman, are fringed with mangrove forests and hence its exploitation also upsets the mangrove ecosystem.

AQUACULTURE

In recent years, culture of shrimps in and around Palk Bay and Gulf of Mannar region is growing very rapidly. Though the shrimp farming activity boosts the country's economy and also local community development, the sector faces a problem of drainage and waste management, which can spill over its effect on the environment as well as affect the industry itself. The shrimp farms, situated along Palk Bay and Gulf of Mannar coastal regions, continuously discharge voluminous untreated drainage water into the sea, which attracted the attention and raised questions among various sector levels. The drainage waters are usually enriched with nutrients like phosphate, silicate and nitrate and toxic gases like ammonia and hydrogen sulphide and have a heavy silt content. Since the coral reef ecosystem is very sensitive to excessive nutrients and a high turbidity of the surrounding water, untreated drainage from shrimp culture activity may have adverse effects.

A recent outbreak of an unknown disease in the shrimp culture ponds along this coast, caused drastic damage to the aquaculture industry. The drainage water from the infected shrimp culture ponds have also been released into the sea. Studies pertaining to this aspect are still lacking.

FISHING

Coral reefs harbour a wide variety of marine vegetation and animals. The vegetation includes different groups of seaweeds like *Sargassum, Caulerpa, Gracillaria, Ulva* etc. and sea grasses. About 160 species of algae have been recorded in the Palk Bay and the Gulf of Mannar region alone. Of this amount 40 species are found to grow in abundance on the islands. During the lowest tide, the beautiful coral reefs and those around the islands get well exposed. People living nearby areas regularly exploit the coral, seaweeds, bivalves, gastropods and sea cucumber for their livelihood. People of different age groups collect them mostly by hand in and around the coral reefs resulting in the disturbance of the water system and increasing the turbulence. Such activity significantly destroy newly growing coral polyps and increase the damage to the fragile coral groups. Moreover, seaweed collectors pick the seaweeds from the substrate to which it has attached itself that are mainly the corals, completely destroy the regeneration capacity of that particular seaweed. They also considerably change the involved coral reef ecosystem.

In the Gulf of Mannar region lobster fishing is an important activity. Lobster fishing is carried out throughout the year with the lobster net locally called as 'Shingi Valai'. The fishermen engaged in lobster fishing spread their nets in the early hours of the day in coral habitats and leave them in location for a day or two. As the gear is commonly placed in the coral reef areas where lobsters are abundant, a huge number of corals both alive and dead get entangled with the net while lifting it and are used for making lime. Apart from this, gastropods like *Chicoreus ramosus, Pleuroploca trapezium, Lambis lambis, Cymbium melo*, starfishes, cargonium, sponges and different species of crabs are also fished and ruthlessly discarded on the shore.

Nowadays some coral associated fauna, like sea fan and sea horses, receive great attention among the marine products exporters due to their remarkable medicinal value. Hence divers, particularly belonging to the Gulf of Mannar region, are venturing into the collection whenever they find favourable conditions for diving. Furthermore, extensive potential seagrass beds are located in Palk Bay, Gulf of Mannar. Around the Gulf of Mannar islands so far 12 species have been reported. They are largely confined in lagoons between shores and the fringing reefs, provide or serve as a conducive habitat for characteristic marine mammals - Dugongs which utilize seagrass beds mainly as feeds. Unfortunately due to the delicacy of the Dugong meat, currently it is being over exploited and is now becoming extinct. The use of nets and explosives for hunting dugongs cause great damage to the seagrass beds (Silas and Fernando, 1988).

TOURISM

In the cultural heritage and history of India also, the Gulf of Mannar occupies a prominent place. The famous pilgrim centre of Rameswaram is situated in the Gulf on the island of Pamban and drawing thousands of pilgrims and tourists daily from all over India and abroad. They are interested in purchasing the beautiful corals. Different species of corals are sold in the shell shops near the temple. In order to meet the demand for this article, the divers regularly exploit live corals, mainly from the Palk Bay region. Some species of the corals are removed from their habitat by using iron rods. The degree of exploitation is very high during the months March, April and May because of the higher number of tourists visiting in those months.

CONCLUSIONS AND SUGGESTIONS

The following suggestions may help to minimise further destruction of this fragile ecosystem:

- Prevention of the discharge of untreated sewage, industrial effluents and waste water from shrimp culture ponds into the sea. The Government should strictly advise the above-said industries to discharge the waste water after treatment.

- Prevention of illegal mining and smuggling of corals.
- Use of explosives and indiscriminate fishing on coral beds must be prevented. Strict vigil has to be maintained by the local government authorities to stop mining and smuggling of corals, use of explosives and indiscriminate fishing. Mesh size regulation and fishing areas are also to be fixed.
- Research activities: The Department of Environment (DOEn), Government of India in association with the Forest Department of Tamilnadu is making efforts to conserve this coral ecosystem for proper utilization. The Gulf of Mannar Marine Biosphere Reserve Research Committee was set up in 1989. Various research projects have been approved and implemented. However, complete baseline data on the flora and fauna of this ecosystem is still lacking. Studies on productivity, reproductive biology, regeneration, growth and transplantation are to be carried out in order to obtain complete details.
- Public awareness: people, particularly living around this ecosystem, should be informed and educated on the high value of this natural resource. The children have to be educated the importance to conserve the natural resources even from the primary school level.

However, any ecosystem could be preserved and properly managed only if the scientists and government succeed in bringing the public together to involve in all conservation and management activities. Further, strict Government regulations could solve the problem considerably.

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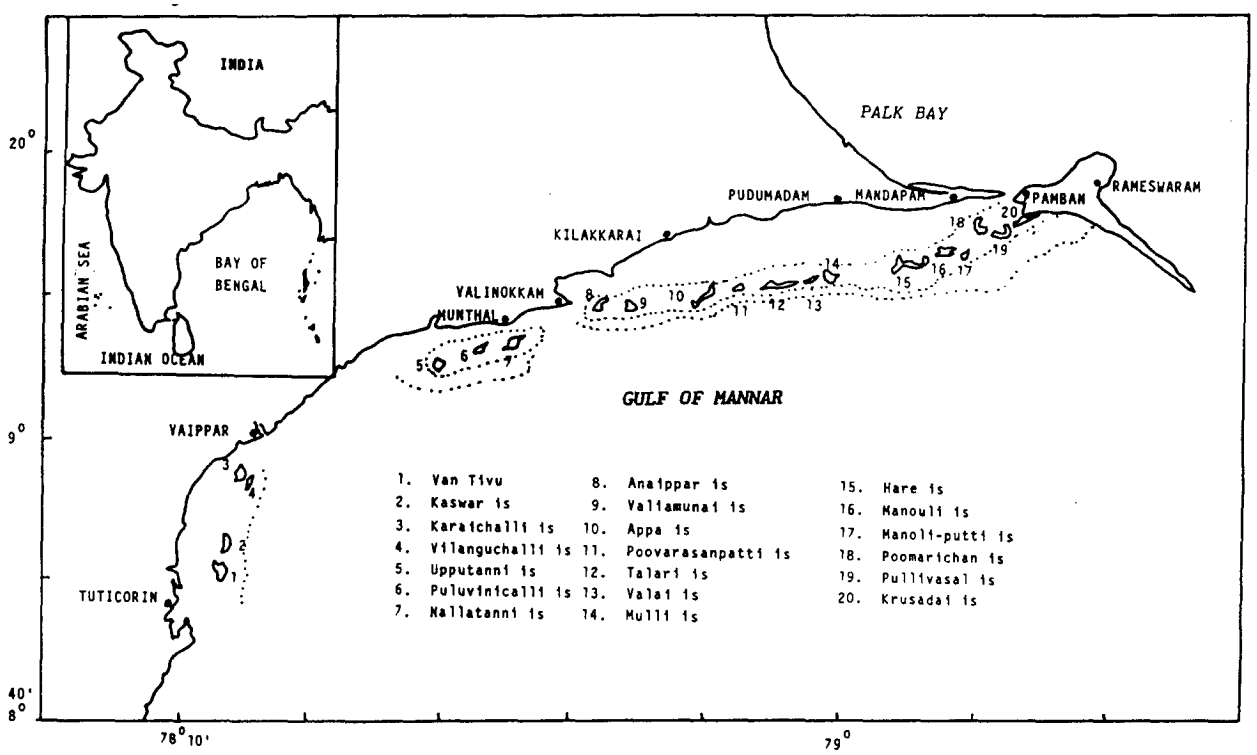
Fig. 1. Map showing the Gulf of Mannar, India.



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ÉVOLUTION DES ÉCOSYSTÈMES CÔTIERS ET OCCUPATION HUMAINE DANS UNE ÎLE SUBTROPICALE DU BRÉSIL

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L'île de Santa Catarina (27° 37' latitude Sud; 48° 27' longitude Ouest; surface totale: 431 km^2), située dans la région subtropicale du Brésil, et contigue à la côte, se caractérise par de vigoureux reliefs d'inselbergs granitiques qui ont dirigé la formation de petites plaines sédimentaires côtières, et qui structurent un paysage très attractif. Des massifs dunaires occupent 11% de cette surface, des mangroves, 14,7%, et un lac et des lagunes en connexion avec la mer, 6,5%. Le littoral est caractérise par un plateau continental étroit. Sur une longueur totale de 180 km, la côte comprend 98 km de plages (Fig. 1).

Les diverses étapes d'occupation humaine ont provoqué des changements de plus en plus profonds dans les écosystèmes littoraux de l'île.

Les premiers peuplements humains connus, sont témoins d'utilisations des ressources marines. Ils datent de 4200 ans AC jusqu'à la colonisation européenne. Les sites archéologiques, dénommées "sambaquis", sont formés par des accumulations de coquilles de mollusques, avec des os et dents de poissons, des débris de crustacés, et des outils lithiques (surtout des haches polies). Ils sont localisés à proximité des baies et des lagunes. Ces sites attestent une large diversité biologique au sein des écosystèmes littoraux.

En tenant compte du nombre (38) et de la taille des sambaquis (1 à 1,5 m de hauteur, et 40 à 50 m de diamètre selon Beck, 1980), il est possible de conclure que la pression extractive à laquelle les écosystèmes ont alors été soumis a été faible, et probablement discontinue.

L'installation des premières familles provenant du Portugal, de 1662 à 1748, apporte un contingent humain de 180 personnes environ, qui est resté assez stable et n'a pas produit d'impacts importants sur les écosystèmes.

A partir de 1748, cette situation s'est profondément modifiée: En moins de 8 ans, plus de 5000 immigrants, pêcheurs et agriculteurs provenant des l'îles Azores et Madeira (Cabral, 1970) sont implantés le long du littoral qui à l'époque était occupe par la forêt tropicale atlantique. Cette forêt est rapidement détruite (Caruso, 1990) pour satisfaire les besoins de matériaux et d'énergie de cette population qui développe une économie industrielle très florissante, baisée sur la chasse à la baleine. A partir de 1930-1940, les activités de pêche des poissons et crustacés migrateurs s'intensifient et donnent lieu à d'importantes exportations de produits salés ou sèches. Ainsi l'Etat de Santa Catarina, se trouve maintenant au premier rang de l'activité artisanale de production halieutique nationale du Brésil.

Depuis un demi siècle, le littoral de l'Etat de Santa Catarina est aussi devenu l'un des principaux pôles touristiques du Brésil, en raison de la beauté de ses paysages et de la qualité de ses plages (Sierra de Ledo et Soriano-Sierra, 1988); des villes balnéaires se sont développées tout le long du littoral et en particulier dans l'île de Santa Catarina, où l'installation de la Capitale administrative de l'Etat induit en outre une croissance rapide de la population permanente qui substitue un nouvel habitat résidentiel de fonctionnaires à l'habitat rural traditionnel.

Le processus d'urbanisation dans cette île est surtout le fruit d'initiatives individuelles. A proximité des plages, l'implantation des infrastructures urbaines et touristiques a pour résultat un déplacement des communautés de pêcheurs, auxquelles elles se substituent souvent.

Actuellement, Florianopolis - Capitale de l'Etat de Santa Catarina - héberge environ 300 000 habitants permanents; 60 000 autres résident dans les petites agglomérations qui se développent autour des villages de pêcheurs. Le littoral de l'île reçoit, de plus, une population fluctuante d'environ 500 000 touristes durant les mois d'été (de décembre à mars).

Dans ce contexte, la diminution de l'espace littoral naturel devient critique; l'absence de stratégie locale de l'occupation du sol, entraîne une modification anarchique de cet espace. Les écosystèmes de la zone côtière subissent des changements affectant aussi bien leurs composantes structurales que leurs processus fonctionnels (Sierra de Ledo et Klingebiel, 1993). On observe ainsi une diminution de la biomasse et de la biodiversité dans les mangroves et sur les dunes; un remblaiement partiel des baies et des lagunes; l'altération de la qualité des eaux et des sédiments par des pollutions organiques et des métaux lourds, déterminant des processus de biomagnification sur certaines espèces de la faune aquatique (Queiros et al., 1994). Au cours des cinq dernières décades, on a constaté l'élimination de 76% de la végétation endémique, la suppression de 10 km^2 de dunes et une réduction de 42% de l'aire initialement occupée par les mangroves (Soriano-Sierra et al., 1993).

Quelques exemples

1) La salinisation de la Lagoa da Conceiçao:

Sur la côte océanique de l'île, la Lagoa da Conceiçao abritait un important écosystème mixohalin, favorable à la reproduction de poissons (Mugilidés) et de crustacés (Peneidés). La pêche de ces espèces migratrices était la ressource principale de cette région. Un unique canal naturel relie cette lagune à la mer; l'obstruction périodique de son embouchure, de juin à septembre, provoquait certaines années un confinement de la lagune et des mortalités massives de la faune, et empêchait les bateaux de pêcheurs et de plaisanciers de sortir de la lagune vers l'océan.

En 1982, une digue a été construite à l'embouchure, pour la mettre à l'abri des apports de sable par la dérive littorale, et permettre ainsi une libre et constante circulation des eaux et des bateaux. Cette communication permanente de la lagune avec la mer n'a pas supprimé l'occurence épisodique des conditions méromitiques responsables de la mortalité des poissons et des crustacés dans le corps d'eau lagunaire.

Dans le cadre d'un suivi bio-écologique de cette lagune, de 1961 à 1994, des mesures mensuelles de la température et de la salinité des eaux ont montré que l'amélioration des échanges hydrauliques entre la mer et la lagune a eu pour résultat imprévu une augmentation progressive de la salinité des eaux lagunaires, avec apparition de sur-salinités par stratification des eaux dans les dépressions fermées de la lagune. Le rétablissement et le maintien des conditions favorables à la reproduction des espèces qui constituaient la richesse économique de cette lagune impliquent une régulation des échanges d'eau avec la mer, à partir de la connaissance et de la gestion du bilan hydrique de cet écosystème.

2) L'erosion des plages

Une alternance de caps rocheux et de plages, ainsi que la présence de champs de dunes côtières constituent l'attrait touristique majeur de la façade océanique de l'île de Santa Catarina. Depuis quelques décennies, les villages de pêcheurs installés à proximité des embouchures des chenaux lagunaires, lieux de capture des poissons et crustacés migrateurs ou aux extrémités abritées des plages, abritées des houles et des vents froids en provenance du Sud, sont colonisés par des constructions de maisons d'habitations de fonctionnaires travaillant à Florianopolis ou de résidences hôtelières accueillant des touristes brésiliens ou étrangers (Uruguay, Argentine) pour des séjours de vacances estivales.

Cette urbanisation est le fait d'initiatives individuelles, souvent initiées par des familles de pêcheurs résidant dans ces villages, et se réalise de façon anarchique, en privilégiant, pour des raisons économiques évidentes, les constructions les plus proches de la plage, car ce sont les plus prisées par les estivants et donc les plus rentables à court terme. Malheureusement, ces constructions "sur la plage" sont maintenant, dans la

plupart des sites, parfois détruites, généralement très fortement menacées, par l'érosion marine. Les tentatives de protection de ces édifices, par des ouvrages en béton, des enrochements ou des accumulations de débris divers, accélèrent le rétrécissement de l'espace sableux intertidal et la disparition de la plage qui était l'attrait essentiel du site. Outre la perte d'un investissement parfois important, ce comportement inconscient et incontrôlé altère irrémédiablement un patrimoine paysager dont l'intérêt récréatif représente une grande valeur économique dans notre société moderne.

Sur certaines plages (P. Brava, P. Jurere-international), des sociétés immobilières ont nivelé des systèmes dunaires pour y construire des résidences hôtelières, rejettant le sable sur la plage qui s'est ainsi trouvée temporairement élargi.

Des études sont menées pour déterminer l'ampleur des évolutions des plages, la nature des facteurs qui les provoquent, et la quantification des paramètres qui déterminent les budgets sédimentaires de sables mobilisés entre le proche plateau continental, les plages et les dunes.

3) La pollution et la destruction des mangroves

Selon la législation, les mangroves sont des zones bénéficiant d'une protection totale et permanente. Cependant, l'expansion urbaine de Florianopolis et l'emprise immobilière des infrastructures touristiques soumettent ces écosystèmes à des modifications de fonctionnement ou même à des éliminations.

Les chenaux qui pénètrent ces mangroves sont dragués et canalisés, pour en assurer le drainage ou même pour recevoir des effluents domestiques non traités. En conséquence, la qualité des eaux est modifiée et dégradée, compromettant le développement de la faune et de la flore aquatiques, en raison d'une pollution organique chronique, qui élève la demande d'oxygene et développe la décomposition anaérobique dans les sédiments. Cette situation est particulièrement critique dans la mangrove d'Itacorubi, qui conformément au Plan Directeur de la Ville de Florianopolis, confine des zones "urbanisées" et des zones d'"urbanisation autorisée", ou encore de "priorité urbaine". En bordure de ce système, sur une superficie de 12 hectares, durant 12 ans, ont été accumulés des dépôts de déchets industriels, hospitaliers et domestiques, avec l'intention de réaliser un remblai sanitaire.

Actuellement, à cette réduction progressive de l'habitat naturel et de la biomasse de la végétation typique, correspond, autant dans l'eau que dans les sédiments, une augmentation des teneurs en métaux lourds, en particulier en nickel et cadmium, qui se retrouvent aussi dans les organismes aquatiques, poissons, mollusques et crustacés qui sont consommés localement par une population à faibles revenus.

Face à ces aménagements par trop irrationnels, les Institutions gouvernementales élaborent des mesures de réglementation et de police, ainsi que des programmes de restauration de la qualité de l'environnement, complétées par la création d'espaces protégés à vocation de "Reserves biologiques". Le plan d'Amenagement Urbain du Municipe de Florianopolis prend maintenant en compte la composante environnementale et la préservation des écosystèmes côtiers.

En réponse aux besoins de connaissances manifestés par les Pouvoirs publics qui ont la capacité juridique à mettre en oeuvre les moyens d'une gestion rationnelle de ces environnements littoraux et de leurs ressources, une équipe pluridisciplinaire de l'Université Fédérale de Santa Catarina et de l'Université de Bordeaux I, développe une étude integrée (Sierra de Ledo et Klingebiel, 1994) qui est une partie du "Programa Institucional de Estudos de Sistemas Costeiros" (PIESC) et du Programme de coopération Europe-Amerique Latine de la Communauté Européenne (C.E.). Cette étude a pour but d'établir les bases scientifiques nécessaires à la définition des types d'utilisation de la zone côtière et de ses ressources dans une perspective de développement durable de la région.

Dans ce contexte, les objectifs du projet visent en premier lieu à l'obtention d'une meilleure connaissance des paramètres régissant le fonctionnement des écosystèmes, en particulier en ce qui concerne les processus hydrodynamiques. En second lieu, ils consistent en l'établissement d'un diagnostic écologique,

illustré par des cartes thématiques accompagnées de textes explicatifs, conduisant à des propositions de suivi de la qualité du milieu côtier de l'île. De cette manière, les responsables de la planification et de l'aménagement de ces espaces côtiers, disposeront d'informations susceptibles de les aider dans le choix des diverses possibilités de mise en valeur compatibles avec la conservation du milieu.

La communication de ces données, du niveau scientifique au niveau politico-économique, sera réalisée lors d'un colloque qui se tiendra dans l'Université de Santa Catarina.

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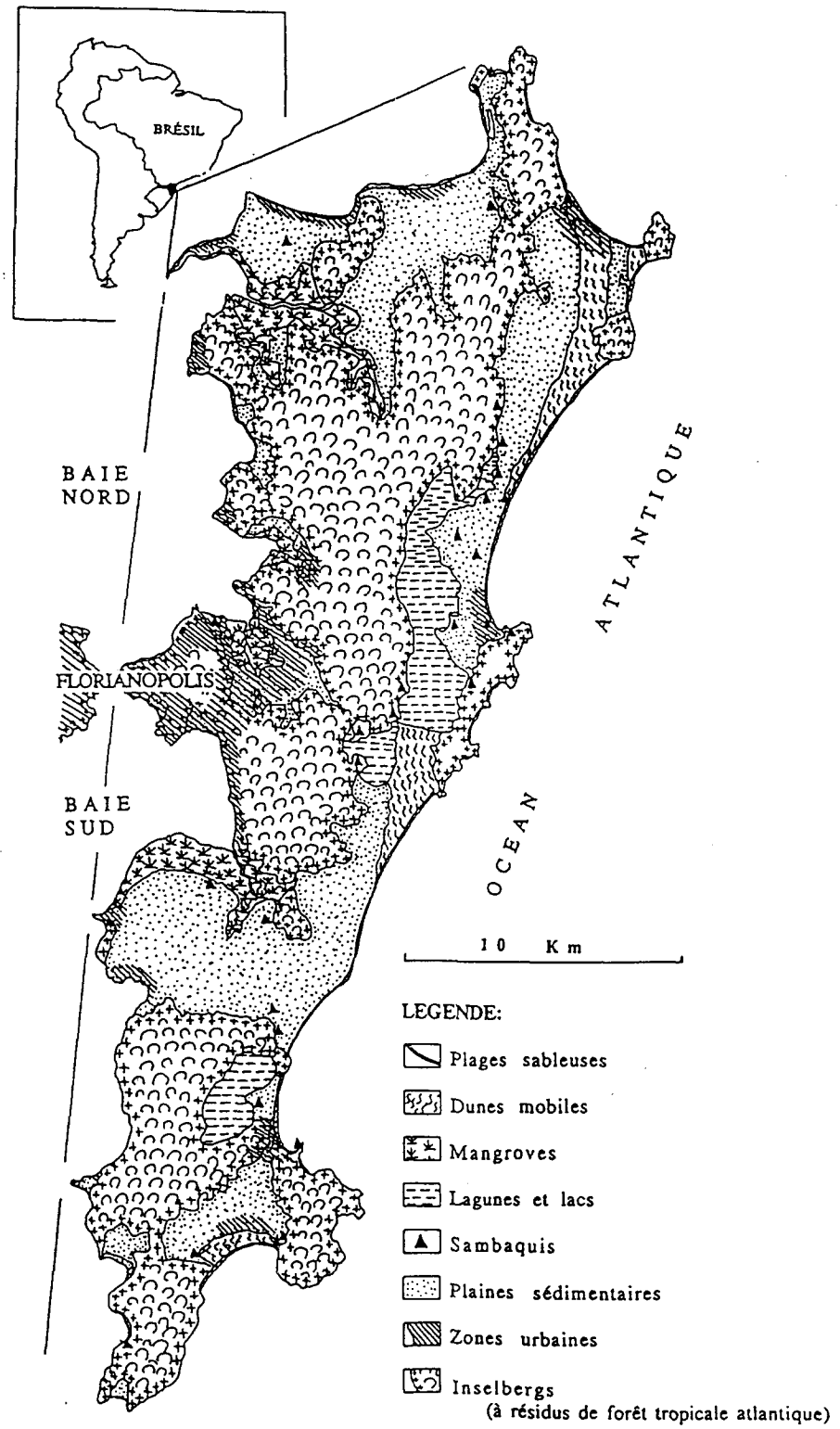
Fig. 1. Site de l'île de Santa Catarina (27° 37' latitude Sud; 48° 27' longitude Ouest; surface totale: 431 km^2), située dans la région subtropicale du Brésil. Le littoral est caractérise par un plateau continental étroit. Sur une longueur totale de 180 km, la côte comprend 98 km de plages.



SESSION IV

Low Tropical Coasts

Session IV-b
Other Coasts

Chairman: R.J. Angulo & S.R. Pezeski
Rapporteur: S.R. Pezeski

Proc. Int. Conf. 'Coastal Change 95' Bordomer-IOC, Bordeaux, 1995, p. 415 - 426

COASTAL CHANGES AND WETLAND LOSSES IN THE MISSISSIPPI RIVER DELTAIC PLAIN, USA

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ABSTRACT

In wetlands of the lower Mississippi delta, anthropogenic factors (river diversions, navigation canals, land conversion, oil drilling activities, etc.) and natural factors (subsidence, saltwater intrusion) have resulted in considerable changes in physicochemical characteristics of wetland soils. The combination of these changes have resulted in vegetation stress and wetland deterioration of substantial magnitude in many coastal habitats including saltmarshes, brackish and freshwater marshes, and coastal forests. Coastal plant communities are confronted with a continuously more hostile environment than in the past. The consequences are a net loss of these resources. Methods such as introduction of freshwater has the benefit of diluting saltwater thus reducing stress on vegetation, however, the costs involved and the limited areas where this method can be applied to are the major concerns. Methods to prevent saltwater intrusion into inland-freshwater areas are primarily based on creating physical barriers such as levees. The approach often results in alteration in hydrology, reduced siltation, thus posing different types of stresses on plants with resultant reduction in plant productivity. While these changes are occurring rapidly, we have achieved some understanding of these ecosystems' structural and functional responses to these stresses in recent decades. Extensive research has been conducted on various aspects of environmental factors and their interactions with the biological systems unique to each habitat. These data bases should be used to formulate changes in regional and habitat-specific wetland management strategies. Such changes are needed to minimize the adverse effects on abiotic and biotic systems and to preserve these valuable natural resources while addressing the problem by finding solutions which are reasonable and cost effective.

INTRODUCTION

Coastal Louisiana contains one of the largest coastal wetland systems of the U.S.A (Fig. 1), approximately 40% of U.S. coastal wetlands and represent wetland losses ranging between 64 to 95 km^2/yr (Dunbar et al., 1990, Britsch and Kemp, 1990). Many factors, anthropological and biological are contributing to the wetland loss including canal dredging, flood control levees, oil and gas recovery operations, land subsidence and sea level rise resulting from the global greenhouse effects are contributing to such losses. If this trend continues, it will result in substantial loss of the wetland resources and the associated industries such as fishing and fur-producing industries.

Based on detailed studies, the present deltaic landscape in Louisiana is a relatively thin layer of Holocene sediment deposits overlying earlier deposits. Rapid delta switching of Mississippi river during the past 7,000 years has resulted in construction of a vast deltaic plain (Kolb and Van Lopik, 1958, Frazier, 1967) (Fig. 2). Parallel progradation of Louisiana coast line occurred at this time due to a number of factors including falling of alluvial valley (Aharon, 1983; Fisk, 1944). The Process was maximized during this

period with the Mississippi River utilizing its sediment load for delta building, resulting in a complex of deltaic sediment deposits approximately 300 km wide and nearly 100 km inland, which is referred to as the deltaic plain. Delta building is a relatively rapid process (Scruton, 1960) leading to the basin-ward extension of marshlands on the subaerial to near-subaerial parts of a newly formed deltaic land mass. Subsequently, as the river abandons its delta, constitutional fluvial process forced by abundant sediment and freshwater are replaced by submergence and wetland loss.

These processes have been known for sometimes but details of the specific processes leading to delta lobe abandonment and the subsequent destructional phases that follows have not received much attention. In coastal Louisiana, where water levels are rapidly increasing largely due to subsidence, a detailed comparison of marsh erosion-accretion processes between sediment-enriched areas such as the modern Atchafalaya Bay area and sediment-deficient marshes such as the Terrebonne and Barataria basin help identify those processes important to maintaining marsh stability (DeLaune et al., 1991, Nyman et al., 1993).

Louisiana wetlands were created over the past several thousand years. The Mississippi River deposited sediment along its way to the sea, sediment primarily deposited along the main channel and distributaries, switching to a shorter route and subsequently building a new delta as this natural phenomena continued (Coleman and Gagliano, 1964). As this process continued, the wetlands resulting from the previous route began to deteriorate to open water while new wetlands being created along the new route which somewhat compensated the loss.

ANTHROPOLOGICAL CAUSES OF WETLAND LOSS

In terms of human activities contributing to wetland loss, several common practices may be responsible. Channelization, levees, draining, land filling and modification of landscape drainage all have adversely affected these ecosystems. These activities in the last century have contributed to the disruption of the natural process of delta building. Extensive levee system built along the river to prevent river overflow and flooding in addition to navigation channels have resulted in increasing river speed thus reducing sedimentation process. Levee construction along the almost entire length of Mississippi route has contributed to the diversion of sediment to the sea and have disrupted delta building processes (Frazier, 1967). Many distributaries no longer exist, consequently the valuable sediment, freshwater and nutrients are mostly lost into the deep waters of Gulf of Mexico.

Various engineering methods have been applied to maintain the present course of the Mississippi River thus preventing large scale switching in delta (USEPA, 1985). U.S. Army Corps of Engineers has constructed river control structure regulating Atchafalaya discharge controlling natural diversion. Nevertheless, Atchafalaya River sedimentation has formed a delta into Atchafalaya Bay, creating new wetlands in the area. Human activities have disrupted the Mississippi River from changing course to Atchafalaya River. Without the control structure presently in place, the majority of the Mississippi River flow would find its way to the Atchafalaya delta creating a much larger wetland than is being formed now.

Canals through their direct and indirect impacts represent another important factor in deteriorating marshes (Turner et al., 1982). These canals provide navigation access of many purposes including those related to gas and oil industry such as pipeline routes and oil and gas drilling activities. Spoil banks created as a result of dredging may disrupt sedimentation and natural hydrology and cause other adverse effects including greater penetration of saltwater into freshwater areas. Erosion imposed by wave actions resulting from travelling boats, saltwater travelling along some of these canals into freshwater vegetation, spoil banks from dredging, draining and filling associated with land development projects, agricultural expansion and navigation all have contributed to certain degree to the disruption of water and nutrient flow to marshes.

One major key factor involved in wetland loss in US Gulf coast is the sediment deficit. Sedimentation process is a requirement for maintaining wetland above sea level. During the last couple of decades, sediment load has decreased dramatically in the Mississippi River (Keown et al., 1980) as a result of human management of the Mississippi River by forcing the river down its present channel. This has deprived wetlands of mineral sediments critical to plant productivity (DeLaune et al., 1990). Maintaining Mississippi River in its present channel halted the delta switching process, causing sediment to be deposited off the continental shelf, and preventing the natural diversion down the Atchafalaya River. The absence of sediment inputs, compaction of existing sediment, and resultant submergence and saltwater intrusion contribute to loss of wetlands. From a historical perspective, deterioration of the coastal wetlands began in the early nineteenth century in approximately the same period that the Mississippi River was leveed. Rate of marsh deterioration was previously estimated at over 130 km^2/yr (Gagliano et al., 1981). Recent estimates, however, have indicated that the loss has decreased (Dunbar et al., 1992). It is important to note that the severity of marsh loss in not uniform throughout the coast. Many factors are contributing here including soil conservation practices and sediment dredging and land disposal (USEPA, 1985). Thus the available amount of sediment for deltaic deposition has diminished, reducing marsh nourishment potential and land building processes.

NATURAL CAUSES OF WETLAND LOSS

Of natural causes, the overall trend of global climate change showing an apparent increase in greenhouse gases and global warming have raised concern that wetland losses may further accelerate in the future (Charney 1979, Nierenberg et al., 1983, Hoffman et al., 1986). The ability of marshes to maintain their elevation at above sea level appears to be critical (Baumann and DeLaune, 1982, DeLaune et al., 1983, Hatton et al., 1983). During 1954-1963 period, while the rate of subsidence were approximately 1.2 cm/yr, some marshes in the area had only 0.72 cm per year accretion (DeLaune et al., 1978, 1983, Hatton et al., 1983).

The process of sedimentation and its continuation is critical to coastal Louisiana due to the fact that coastal areas are flat areas. The subsidence is due to tectonic subsidence as well as compaction (Adams et al., 1976, Mossa, 1980). Tectonic subsidence is large-scale downward displacement due to sedimentary loading and settlement (Adams et al., 1976) primarily linked to the Mississippi River delta building processes (Coleman and Gagliano, 1964, Boesch et al., 1983). With land subsidence estimated at as much as 1.5 to 3.0 meters per century (Russell, 1936). The compaction component is due to many factors including overlying weight due to natural or man-made levees, buildings and developments causing surface sinking as soil become compacted. Another factor is subsurface withdrawal caused by oil and gas recovery operation causing localized surface subsidence (Boesch et al., 1983, Martin and Serdengecti, 1984). Drainage activities lowering water table also affects by dewatering the wetland (Mossa, 1980). Urban development, agricultural activities and flood-control projects may have significant impact on enhancing surface subsidence (Gagliano, 1973).

The combined effects of subsidence and sea level rise, otherwise known as "relative sea level rise, RSLR" represent the net effect of the two factors, subsidence and sea level rise. Global rates were previously estimated from 1.0 to 1.5 mm per year (Barnett, 1984). In Louisiana, RSLR was estimated to be 9-13 mm per year (Baumann and DeLaune, 1982, Ramsey et al., 1985). Gornitz et al. (1982) estimated eustatic rise of 0.24 cm/yr for the Gulf of Mexico as compared to reported global eustatic rise of 0.09 cm yr-1 (DeLaune et al., 1992). Along the Louisiana coast, relative sea level rise is rapid (DeLaune et al., 1992, Penland and Ramsey , 1990). Water level changes are most rapid in the region of active deltas, while it is generally slowest at sites of oldest deltaic deposit. Most recent reported average water level rise for specific sites in coastal Louisiana is 0.76 cm/yr (DeLaune et al., 1992).

Comparison of submergence rates along the Louisiana gulf coast to gauging stations at other

gulf coast states reported by Penland and Ramsey (1990) demonstrates that Louisiana is experiencing the highest submergence rates of all coastal wetlands in the northern Gulf of Mexico region. For instance, Penland and Ramsey (1990) reported a relative sea level rise along the Texas coast of 0.33 cm/yr (Port Isabel) to 0.62 cm/yr (Galveston). In Gulf coastal regions east of Louisiana, Penland reported rates of 0.15 cm/yr (Biloxi), 0.23 cm/yr (Pensacola), 0.17 cm/yr (Cedar Key), 0.10 cm/yr (St. Petersburg), and 0.22 cm/yr (Key West). Assuming the eustatic sea level to be 0.23 cm/yr for the gulf based on the geologically stable Key West station, it becomes obvious that Louisiana is experiencing water level increases of much larger magnitude than eustatic changes. Based on these analysis, subsidence or compaction of coastal sediments along the Louisiana Gulf Coast is significantly greater than eustatic sea level rise (Ramsey and Penland, 1989). Subsidence along the coastal Louisiana in many instances exceeding 1.0 cm/yr, is greater than most other locations on the northern Gulf of Mexico coast (Penland and Ramsey, 1990). At certain locations (deltaic regions), water level changes due to subsidence are five times that of sea level rise. The importance of submergence in wetland loss is easily recognized when comparing loss rates to subsidence rates. Subsidence combined with deficiency of marsh soil accretion, are the primary process contributing wetland loss in coastal Louisiana (DeLaune et al. 1992).

THE SIGNIFICANCE OF MINERAL MATTER SUPPLY

Accretion is accomplished through a combination of mineral sediment accumulation and peat formation. The two are interrelated because the influx of sediments also supplies nutrients for plant growth (DeLaune et al., 1979). Enhanced plant growth results in greater peat formation and increased stem density, allowing further entrapment and stabilization of sediment. Several factors may influence the rate of formation and depth of marsh soils including hydrology, local subsidence, eustatic sea level rise, oxidation, and the compaction of surface peats (DeLaune et al., 1992). The oxidation and decomposition process in surface peats can annually remove several hundred grams of organic carbon through CO_2 and methane emission to the atmosphere (Smith et al., 1983, DeLaune et al., 1983, DeLaune et al., 1992). To counter submergence (the combination of global sea-level rise and subsidence), the marsh surface must accrete vertically by forming additional marsh soil (Fig. 3). Marsh soil formation during submergence can be self regulating because as flooding of the marsh surface increases, tidal delivery of mineral sediment increases, and decomposition increases (Mitsch and Gosselink, 1986). However, in some cases soil formation can be inadequate to maintain the marsh surface at the level of the intertidal zone (DeLaune et al., 1983a), resulting in excessive flooding of the marsh surface. Soil waterlogging stresses can become severe enough to cause vegetation dieback (DeLaune et al., 1983b, Mendelssohn and McKee, 1988) which may lead to pond formation.

The significance of mineral matter is due to the fact that it provides plant nutrients, buffers against sulfide toxicity, and promotes soil drainage. There are numerous studies supporting this hypothesis. For instance, King et al. (1982) reported a positive relationship between soil Fe concentrations and vegetation productivity in a Georgia marsh. Broome et al. (1975) found a positive relationship between soil P and saline marsh vegetation productivity in North Carolina. Bradley and Morris (1990) observed a positive relationship between soil bulk density and soil water percolation velocity in South Carolina. Soil bulk density is a function of soil mineral matter content (Hatton et al., 1983), and end-of-season standing crop biomass of *Spartina alterniflora*, a major U.S. Gulf coast species, is positively related to soil P, soil Fe, and soil bulk density in Louisiana marshes (DeLaune and Pezeshki, 1988). Mineral sedimentation is often a function of tidal action, but delivery of sediment by winter storms is more important in Louisiana (Reed, 1989). It has been experimentally shown that sediment addition to marsh surface increases plant productivity in deteriorating saltmarshes (DeLaune et al., 1990). Raising the marsh surface approximately 10 cm with the equivalent of 94 kg

sediment/m^2 doubled plant above-ground biomass production (Fig. 4). The sediment addition enhanced shoot regeneration as well as height growth substantially compared to control plots. Enhanced production of new shoots per unit area of marsh resulted in increased leaf area which allowed a greater capacity for net photosynthesis and contributed to increases in above-ground biomass of sediment treated plots (Pezeshki et al., 1992). These studies support the hypothesis that supplying sediments to the sites of abandoned delta lobes will help reverse the current land loss trend locally. However, from a practical stand point, there is simply not enough sediment available from Mississippi-Atchafalaya River sources to restore all of Louisiana's wetlands.

THE SIGNIFICANCE OF HYDROLOGY AND SALTWATER INTRUSION

Frequency, duration, depth of flooding and concentration of salt are important factors which affect plant distribution, productivity and coastal marsh stability. Sediment physicochemical characteristics become critical to plant productivity once soil is flooded including pH, redox potential and ionic content (Armstrong, 1972, DeLaune et al., 1976). Under reduced soil conditions (low redox potential) organic substrates are not decomposed and phytotoxic compounds such as H_2S are formed which create additional stress on vegetation (Ponnamperuma, 1972, DeLaune et al., 1983). This is well demonstrated since the zonation of plants in U.S. Gulf coastal marshes is a classical example of how plant zonation is closely associated with dominant environmental gradients, in this case, governed by sea level and tidal cycles as has been reported elsewhere (Hinde, 1954, Adams, 1963).

Saltwater intrusion influences survival, growth and species composition of wetland habitats along the U.S. Gulf coast. The net effects of sublethal salt stress is a reduction in growth (Waisel, 1972). For most species growing naturally in salt- and brackish marshes, elevated salinity does not create a favorable environment for maximum growth and productivity (Parrondo et al., 1978, Pezeshki et al., 1989). In fact, numerous studies under a broad range of laboratory and greenhouse conditions have shown that salinity in the range endured by these species in U.S. Gulf coastal marshes in fact reduces the growth potential of major species from Louisiana brackish and saltmarsh communities (Gosselink et al., 1977, Drake and Gallagher, 1984, Bradley and Morris, 1991, Pezeshki and DeLaune, 1991, Hellings and Gallagher, 1992).

As it is evident from the existing literature, saltwater intrusion can significantly impact survival and growth of wetland species from various habitats in U.S. Gulf coast. There are numerous examples documented in the literature. For example, in saltmarsh species such as *S. alterniflora* (Gosselink et al., 1977), in *D. spicata*, plant dry weight was reduced by 35% elevated salinity (Parrondo et al., 1978), *S. cynosuroides* (Gosselink et al., 1977), in *S. alterniflora* and *S. cynosuroides*, plant dry weight was reduced 80% in response to 540 mol/m^3 salt treatment (Parrondo et al., 1978).

In fresh and brackish marsh communities, saltwater intrusion is expected to cause substantial stress on plants. For instance, salinities ranging between 170-200 mol/m^3 caused leaf tissue death, severe injury and death of plants in *Panicum hemitomon*, a dominant fresh marsh species (Pezeshki et al., 1987b). Population of *S. patens*, a dominant brackish marsh species, showed reduced growth in response to elevated floodwater salinity from 85 to 430 mol/m^3. Various biomass components including foliage and roots were reduced significantly (Pezeshki and DeLaune, 1991).

Marsh loss or wetland deterioration is governed by a feedback loop of plant flooding and salinity stress and inadequate vertical accretion resulting from coastal submergence (Nyman et al., 1993). Vertical accretion depends directly on organic matter and mineral sediment accumulation, but plant growth, reduced because of stressful conditions, resulted in inadequate soil organic matter to counter submergence. Thus depressed plant productivity may increase the vertical accretion deficit, initiate another cycle of declining plant production and increasing vertical accretion deficits (Nyman et al., 1993). Although increased tidal flooding usually increases mineral matter

accumulation (Mitsch and Gosselink, 1986), tidal flooding is relatively unimportant to sedimentation in coastal Louisiana, and winter storms are more important (Reed, 1989). Thus, the most important sedimentation events probably have not greatly increased in frequency even though tidal flooding and salinity have increased (Nyman et al., 1993). The predicted global warming, if true, will cause a much greater impact of sea level rise in Louisiana Gulf coast due to warming effects leading to expansion of ocean water and melting of glaciers (Nierenberg et al., 1983, Revelle, 1983, Hoffman et al., 1983). Saltwater intrusion, a by-product of land subsidence, sea level rise, barrier island erosion, canals and many other factors, causes wetland deterioration particularly in freshwater areas. The decline of cypress forests in coastal Louisiana is an example of how these environmental factors may adversely affect plant communities and how vulnerable these communities may become. These swamp forest are presently being converted to open waters at an alarming rate.

METHODS OF CONTROLLING WETLAND LOSS

There are many methods which may help reduce the rate of wetland loss including freshwater diversion into marshes, modification of patterns of water and sediment flow and barrier island restoration, etc. Barrier island restoration is aimed at maintaining these islands. Such efforts will improve coastal wetland protection against storm and wave erosion impacts. The restoration does not interfere with any other land development and/or any other activities. The measure however, has limited impact as it does not prevent wetland losses due to submergence and other factors. Many factors may have contributed to shoreline erosion force which appear to have increased over time exceeding ten meters per year along the barrier coast. These factors include subsidence, reduced sedimentation, sea level rise, and other factors (Penland and Boyd, 1982, Penland et al., 1985). The erosion threatens coastal areas including some industrial and residential developments creating potential threat for major cities such as New Orleans in the event of severe storms.

Wetland restoration has been used as a measure of dealing with wetland loss. For instance, dredged materials from canals could be used in marsh building efforts. Drained areas could be converted to wetlands. These techniques, however are limited in scope since dredged materials are limited.

Marsh management refers to a host of approaches aimed at minimizing the impacts of human activities and maintaining marsh ecosystems. In coastal Louisiana, such activities include regulation of inflow/outflow of water from a given marsh system using a system of levees or dikes or other types of flow control structure. Drainage using pumps in order to regulate water level is also practiced in certain areas. Many management plans in the area incorporate control of water levels and salinity using techniques for restriction of saltwater inflow and increase freshwater output or inputs. These methods, however, have limited effects. If sea level rise continues, it may require pumping of water in order to achieve any control over water levels.

Periodic sediment spray on a marsh surface has also been considered as a technique. Such techniques provide nutrients for the vegetation thus enhancing plant growth (DeLaune et al., 1990, Pezeshki et al., 1992) which also enhances vertical marsh accretion. Logistics and cost effectiveness of this technique remains to be resolved.

Land use activities are also major factors. For instance, lower marsh traffic, lower drainage activities, slower speed of boats, decreased dredging activity in existing canals, refilling or plugging some of the existing canals may be used as alternative management strategies. These strategies, however, will not prevent wetland losses completely as subsidence and sea level rise will continue which would cause some wetland degradation.

Several measures were considered to be important in slowing the rate of wetland loss in Louisiana including: diverting the Mississippi River route to maximize marsh creation, reduction of canal system, creation of barriers to protect wetlands

from excess flooding and saltwater intrusion (USEPA, 1985). Other options include construction of freshwater diversion structures allowing introduction of freshwater into marshes thus providing additional sediments and reducing salinity which will increase vegetation productivity. Such plan is also limited by the amount of water which can be diverted as it will affect flow rates in the river main channels and that the sediment deposited will not be enough to compensate for the combined subsidence and sea level rise. The strategy, nevertheless, has been considered as an excellent short-term plan for wetland protection (USEPA, 1985).

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Fig. 1. The Louisiana coastal zone (shaded area).

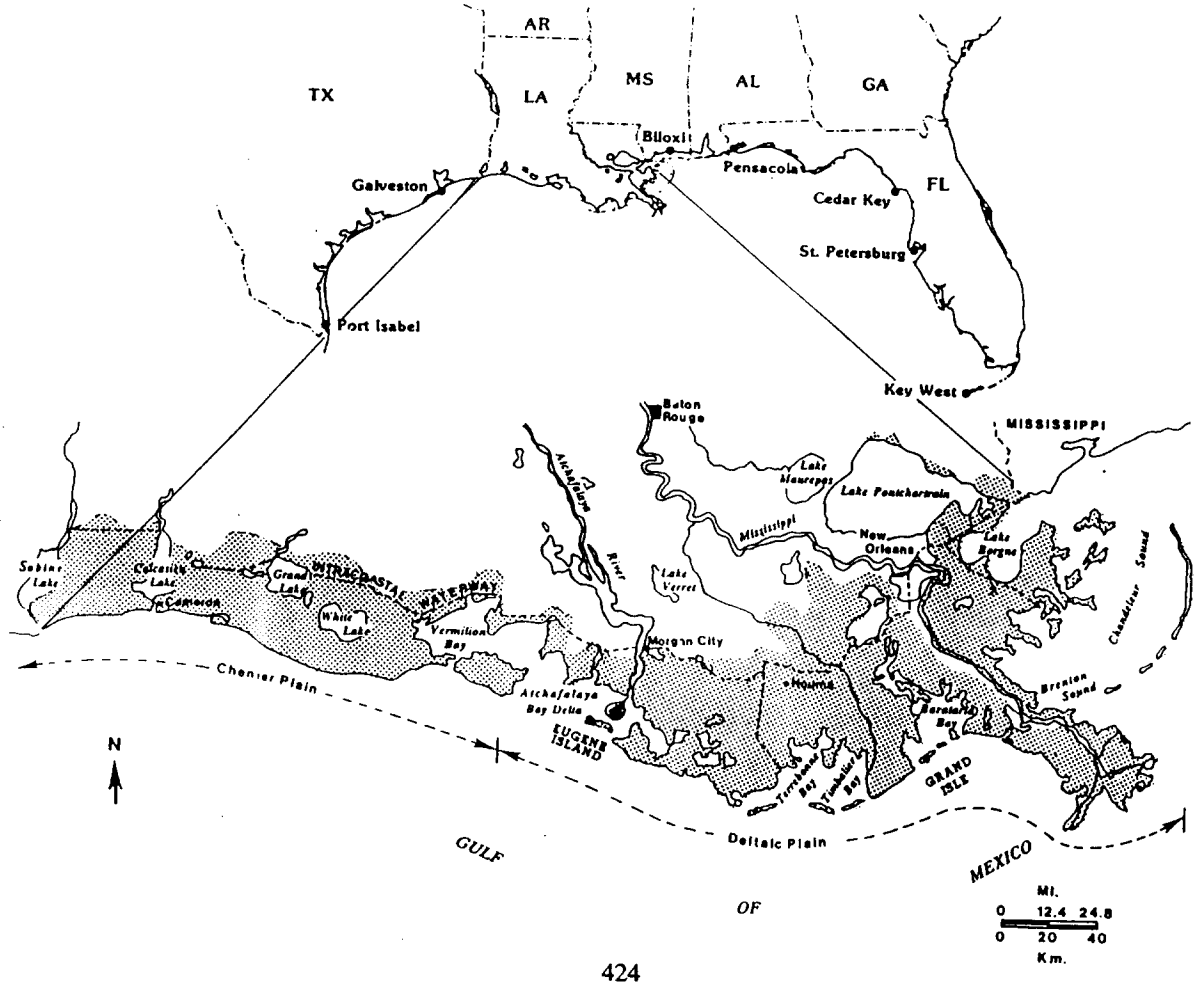


Fig. 2. Mississippi River delta; after Kolb and Van Lopik, 1958).

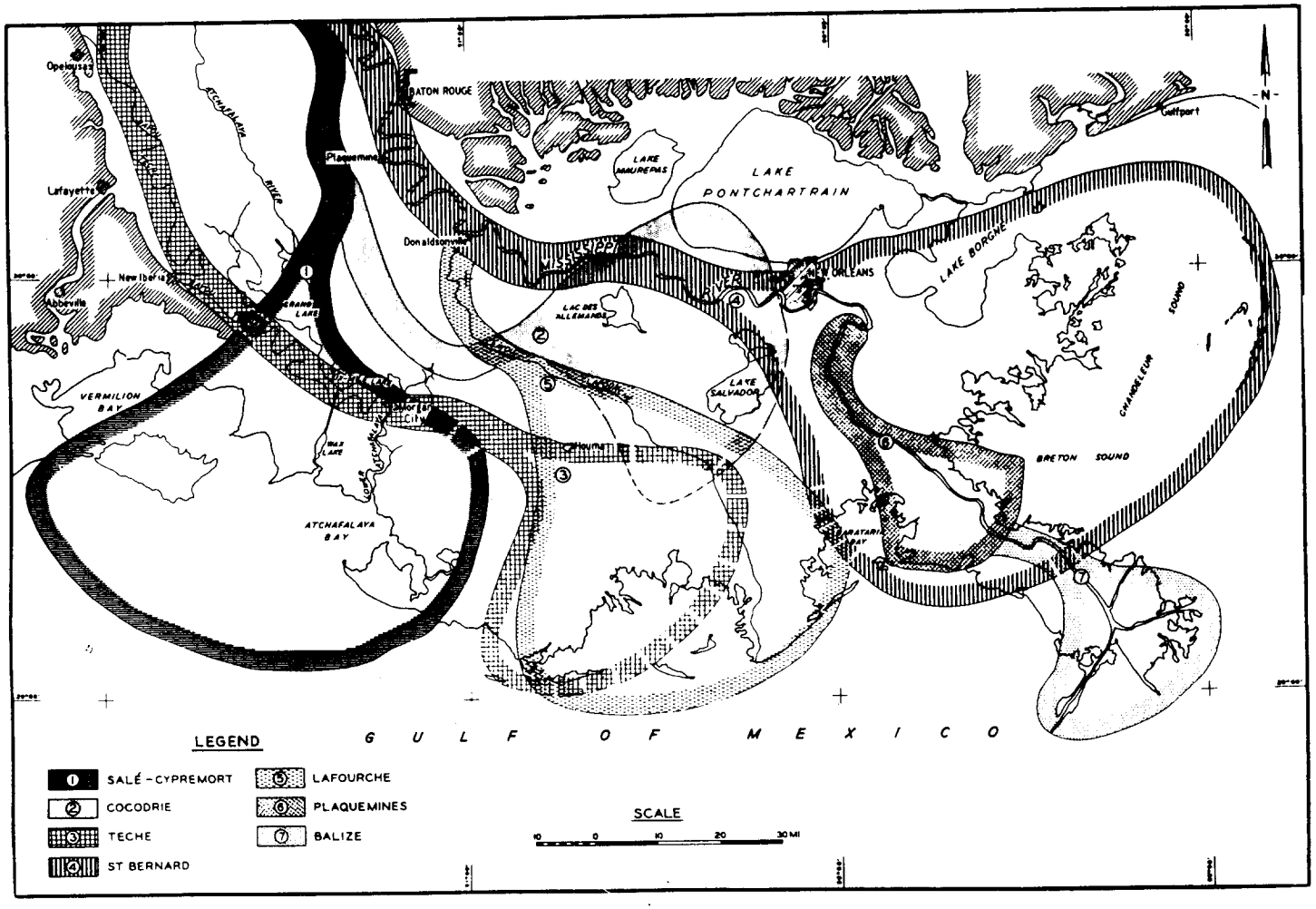
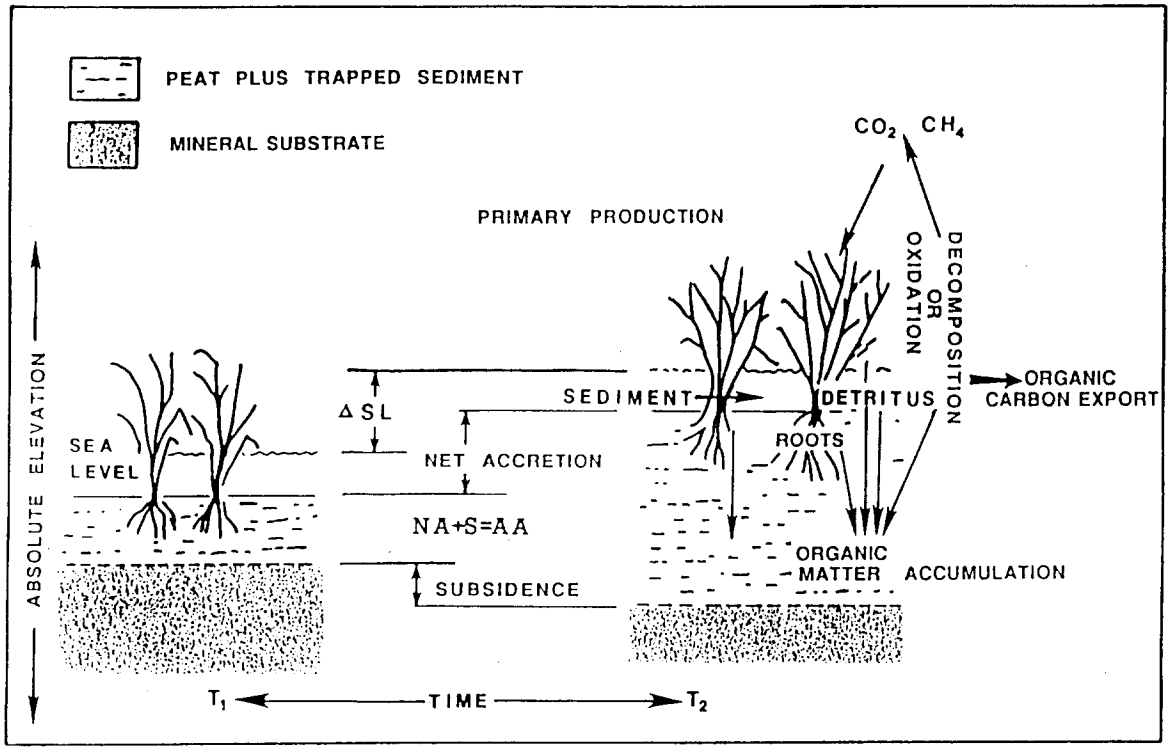


Fig. 3. Schematic model of processes governing marsh accretion (ΔSL = sea level, NA = net accretion, S = subsidence). From Delaune et al. (1990).



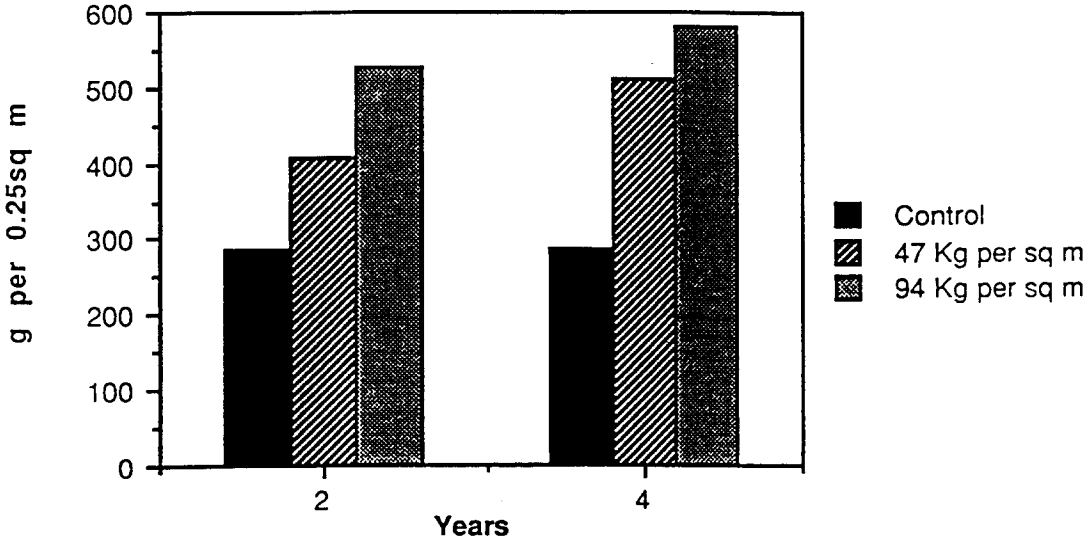


Fig. 4. Above-ground biomass production in *Spartina alterniflora* responded positively to sediment addition two and four years after treatment initiation. From Delaune et al. (1990).

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NATURAL DYNAMICS AND LAND USE ON THE COAST OF PARANÁ, BRAZIL: BACKGROUND AND PROSPECTS

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ABSTRACT

The problems brought about by land occupation on the coast of Paraná by ports, sea-side resorts, farming, fishing and environmental protection are illustrative of the current situation in Brazil, a developing country where millions of dollars have been drawn from scarce financial resources over the past decades to engineering works whose need and effectiveness are, at least, questionable.

Systematic environmental analysis reveals that such structures often result inefficiently, for the totality of coastal dynamic factors involved is seldom taken into account in their planning. Also, and more seriously, chain environmental effects induced by positive feedback lead to unstabilization of large coastal areas and hence, to new problems. Many of such problems could have been avoided if simple, sometimes quite obvious prevention steps had been taken.

Yet, expeditious process-product geological and geomorphologic studies of ancient and present coastal features through aerial photographs and satellite images, would suffice for important dynamic factors such as waves, tides and tidal currents to be better known, the scarcity of data is not rarely assumed to justify the so called emergency works that are laid down with little environmental background information.

Angulo (1993a,b,c) presents an overview of the evolution and magnitude of morphodynamic changes over the coast of Paraná. The coast is divided into three different sectors:

(a) open sea, with sandy beaches and wave-controlled dynamics;

(b) estuarine, with tidal flats mostly covered by mangroves under tide-controlled dynamics; and

(c) river-mouths, with sandy beaches and wave- and tidal current controlled dynamics.

Cyclical and unidirectional erosion, sedimentation and threshold phenomena are reported. In several situations, the causes of erosive processes can be identified, and the effectiveness of the engineering works assessed, which would certainly be helpful in land use planning, zoning and regulation, and would also discourage certain types erosion control works.

INTRODUCTION

The coastal zone of Paraná, in southern Brazil, is confined by the latitudes 25° S and 26° S and by the longitudes 48° W and 49° W. The general NE trend of its 105 km of sandy beaches is broken by three inlets, one at Paranaguá Bay (Knoppers et al., 1987), one at Guaratuba Bay and the other one at Superagüi Channel (Fig. 1).

Climatologically, the coastal plain of Paraná corresponds to a humid subtropical mesothermal one, with hot summers (Cfa) in the classification of Köeppen (IAPAR, 1978). The mean annual temperature varies between 20.8 °C and 22 °C (IPARDES 1990, 1991). Wind regime is basically conditioned by the South Atlantic Anticyclone and by the Atlantic branch of the Polar Anticyclone (Bigarella et al. 1978). The prevailing winds blow from the south and the east quadrants. South winds are stronger, reaching to 12-14 m/s. Rain over the coast of Paraná is either cyclonic, orographical, or caused by convection. The mean annual rainfall amounts to 2,500 mm (IPARDES 1990). In summer, rainfall amounts to 100 mm or, occasionally, to about 400 mm per 24 hours.

The coast of Paraná includes a mountain range system called Serra do Mar and extensive coastal plain cut by estuarine complexes. Two different types of mountains form Serra do Mar: plateau borders and those resultant from differential weathering. The former, about 900 m high, result

from desiccation of the borders of Curitiba Plateau, to the west. The latter, whose altitudes reach from 1,300 m to 1,800 m, i.e., from 400 m to 900 m above the plateau level, consist of weather-resistant granites and volcanic rocks.

Altitudes at the coastal plains are progressively lower than 20 m above sealevel. Isolated hills, hundreds of metres high, are occasionally present. The coastal plain of Paraná is divided into two different sectors, one to the north, the other to the south of Serra da Prata, a northwest branch of Serra do Mar that reaches to the sea at Caiobá. To the north, the coastal plain is wider, reaching to 55 km at the latitudes of Paranaguá. Three estuarine complexes lie within this coastal sector, namely Baía de Paranaguá, Dos Pinheiros bay-Superagüi channel system and Ararapira sea. Paranaguá Bay stretches along two main axes. Where along a 45 km long, about 7 km width east-west one, it includes Antonina Bay and Paranaguá Bay itself; where along a north-south axis, it includes Das Laranjeiras Bay, which is approximately 30 km long and up to about 13 km wide. Except for their main channels, where it can reach more than -20 m, the mean depths in these bays are normally shallower than -10 m. To the south of Serra da Prata lies Guaratuba Bay, which consists of a shallow east-west 16 km long and 3 km wide water body (low tide considered; 10 km when tidal flat is considered).

Geologically, the coast of Paraná comprises two different domains: the continental shield and a Cenozoic sedimentary cover. The continental shield consists of Arquean granulitic rocks, Early Proterozoic gneiss and migmatite, Proterozoic and Cambrian granites, cambrian igneous and sedimentary rocks, and Mesozoic intrusive rocks (MINEROPAR 1989). The Cenozoic sedimentary cover includes Early Miocene to Holocene continental talus, colluvia, fluvial, alluvial fans and cones, as well as strand plain (sandy shoreface, beach and foredune) and estuarine-lagoonal sediments (tidal flat, lagoonal and estuarine shoal. All these coastal sediments were deposited during the regressive periods that followed two transgression peaks at 120,000 and 5,100 yr. BP (Martin et al. 1988, Angulo 1992). The coast of Paraná is under semidiurnal microtidal (< 2 m) regime. Calculations using Defant's equation (Defant 1958 and Komar 1976) on marigrams from Paranaguá port indicate 0.24 for a period of one year. Such a result lies too close, however, to those characteristic of predominantly semidiurnal mixed tides, which means that secondary tides occur within shorter periods of time (Angulo 1992).

Due to the coastal configuration and tide regime, tidal currents are generated at the inner and outer parts of the estuaries, of which little is known. The scarce oceanographic data, available from a campaign carried out by the Instituto de Pesquisas da Marinha (a navy's research institute), indicate that ebb currents are faster (Bigarella et al. 1978). Since measurements were taken under unstable weather (Knöpers et al. 1987), the indication should only be regarded as a momentary example. Also, the low number of measurement sites makes identification of preferential ebb and flow patterns virtually impossible. The wave regime of the coast of Paraná is unknown.

LAND USE

Land use on the coast of Paraná is diversified. Two ports are operated at Paranaguá Bay: Paranaguá, through which most of the Brazilian grain is exported, and Antonina, a port of secondary importance. At Ponta do Poço, (outer Paranaguá Bay), except for an oil platform assembly plant, industrial and commercial activity is incipient. Paranaguá is the biggest city on the coast of Paraná, with a population of 100,000 inhabitants. Other cities on the coastal zone of Paraná are Antonina, Morretes, Guaraqueçaba, Matinhos, and Guaratuba. Matinhos and Guaratuba, with their extensive open-sea beaches, are important tourism centres. In Antonina, Morretes and Guaraqueçaba, agriculture is the most important activity. Land use on the coast of Paraná is governed by several environmental regulations. Examples are the decree 5055 of 1989, the decree by which Serra do Mar was put under state safeguard and the establishment of Superagui National Park and Guaraqueçaba environmental protection area. Islands, either oceanic or estuarine, and the stripe 33 m from high tide landward are under federal jurisdiction.

LAND USE VS. COASTAL DYNAMICS

In the first hours of September 23th, 1968, under low tide, a 100 m long and 30 m wide part of the city of Guaratuba disappeared under the homonym bay. According to Bigarella & Becker (1975), the mass movement was anthropogenically triggered. A pier, perpendicular to the coastline, generated eddy currents and interrupted sediment transport, which led to erosion downstream. Embankments and a seawall had also been built along part of the bay. By 1968, erosion reached the foundations of the seawall, which, together with low tide and high water table, triggered a rapid mass movement by which sediments an buildings were carried underneath the waters. This is the only event on the coast of Paraná reported to have involved mass movement. Fortunately enough, coastline shifts seldom take place so quickly. In the 1960s, one of the most sought after resorts on the coast of Paraná, Praia Mansa de Caiobá, underwent erosion. The process, which was intense enough for community and government to join forces, is thought to have been triggered by a series of factors. As stressed by Motta (1976), at that coastal sector development invaded the swash zone. A seawall along the beach caused total reflection of waves. According to Angulo & Andrade (1982), the erosive potential of waves had possibly been made stronger by a 300 m shift of the frontal bars from the coastline.

Praia Mansa de Caiobá is a good example of how difficult and expensive erosion control can be. At that beach, which is only 600 m long, US$ 1.3 million were spent until 1982 to control erosion (Lindroth 1982). Despite the actual causes of the process remain undetected, steps were suggested to stop erosion. One step, put forward by the Laboratório Nacional de Engenharia Civil de Portugal, would include the construction of rockmound structures parallel to the beach, a groin, and artificial feeding (LNEC 1977). However, the project was interrupted at the initial phase due to technical problems (Lindroth 1982). A seawall and a series of small gabions built by Empresa de Obras Públicas do Paraná stopped erosion, and the beach was partially recovered. Praia Brava de Caiobá was another sector of the coast of Paraná to experience problems caused by marine erosion. At the south end of that beach, erosion was found to have been concomitant to the migration of a transversal bar. Urbanization of Praia Brava took place in the 1960s, when a transversal bar caused waves to be refracted, which in turn resulted in an exceptional widening of the beach. As migration of the transversal bar progressed northward, wave refraction became lower and the shoreline naturally tended to return to its original position. This natural process, however, was impeded by the advanced urbanization of the area, and prevention works were built to stop erosion. Rockmound structures were precariously laid. By 1981, erosion at the central parts of Praia Brava reached great proportions. The beach was eroded and a seawall was totally destroyed. Pavement and part of an avenue were also affected. According to Angulo & Andrade (1982), erosion at Praia Brava followed the littoral's dynamic tendency to re-reach equilibrium, that had been broken where a rectilinear stretch of sea-side avenue was built. Embankments and a seawall were set along part of the beach. Only the invaded sector underwent erosion, and the seawall was totally destroyed. At other sectors of the beach, where no prevention works had been built, no erosion was observed. However, owing to the advanced urbanization of the area, a shift in the avenue's line was impracticable. In the middle of 1985, seawalls and groins were set to stop erosion. By 1994, deposition of sand adjacent to the groins amounted to 27.1 m^3 per metre shorelength, as compared to two local profiles, one of 1981, the other of 1993 (Angulo & Soares 1994).

In the north part of Praia Brava, intense erosion was observed after erosion control works were laid at the central parts of the beach. Seawalls and groins of gabions were built. Embankments to enlarge a lawn area alongside the avenue advanced over part of the beach. Such works did not resist storm waves. At Matinhos, to the north of Praia Brava, a wide pavement invaded part of the beach. Storm waves reflected by the seawall eroded the beach, and the pavement was destroyed. In 1994, just before summer, the local authorities decided for artificial feeding of the

beach with shoreface sands. To the north, still in the municipality of Matinhos, several km of sea-side avenue were traced. Again the avenue invaded the beach in some sites. Rockmound structures were built to prevent erosion.

In the early 1980s, a wide pavement in the north of Guaratuba beach was partially destroyed twice. Despite the fact that the pavement had invaded the upper part of the beach, destruction was found to have not been caused by waves. EPI (1980) and Angulo & Andrade (1982) reached the same conclusion that erosion there had been triggered by both runoff and an inefficient drainage system.

Erosion has been observed in other parts of the coast of Paraná such as Barra do Saí, between Pontal do Sul and Ponta do Poço, Ilha do Mel, Ilha das Peças and Barra do Ararapira over the past decades. Population of those areas, however, is too low to justify governmental action. Between Pontal do Sul and Ponta do Poço, erosion was caused by coastal dynamic changes induced by the construction of a channel that interrupted longshore drift (Angulo 1993). Landowners had then to have engineering works laid down.

On Ilha do Mel, naturally induced erosion has led to coastline shifts of tens of metres in some sites. As a consequence, many houses have had to be abandoned.

In the far north coast of Paraná, a continual southwestward migration of the inlet that connects Mar de Ararapira with the Atlantic Ocean has caused more than 100 ha of the strand plain to be eroded over the last 30 years. Fishing villages had to be rebuilt elsewhere on the coast.

The most intense erosive process on the coast of Paraná over the last 30 years, however, occurred at the south end of Ilha das Peças, an unpopulated area where coastline shift has been of approximately 1,300 m (Angulo 1993).

Not only erosion, but also marked deposition of sediments has been observed on the coast of Paraná over the past years. At Praínha, the coastline has prograded 200 m in less than 30 years. In 1980, areas newly emerged were developed.

The same occurred at Pontal do Sul, where the coastline has prograded about 300 m. The emerged area was soon turned into a housing estate, but former owners of "sea-side" estates would not accept any facilities built between their properties and the sea. The new estate was embargoed in justice.

DISCUSSION

As shown in this brief account, land use on the coast of Paraná has almost always disregarded coastal equilibrium aspects. Occupation has characteristically sprawled as near as possible to the coastline, sometimes over beaches themselves. As population increases, beaches are further invaded by sea-side avenues and other facilities. Alterations in littoral dynamics caused by land use often lead to erosion, which endangers facilities. Praia Mansa, Praia Brava, Matinhos and Pontal do Sul are examples of such problems.

Another aspect that becomes evident is that large areas are unstabilized by chain reactions triggered by inadequately projected erosion prevention works. New works are then necessary. Praia Brava is illustrative of such situation. The marine erosion observed in the central part of Praia Brava in the early 1980s was found to have naturally followed alterations in littoral dynamics when the beachface was invaded for the construction of a sea-side avenue, which affected the original sinuosity of the coastline. Seawalls and dikes of gabions were used to stop the process. As the net littoral drift along the coast of Paraná is northward, however, deposition was intensified in the central part of the beach, whereas erosion prevailed to the north. The same mistakes have been made along other sectors of the coast. First, beaches are invaded and unstabilized. prevention works are laid down to prevent erosion. Adjacent areas are unstabilized, and new prevention works become necessary.

Risk housing estates quickly sprawl over areas newly emerged such as Prainha de Caiobá. The problem has not become really serious yet because population over most sectors of the coast of Paraná is still sparse. Many of such problems could have been avoided if simple, sometimes quite obvious steps had been taken. The scarcity of data concerning littoral dynamics, waves, longshore currents and tidal currents, on the coast

of Paraná is often used to justify so called emergency works that are laid down without any environmental background information. Expeditious geological and geomorphological studies on coastal features, aided by recent and former aerial photographs and satellite imagery, would allow important aspects of the littoral dynamics to be better understood. Such kinds of studies allow processes to be inferred from their products, i.e., geologic and geomorphologic features.

At shallow parts of bays, for example, morphologic properties of sedimentary deposits, reflect sediment transportation, which is controlled by oceanographic factors. At Guaratuba Bay, sediments accumulate from the islands downdrift, which indicates primary transportation by ebb-tidal currents (Bigarella & Salamuni 1962). Within 3 km from the inlet, however, sediments accumulate upstream, which indicates local predominance of flow-tidal currents (Angulo 1992). In areas where littoral dynamics is influenced by estuarine inlets, the spatial arrangement of shallow sedimentary deposits is normally more complex, with tidal deltas and associated features, which result from interaction of flow tide and ebb-tidal currents, waves and longshore currents (Angulo 1992). In several cases, migration of sand bars, sand waves and subaqueous dunes can be traced from aerial photographs, and the prevailing currents can be inferred. The northward migration of creek mouths is morphological evidence that the net littoral drift on the coast of Paraná is to north (Bigarella et al. 1966; Angulo 1992). The northward littoral drift is probably due to the action of south and southeast waves generated by winds of the South Atlantic Anticyclone, especially those related to cold fronts.

Geological and geomorphological studies allowed to determine, for example, that tidal inlet-influenced beaches have their variability controlled by ebb-tidal delta shoal migration (Angulo 1992, 1993a, 1993b). Oceanic coasts normally remain stable over long periods of time. At the open beaches of Paraná, little progradation or erosion have been observed over the last 40 years, as depicted from different series of aerial photographs (Angulo 1993c; Angulo & Soares 1994). The sedimentation and erosion processes observed between 1981 and 1993 along beach profiles are attributed to normal meteorological changes, which influence beach morphodynamics. These beach profiles seem not to have been influenced by factors such as sea level change, which controls the evolution of large coastal sectors (Angulo & Soares 1994).

Angulo (1993) classifies different sectors of the coast of Paraná into three basic types according to their natural dynamics:

(a) open sea with sandy beaches and wave-controlled dynamics;

(b) estuarine with mangroves over tidal flats and tide-controlled dynamics; and

(c) estuarine inlets, with sandy beaches and wave and tidal-current controlled dynamics (Fig. 1).

Based on such studies, evolution and magnitude of changes in littoral dynamics are drawn for several sectors of the coast. Cyclical and unidirectional erosion/sedimentation processes as well as threshold phenomena were identified. In many cases, the causes of erosion and the efficacy of the prevention works were assessed. Estuarine and open coasts were found to have remained stable over the past decades, showing no significant changes, except where altered by human activity. coastal inlets, in turn, have shown to be areas of great morphodynamic instability, where coastline shifts of more than 1,000 m and erosion of more than 100 ha of strand plain have been occurred in less than 30 years

CONCLUSIONS AND RECOMMENDATIONS

Natural erosion and sedimentation along the coast of Paraná over the past few decades and the subsequent coastline shifts have been substantial enough to be considered in land use planning. The importance of knowing littoral morpho-dynamic patterns in the identification of areas of different stability has became more and more evident. As a rule, urbanization of the south coast of Paraná has taken place exceedingly near shoreline and even over the beaches. In many cases, natural or anthropogenic shoreline changes are only taken into account when erosion actually reaches facilities and urgent erosion control is

required. Areas newly emerged by deposition of sediments have been immediately turned into housing estates. Classification of coastal sectors according to their morphodynamic stability is an important planning instrument, through which reliable retreats can be established for each case. Despite lacking more detailed studies on littoral dynamics, the available data and classifications allow preliminary land-use regulation to be put forward.

On the coast of Paraná, open beaches, where littoral dynamics is controlled by waves and longshore currents, seem to have reached equilibrium, showing no significant shifts over the past four decades. Buffer zones of 30 m from high tide, as commended by legislation, are normally reliable. For coasts influenced by inlets of estuarine-lagoonal systems, however, new land use regulations seem necessary according to each coastal sector in particular. Some steps are put forward:

1.- buffer zones of approximately 100 m in areas of coastline shifts inferior to those observed over the last 40 years;

2.- non-occupation of areas that emerged during that period of time, owing to their high instability and liability to reversion;

3.- non-occupation of sectors where coastline shift has amounted to hundreds of metres, such as the south end of Ilha das Peças;

4.- non-occupation of areas with a tendency to continuous erosion, such as the left margin of the mouth of Ararapira Sea.

Being less likely to represent material losses, leisure facilities should be a first priority in unstable areas. The observation of safety retreats for buildings and other seaside facilities and the non-occupation of inappropriate areas would represent a less risky occupation, even for the beaches themselves. Reduction of land use risks would also benefit the whole country as less money would have to be spent to control erosion. Environmental control would be made easier. Expeditious process-product geological and geomorphological studies of ancient and present coastal features would provide sound basis for coastal land-use planning, zonation and legislation. Such studies would also allow the suitability of preventive measures to be more precisely assessed.

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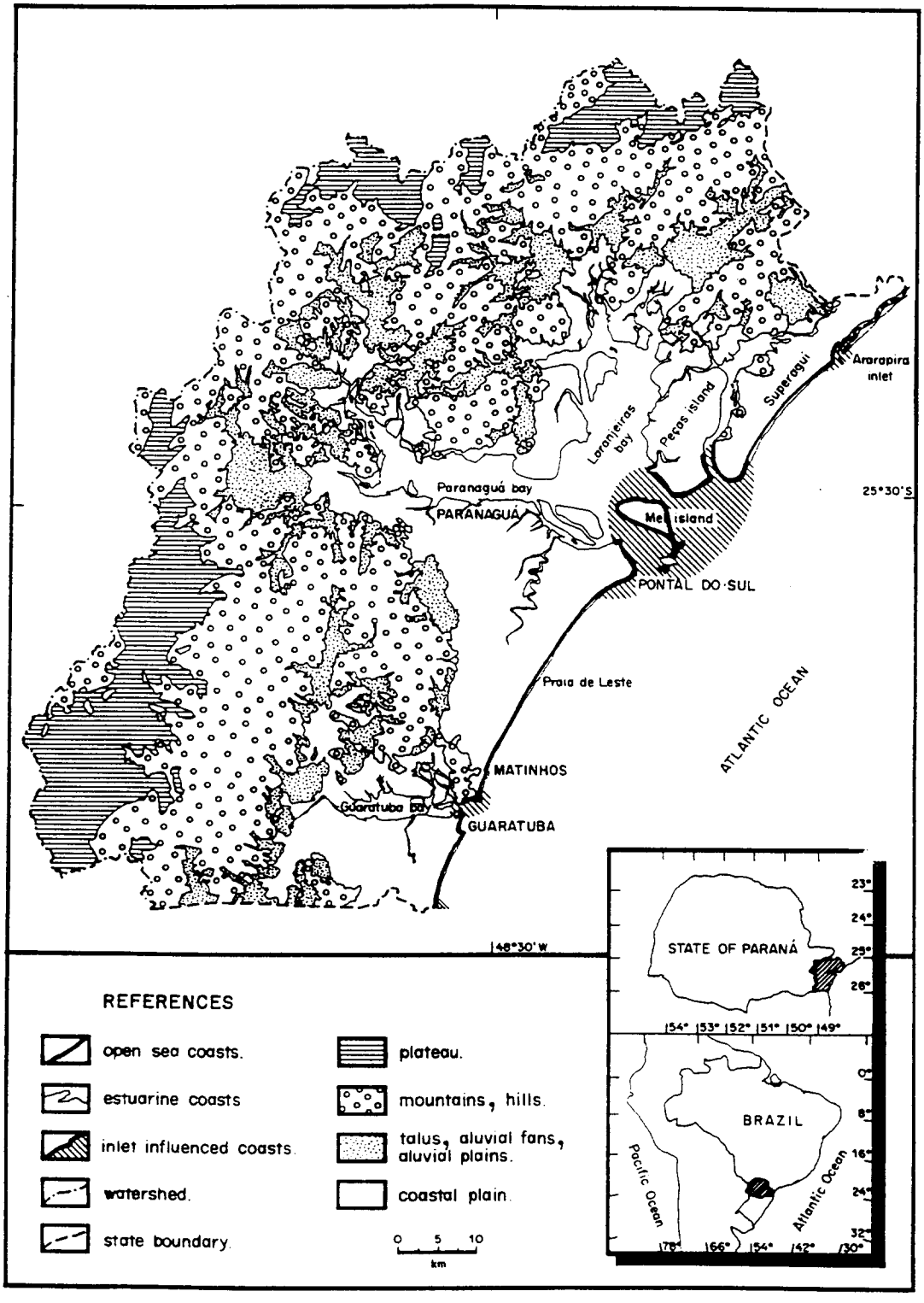
Fig. 1. Coastal zone of the State of Paraná.



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EVALUATION OF CHACAHUA-PASTORIA AND CORRALERO COASTAL LAGOONS, OAXACA, MEXICO

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**PRONASOL.

ABSTRACT

Coastal lagoons in Oaxaca show a high degree of isolation induced in most of the cases by human action, in consequence socio-economical activities had been negatively affected. Adequate management of the coastal zone should be a holistic one, but in the most of the cases this is not applied. Scarce resources make even more necessary the implementation of techniques to make correct low-cost decisions.

The diagnostic realized to propose solutions for Chacahua-Pastoria and Corralero lagoons, was realized with help of local organized fishermen. Sandy material from the marine side was collected in each lagoon, representing both sides of lagoon inlets for several kilometres, the samples were collected at a 5 m. average depth. Samples were taken with a manual core in the offshore zone and in active or inactive access channels zone.

Aerial photographs of each zone in different years and months (1979-1988) were obtained, each photo was treated with 2 different processes: Xerox copies on acetate film and electronic capture [scanning], in both cases shoreline relative movement and structures such as flood deltas and sand ridges were compared. Paired use of aerial photos and acetate copies is the most economical and effective evaluation technique.

In the processed images, it was incorporated sediment characterization, using these data, littoral transport, and erosion / sedimentation zones were identified. Statistical analysis of sediment samples from coastal zone at Pastoría-Chacahua and Corralero lagoons, indicate a West-Southeast predominant current and the presence of minor magnitude counter currents.

Analysis of coastal structures such as sand ridges and its evolution, allowed us to identified decreases in sediment and water inputs at the coastal zone by Rio Verde, the main river, due to its reduction by the construction of a dam upstream, causing coastal sand deposits erosion and shoreline modifications. Limitation of fresh water to coastal lagoons resulted in environmental quality decrease around them, and a decline in health and productivity for ethnic groups who live around the margins of the lagoons.

Recommendations derived from this paper include; guidance to coastal orientation of protection structures, dredging plans and combined management of fluvial input to lagoons and beaches, both, water and sediment volumes.

INTRODUCTION

Coastal lagoons around the world are subject to economical use by the people who lives around or near them, a major problem related to their existence is proper communication to the open sea, in order to preserve their ecological characteristics that make them premium mediums for species reproduction and capture. The closure of a coastal lagoon could be related to sea-level rise or fall, as well as to the human interaction with the environment, such as the development of coastal structures or sediment entrapment due to the deployment of a dam on a river. On top of the problem, most of the times the urgency of a solution, requires that the decisions should be taken with a limited time to undertake more complete studies. Here we are presenting one particular way to help the agencies involve in such decision taken, to improve their rate of success both for the long run, as well as on the economic side.

In Mexico, in the State of Oaxaca, three coastal lagoons (Fig 1) are having some degree of isolation (Torres-Moye, et al., 1993), clearly

related to the closure or partial closure of the mouths to the sea. The study area encompass more than 90 km along the coastline, and on those lagoons and around their shores several communities of fishermen are living, having major health and economic problems due to the actual state of the lagoons.

The propose scope of work considers the fact that a lot of the coastal lagoons around the world are beyond economic wealth, therefore an economical but yet appropriate procedure should be applied in order to proposed acceptable measures to assure long lasting connections to the open sea, and an proper coastal management in general.

METHODS

Sedimentology

Assisted by organized fishermen of each region, 14 samples of sandy material were collected, from Pastoria-Chacahua Lagoon, 6 from Corralero Lagoon, and 3 for Río Verde coastal zone. These samples represent both sides of channel accesses for several kilometres (Fig 2, 3, 4). 3 samples from Pastoria and 2 from Chacahua channels zone were also collected, 1 sample of material that closes each channel access from Chacahua and Corralero Lagoons was collected too, the last samples were independent from the representative ones of the coastal zone. The samples were collected with a manual core. Average depth in the sampling places was 5 m., all the sampling sites were out the surf break zone. The channel depth was variable depending on the conditions in each zone. Average weight of the samples was 300 g by station.

In the lab, soluble salts and organic matter were removed from samples using distilled water and hydrogen peroxide respectively. Granulometric class separation was realized using a set of sieves with 0.5 ϕ (Phi) intervals in a range from 0.0 ϕ to 4.0 ϕ (Phi), using the proposed methodology by Folk (1974). Textural parameters obtained from sample fractions were analyzed using the statistical method proposed by Carver (1971) and they were average, classification and asymmetry. The statistical parameters were interpreted to determinate main littoral currents in the area, using the method proposed by Sunamura and Horikawa (1971).

SHORELINE VARIATION

Initial methodology consists in typical photogrammetric work, with the use of black and white aerial photos from the INEGI agency, from different scales 1:80,000 and 1:75,000, and different months for each lagoon; for Pastoría-Chacahua March 1979, and March, April, and November from 1985; Rio Verde the photos were taken in February of 1980, and in March and December 1985; for Corralero only March of 1979 and December 1988. Base line maps were elaborated at 1: 20,000 for the three lagoons and Río Verde (Fig. 2, 3, 4), which turned out to be a very simple task, using the Xerox copies on acetate. On those charts, the relative position of the shoreline was marked for each date. Based on the same base line map a detail chart was developed for the access channel for Pastoria. The area for the flood delta deposit in the Pastoria lagoon was calculated for each date. The relative movement of the shoreline allowed us to estimate the general dynamics over that part of the coast.

DISCUSSION

The results obtained from the textural analysis from the sediments as well as the relative movement of the shoreline, are presented here and considered as indicators of the littoral processes, that are taken place and are more critical over the three lagoons and adjacent coastal areas.

Sedimentology

The median size for the samples taken was 2.54' (1.35 mm) for the Pastoria lagoon seaward shoreline, 3.10' (1.63 mm) for Chacahua, and 2.37' (1.24 mm) for the Corralero lagoon. The interpretation for the size variation for the coastal area between the mouths of Pastoria and Chacahua lagoons (Fig. 5), shows a predominant littoral current from west to southeast with minor currents in the opposite direction. This system explains the sediment transport from Río Verde to the mouth of the Chacahua lagoon. The sorting of the sediments as well as the skewness support

the interpretation. The results obtained from our analysis coincided with those of Carranza Edwards (1988) and SEPESCA (1990).
The interpretation by itself was enriched by the direct observation over return-currents, nevertheless, those observations are considered only as hints, even so the same predominant directions were possible to observed from the aerial photographs. At the same time the observations from the inhabitants were highly coincident with the analysis made over the samples.

Shoreline variation

From the base line map of each region the maximum movement of the shoreline was delineated as well as the infilling of the flood delta for the Pastoria lagoon, and the rate of erosion for the inner beach on the SE side of the access channel for the same lagoon.
For Chacahua it is possible to determinate that from 1979 to 1985 the shoreline was progradating (Table 1), in particular from Río Verde to the mouth of the lagoon. Adjacent to the mouth to the south, an erosion area was detected , reverting to progradation up to the access channel for Pastoria, and the same pattern repeats itself after the mouth. This erosion over the beach is due to sediment being capture by the currents developed by the tides, and their deposition inside the channel and eventually the lagoon.
For the Corralero area, retrogradation was observed between 1979 and 1985 for the westernmost part of the beach, changing to progradation approaching the mouth, with the same general results of filling the access channel. To the SE adjacent to the mouth the same pattern of an erosional area reverting to a progradation further down the coast.
For Table 1 the relative movement is considered [+] seaward and [-] when landward.
Río Verde is the principal river in the region, and when it finally reaches the sea becomes a great feature to illustrate the prevailing conditions over the area (Fig 4). In general, the shoreline is being eroded, as shown by the removal of an asymmetrical delta present up to 1980, with a great extension over more than 8 KM to the SE from its mouth. Even so accretion is observed after 1980 is never as great as first observed for that year. The western margin had the same behaviour.
The flood delta in Pastoria (Fig. 6), shows the result of the tide current action, with an increase in its area, observed from the air photos, and the sediment dispersal continues into the whole lagoon. All the lagoons showed at the bar several beach ridges, which are being eroded, as appreciated from the study of the air photos
Table 2 was developed over the base line map, and the areas of expansion for the delta were measured in hectares.

CONCLUSIONS

Analysis of coastal structures such as sand ridges and its evolution from the air photos, allowed us to identified decreases in sediment and water inputs at the coastal zone by Rio Verde, the main river, due to its reduction by the construction of a dam upstream after 1980, causing coastal sand deposits erosion and shoreline modifications. Limitation of fresh water to coastal lagoons resulted in environmental quality decrease around them, and a decline in health and productivity for ethnic groups who live around the margins of the lagoons (Torres-Moye et al., 1993).
Recommendations derived from this paper include; guidance to coastal orientation of protection structures, such as groins or jetties, in which for the studied area the principal sediment input is W-SE, therefore, the main consideration in any coastal structure should be based in this fact. In the past, dredging plans have failed, when the material dredged was deposited within the access channel or to the west of it, any removal should be made to the east or SE of the mouths. Finally, management of fluvial input to lagoons and beaches, of both, water and sediment volumes, was cancelled with the construction of a dam upstream for the Río Verde. This management should be carefully evaluate to regain the quality for the waters within the lagoons for aquiculture purposes, and the sediment input to the beach to stabilized the shoreline, implementing a sediment bypass around the dam, to develop a beach erosion control

mechanism, a technique used in other areas (Wasly, et al., 1991).

ACKNOWLEDGMENTS:
First and foremost to the inhabitants of the lagoons who were part of the research team at all times, and from whom we were able to predict the behaviour of the systems. We would like to thank OCEAN. César García, who elaborated the base-line maps with his students. To the Instituto Nacional Indigenista for the original invitation to participate in the project. To our wives and relatives for their understanding.

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Table 1. Shoreline variations

Years/month	Locality	Variation (m)
1979-March 1985-November	Chacahua-E	+160 ±16
1979-March 1985-November	Pastoria-W	+120 ±12
1979-March 1985-November	Pastoria-E	+160 ±16
1979-March 1988-November	Corralero-W	- 80 ±8
1979-March 1988-November	Corralero-E	+ 60 ±6
1980-February 1985-March	Rio Verde-E	+ 80 ±8

Table 2. Pastoria flood delta variations

Year	Month	Measured area (ha)
1979	March	0.0 - 43.87
1985	April	16.2 - 64.9
1985	November	40.6 - 105.5

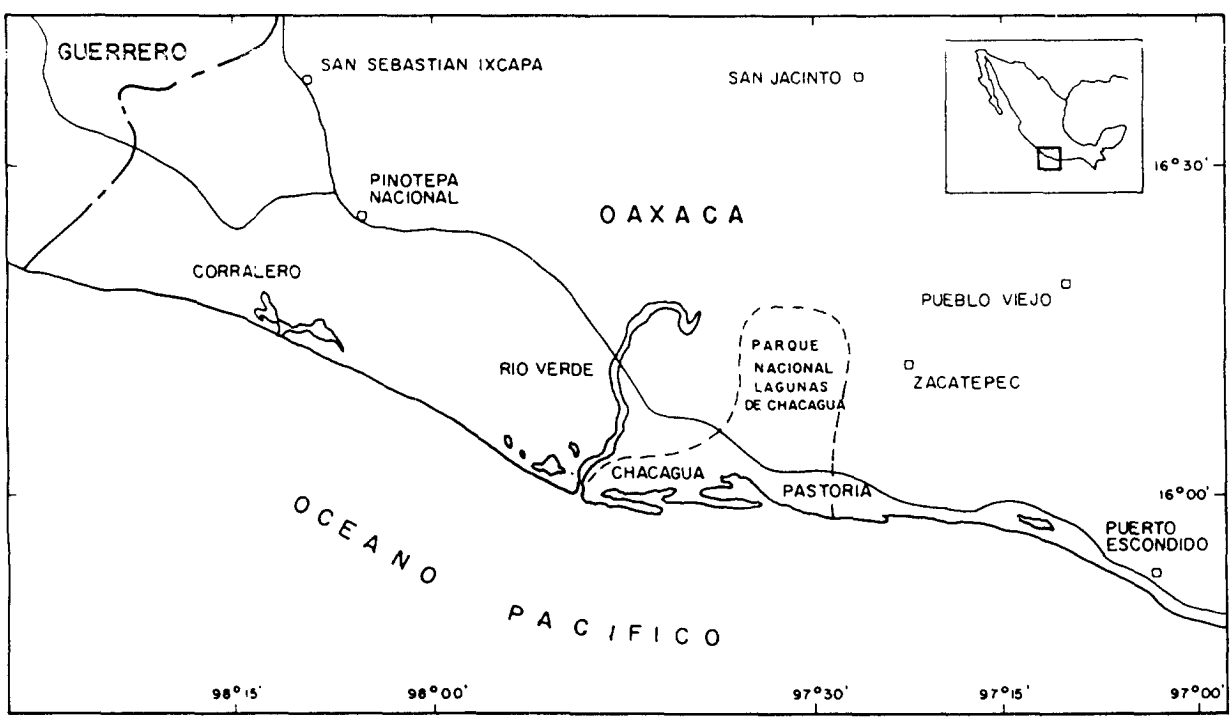
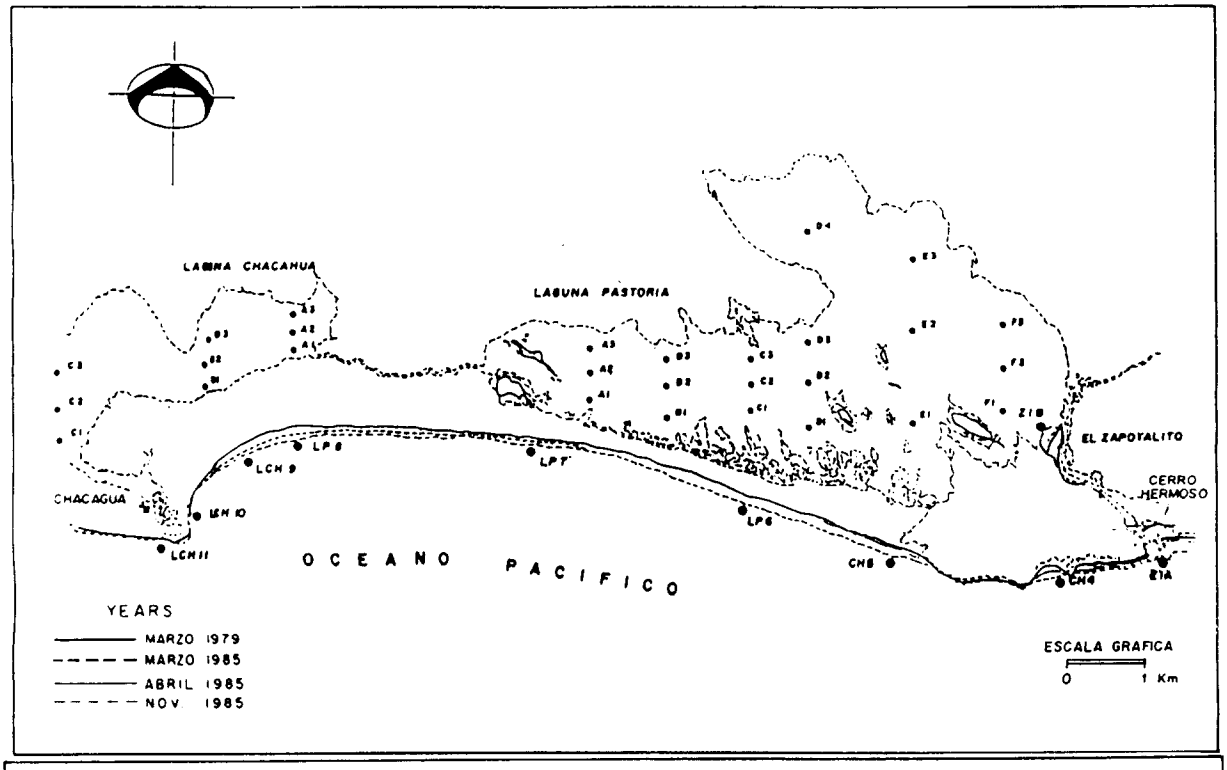


Fig. 1.- Location of the three coastal lagoons on the Mexican Pacific coast.

Fig. 2.- Chacahua and Pastoria lagoons, showing the relative movement of the coast line for different years. The dots represent the samples took for this study.



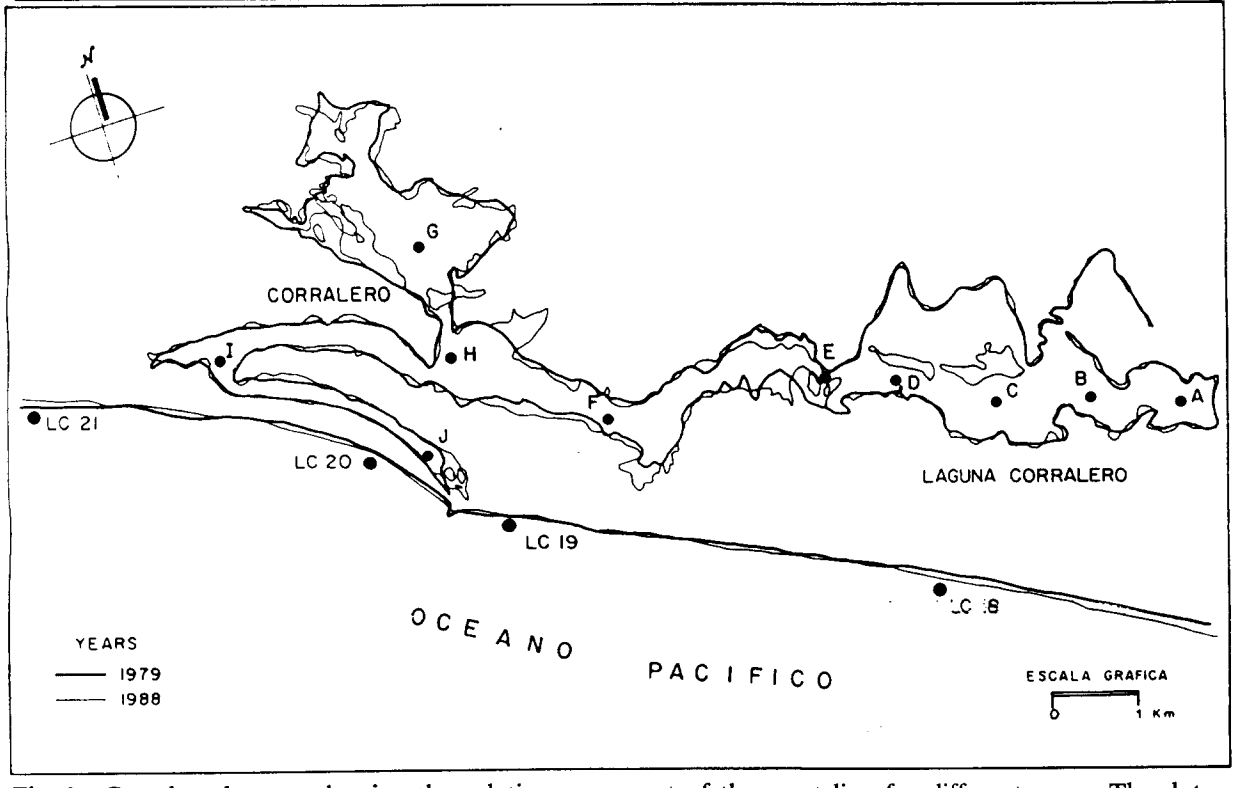
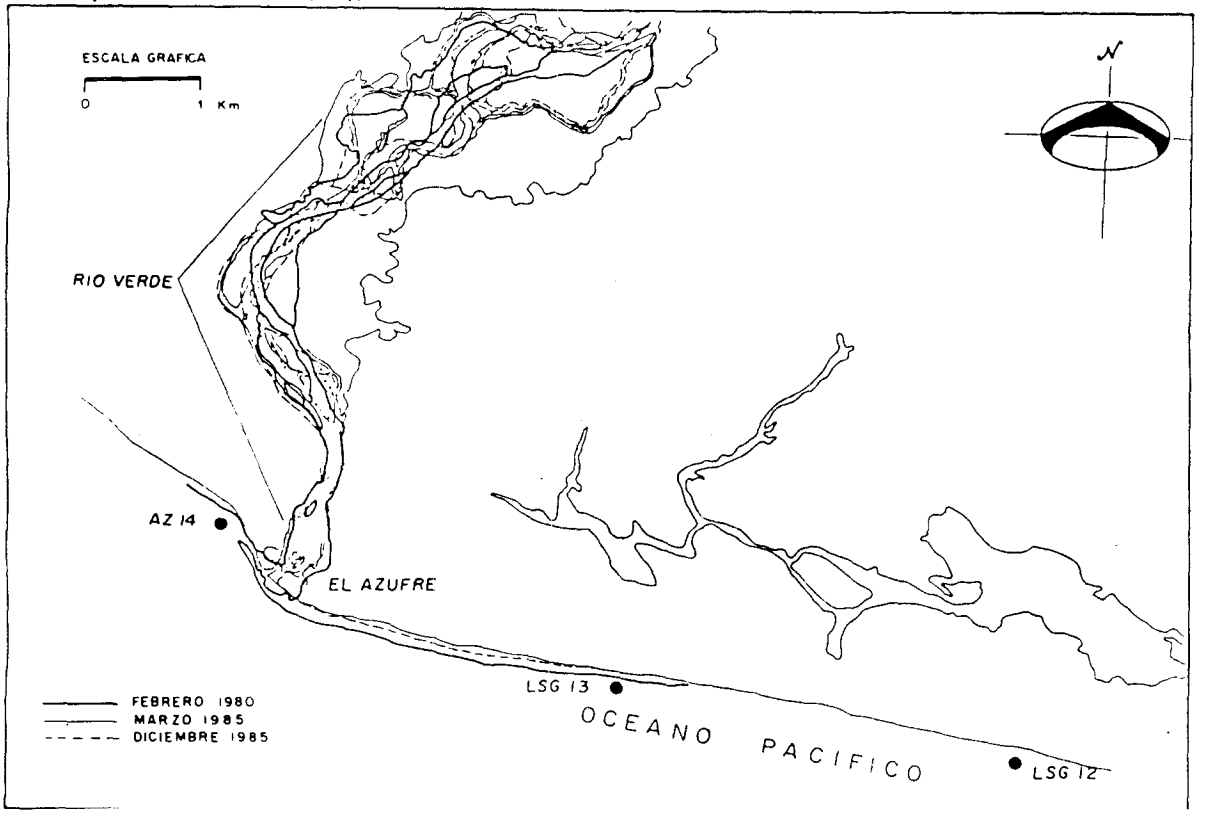


Fig. 3.- Corralero lagoon, showing the relative movement of the coast line for different years. The dots represent the samples took for this study.

Fig. 4.- Rio Verde, showing the relative movement of the coast line for different years. The dots represent the samples took for this study.



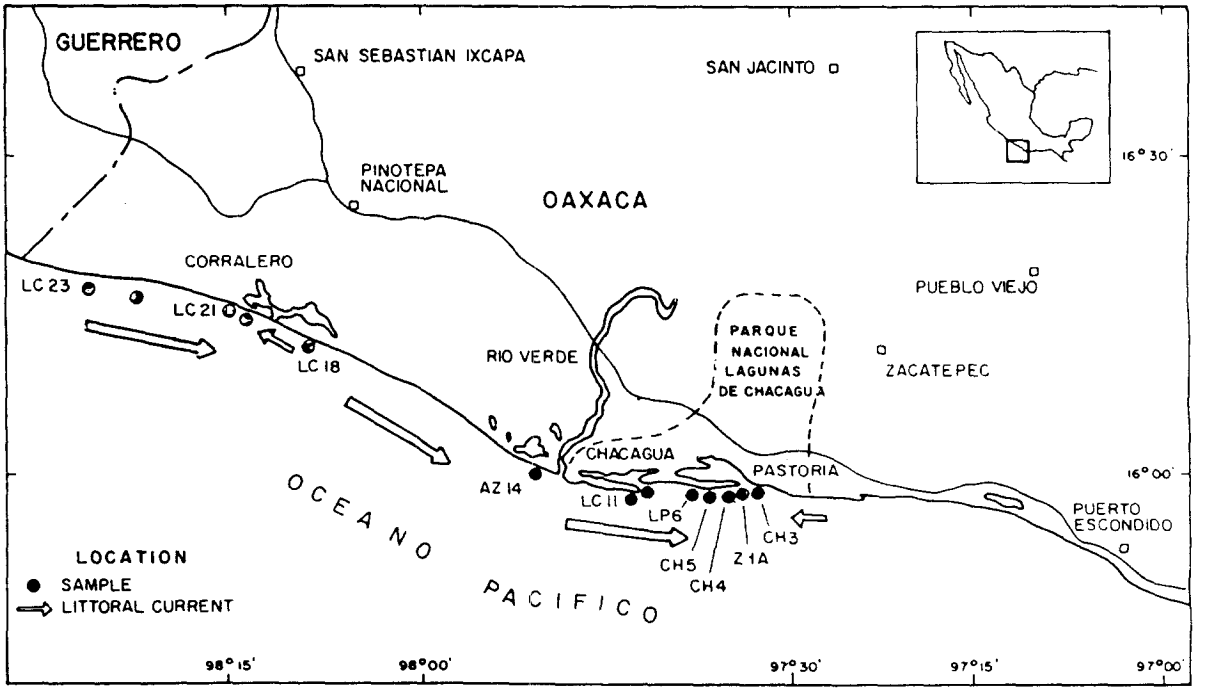
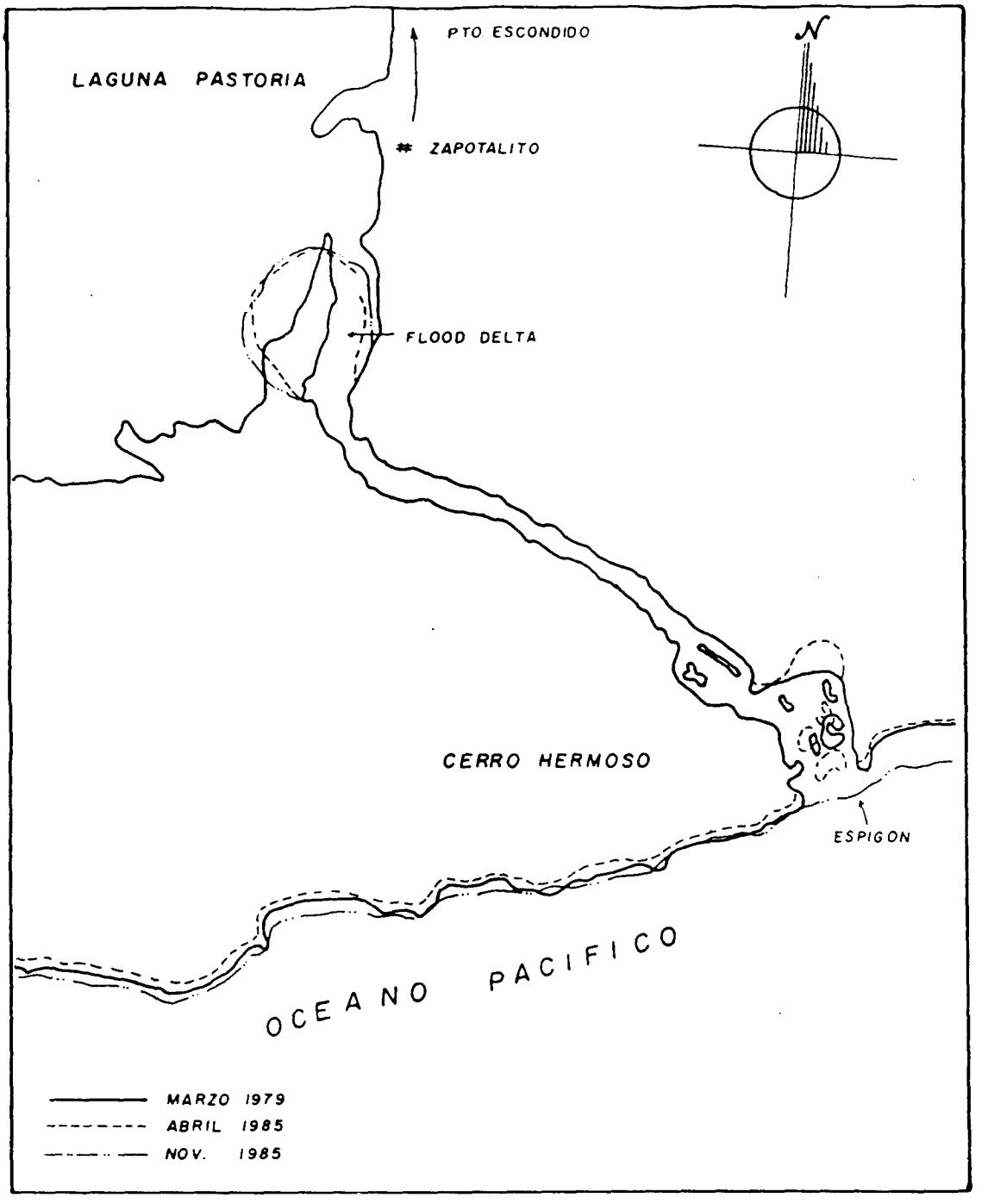


Fig. 5.- Interpretation of the littoral current. The major arrows showing the most prevailing currents, and the small ones the minor components. The results are based on the model proposed by Sunamura and Horikawa (1971), for textural parameters for the sediments.

Fig. 6.- Flood delta growth from 1979 to 1985 at the mouth of Pastoria lagoon. Also showing the relative movement of the shoreline on the coast, and the sea communication morphology.



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VARIATION OF COASTAL DYNAMICS DURING THE LAST 7000 YEARS ALONG THE CENTRAL BRAZILIAN COAST

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INTRODUCTION

A submerging coast does not exhibit the same morphological features as an emerging coast because the relative sea-level change in part determines coastal sedimentation. This occurs in two ways, by partially controlling the supply of sand and by regulating the geometry of the deposits. Moreover, this pattern changes with the direction and intensity of the longshore current. Under conditions of rising sea-level, on a gently sloping sandy coast, barrier island/lagoonal systems are the dominant mode of sedimentation, and beach-ridge plains are virtually absent. In contrast, a sea-level fall creates highly unfavourable conditions for the genesis and maintenance of barrier island/lagoonal systems. Lagoons and bays become emergent and beach-ridge plains rapidly prograde, resulting in regressive sand sheets. A sandy coastal zone has a profile in equilibrium, which is determined by the local hydrodynamics and the grain size of the sediments. The rule of Bruun (1962) states that the equilibrium destroyed by a relative sea-level rise would be re-established by a landward displacement of the beach profile. This results in an accelerated erosion of the beach prism and transfer of eroded sands toward the inner shelf. Even though this rule was established for a rise in sea-level, it is logical to suppose that a fall in sea-level would also destroy the equilibrium profile. This results in an erosion of the inner shelf bottom and by transfer of the eroded sand toward the beach prism. Sands generated by a fall in sea-level and river-borne sediments will be moved along the beach by the longshore current. The direction of longshore sand transport depends on the orientation of swells. In a coast subjected to various swell patterns, the "efficient swells" are defined as those which determine the resulting longshore transport direction. Such swells are not necessarily the most prevalent but the more powerful. This transport can continue until the sand is trapped or blocked by an obstacle. This explains the great differences occasionally found between two regions that have been subjected to the same fall in relative sea-level. Sandy deposits are small or even absent in transit regions and very large in regions where a trap or an obstacle causes accumulation of sand. Obviously, all changes in relative sea-level and in sand transport direction will be accompanied by remarkable changes within the geometry of the deposits.

CHARACTERISTICS OF THE CENTRAL BRAZILIAN COAST

The existence of extensive quaternary coastal plains is one of the characteristics of the central part of the Brazilian coast. Some plains can be situated at the mouth of major rivers, others do not have to be related to a present or previous river. A second characteristic of this coast is that, during the Holocene, it was submerging, as opposed to various other regions of the world, until approximately 5 100 yr B.P. Since then there has been a general emergence. Nevertheless, the regular fall in sea-level was interrupted by two high frequency sea-level oscillations with an amplitude of 2-3 m during a period of no more than 200-300 yr. A third characteristic of this coast is that it is a high-energy environment, where the longshore current plays an essential role in the transport of coarse sediments (Martin et al. 1987). The patterns of swell systems along this stretch of coast are not well known, but there is sufficient data to show that they originated from the north-east and the south-south-east., generated by two wind directions. The winds from

the north-east are related to the recurrent trade winds active during the entire year, while those from the south-south-east are related to "cold-fronts" which periodically reach the central part of the Brazilian coast, mainly during autumn and winter. The southern sector swells, in spite of their low frequency, are much more powerful than those the northern sector and, in consequence, the predominant longshore transportation of sediments occurs from south to north. These pattern can be disturbed by strong El Niño events. When this phenomenon is active, as in 1983, the passage of middle and high troposphere wave fronts from the south is blocked by a strong and permanent jet current. During the blockage period, the frontal zones remain for a long time in southern and southeastern Brazil.

Simultaneously, swells from the southern sector, generated by the frontal zones, do not reach the central part of the Brazilian coast. In this case, the northern sector swells become effective, provoking a longshore transport from north to south (Martin et al., 1993).

HOLOCENE EVOLUTION OF COASTAL PLAINS NEAR SOME IMPORTANT RIVER MOUTHS. EXAMPLE OF THE RIO DOCE.

Some detailed studies carried out on the coastal plains of the Paraiba do Sul (21° S), Doce (19° S), Jequtinhonha (16° S) and Sao Francisco (10° S) rivers showed that their Holocene history had been strongly controlled by relative sea-level changes and longshore transport directions (Dominguez et al., 1987).

The Rio Doce coastal plain, stretching in a nearly N-S direction, has a maximum width of about 38 km and length of about 130 km. The buildup of the Holocene part began (about 7 000 yr B.P.) with the formation of a barrier island / lagoon system and the construction of a huge intra-lagoonal delta. After 5100 yr B.P., on the seaward side of the barrier islands, sandy terraces, covered by aligned beach-ridges, developed. Detailed mapping of these alignments shows the existence of well-established unconformities. They are related to a sequence of alternating erosional and depositional periods, which indicate changes in coastal hydrodynamics as a consequence of relative sea-level oscillations and/or reversals of longshore transportation (Martin and Suguio, 1992). The abrupt relative sea-level rises, between 3900 and 3600 yr B.P. and between 2800 and 2500 yr B.P., are reflected by major unconformities. On the other hand, secondary unconformities in beach-ridges alignments similarly show the existence of periodic reversals in the direction of longshore sand transport: depositional periods caused by southern sector swells. alternating with erosional periods caused by the northeastern swells. A detailed study of the whole sequence indicates the following:

(1) Before 5100 yr B.P., the absence of beach-ridges (submergence episode) does not permit inferences to be made about longshore transport directions;

(2) Between 5100 and 3900 yr B.P. (emergence episode), the longshore sand transport that is normally northward, reversed southward during seven separate episodes (with duration of some tens of years) implying that during these intervals the southeastern swells did not reach the study area;

(3) Between 3900 and 3600 yr B.P., rising sea-level did not permit beach-ridge formation which would have permitted the direction of longshore sand transport to be determined;

(4) Between 3600 and 2800 yr B.P. (emergence episode), longshore transport was continuously northward: the southeastern swells were a permanent feature;

(5) Between 2800 and 2500 yr B.P., a relative sea-level rise prevented formation of beach-ridges, making it impossible to determine the direction of longshore sand transport;

(6) After 2500 yr B.P. (emergence episode), the longshore transport reversed southward three times. During those three intervals the southeastern swells did not reach this region.

The reversals can only explained by changes in efficient swell directions and therefore in the wind regime, such as that which occurred in 1983 on a Salvador (State of Bahia) beach (Farias et al., 1985). As strong El Niño events are able to produce indirectly, over several months, the same kind of disturbance in longshore sand transport, we infer that the long periods (some tens of

years) of reversed longshore transport are associated with long periods of blocking conditions of frontal systems related to El Niño-like conditions. (Martin et.al., 1993).

The sandy terraces situated at mouths of the Paraiba do Sul river indicate changes in local hydrodynamics similar to those observed at the Doce river mouth. The abrupt relative sea-level rises between 3900 and 3600 yr B.P. and between 2800 and 2500 yr B.P. are reflected by major unconformities. On the other hand, secondary unconformities in beach-ridges alignments similarly show the existence of periodic reversals in the direction of longshore drift. In contrast, the morphological records show that, at the Sao Francisco river mouth, the longshore current flowed permanently from north to south, as a consequence of effective swells from the east-north-east. This corroborates the fact that, in a normal situation, the swells from the south-east rarely reach this region today. The blockage of these swells does not change the littoral dynamics of the Sao Francisco river mouth, which is permanently controlled by swells from the east-north-east.

CONCLUSIONS

Studies carried on the Central Brazilian Coast show that reversals in longshore sand transport with a duration of some tens years are able to produce local large erosions in a prograding zone even during a period of sea-level fall.

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TIDAL AND SUBTIDAL DYNAMICS OF THE PATOS LAGOON (BRAZIL)

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THE AREA

The Patos Lagoon (Fig. 1) situated in southern Brazil about 31° S and 51° W is a typical example of a choked (Kjerfve, 1986) water body. It has a surface area of 10,360 km^2 being 250 km long, 40 km wide and 5 m deep. It is connected with the South Atlantic Ocean through a 22 km long, 2 km wide and 12 m deep channel. Tides are mixed, mainly diurnal with a parameter F (Defant, 1961) equal to 2.42 (Herz, 1977).

The wind pattern shows a dominance throughout the year of the north-easterly (NE) winds. During summer and spring easterly (E) winds are also existing in this region indicating a sea breeze signal influence. The importance of south-westerly winds increases during autumn and winter as frontal systems are more frequent over this area. Typical wind speeds are between 10 to 15 km/h (3 to 5 ms^{-1}).

This lagoon drains a hydrographical basin (Fig. 1) of almost 200.000 km^2, formed by rivers which exhibit a typical mid-latitude flow pattern: high discharge in late winter and early spring followed by low to moderate discharge through summer and autumn. They also present large year-to-year discharge variations. A mean annual value (Bordas et al.,1984) is around 1,000 m^{3}s^{-1} with monthly means ranging from 700 m^{3}s^{-1} during summer up to 3,000 m^{3}s^{-1} in spring. River discharge peaks of 20,000 and 12,000 m^{3}s^{-1} have been observed by Rochefort (1958) and Moller et al. (1991) and respectively.

Early studies carried out during the construction of the 4 km long jetties at the lagoon's entrance (Malaval, 1922) have pointed out the main influence of the wind on the circulation of this lagoon. NE winds favouring seaward flows while southerly winds causing opposite effects. Concerning freshwater discharge effect Costa et al. (1988) have concluded that during periods of high river discharge in winter and spring months only very strong southerly winds (>1 3 ms^{-1}) would be able to force salt water to enter into the lagoon. Moller et al. (1991) have shown that for river flows in excess of 3,000 m^{3}s^{-1} the mixing zone would be transferred to the inner continental shelf The inner limit of the salt water penetration is around Ponta da Feitoria region.

The main objective of this paper is to discuss the relative importance of winds, tides and river flow in the barotropic circulation of Patos Lagoon. The propagation of tidal and subtidal frequency oscillations have also been discussed. To achieve these objectives time series analysis techniques have been performed using wind and water level records obtained along the lagoon for the whole year of 1988.

CONCLUSIONS

This study points towards the fundamental importance of Patos Lagoon morphology on the way this system responds to local and non local forcing mechanisms. The southern and the central/northern regions that are separated by the sandy banks off Ponta da Feitoria are submitted to different wind forcing and also react in a different manner concerning river discharge effect. The time scales of the low frequency circulation of Patos are associated with frontal system passages in the time interval between 3 and 20 days. The dynamics of the central-northern area is driven by the local longitudinal wind that forces the setup/setdown mechanism of oscillation. Only during strong flood periods (Q > 4,000 m^{3}s^{-1}) this situation is unlike to be observed. The southern area is mostly influenced by the subtidal oscillations generated offshore through non local wind effect. These oscillations are filtered as they propagate into the estuarine region and are totally attenuated when they reach Ponta da Feitoria. The non local wind effect dominates circulation

when river flow is lower than 1,000 m^3s^{-1}. Freshwater discharge values higher than 1,500 m^3s^{-1} can produce water level oscillations that interfere with those associated with offshore winds. The role of morphology in this process is also discussed.

Concerning tidal frequency oscillations (f > 0.04 cph) two types of motions are observed in the lagoon. In the southern area they are of tidal origin, dominated by the O_1 (tidal period; 25.82 hours) component, and account for 35% of the total variance in the channel area. They are also filtered as they propagate into the lagoon but 20% of the original signal is still present at Ponta da Feitoria. On the other hand in the central-northern region they are associated with breeze effect and are only observed in spring and summer.

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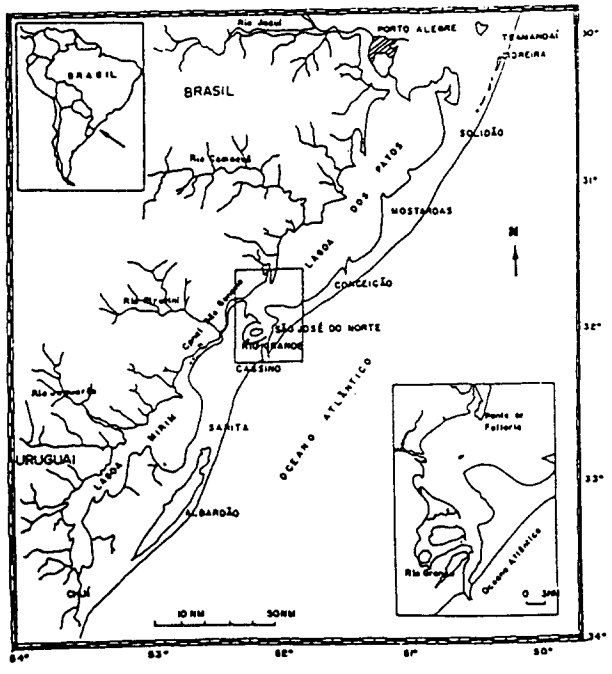
Fig. 1. The Patos Lagoon and its estuarine area.



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THE MORPHOLOGICAL EVOLUTION OF SALTMARSH TIDAL CREEK NETWORKS IN THE DYFI ESTUARY, WALES

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Tidal creeks are arguably the most distinctive features of a saltmarsh. Numerous researchers have investigated the hydrodynamics within saltmarsh tidal creeks, and suspended sediment transport through a saltmarsh drainage basin. These studies have broadened our understanding of hydrodynamic processes and material exchange within the saltmarsh tidal creeks; however, the morphological evolution of saltmarsh tidal creek networks (Knighton et al., 1992) through time has received little attention.

The Dyfi Estuary is located in the central part of Cardigan Bay, Wales (Fig. 1). In the Dyfi, the mean spring tidal range (4.5 m O.D.) and the mean neap tidal range (3.4 m O.D.) are associated with strong tidal currents. The entire area (about 17 km^2) of the Dyfi Estuary is inundated at the highest spring high tides. It is funnel-shaped, but is restricted at the mouth by a beach-spit which extends from the southern side of the estuary. Behind the spit is an extensive area of saltmarsh fringing the southern side of the Dyfi, which is traversed by tidal creek networks. Obviously, the Dyfi could provide an example of the morphological evolution of saltmarsh tidal creek networks.

Air photos collected from five sources (Table 1) were used to reconstruct planimetric changes of saltmarsh tidal creek networks in the Dyfi Estuary (Fig. 2). In the Dyfi, there are at least four orders of tidal creeks following the order designation system suggested by Horton (1945). Rates of these changes have been evaluated with reference to creek length and creek density. Creek densities have been increasing during their development, ranging from 8 to 11 km/km^2 These suggest that the Dyfi tidal networks have in 24 years increasingly extended into the present saltmarsh study area.

These changes are mainly attributable to the instability of the main Dyfi tidal channel, flood and storm surges, saltmarsh vegetation, elevational differences of the estuarine intertidal zone, and sea level fluctuations (Shi, 1993). There are also complex interactions among these variables. Other less significant variables include the elevational difference, sediment composition of creek banks, sediment supply and sediment transport. The dispersal of tide and wave energies associated with storm surges is chiefly responsible for the morphological development of the Dyfi tidal creeks. The stage-prism asymmetry hydrodynamic model is applicable to explaining the Dyfi estuarine tidal creek development. A form-process feedback between the vertical growth of the Dyfi saltmarsh surface and the hydrodynamics of its network is also important in governing the Dyfi tidal creek network development. The expansion of the Dyfi saltmarsh tidal creek networks is one symptom of a rising sea-level that is potentially injurious to coastal wetlands. The rapid development of the Dyfi tidal network could result in the loss of the Dyfi estuarine wetlands.

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Table 1. Sets of aerial photographs examined in this study. A: black-and-white aerial photos; B: colour aerial photos

Date	Type	Approximate resolution	Approximate scale	Source
16.08.1966	A	2.5 m	1:25,000	Hunting Surveys Ltd. UK
...09.1971	A	2.0 m	1:20,000	Fairey Surveys Ltd. UK
29.10.1983	A	1.0 m	1:10,000	Min. Agriculture, Fisheries and Food, UK
02.11.1986	B	1.0 m	1:10,000	J.A. Storey & Partners, 92-94 Church Rd. Mitchan, Surrey, UK
20.06.1989	B	1.0 m	1:10,000	University of Cambridge, UK

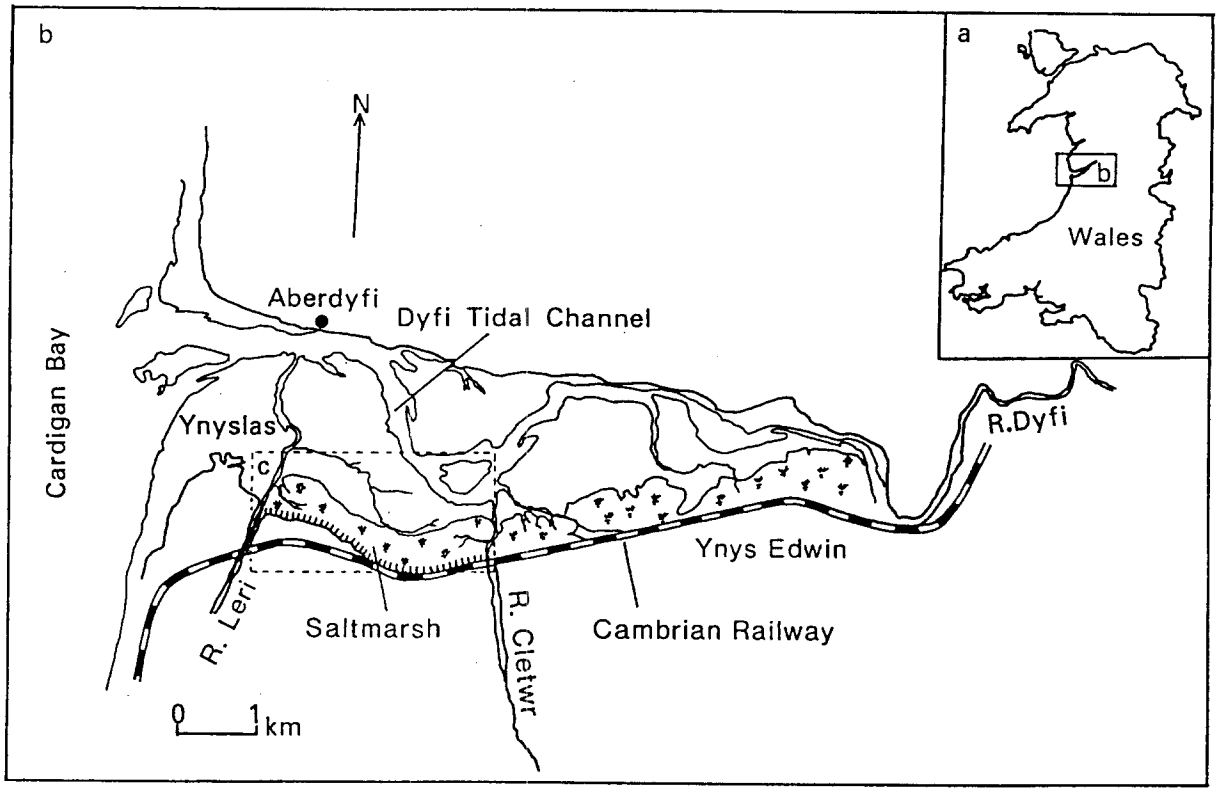
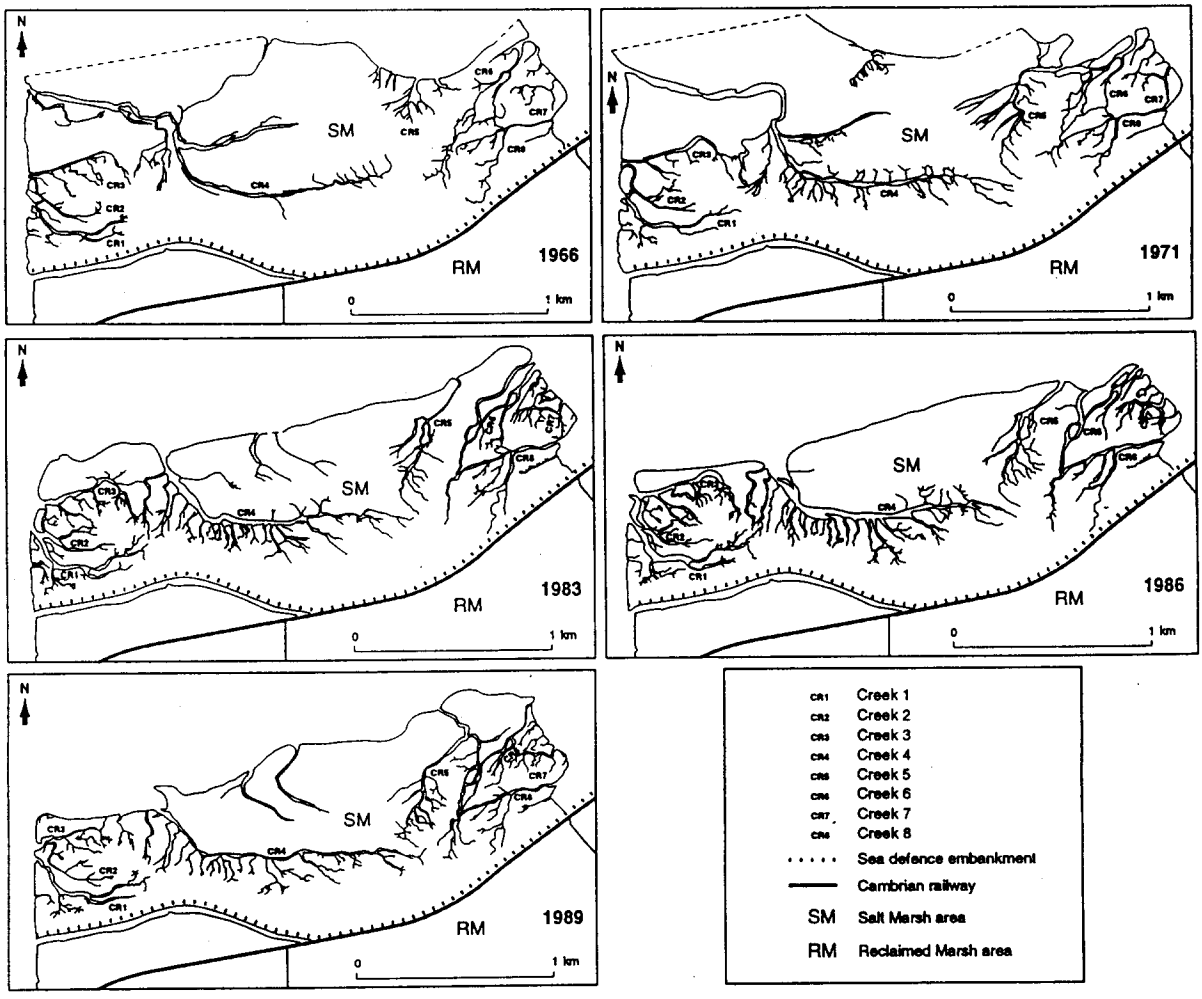


Fig. 1. a: Location of the study area within Wales, UK; b: The main geomorphological features of the Dyfi Estuary; c: The present study area.

Fig. 2. Planimetric changes in the tidal creeks traced from the aerial photographs (1966-1989).



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COASTAL MORPHOLOGICAL CHANGES CONCERNING; THE MANAGEMENT OF COASTAL ZONE IN VIETNAM.

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KEYWORDS: morphological changes, coastal zone, natural evolution, erosion, deposition, human activities, management, environment, risks, floods and inundation, siltation, tropical feature, Vietnam.

ABSTRACT

During the last decades, the coastal morphology of Vietnam has been changed by deposition and erosion processes. Eight types of coastal morphological changes (CMC) have been identified. They have been created by both natural evolution and human activities, direct and indirect. Recently, the unusual changes in meteorology, hydrology and sea level rise have taken an important role for CMC. Apart from the increase of the land resource in the deltas, most of CMC has made a negative impact on coastal inhabitants, economy and environment. Linked with CMC there are serious coastal risks such as flooding, erosion and port siltation. CMC is very important for the social - economic development of a developing country such as Vietnam.

INTRODUCTION

At 3,200 km length and with over 3,000 islands, the coastal zone of Vietnam is a very important space for the inhabitants and economy. In this zone, there exist the big settlements and economic bases with a focus on activities such as: fisheries catch, aquaculture, land reclamation, navigation-ports, tourism, etc. There are also the problems that need to be solved for the management and social - economic development concerning the CMC. In recent decades, coastal morphology has been changed significantly that has led to a negative impact on environment. Recently, these changes and their role for coastal management have been investigated (Hoi et al., 1992; Minh, 1991; Than, 1986, 1992; Than et al., 1992b). This paper is only a general outline about CMC and some relevant problems of coastal management.

TYPES OF COASTAL MORPHOLOGICAL CHANGES.

The CMC in Vietnam have been abundant and complex (Fig. 1) and occurred on different scales, time and duration. In fact, every change has been relative to the deposition and erosion processes. Initially, 8 types of CMC have been identified.

Expanding seaward of the deltas

With the area of 15,000 km^2, the Red River Delta (RRD) in the North is banked by Red River, which has a sediment discharge of 114 million tons/yr. Having a sediment discharge of 98 million tons/yr, the Mekong River builds up the Mekong River Delta (MRD) 30,000 km^2 in area in the South. The mangroves have made an active contribution to the deposition in these deltas (Hong & San, 1993; Thanh et al., 1984). With progressive deposition, both deltas have expanded seaward at the rate from 10 - 100 m/yr, mean 30 - 50 m/yr, maximum 120 m/yr in RRD (Lan & Than, 1991; Huy, 1994) and 150 m/yr in MRD (Son & Phung, 1979). In the last one, the most violent deposition has been in Ca Mau Peninsular (Fig. 2) where seaward expansion rate has been from 50-80 m/yr, maximum 120-150 m/yr and the area has increased by 130 ha/yr during 1886-1985 (Thinh, 1992).

In Ca Mau Peninsular, the deposition has been more violent in the coastal side of Thailand Gulf and the alluvial cap has been plunged southwestward by longshore sediment drift from northeast.

In Kim Son coastal area (Fig. 3), which lies in the southwest RRD, the expansion rate has been

noted as the greatest in this delta, mean 60-100 m/yr, maximum 120 m/yr during last century (Lan & Thanh, 1991).

In all of the RRD, the flood plain has been continuously diked, so there are only about 50,000 ha of tidal flood plain at present. During 1938-1992 the high tidal flood plain has expanded by 360 ha/yr and the low tidal flood plain by 200 ha/yr. They are the results of very complex equilibrium of deposition and erosion.

In the centre there often exist sand spits franking the small river mouths where the deposition has developed by filling, and the expansion rate has been 2-5 m/yr, rarely reaching 10 m/yr.

Coastal erosion developing wide scale

The coastal erosion has occurred widely from North to South, typical in Cat Hai, Dong Chau, Van Ly, Hau Loc (North), Cua Hoi, Canh Duong, Phan Ri (Centre), Can Gio, Go Cong and Ganh Hao (South). The erosion rate has been often 2-10 m/yr, many places 15-25 m/yr and even 30-50 m/yr. The coastal erosion has occurred in the deltas, estuaries, lagoons, bays and coral islands. Some examples are presented as follows.

Erosion in the deltas

The large deltas have been expanding seaward very quickly by deposition. However, some coastal parts have eroded seriously.

Ganh Hao coast (in MRD), which is nearby the northeast of Ca Mau has eroded on the length of 60 km. A part of it named Bo De coast has eroded at the rate of 30-50 m/yr. during last century on the length of 36 km. Every year the sea invades landward 112 ha (Thinh, 1992).

Van Ly coast (in RRD), which is in the northeast of Kim Son area, has eroded over a length of 30 km at the rate of 10-15 m/yr, maximum 20-25 m/yr during over last 50 years (Huy, 1994).

Erosion in the estuaries

There are two typical estuaries where the tide reaches a range of 3.5-4 m. They are Bach Dang estuary situated in the northeast of RRD and Dong Nai estuary in the northeast of MRD. Compared with the deposition, the erosion in the estuaries has been dominant (Thanh et al., 1984, 1991). The erosion of the Cat Hai island coast in Bach Dang estuary is a typical example (Fig. 4). This sand island is 15 km^2 in area and 7 km in length of seaward coast. During 1938-1991 the mean rate of erosion was 4-8 m/yr, maximum 20-25 m/yr. At present, a 4 km section of the coast has been embanked with stones, but the waves have pushed the embanked coast landward at 1.4 m/yr. The seaward low tidal flat with an area of about 1,000 ha has disappeared during the last 50 years due to the erosion (about 32 m/yr) (Thanh et al., 1992a). Can Gio coast in Dong Nai estuary has been eroded at the rate of 5-10 m/yr during the recent years (Tac, 1991; Thinh, 1992).

Erosion of the sand coast in the Centre

In the Centre, the erosion has been often short in duration and not great in rate, only 2-5 m/yr, but has happened unusually and suddenly. The coast can be eroded violently in the NE wind season and banked in the SW one (Minh, 1991; Hoi et al., 1992; Long, 1992).

In general, the development of erosion is very complex and tends to increase clearly, especially in the North and South. In the North, the strong erosion happens during the SW windy season from May to September (rainy). In the South and Centre, the serious erosion occurs during the NE windy season from November to March. The time of erosion could range between 50-70 years or even over a longer period.

Deformation of the channels linked with siltation

The coastal deposition and erosion processes lead to the channel deformation consisting of the changes in depth, width, shape and situation. In general, the development of the deposition bodies such as beach ridges, banks, flood and ebb tidal deltas and the widening of the profile by erosion have caused the deformation linked with the siltation. The siltation of navigation channel to Haiphong Port is a typical example (Thanh & Hoi, 1992). Haiphong Port is one of the biggest ports, built from 1876. Since 1920, the depth of the navigation channel has decreased from 6 to 4 m, while the dredged amount increased from 2 to 4 million tons/yr. With the length of 36 km, the navigation channel is divided into 3 parts. Part 1 (landward) about 7.5 km curved strongly due to deposition in one side and erosion in other side. Part 2 (middle) about 12.5 km widened by erosion

on both sides combined with an decrease of bottom depth. Part 3, about 16 km (seaward), deformed most violently under the influence of waves and tidal currents. In this part, the channel axis has moved southwestward, while the development of the ebb tidal delta has tended to separate it into secondary small channels. Both natural and human factors have contributed to the channel deformation.

Built from 1981, Cua Lo Port (Nghe An Province) was designed for the ships over 10,000 DWT. In fact, only ships of 5,000-7,000 DWT have reached the port. The development of a flood tidal delta supplied sediment from longshore sand drift have caused the siltation.

Moving and closing of the lagoonal inlets, small river mouths and tributaries

Moving and closing of the lagoonal inlets

In the Centre, there are about 12 lagoons of which the largest one is Tam Giang with a length of 70 km and area of 21,600 ha. The inlets have moved continuously and have been closed by sediment filling sometime. The Tra O, An Khe lagoons have only one inlet, closed in the dry season and open in the rainy one (September-November).

There were times, when the inlets were not opened in the rainy season, so the people had to dredge for the flood control. The unique inlet of O Loan lagoon has moved northward by a distance of 5 km within a period of a few decades. Every period is finished by closing the old inlet in the north and opening suddenly a new one in the south of sand barrier.

Tam Giang lagoon (in Hue City) has 2 inlets which lie at a distance about 40 km (Fig. 5). Many years ago, Tu Hien inlet (southeast) was a unique one. In the flood in 1401, Thuan An inlet (northwest) opened and became the main inlet. From then, Tu Hien inlet has been closing and opening many times with a period of many years. The last time, Tu Hien inlet was closed from 1979-1990 and has been opened from 1990 to now. Situated in the highest rainfall region of Vietnam (about 3,000 mm/yr), the closure of Tu Hien inlet caused serious the flood-inundation. Thuan An inlet has been moving over a distance of 8 km. In the last century, it has moved northward at the rate of 40 m/yr.

Moving and closing of the small river mouths

In the Centre, there often exist the sand spits flanking the river mouths on one or two sides. The interaction between the river flow and longshore sand drift has made the mouths move, widen, narrow or close with the seasons. In the dry season, the longshore sand drift pushes a small river mouth southward. In the rainy season, the flood flow cuts off the sand spit and opens a new mouth. The Ve River mouth (Quang Ngai Province) is closed in the dry season, opened in the rainy one. Ban Thach River mouth (Phu Yen Province) can be closed suddenly after some years. The mouths of some rather large rivers as Thu Bon, Da Rang are often widened in the dry season and narrowed in the rainy one. In front of these mouths, the submerged bars can appear and become dangerous for boats and ships (Minh, 1991; Hoi et al., 1992).

Moving of the tributaries

The mouths of large tributaries of Red River such as Day (Fig. 3), Ba Lat, Tra and Thai Binh has been alternatively moving northeast and southwestwards during a period of 30-50 years. During 1938-1971, they moved northeastward and between 1971 to present southwestward. At the time of direction change (about 1971), the mouths were obstructed and inundation occurred. When the river mouths moved to one side, the sand bars appeared in front of them.

Moving of the sand dunes and barriers landward

There exist many sand dunes and barriers with the height from 10-30 m, some of 50-80 m, on the coast about 1000 km from Ha Tinh to Binh Thuan provinces (Centre). In the dry season (April-September), the wind action moves them landward. In some locations, the strong waves push the sand spits or barriers lagoonward or river mouthward (Hoi et al., 1992). The dunes and barriers have moved at the rate ranging from 2 to 15 m/yr, filled the rice fields, houses, roads, etc. "Flying sand" in the dry season and "flowing sand" in the rainy one are the risks in the Centre.

Denudation leading to lowering the surface of mangrove forests

There are over 30,000 ha of mangrove forests in the Northwest coastal zone where little sediment is supplied from river, the wave action is weak, but the tidal range reaches 4 m in height. The strong tidal current has directly denuded and lowered the surface of mangrove forests. On the other hand, dense tidal creeks lead to narrower creeks in the area (Thanh et al., 1991a,b). Consequently, the mangrove forest tends to be degraded. The mangrove cutting by man has led to increase of the denudation and erosion.

Deformation of coral islands by the alternate wind seasons

This deformation was noted in the Paracel islands (Krempf, 1927). It has been recognized in the Spratly islands, too. The Spratly coral island is longer in NE wind season (700 x 300 m) and shorter in SW wind season (650 x 320 m) due to the changes of the beach deposition and erosion on the coast. In the long-term, the coast is eroded in the NE, N and W and deposited in the SW and E. The island position tends to move very slowly SE ward of the coral reef flat. The coastal erosion tends to be more and more extensive (Than, 1994).

Human activities have created directly the great changes in coastal morphology

Systems of sea dikes, land reclamation, salt fields and aquaculture pools

There are 2,000 km of sea dikes on the coastal length of 3,200 km. Almost all areas of RRD are closed by dikes built in the last thousands of years. In this time, the area of tidal flood plain above mean sea level has been diked for land reclamation or aquaculture (Fig. 3). During the last decades, over 10,000 ha of mangrove forests in the North have been turned into the aquaculture pools leading to destruction of the mangroves. There were no dikes in MRD, but recently tens thousands hectares of mangrove marshes were closed by dikes for aquaculture. Only in Minh Hai Province, during 1982-1987, the mangrove area decreased from 98,044 ha to 75,129 ha for brackish aquaculture ponds. In the South, brackish aquaculture area increased from 50,000 ha to 120,000 ha during 1981-1987 (Hong & San, 1993). So, flooding in this delta has increased dramatically. At present, there are about 200,000 ha aquaculture pools in the coastal zone of Vietnam.

Systems of dams, gates, bridges and roads

Construction for irrigation channels and transportation is developed very widely in the coastal zone. They are embanked on the transversal profiles of the tributary, channels leading to closure of coastal water bodies. Dinh Vu Dam in Haiphong is an example of such a typical impact.

Systems of dredged channels and rivers

These artificial flows are abundant in RRD and MRD for waterways and hydraulic irrigation. They have changed the flow structure and suspended sediment distribution in the coastal zone.

Systems of ports, harbours and urban structures

There are 37 ports and harbours and hundreds of small fishery harbours in the coastal zone. The biggest ports such as Haiphong and Saigon are in the estuaries. Navigation dredging makes significant influence on the coastal morphology and dynamics. Many big cities and towns such as Halong, Haiphong, Danang, Qui Nhon, Nha Trang, Vung Tau ..etc. lie in the coastal zone. At these locations, there are 12 urban areas with populations ranging from 100,000-1,000,000. The coastal urban development has affected CMC as well.

Mining activities

The mining activity in Hongai (North) is most typical. Every year, 10 million m^3 of rocks and soils are dumped to block the coastal streams, fill the tidal flats and the mangrove forests. The exploitation of sand for construction or glass and heavy minerals are carried out in many places, leading to increased coastal erosion and further damage the natural landscape.

CAUSES OF COASTAL MORPHOLOGICAL CHANGES

Having intrinsic and direct causes, the CMC has been created by deposition and erosion under the interacting influence of endogenic and exogenous

processes and human activities. The tropical factors have certain influence on the CMC.

The cause of coastal morphological changes

Natural evolution

The long-term changes are interactions resulting from natural factors. The large deltas have expanded seaward quickly by the large amount of sediment supplied from the rivers. Although the sea level rise is due to both the tectonic subsidence (Can, 1985) and the eustatic rise, the deposition rate is greater than submergence. The migration of tributaries is the results of deltaic development. In the estuaries (or negative deltas), the erosion process is the dominant factor due to the submergence without sedimentary compensation as a result of sea level rise and high tidal range (Thanh et al., 1984, 1991a, 1992a). The migration and closure of lagoonal inlets and river mouths and the migration of sand dunes in the Centre relate to the local seasonal changes of hydrological and meteorological factors, lithology and geological structure (Hoi et al., 1992).

Unusual changes in meteorology, hydrology and sea level rise

It may be that the human activity on the global scale has contributed to these changes. During the last 30 years, the number of tropical cyclones and storms in Vietnam has increased from 7.5 to 8.4 storms/yr. Only in the Western Coastal Zone of Tonkin Gulf the storms have increased from 2.77 storms/yr (1911 - 1965) to 4.28 gusts/yr (1954 - 1989) (Thuy, 1990). The storm distribution has also changed in the different coast parts. Many years ago, there was only 1 storm/50 yrs in the South, but 0.5 - 1 storm/yr at present. Recently, heavy rainfall often occurs over a few days.

Storm surges have a special significance in the Western Coastal Zone of Tonkin Gulf. During 1954-1984, 50% of storms reached 1.0 m in surge, 20% reached 2.0 m and a maximum 3.0 m in surge. In the Centre and South, the storm surge has been only 0.5 m in general and 1.4 m maximum (Ninh et al., 1992). Linked with spring tides, the storm surges have made very high waves that damage dikes, destroy coastal constructions and create great deformations of the coastal morphology.

There is lots of evidence for the sea level rise. At the State Hydrology Station in Hon Dau Island, it was recognized that mean sea level increased to 2.24 mm/yr during 1957-1990 (Thuy & Khuoc, 1994). Being mainly eustatic rise added to the tectonic subsidence, the sea level rise has been one of the principal causes leading to the erosion (Thanh et al., 1994).

Changes in sediment supplies and direction of longshore drift

These are the results of both natural evolution and human activities. Most of the erosion cases are due to sediment deficiency. The coastal shape change, the degradation of this tributary or the development of others, the decrease or increase in the sediment supply has led to erosion or deposition in the coastal areas. The Van Ly eroded coast, where all tributaries were blocked by the dikes, is a typical example of the lack of sediment supply (Huy, 1994). One of the causes leading to the siltation in Haiphong Port is the increase of the sediment amount supplied from Cam River. During 1960-1990, the water discharge of Cam River increased from 9 to 13 km^3 and the suspended sediment content changed from 0.20 to 0.34 kg/m^3. That has been a result of the damage of upstream forest and the change of flow structure downstream.

Human activities

Apart from the direct changes, human activities have an indirect impact on CMC. The damage to upstream and mangrove forests, building of dikes, dams and other constructions have changed the solid and water discharges, flow direction, coastal shape and structure of estuaries and lagoons, changing the coastal deposition - erosion equilibrium. The human impact has strengthened the natural changes and created unusual and sudden ones. After building the Dinh Vu Dam, the depth of Part 2 of the navigation channel to Haiphong Port decreased suddenly from 10-15 m to 4-6 m. In another example, by dredging the New River in 1934, Thai Binh River, which was the second largest in the North, has become very small one. Some giant dams for hydroelectric power have just been built in the upstream of Da River (a large branch of Red River) and Dong

Nai River. Their impact on coastal zone can be very great, but has been not estimated.

The damage to mangrove forest in Vietnam is an important example. In 1943, there were about 400,000 ha of mangroves, of which 250,000 ha were located in the South. In 1987, there were only 252,500 ha mangroves, of which 46,400 ha were located in the North, 14,300 ha in the Centre and 191,800 in the South. The mangrove areas have been continuously reduced. The mangrove forests have been destroyed for wood, aquaculture, agriculture.. etc. The impact of massive use of herbicides during the Second Indochina War (1962-1971) has destroyed and degraded about 104,900 ha mangroves in the South and Centre (Hong & San, 1993).

Some tropical features of the coastal morphological changes

The CMC in Vietnam are under the clear influence of the tropical features. The very dense mangrove forests strongly enhance deposition and restrict erosion (Thanh et al., 1984). The development of coral reefs supplies the sediments for the beaches and defends the coast from erosion by waves. It seems that the coastal sediments supplied from the illite weathering production are deposited favourably by the colloidal mechanism in the coastal alkaline environment. This can be one of the causes which contribute to the quick deposition in the deltas. The seasonal climate factors and the role of tropical storms are important for the CMC, but not estimated in detail. The difference in the CMC in the coastal parcels depends on the coastal type, the seasonal features and the interaction of the river, wave and tide dynamics.

COASTAL MORPHOLOGICAL CHANGES AND MANAGEMENT.

Vietnam is not a large country but has a high population density. That the large deltas expand seaward by hundreds of hectares every year brings the precious land resource for the development of agriculture, aquaculture, mangrove forestry, settlement and new economic areas. However, the lack of scientific base including the CMC has led to the poor use and even the failure to use the new expanded land. Recently, the building of aquaculture pools without planning has contributed to the serious flooding in MRD.

Almost all of the CMC has a negative impact on the inhabitants, economy and the environment. The erosion and the migration of sand dunes have threatened directly the settlement and economic areas, destroyed the dikes and constructions and restricted the mangrove forests and coastal land. In Cat Hai Island, which is a rich and crowded site, the coastal erosion has been one of the principal causes of population decrease recently. Thousands of people have had to move out of Van Ly eroded area.

The deformation linked with siltation of channels has decreased the benefits of the ports, for example, Cua Lo and Haiphong. Many years ago, it was easy to enter Haiphong Port for the ships over 10,000 DWT, but only those of 5,000-7,000 DWT can enter the port at present. The channel siltation becomes the most important factor for the reconstruction and development of this port, which was the biggest one in Vietnam in the past (Thanh & Hoi, 1992).

The migration and closure of lagoonal inlets and river mouths and the migration of deltaic tributaries have caused floods, inundations and traffic snarls. The floods and inundations have been heavy risks in the Centre. For example, in Tam Giang Lagoon, during the closing of Tu Hien inlet (1979-1989), there were many floods and inundations. Hundreds of people died in this lagoon by the floods in the storm at 15 October 1985.

In fact, there have been many risks and failings for coastal management concerning the CMC created by both natural evolution and human activities. From them, flood - inundation, erosion and port siltation are the heaviest risks. In a developing country such as Vietnam, the CMC become a very urgent environmental problem. The sustainable development of the coastal zone requires careful assessment of CMC. So, it is necessary to survey in detail in the scale, cause, and impact of the CMC. The implementation of this is difficult, requiring the cooperation and help from the international experts and organizations in science and management.

CONCLUSIONS

Morphological change is the one of the focus problems for the management and sustainable development of the coastal zone in a developing country such as Vietnam, During the last decades, the coastal morphology has changed dramatically through deposition and erosion processes. Eight types of changes have been identified:

- seaward expansion of the deltas;
- erosion on a wide scale;
- channel deformation linked with siltation;
- migration and closure of lagoonal inlets, river mouths and tributaries;
- migration landward of sand dunes and barriers;
- denudation of mangrove forests;
- deformation of coral islands and
- changes by the direct human activities.

These changes have been created by both the natural evolution in response to tropical features and human activities direct and indirect. Recently, the unusual changes in meteorology, hydrology and sea level rise have had a very important role for the coastal morphological changes (CMC). The human activities have caused unusual and sudden changes in coastal morphology. The CMC have led to new interactions and caused a chronical a lack of coastal environment. Apart from the increase of land resource in the deltas, most of the CMC have had a negative impact on the coastal inhabitants, economy and environment. Linked with the CMC, there are the heavy coastal risks, for example, floods-inundation, erosion and port siltation. So, the CMC is very important for suitable and integrated management and the economic - social development of coastal zone in Vietnam.

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Table 1: The area increase of Ca Mau Peninsular

Period (year)	Deposition area (ha)
1886-1940	5,900
1940-1965	3,200
1965-1985	3,260 +
total 1886-1985:	12,360

Table 2: The expansion rate of Kim Son area during the periods indicated.

Period (year)	Expansion rate (m/yr)
1470-1982	44
1932-1982	100
1958-1982	108
1982-1989	60 (maximum 120)

Table 3: Deposition - erosion equilibrium in the coastal zone of RRD during 1938 - 1992.

Flood Plain	Deposition (ha)	Erosion (ha)	Equilibrium (ha)
High tidal	20,860	1,350	19,510
Low tidal	14,000	3,240	10,760

Table 4: The area decrease by erosion in Bo De Coast.

Period (year)	Erosion area (ha)
1886-1940	6,500
1940-1965	2,400
1965-1985	2,400 +
total 1886-1985:	11,300

Fig. 1 Distribution of main coastal morphological changes in Vietnam.

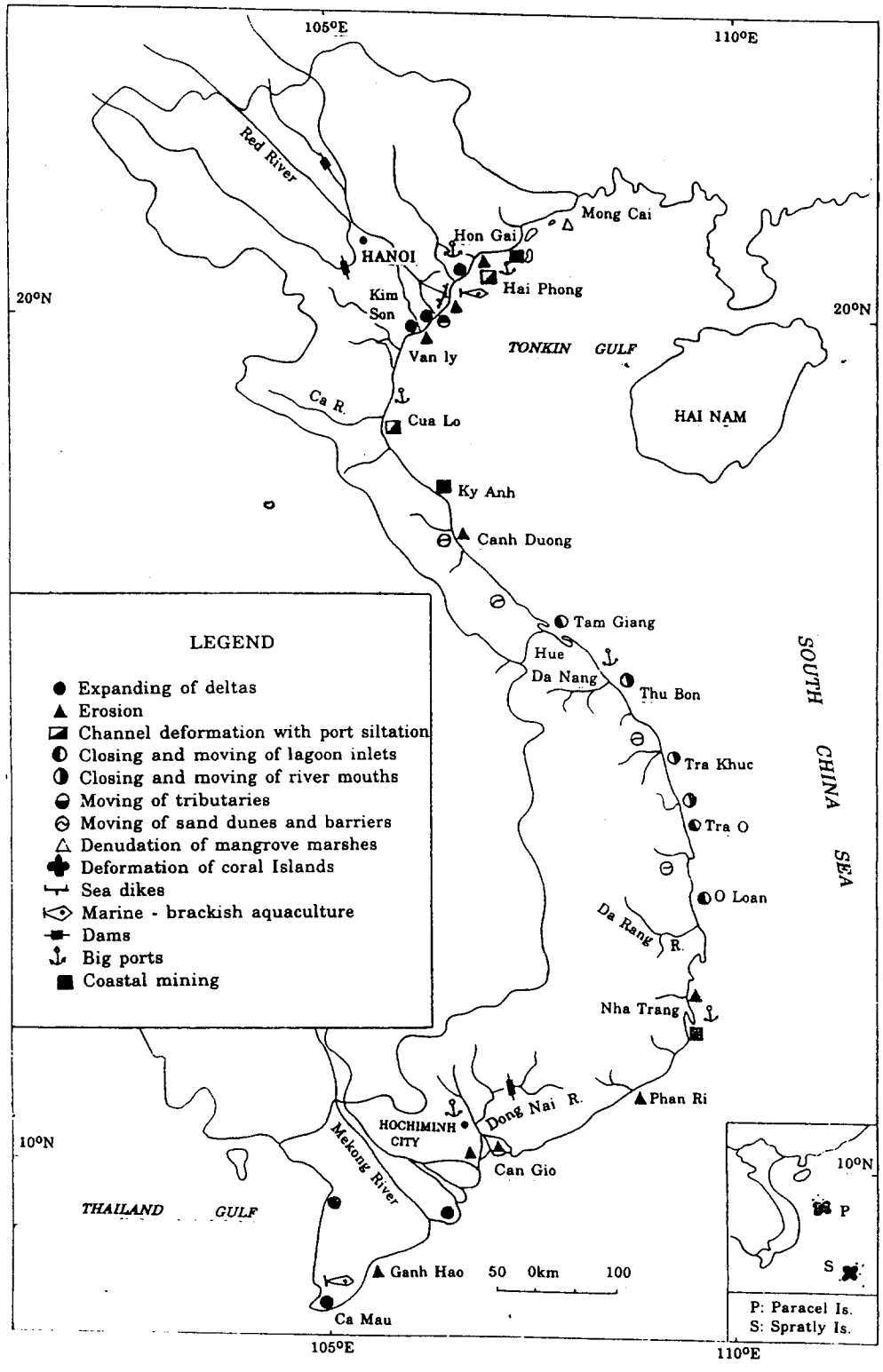
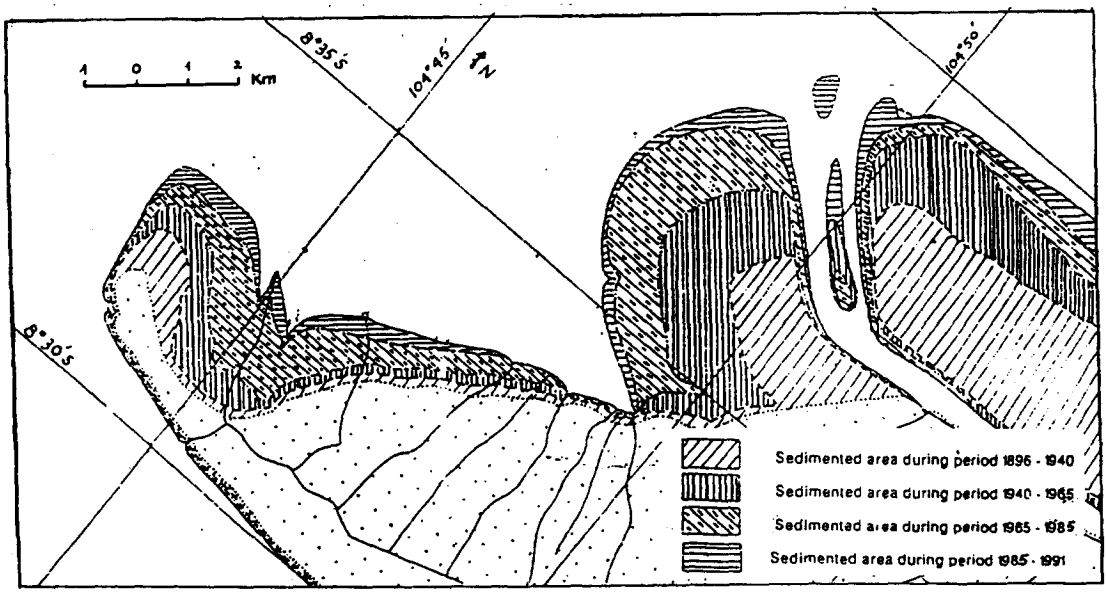


Fig. 2. Deposition process in Ca Mau Peninsular (Mekong river delta). Coastal shores: ..... 1896; ---- 1940; -·-·- 1965; —·—·— 1985; ——— 1991. (Thinh, 1993).



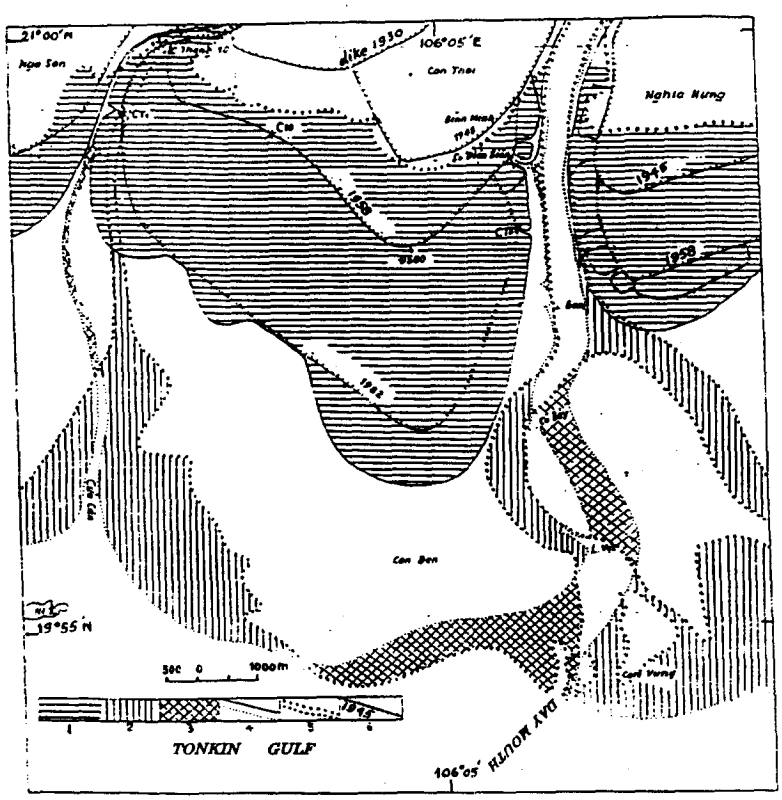
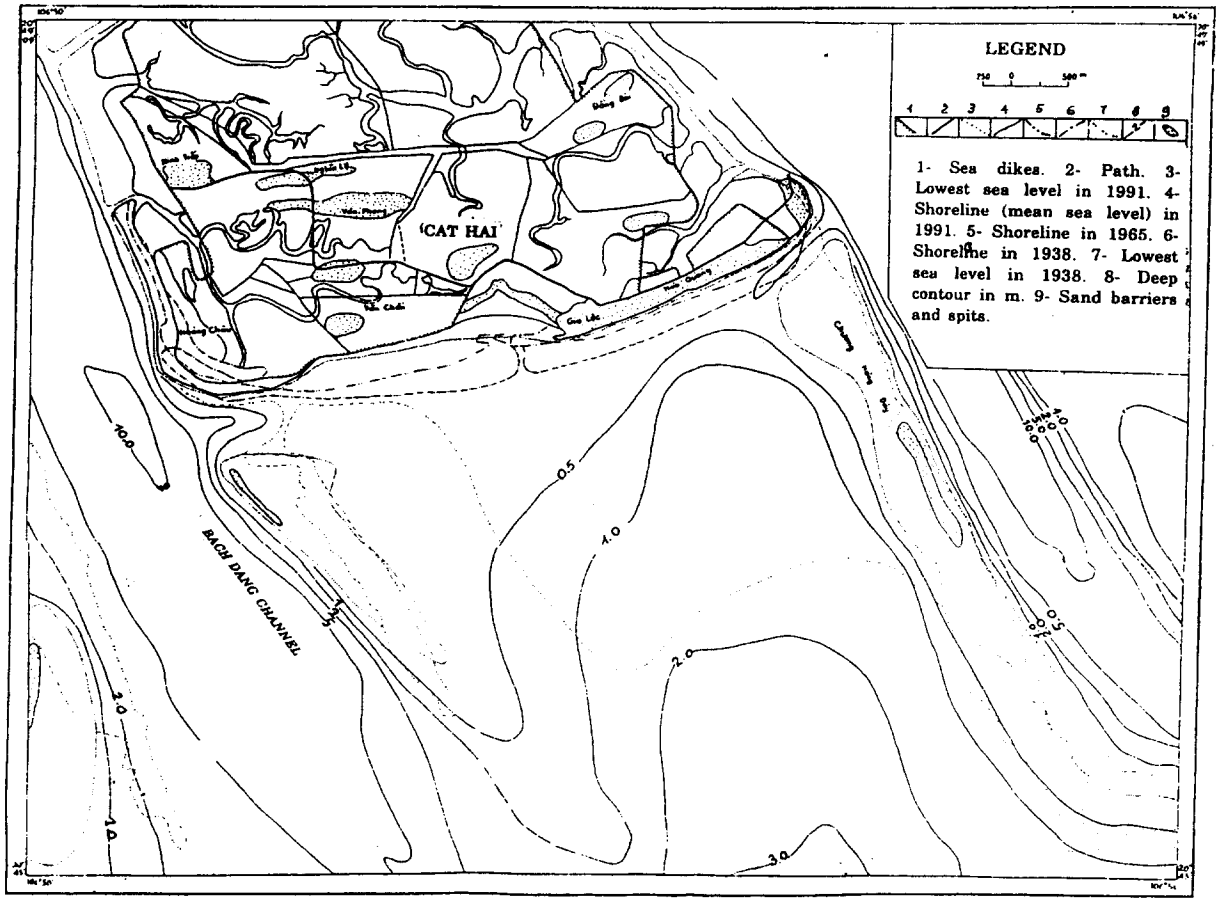


Fig. 3. Morphological changes in the Kimson area between 1938 and 1989 (Red river delta). 1: Deposition of high tidal flood plain; 2: Deposition of low tidal flood plain; 3: Erosion of low flood plain; 4: The lines of mean and lowest sea level in 1989; 5: The lines of mean and lowest sea level in 1938; 6: Sea dikes and building time.

Fig. 4. Shoreline change by erosion of the Cat Hai Island (Bach Dang estuary) between 1938 and 1991.



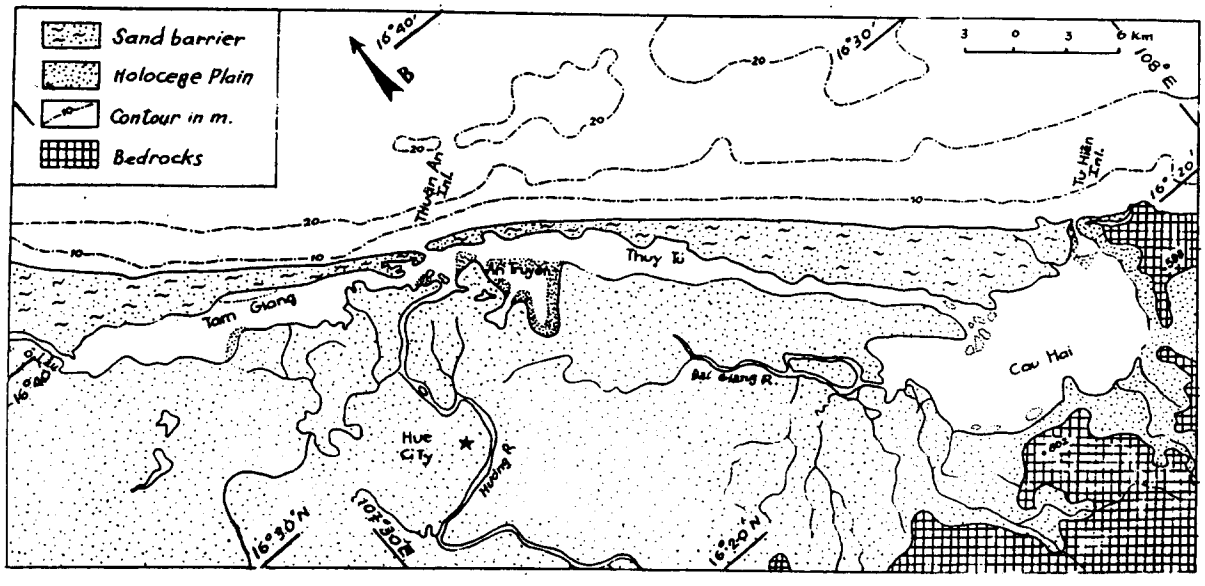


Fig. 5. Morphology of the Tam Giang lagoon.

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EVOLUTION OF THE SEA OF AZOV EASTERN COAST UNDER THE INFLUENCE OF ANTHROPOGENIC STRESS

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KEYWORDS: anthropogenic impact, beach nourishment, beaches, coastal protection, coastline evolution, degradation, ecology, Kuban river delta, sediments, Sea of Azov.

ABSTRACT

Recently, economic activity in the basin of the Sea of Azov resulted in a sharp change of the conditions of coastal evolution. Ancient accumulative forms which were steady for centuries began to be destroyed. The need for coastal protection from wave erosion became apparent. The main reason for recession of the shores lies in the decrease of deposits arriving into the coastal zone from the Kerch strait seabed and carried by longshore flow from the Kuban river delta.

INTRODUCTION

Not long ago the Sea of Azov was leading the basins of the World ocean in fish catch per unit area. A high fish-productivity was due to ample places for spawning, low water salinity (1.05%), a large inflow of clean fresh water (40-60 km^3), and a high trophic level of the shallow water. According to Volovik (1985), annual fish catch between 1930 and 1978 was 179 thousand tons. An annual catch of migratory, fluvial anadromous and fresh-water fish decreased from 176 thousand tons in 1936 to 4-5 thousand tons in the 1970s. The catch of migratory fish and sturgeon has been reduced between 5 to 15 times. In 1994, in Russia, there were approximately one thousand tons of sturgeon caught.

The main reason for the decline the fish catch was the great anthropogenic impact not only on the ichthyofauna but on the whole nature of the Sea of Azov. The most destructive events for the Sea of Azov were the construction of the Tsymlyanskoe and Krasnodar water storage basins which changed the regime of the Don and Kuban rivers, decreasing the stream-flow and runoff; the discharge to sea of highly toxic compounds from plants and factories and pesticides from rice fields; filling up of the firths' mouths or the installation of sluices in them preventing river runoff from the firths. These factors together resulted in rather unfortunate natural, ecological and social conditions. Sea-water pollution led to great reduction in fish productivity and fish catch so that fishermen were forced to find another job. The lowering of river solid runoff stimulates the erosion and retreat of sea coasts. This region is chosen for analysis as far as it is a good example of unwise treatment of nature.

The ecological catastrophe that has occurred at the Sea of Azov during the last 30 years has been described in literature (Kuksa, 1994). But the factor that accompanied the construction of the water storage basin, i.e. the cutting of sediment discharge, was undervalued. In any case, it was not taken into consideration when projecting the Krasnodar water storage basin. By the way, a deficiency of sediments in the coastal zone radically changed the coastal processes, i.e. accumulative coasts were replaced by abrasive ones, and the growth of the shore due to the Kuban River deposits changed shore erosion. This problem is discussed here. The coastal processes from the Dolgaya Spit in the North to the Chushka Spit in the South are analyzed. These coastal sections represents a common lithodynamic system (Figs. 1, 2).

THE RECENT EVOLUTION OF THE KUBAN RIVER DELTA.

The coastal section studied and the adjacent Taman peninsula were formed by the Kuban River during the historical period. Sediments transported by the Kuban River filled up the straits between five islands that earlier had been in peninsula's place, and were described by Straton in the second century B.C. But at the beginning of 14th century a monolithic Taman peninsula has already existed according to evidence of Pedro Visconte. Then the paleochannel of the Kuban River changed its position and filled an ancient bay stretching between the Krasnodar city and the modern coastline of the Sea of Azov. The Southern branch of the Kuban River fell into the Kerch Strait. Then it shifted to the South and began to discharge into the Black Sea (Suvorov, 1775). At the end of the last century this branch disappeared, but the water flow through the Protoka was intensified.

Generally, the moving of the whole region towards the Black Sea and the Sea of Azov took place during this historical period. The coastline was composed of sediments brought mainly by the arms of the Kuban River and from the firths, beds and mouths as well. Shells of *Cardium edule, Mytilaster, Sindesmia* were brought from the sea bottom. The coastline was composed of basic rocks only in some sections. The process of accumulation prevailed over abrasion here till the middle of the present century.

VARIOUS ANTHROPOGENIC IMPACTS

The natural system examined has suffered from anthropogenic impacts since the middle of the last century when people began to dig canals connecting typical brackish lagoons with flowing firths. This resulted in a redistribution of runoff but in general it was a positive event since it increased the area of spawning. In the beginning of this century the construction of levees in the Kuban River arms began, and this reduced the area of the inundated land during floods. At the same time the inflow of flood water into firths and lagoons ceased and this worsened the conditions for fish spawning and growth.

During half a century and longer the overlapping of the firth mouths with sluices or the filling by soil was carried out. This provoked the more rapid silting and rushing of the firths and reduced the age of their vital activity.

In general, the described measures have not provoked the principle changes in the Kuban River delta evolution. The marine coastal dynamics resulted in attenuation of the river sediment transport through the firth mouth to sea. For this reason the delta began to build-up only on the sections of open firth mouths and large Kuban branches. Arrangements carried out since the beginning of the 1950s were the most important and may have had irreversible consequences for fish reserves, ecology and coastal dynamics of the Sea of Azov. In 1953 the Tsymlyanskoe water storage basin was built, after that the annual regime of the flow of the Don River changed, its value decreased by 8 km^3 per year. The value of these flood waters that created favourable conditions for spawning and for the salinity being 1.0%, has become more than twice less (from 17.2 km^3 to 8.3 km^3). As a result the process of sea salting began, and therefore the areas of fresh-water fauna were reduced too. When the water flow was reduced, the sediment discharge of the Don River decreased as well (from 8.6 to 2.1 million tons), and the sediment amount of the wave field was reduced by one order of magnitude (from 1.7 to 0.15 million tons).

Until 1949 average annual discharge of the Kuban River was 12.9 km^3/yr, the water turbidity was 0.64 kg/m^3, the sediment discharge was 8200 thousand tons. After the starting of the Stavropol canal (1966), the water flow and sediment discharge became slightly less. But the overlapping of the Kuban River bed by the dam of the Krasnodar water storage basin in 1973 exerted the greatest influence. As a result, the average water flow became 9.6 km^3/yr. Water turbidity was reduced to 0.1 kg/m^3, and sediment discharge to 860 thousand tons. The content of sandy fractions in the Kuban River sediments was 30% during the flood period and 3.6% during low-water, the corresponding values for the Protoka River were 11% and 0.5%. The change of

the Kuban River sediment discharge between 1928 and 1989 is shown in Fig. 3, and the change of the water discharge and of solid runoff before and after the regulating of the Kuban River flow is shown in Fig. 4. After regulating the Kuban River flow, the water balance and drainage network of its delta changed, the rate of the delta evolution was reduced, and the salinity of the coastal water increased by 0.3-0.4%. The adverse effects upon the dynamics of the described coast of the Sea of Azov were due to the protective constructions of various kinds and the under- and above water pits for the extraction of sandy-shelly material. The Dolgaya Spit has suffered most of all from the removal of shelly material out of the spit body and neighbouring islands. Since 1950 till 1975 its length shortened from 4.5 to 0.3 km. During this period more than 2 million tons of shell were removed from the spit. Since 1975 the production of the *Cardium* mollusc has increased and therefore the sea coast of the spit has become a stable one, but the coast of the Taganrog Bay continues to go through a declining phase.

THE DYNAMICS OF THE COASTS

Fig. 5 shows the scheme of the coastal dynamics. Let us begin from the southern extremity of the examined coastal section, namely the Chushka Spit. This spit was formed by sandy sediments entering from the Temryuk Bay. According to Straton's (2^{nd} century B.C.) description it was a sandy island. On the maps of the 18^{th} century, the spit has its modern shape. There is no information about the facts that in 18^{th}-19^{th} centuries the spit was eroded and turned out to be an island. But in our time, i.e. the beginning of 1950s during a strong storm the foundation of the spit was washed out and during a short period it existed again as an island. The reason was the construction of the mole on the Ahileon Cape which stopped the sediment flux from the bay. Owing to the deficiency of sediments, erosion of the near root part of the spit has occurred.

In 1953 the port of Kavkaz was built on the spit. Its northern jetty stopped sediment flux from the North, became the reason for the degradation of the spit's southern part. Today this part has no nourishment. As a result its height is reduced, the coast becomes bogged up and numerous channels have started to break up the spit's body into separate islands.

To prevent the spit erosion on the coastal section between the Ahileon Cape and the port, in the 1950s more than 100 groins were built which retained sand in the spaces between them. Due to such a protection, the coast on this section is relatively stable. Sedimentary flux, i.e. 15-20 thousand cubic meters of sand, passes round the groins, then the port jetty, and is deposited in a shipping canal which is regularly dredged. Thus, it can be said that the southern part of the Chushka Spit is destroyed and in due course will disintegrate to a number of islands which will be washed out, if appropriate measures not are taken. The existence of the northern part of the spit depends entirely on the sedimentary flux from Temryuk Bay. If this flux is reduced, there will be trouble with the coast on this part of the spit.

In the North, the Chushka Spit borders of the Ahileon Cape which is composed of clays and sandy loams and is being eroded at the rate of 0.5 m/yr. The rate of erosion depends on the capacity of a sandy beach, i.e. the wider the beach, the less is the rate of abrasion (Yesin et al., 1980). Sand that composes the beach here is also brought from Temryuk Bay and partially from the eroded coast.

To the East the cape is the section 1 (Fig. 2). According to observational data the coast was retreating here till 1974. Today it is retreating at a rate of 1.7 m/yr according to observations during 1974-1990. Farther to the East the section 2 is situated. Here is a wide sandy beach of recreative importance. Until 1974 it was stable or even grew. But now it is being washed out at a considerable rate. It gets additional nourishment owing to erosion of the left-bank part of the delta and of the Akhtanizovsky firth mouth. The same material is partially transported to the West to the Chushka Spit. The section 3 is situated directly in the delta. Until 1974 its growth rate was at 35 m/yr. Then this rate decreased to 10 m/yr.

When analyzing the velocity characteristic for the coastal dynamics before and after 1974 (Fig. 2) we notice the following regularity. For those coastal sections that before 1974 were moving to sea at a

high rate, the rate of this process was reduced several times. Those coastal sections which were moving to sea at small rate after the regulating of the Kuban River flow became stable or began to wash out. The rate of erosion has considerably increased for the coastal sections that had been eroded earlier. Today 64% of a total length of the delta sea edge are retreating, 25% is stable and growth of the coast occurs on 11% of its length. Thus, an outstanding thing has happened this century, which must occupy a definite place in the history and the budget of the Krasnodar region, namely our fellow men and contemporaries succeeded in turning back a global natural process that continued longer than two thousand years, i.e. the Kuban River delta moving towards the Black Sea and the Sea of Azov. During this period, the river formed the land from Krasnodar to Anapa, Temryuk, Primorsko-Akhtarsk. But now the process is reversed, i.e. the sea advances to the land. To stop this process in the near future it is necessary to spend the equivalent of many million of dollars.

The main reason of the described event is an unwise economic activity which resulted in deficiency of sediments practically all over the coastal section. Really, direct shell removal from the beaches and spits has exhausted the latter, a full overlapping of the firth mouths and the construction of locks in them have hampered the sediment drift from the firths to the sea, the Krasnodar water storage basin has prevented the river sediments from discharging to the coastal zone. Thus, the sediments, that should like to enter the coastal zone of the Sea of Azov by different ways and thus to form not only a stable coast but a coast that is actively moving towards the sea, nowadays are accumulated in the Krasnodar water storage basin and in the firths. Then the latter are being silted and become shallow.

THE PROGNOSIS OF THE COASTLINE EVOLUTION

Available data from field observation allows us to describe the evolution of the Sea of Azov and the Chushka Spit coastlines in the near future if the measures on coastal protection against erosion are not taken.

Let us examine the Sea of Azov coastline to the West of the Kuban River. Here the Kuban River and the mouth of the Akhtanizovsky firth were the basic sources of sediments entering the coastal zone. After the flow regulation, sediment deficiency has occurred in the coastal zone on the left-bank part of the delta, and then its erosion began. Sediments were transported from this section to the section 2, and they nourished beaches there. Partially the sediments from the eroded mouth of the firth are brought here too. As is seen from Fig. 2 the erosion of the beaches begins here, nevertheless. The material from above mentioned sources is transported to the West towards the Ahileon Cape, it passes round the cape and feeds the Chushka Spit. Thus, the coastal stability on the section 2 and of the Chushka Spit coast depends on the volume of sandy material on eroded sections and on their rate of erosion. Unfortunately additional research is necessary for the assessment of this rate and for quantitative prognosis of the coastal evolution.

The qualitative picture of the future coastal processes is quite clear. As long as the delta will be eroded and sedimentary flux discharge on the section 2 will be reduced, the erosion of this section will begin, and nourishment of the Chushka Spit will depend on the erosion of the beaches on sections 2, 3. Then their catastrophic erosion will begin, similar to Chushka Spit, since the bottom nourishment is not enough for the coastal stability.

The outwash of the beaches near the basic coast of the Ahileon Cape will intensify the rate of erosion on this section too. Thus, in the future, regulation of the Kuban River flow will result in disastrous reformation of the coastline on its left bank on the coastal sections between the delta and the port of Kavkaz on the Chushka Spit. The southern part of the spit without sediment nourishment will disintegrate to several islands and will disappear in the near future.

On the right bank of the Kuban River there are two sources of sediments, namely the Kuban itself and the Protoka River. A part of sediment is brought from Kuban to the right bank and is

transported to the North. Today this coastal section suffers from a deficiency of sediments. The land protrusion occurs only in the delta of the Protoka River. Mouths of some firths are filled with sediments, those deposits are not transported to the sea. Thus, the character of the coastal processes here has changed due to different factors, i.e. accumulation has been replaced by abrasion. Usually in such a situation the reformation of the whole coastal system occurs, and the coasts that have been stable earlier, are affected by the abrasion process. It is very likely that the coastal evolution will develop in similar way. In this case we may expect the intensification of the abrasion process in the near future.

CONCLUSIONS

The coastal processes on the coastal section between the Chushka Spit and the Achuevskaya Spit have changed, i.e. the accumulation of material has been replaced by wave erosion as a result of regulating the Kuban River flow, the cutting of its sediment discharge and economic activity in the firths.

Thus, economic activities in the Kuban River basin have stopped the geological process of delta protrusion and of a vast valley formation and changed it to coastal retreat over a section of 180 km in length. We have every reason to conclude that the erosion of the coast will intensify in the next decade in view of reformation of the whole coastline.

ACKNOWLEDGEMENTS

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Fig. 1. The Sea of Azov.

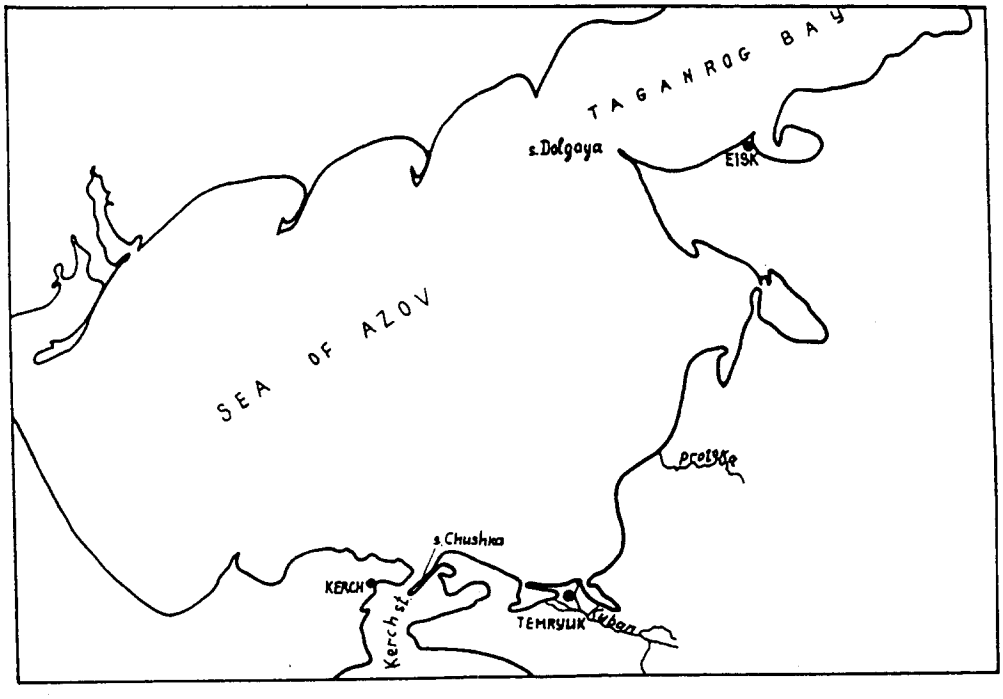
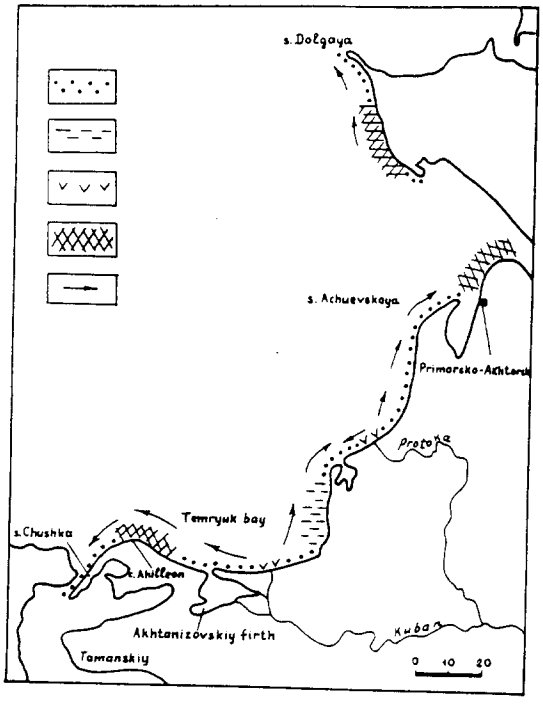


Fig. 2. The Sea of Azov eastern coastal lithodynamic system. 1: sand, 2: silt, 3: Kuban River deposits, 4: fundamental beach, 5: sediment flow directions.



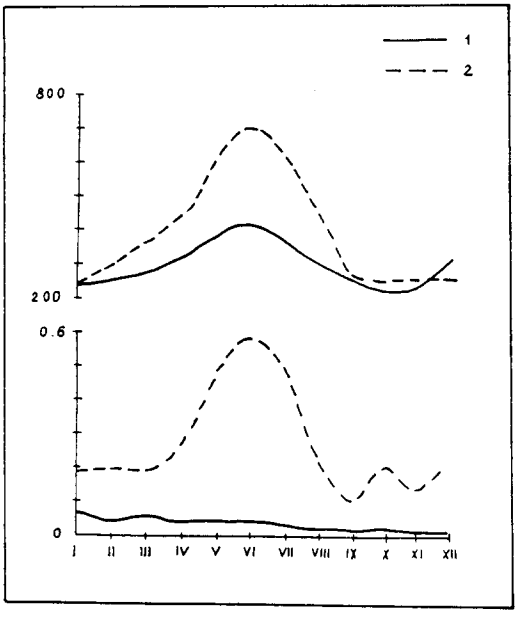
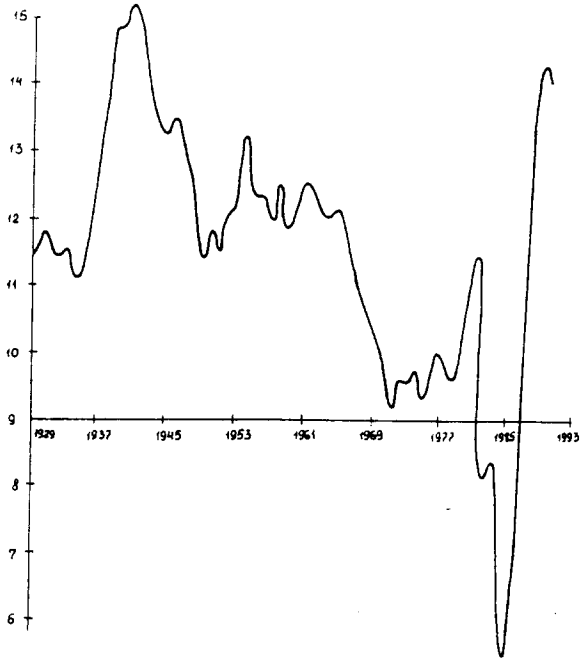


Fig. 4. Above: Change of the water discharge in m^3/s and Below: Change of solid runoff in tons/s; (1) —— 1: before and - - - 2: after the regulation of the Kuban River flow. Horizontal axis months of the year.

Fig. 3. The change of the Kuban River runoff since 1928 till 1989.



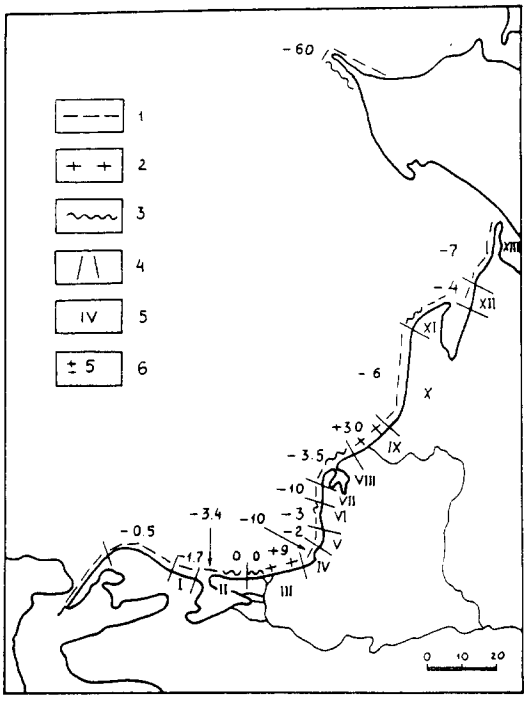


Fig. 5. Rates of coast increasing and retreating, m/yr. 1: wave erosion, 2: delta increasing, 3: stable beach, 4: coastal sections boundaries, 5: number of coastal section, 6: rate of coastline changing.

SESSION V

Aquitaine, Mediterranean & other European Coasts

Chairman: P. Buat-Menard & Y. Dolotov
Rapporteur: C. Latouche

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ÉVOLUTION PASSÉE ET FUTURE DE LA LAGUNE D'ARCACHON (FRANCE)

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RÉSUMÉ

La lagune d'Arcachon située en Aquitaine est un vaste plan d'eau de 160 km^2 à pleine mer de vives-eaux qui se réduit à 40 km^2 au moment des basses-mers (Fig. 1).

Des cartes bathymétriques fiables existent depuis le début du 18^e siècle, ce qui a permis d'effectuer des comparaisons et de suivre l'évolution morphosédimentaire de la lagune depuis presque 3 siècles.

On observe un comblement progressif de la partie nord de la lagune associé à une diminution de la compétence hydraulique des chenaux de liaison. Le comblement résulte d'une part des apports sédimentaires par les petits cours d'eau et, d'autre part de l'éloignement progressif de cette zone, de l'océan ouvert au fur et à mesure de l'allongement vers le Sud de la flèche littorale du Cap-Ferret. Ainsi, on démontre que le volume liquide sous étiage à l'intérieur de la lagune fluctue en fonction des avancées et reculs temporaires de la flèche littorale. En période d'avancées vers le Sud de la flèche, le volume liquide subtidal diminue, En période de régression de la flèche vers le Nord, et donc de meilleure communication avec l'océan, le volume liquide augmente.

Sur une longue période de temps (plusieurs siècles), l'allongement de la flèche littorale vers le Sud est continu sous l'action de la dérive littorale toujours orientée du Nord vers le Sud sud la côte aquitaine. Le sable déplacé sous l'action de la dérive (de l'ordre de 500.000 m^3/an) provoque l'instabilité des chenaux d' accès à la lagune. Le chenal principal migre du Nord vers le Sud (de l'extrémité de la flèche du Cap-Ferret à la dune du Pilat) selon un cycle d'évolution d'environ 80 ans. Chaque cycle est composé de 3 stades principaux se succédant dans le temps dans un ordre qui peut varier.

On peut ainsi distinguer:

- un stade A correspondant à la formation de deux chenaux extérieurs d'inégale importance, soudés à leur extrémité nord ou reliés par un chenal intermédiaire;
- un stade B présentant un seul chenal;
- un stade C présentant deux chenaux bien individualisés.

La Fig. 2 présente la succession des stades depuis 1826 avec l'individualisation de deux cycles. Les trois phases s'agencent dans:

- le sens A-->B-->C-->A pour un premier cycle de 79 ans et dans
- le sens A-->C-->B-->A pour un second cycle de 82 ans.

La morphologie actuelle des chenaux d'accès montre que l'on se situe aujourd'hui à l'amorce d'un nouveau cycle d'évolution. Le développement d'un chenal au Nord limitera la progression de la flèche vers le Sud pendant les prochaines années. On se trouve donc dans une phase de relatif équilibre dont la durée ne peut être précisée. Sur une longue durée (plusieurs siècles), la transgression marine holocène se poursuivant, le destin de la lagune d'Arcachon paraît être inéductable. A terme, la communication avec l'océan sera coupée et la lagune deviendra un lac semblable à celui de Cazaux situé plus au Sud.

Le mécanisme de cette fermeture est simple. Depuis l'amorce de sa formation, vers 2 000 ans BP, la progradation de la flèche du Cap-Ferret vers le Sud s'effectue suivant des cycles d'avancées et de reculs d'une durée moyenne de 250 ans. Mais le bilan net est un allongement progressif vers le Sud. Cette progression provoque l'erosion de la rive sud de la lagune dans la zone de la dune du Pilat, car l'écoulement hydraulique

tend à assurer la pérennité de la section mouillée. Dans le même temps, l'exutoire à l'océan qui, au début était orienté Est-Ouest, pivote progressivement vers le Sud, au cours du temps pour s'orienter parallèlement à la côte. Aujourd'hui, la lagune débouche à l'océan par un "conduit", encombré de bancs de sable (bancs d'Arguin, du Toulinguet), large de 3 km et long de 5 km. Dans les prochains siècles, la poursuite du pivotement et l'allongement du chenal d'accès rendront de plus en plus difficile la communication avec l'océan. Finalement, l'ouverture se fermera par diminution de la puissance hydraulique entraînant une réduction progressive de la section mouillée.

La lagune d'Arcachon aura suivi avec quelques siècles de retard la destinée des autres lacs côtiers aquitains. En effet, il y a 3 000 ans, ces lacs aussi étaient des lagunes situées à l'arrière d'un cordon littoral et communiquaient avec l'océan par un chenal permanent.

Fig. 1. La lagune d'Arcachon située en Région Aquitaine de France.

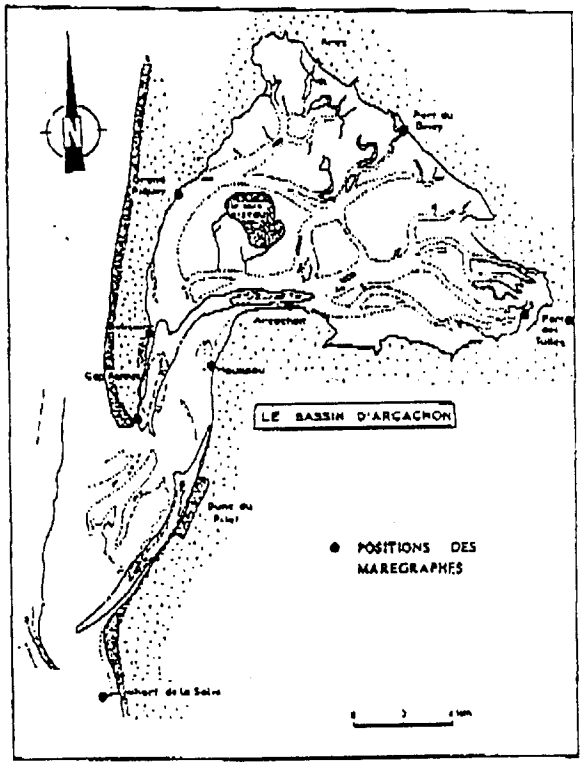

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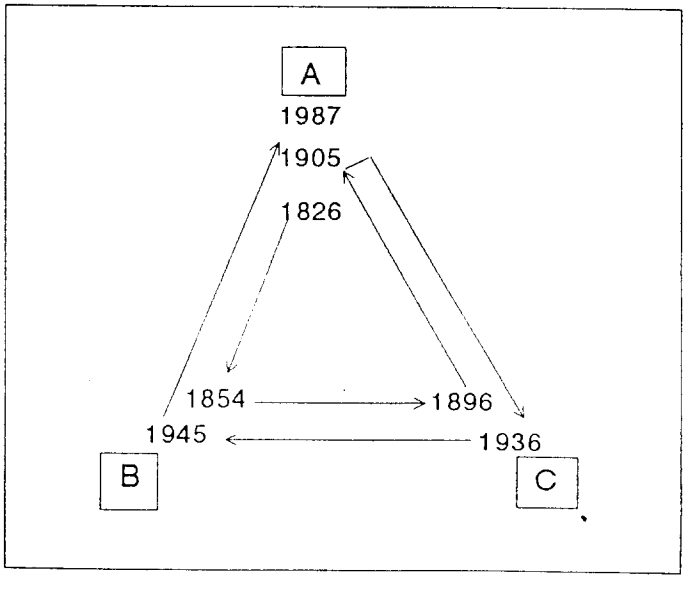
Fig. 2. Succession des stades du chenal principal, qui migre du Nord vers le Sud de l'extrémité de la flèche du Cap-Ferret à la dune du Pilat, depuis 1826. Le stade A correspondant à la formation de deux chenaux extérieurs d'inégale importance, soudés à leur extrémité nord ou reliés par un chenal intermédiaire; le stade B présentant un seul chenal; le stade C présentant deux chenaux bien individualisés.



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COASTAL CHANGE IN ALBANIA - A CASE STUDY FROM KARAVASTA LAGOON

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KEYWORDS: Karavasta Lagoon, geomorphology, beach ridges, erosion, pollution.

ABSTRACT
A study of Karavasta Lagoon, located on the central Albanian coastline, has involved the use of satellite imagery, aerial photographs and field-work, to examine the natural and man-made processes that have contributed to coastal change. The coastal sedimentary environment is extremely dynamic and dominated by large amounts of sediment delivered by the adjacent Shkumbini and Semani rivers. Following a long period of accretion, the position of the coastline has, over the last few decades, started to recede. Coastal configurations and morphologies have been readily upset by the shifting of river courses and by human intervention, particularly reclamation. Damage to the biodiversity of this sensitive environment may also be caused by the uncontrolled use of agricultural chemicals which contaminate water courses and lagoons and may cause eutrophication.

INTRODUCTION
The Albanian coastline is about 400 km long, two-thirds of which border the Adriatic Sea and one-third the Ionian Sea (Fig. 1). The morphology of the Ionian coastline is characterised by mountainous terrain composed of Cretaceous and Jurassic limestones and dolomites. The Adriatic coast is characterised by a lowland plain of Holocene sediments reaching widths of up to 35 km. Numerous rivers wind their way across the coastal plain delivering sediment to a wide variety of coastal environments. These include the Drini, Mati and Ishmi rivers feeding the Patok spit and lagoonal system, the Shkumbini and Semani rivers to the north and south of Karavasta Lagoon and the Vjose river debouching near Narta lagoon (Fig. 1).

This paper mainly relates to the area around Karavasta Lagoon located in the central part of the Albanian coastline (Fig. 1). The lagoon has a length of 10.6 km, a width of 4.3 km and a reported maximum water depth of 1.5 m (Fig. 2). It lies to landward of an 11 km-long north-south oriented spit (Divjaka Spit) which appears to have grown from sediment supplied by the Shkumbini river. On the seaward flank of the spit is Divjaka Beach backed by low dunes occupied by Divjaka Pine Forest. On the landward side of the spit is a narrow strip of saltmarsh. Local historians report that the lagoon started its formation about 400 years ago. Austro-Hungarian maps printed in the 19th century show that the shape and aerial extent of the lagoon were similar to the present day.
The extensive areas of lagoon, dune and marsh at Karavasta provide habitats for a large variety of fauna and flora. Karavasta Lagoon is an internationally important area for aquatic birds, particularly the rare Dalmatian Pelican which nests there. The lagoon is also important for the local economy in its fisheries. However, most importantly for future economic growth, Karavasta Lagoon and Divjaka Pine Forest will become increasingly important for eco-tourism development. Albanian environmentalists now recognise the importance of the Karavasta area and are seeking to develop a coastal tourism package based on sound environmental and natural resource management. This kind of strategy will benefit from a thorough knowledge of the sedimentary processes, both natural and influenced by man, that have contributed, and will

contribute to coastal change that may affect future development plans for the coast.

The objectives of this paper are, therefore, threefold;

- to describe the geomorphological characteristics and land-use patterns of the Karavasta area and the methods used in their assessment;
- to show that the coastal lowlands have changed significantly both over short-term (10 year) periods and over longer (1000 year) time scales; and
- to show that man may play a large part in future short-term coastal change.

GEOMORPHOLOGY AND LAND-USE

a) Methods

The geomorphology and land-use of the Karavasta area have been studied using multispectral Landsat (TM186/032) imagery acquired on 2 October 1986. The imagery consists of conventional False Colour Composites (CC4-5-7 and CC3-2-1) and Principal Component images (PC4-5-6 and DC4-2-5) derived from transformation of six reflecting input bands (Drury, 1990; Gupta, 1991). Principal Component transformations improve discrimination of objects and provide different contrasts to those of the Colour Composite images. The Colour Composite images provide information on the nature of objects according to the scheme in Table 1. The geomorphological units present at Karavasta Lagoon have been identified by interpretation of changes in tone and texture using the techniques outlined in Mantovani and Marcolongo (1992).

The spectral response of vegetation is shown in Fig. 3A where it is related to the visible and infra-red bands. Pigmentation is the controlling factor within the visible bands (wavelength between 0.4 and 0.75 μm). At wavelengths close to 0.5 μm (green) the chlorophyll content will control the colour response, so that healthy vegetation will show as bright green on the CC3-2-1 image. As the chlorophyll content decreases, plants will reflect more towards the red spectra and will appear yellow/brown on the CC3-2-1 image. The reflectance of vegetation within the near Infra-Red (0.8-1.3 μm) is controlled by the structure and thickness of leaves. Within the mid Infra-Red (1.3-2.6 μm), the reflectance is mainly controlled by the water content in the tissue of leaves. As the water content increases the reflection decreases (Fig. 3B). The spectral response of soil is shown in Figs. 4A and 4B where it is related to grain size and water content. For dry soils the reflectance increases as wave length increases. Reflectance curves for silt having a water content of 5, 10 and 20% are shown in Fig. 4B. The curves show that as wave length increases there is a general increase in reflectance with the exception of two minimum values at wave lengths of 1.5 and 2.0 μm (mid-Infra-Red) (Sabins, 1978; Goetz et al., 1983; Gupta, 1991).

Natural landscapes shaped by different geomorphological agents produce different types of textures and patterns. For example, the present meanders of rivers have a characteristic curvilinear shape and beach/dune ridges generally show a concavity seaward and indicate stages of coastline progradation. Man-made features like fields are generally arranged parallel to the coastline or to the main rivers or streams. They produce gridded patterns, the size of each field (grid) being related to soil productivity. Small fields are normally in fertile soils which can be used for different types of crops. Large fields are normally in finer grained soils which are not very fertile and are used only for one type of crop. Old river meanders can be identified by the radial orientation of fields.

b) Results

Fig. 5 describes the eight geomorphological units that have been identified using the Landsat imagery.

Units 1 and 2 are the youngest in age. Unit 1 is elongate and likely to be sandy (yellow or white on most of the images) and poorly vegetated. Unit 2 is densely vegetated, corresponding with Divjaka Pine Forest, and has a strong red colour on the CC4-5-7 image indicating a high reflectivity. Along the borders of the unit the red colour is not so bright or the colour changes to blue (on the PC4-5-6 and DC4-2-5 images) indicating a high water content in the soil. Ground truthing indicates that units 1 and 2 are marine and fluvial sediments reworked by coastal processes. Most of unit 2 is

richer in vegetation cover than unit 1 and in its southern portion it is composed of silty soil reclaimed for agriculture.

Units 3 and 4 are oriented parallel to the coastline and probably represent former marine or lagoon sediments which are now reclaimed and exploited for agriculture. Based on aerial photographic interpretation of coastline progradation (see section on long-term coastal change) it can be shown that unit 4 is older than unit 3. Unit 4 comprises a series of small fields with relatively high colour contrast representing variety in the type of crops. Unit 3 comprises larger fields than unit 4 (soil is probably finer and less fertile) and has a lower colour contrast between elements. The well developed field pattern of both units obscure the original morphology of the elements. However, old dune ridges are recognised in the westernmost portions of unit 3.

Units 5 and 6 correspond with the present day Karavasta Lagoon where they interdigitate with the marine units 1 and 2. They are distinguished most effectively on the PC4-5-6 image. The similarity in brown colour of unit 5 with that of the marine environment on the PC4-5-6 image may indicate that this unit is of deeper water than unit 6. Unit 6 appears a bright blue colour on the PC4-5-6 image corresponding to areas of a black/red mottle on the DC4-2-5 image. The red mottle on the DC4-2-5 image corresponds to the green (vegetation) signal on the CC3-2-1 image. The overall blue tone on the PC4-5-6 image, therefore, suggests the presence of submerged vegetation.

Units 7 and 8 are located along the Shkumbini and Semani rivers and have a pattern of land use that is orthogonal to that of units 3 and 4. They have a fluvial/alluvial origin with abandoned meanders and overflooded areas.

LONG-TERM COASTAL CHANGE

Long-term coastline changes were assessed by examining aerial photographs collected by the Royal Air Force (UK) on 6 June 1943. Fig. 6 shows an aerial photograph of the northern part of Karavasta Lagoon and the Shkumbini delta. The geomorphology is dominated by a series of north-south oriented, curved (concave seaward) beach/dune ridges. The ridges form a strandplain with a maximum width of about 6 km, providing evidence for extensive westward (seaward) progradation of the shoreline.

The strandplain comprises three distinct beach/dune ridge systems distinguished by slightly different orientations. The oldest and innermost system is truncated in the north by a younger more widespread system part of which incorporates Divjaka Beach. A third much smaller system onlaps the second system and is partially buried by the more recent sediments of the Shkumbini delta (Fig. 6). These different episodes of ridge formation are probably related to discrete shifts in the position of the outflow of the Shkumbini river.

The expression of the beach/dune ridge system can be seen clearly to the north where the ridges are lying above sea level (Fig. 6). Further south the ridges have been submerged by Karavasta Lagoon, apart from the youngest series of ridges which are preserved above sea level as the spit and afforested dune system which separates the lagoon from the sea. After the formation of the youngest ridges the growth and accretion of the system came to a halt and was replaced by the growth of Shkumbini delta. There are, therefore, two important long-term changes in coastal configuration that we have to understand:

What caused the beach/dune ridge system to become differentially submerged? One possibility is differential subsidence related to local differential downloading of the crust in the south. Divjaka spit and dune system have survived because the build-up of dune sediment has kept pace with local subsidence. Alternatively, the submergence may be related to a neotectonic event(s).

Why did beach/dune ridge formation end to be replaced by delta formation? Without dates it is difficult to ascertain the reason but we can envisage that it may be related to local change in sea level, circulation and/or sediment supply.

SHORT-TERM COASTAL CHANGE

Short-term coastline changes (erosion/deposition) were assessed by comparing the 1943 aerial

photographs, the 1986 Landsat images and information from published sources and hydrographic charts produced in the period 1892 to 1944. In considering short-term change, it is important to understand the present-day coastal dynamics in the Karavasta area. Published and unpublished data sources by the Albanian Hydrometeorological Institute were utilised in this summary.

a) Coastal dynamics

Large amounts of suspended sediment are supplied to the coast by the Shkumbini and Semani rivers. In the upper reaches of the river systems wide expanses of gravel are deposited during heavy rains and floods in Winter. Beneath many of these flood plains are preserved thick sequences of Quaternary gravel forming freshwater aquifers (R. Eftimi, pers. comm.).

Pano (1992) has estimated the average sediment discharge by Albanian rivers to be 65.7 million tonnes/year over the period 1948 to 1990. Of this, 7.2 million tonnes/year are brought down by the Shkumbini and 16.5 million tonnes/year by the Semani. Pano (1992) also proposes that about 19% of the total sediment is carried as bed load and redistributed along the beaches by the action of waves. From this estimation it follows that the suspended load discharged by rivers is in the order of 53.2 million tonnes/year. Human factors that may have altered sediment discharge in recent years include the building of dams in the upper reaches of the rivers, water pumping for irrigation purposes, reclamation of floodplains and removal of sand and gravel from the river beds to supply the aggregate industry.

Water exchange between Karavasta Lagoon and the Adriatic Sea takes place through three (south, central and north) tidal channels through Divjaka Spit described by Pano and Hysi (1982). The hydrological characteristics of the channels are shown in Table 2. The southern channel connects Karavasta Lagoon to a recently formed unnamed lagoon (Fig. 2), created by the growth of a spit from the former mouth of the Semani river (Fig. 7). A small channel through the spit connects the lagoon to the sea. The growing spit is tending to close the seaward entrance of the central channel to the extent that the latter is periodically dredged to allow free water exchange between Karavasta Lagoon and the sea.

Littoral drift patterns show the presence of two adjacent cells along the spit-barrier system at Karavasta. From the mouth of the Shkumbini river, sediment is transported southwards. Landsat CC3-2-1 and PC4-5-6 images show the presence of a gyre in the pattern of nearshore currents, rotating anti-clockwise. It appears that the southern boundary of the cell corresponds to the central tidal channel through Divjaka Spit. From the former mouth of the Semani river, the sediment produced by the erosion of the old river delta has created a second littoral cell. The northern boundary of this cell also corresponds to the central tidal channel.

The dominant winds measured at Fier are southeasterly (17.7% frequency), easterly (14.8%) and northwesterly (13.8%). Southeasterly winds occur in Autumn and Winter, while northwesterly winds are more frequent in Spring and Summer. Calm weather occurs about 23.5% of the year. According to Pano and Selenica (1967), the highest waves observed along the Albanian coastline have a deep water direction from the north-west and the west with a maximum wave height of 3.5 m nearshore.

b) Coastal change

i) Semani river and adjacent coast

Over the last 150 years the mouth of the Semani has often changed its position. In 1870, according to Boçi (1994), the main river mouth and delta was about 20 km to the south of Karavasta Lagoon. Between the end of the 19th century and 1957 the sediment input to the delta decreased and the delta complex moved north. This created two new channels adjacent to the southern end of Karavasta Lagoon. The northern channel produced shoreline accretion between 1870 and 1937, while the southern channel was more active in the period 1937 to 1968. Between the 1950s and the present day, the delta migrated southwards and seems to have reached its present position in the 1970s.

The changing course of the Semani river from one adjacent to Karavasta Lagoon to its present

position is demonstrated in Fig. 7 which compares a 1943 aerial photograph with a 1986 Landsat image. The aerial photograph shows the Semani river following a natural northerly course and depositing large amounts of sediment. On the 1986 Landsat image it is a dry river bed; the course of the river has changed to enter the sea 5 km or so to the south of the image. Pano (1992) believes that this latest shift in position was caused by major floods in 1962/63. It is also possible that reclamation works in the area between 1954 and 1968 had an influence on the river position.

The shifting position of the river system in combination with reclamation is now creating serious erosional problems for this part of the coast. A major source of sediment has been shifted south and the beach system in front of the old abandoned channel is now actively eroding. Sediment from this erosion is transported north to form the new spit (Fig. 7). Boçi (1994) believes that erosion started here in the 1970s at a rate of 35 m/year and Pano (1992) indicates that the recession rate may have been as high as 50 m/year. Evidence for the erosion is the partial drowning of military bunkers built in the 1970s which were originally set back from the beach. A second stretch of the coastline to the south of the Semani delta is also eroding. According to Boçi (1994) the erosion started at the end of the 19th century at a recession rate of about 30 m/year. This is far higher than the 15 m/year indicated by Paskoff (1985).

ii) Shkumbini river and adjacent coast

According to Boçi (1994), the position of the Shkumbini delta in 1870 was in the same area as the present delta. Maps published in 1918 show that the main river course was split into two channels that existed until 1968. The northern channel was probably carrying more sediment than the southern channel because the coastline on the 1968 map shows accretion in the north. Between the early 1970s and 1990 sediment input from the northern channel decreased and the coastline started to erode while the southern channel continued to produce shoreline accretion.

POLLUTION

Large areas around Karavasta Lagoon have been reclaimed and are used for agriculture (Fig. 7) leading to an increased use of agricultural fertilisers and pesticides. The agricultural pollutants contaminate groundwater resources and may ultimately reach the coastal zone. The Semani also discharges high quantities of pollutants from factories producing fertilisers in Fier, paper-pulp in Lushnja, textiles in Berat and oil refineries in Kucova. The Shkumbini also contains pollutants discharged by metallurgic plants in Elbasan. A consequence of this pollution may be the eutrophication of Karavasta Lagoon. It must be noted, however, that we have no evidence to suggest that the lagoon has reached a eutrophic state. However, if eutrophication does take place, it would have serious consequences for the biodiversity of the lagoon.

CONCLUSIONS

This study has involved the use of satellite imagery, aerial photographs and fieldwork, to examine the natural and man-made processes that have contributed to coastal change. It has shown that the coastal sedimentary environment in the Karavasta area is extremely dynamic and dominated by large amounts of sediment delivered by the Shkumbini and Semani rivers. Following a long period of accretion, the position of the coastline has receded by hundreds of metres over recent decades and the configurations of local morphologies have been readily upset by human intervention. Reclamation of the coastal lowlands and the changing positions of river courses leading to cut off of sediment has created serious erosional problems along many parts of the coast. A consequence of this erosion may be the loss of lagoonal areas through the removal of spits and barrier beaches that currently separate them from the sea. Damage to the biodiversity of the region may also be caused by the uncontrolled use of agricultural chemicals which contaminate water courses and lagoons and may cause eutrophication. A broader knowledge of the lagoon and surrounding environments is therefore important to support integrated management and development of sustainable tourism initiatives.

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Table 1. Tone of objects identified on Colour Composite Landsat images.

Nature of object	CC 4-5-7 Images (Infra-Red)	CC 3-2-1 Images (Visible)
Vegetation	Red	Brown
Water	Dark Blue	Dark Blue
Suspended sediment	Black	White-Blue
Non-cultivated land	Blue	Pale Brown
Sandy dunes	White	White

Table 2. Hydrological characteristics of tidal channels connecting Karavasta Lagoon with the sea (after Pano and Hysi, 1982).

CHANNELS	Water Discharge (m^3/s)	Average Speed (m/s)	Width (m)	Average Depth (m)	Length (m)
Northern	5.44	0.38	17.7	0.80	700
Central	15.5	0.34	28.2	1.62	1200
Southern	5.54	0.56	24.5	0.67	300

Fig. 1. Index map showing coastal locations described in the text. Study area is boxed.

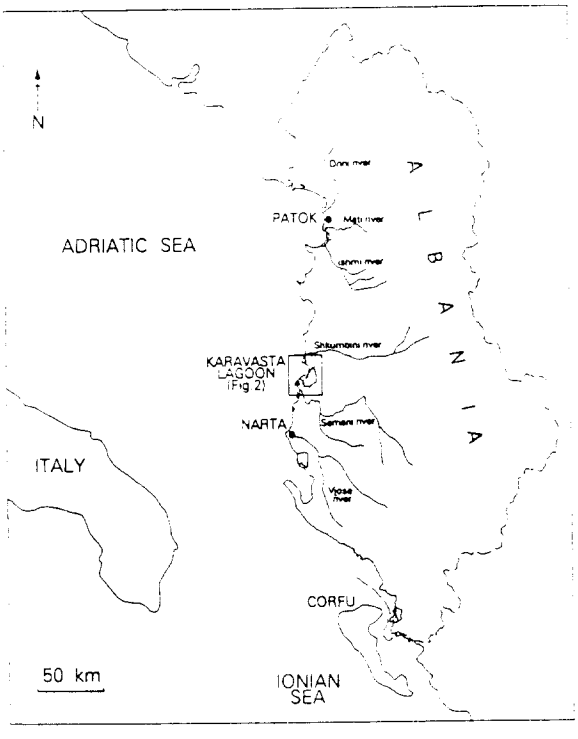


Fig. 2. Map of Karavasta Lagoon to show its physical setting. Location is shown in Fig. 1.

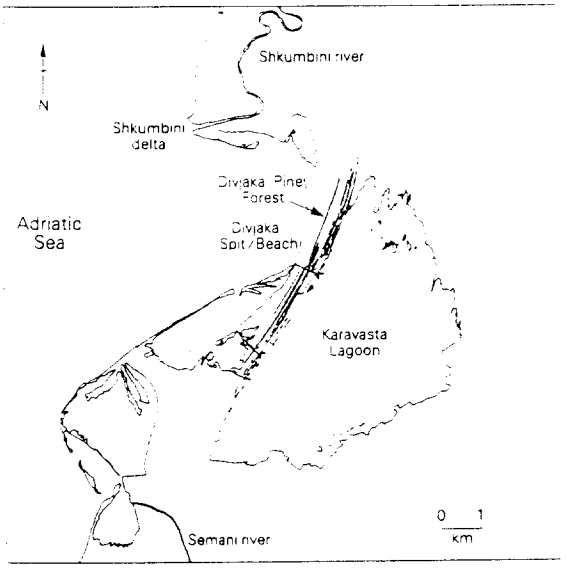
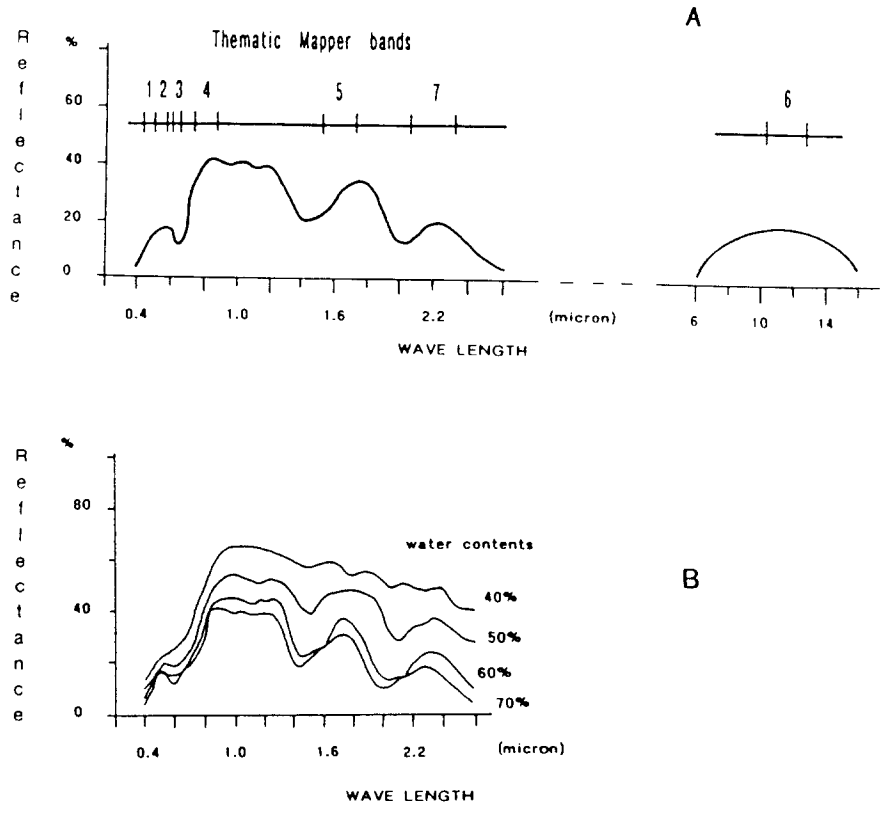


Fig. 3. A: Spectral response of vegetation in the Landsat TM registration bands. B: Changes in the reflectance of vegetation due to different water contents. After Goetz et al. (1983).



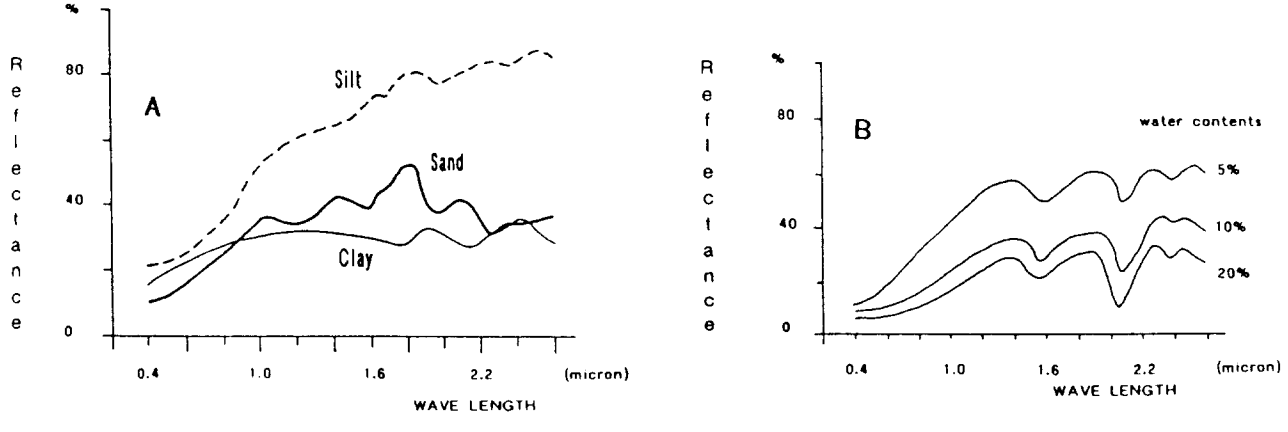


Fig. 4. A: Reflectance curves of sandy, silty and clayey soils. B: Reflectance curves of silty soil with changing water content.

Fig. 5. Interpretation of Landsat images into geomorphological units. Units 1 and 2 are marine and fluvial sediments reworked by coastal processes. Units 3 and 4 are marine and lagoonal sediments. Their morphology is obscured by a well developed field pattern. Units 5 and 6 are the present-day Karavasta Lagoon. Units 7 and 8 are fluvial and alluvial sediments. Field patterns are parallel to the Shkumbini and Semani rivers.

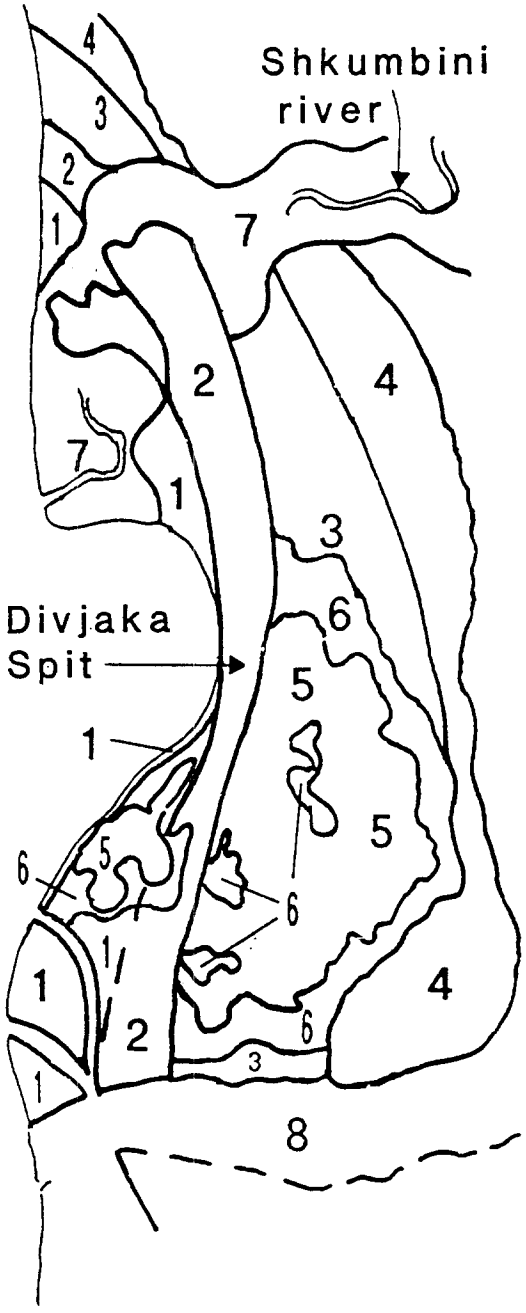
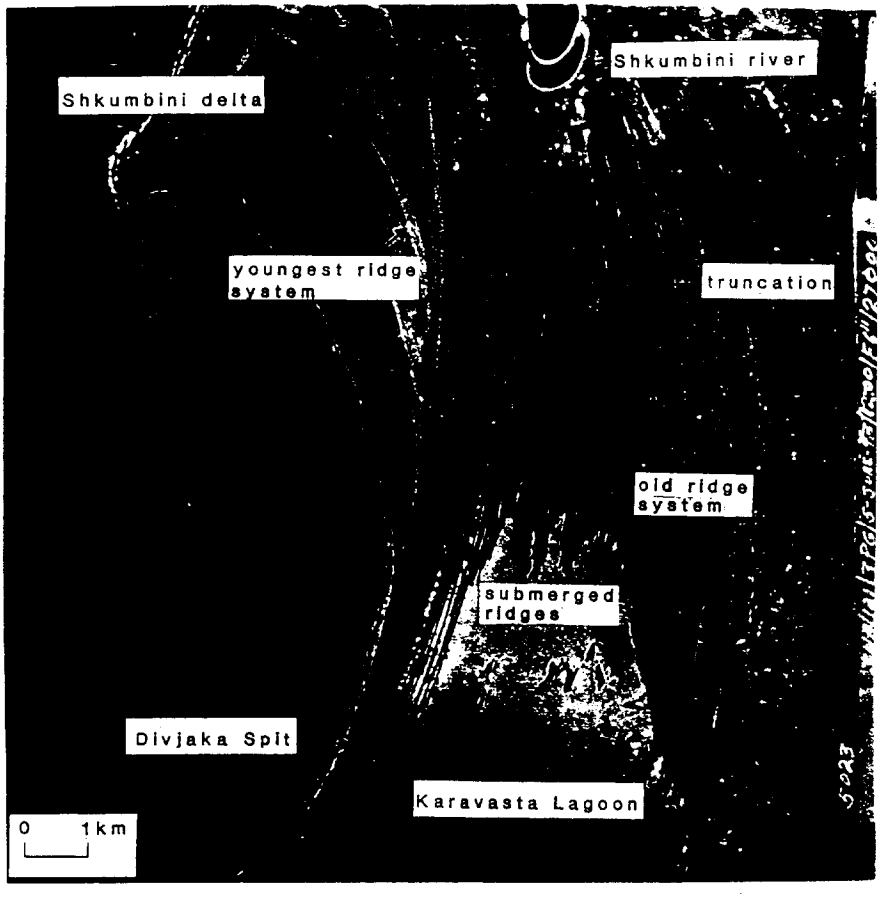


Fig. 6. Aerial photograph (1943) of beach/dune ridge systems preserved to the north of Karavasta Lagoon. Reproduced with the permission of the Ministry of Defence, UK.



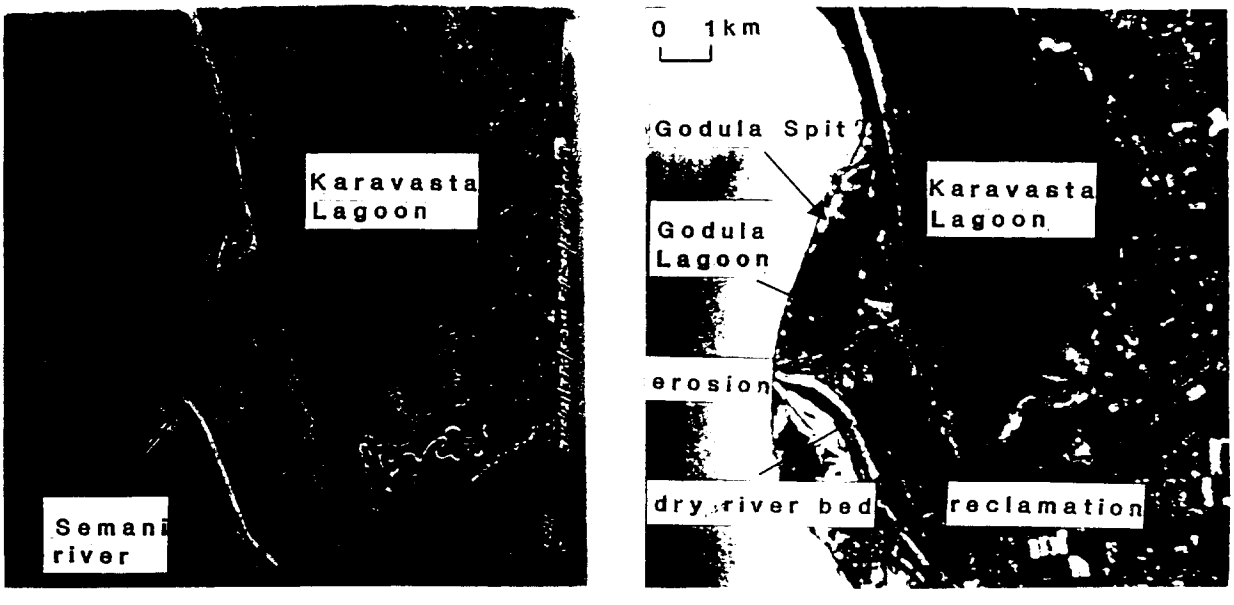


Fig. 7. Comparison of 1943 aerial photograph (left) and 1986 Landsat image (right) of Karavasta Lagoon and Semani river. Aerial photograph reproduced with the permission of the Ministry of Defence, UK.

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MICROPALAEONTOLOGICAL DATA ON ENVIRONMENTAL CHANGES DURING THE HOLOCENE FROM THE EASTERN CANTABRIAN ESTUARIES (BAY OF BISCAY)

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KEYWORDS: Benthic foraminifera, Estuarine palaeoenvironments, Sea-level changes, Holocene, Bay of Biscay.

ABSTRACT

The estuarine sedimentary environments are marginal areas located in the narrow transition zone between the marine and the continental domains. Consequently, they are very sensitive even to small changes in sea level. The Holocene transgressive episode has provoked the deposition of great volumes of well preserved estuarine sediments disposed in complex sequences. Their study will help to understand sea-level and coastal changes during the Holocene.

The Holocene sedimentary infilling of these tidal environments was studied by means of several boreholes drilled along different estuaries. This work includes data from the estuarine deposits of Santoña, Bilbao and Bidasoa. The sedimentary sequences obtained are represented by sands, muddy sands and fine materials containing a high calcareous biogenic content in some parts and abundant vegetal remains in other sections. The analysis of the micropalaeontological content (benthic foraminifera assemblages) associated with these Quaternary deposits provides one of the most useful methods to interpret the environmental conditions under which these sediments have been deposited.

INTRODUCTION

The northeastern coast of Spain is characterised by calcareous Mesozoic rocks forming high cliffs with sand beaches and long, narrow estuaries. These are separated from the open sea by sandbars and sandy beach deposits.

These coastal sedimentary environments are marginal areas located in the narrow transition zone between the marine and the continental domains. Consequently, they are very sensitive to even small changes in sea level. The Holocene transgressive episode caused the deposition of large volumes of well preserved coastal sediments containing marine, brackish and freshwater units in complex sequences. Study of these sequences will help us to understand sea-level and coastal changes during the Holocene.

The analysis of the micropalaeontological remains, particularly the study of benthic foraminifera assemblages associated with these Quaternary deposits, is one of the most useful methods that makes possible the interpretation of the environmental conditions under which these sediments were deposited. These organisms are very sensitive to temperature changes (climatic indicators) and due to their exclusive marine habitat (brackish, normal marine and hypersaline) can provide valuable evidence on the sea-level position. The foraminiferal assemblages present in the sediments from the coastal and shelf environments are dominated by benthic species, in contrast with deep-sea sediments where planktonic foraminifera are particularly abundant.

In this work the benthic foraminifera assemblages are used in order to interpret the depositional environment of the estuarine sediments, to reconstruct the history of the sedimentary infilling of these marginal marine environments and to increase the knowledge on the sea-level changes during the Holocene.

MATERIALS

The estuaries of Bidasoa, Bilbao and Santoña are located in the eastern area of the Cantabrian

coast, in the southern Bay of Biscay (Fig. 1). They represent three of the largest and most important estuaries of this area but, unfortunately, the human pressure suffered by this littoral zone during the last century has provoked a radical transformation of these estuaries by land reclamation, urban construction, waste disposal, industrial pollution, recreational facilities and so on.

Nowadays the Bidasoa estuary has lost 70% of its original estuarine surface and since 1991 has been affected by a 'Special Plan for the Protection and Recuperation' of the area in which local authorities are involved. The Bilbao estuary represents the most polluted area of the whole Cantabrian coast. Today the original estuary has been completely occupied by urban, industrial and port structures that, in the last 100 years, have produced the artificial modern estuary. The Santoña estuary was declared a 'Natural Reserve' in 1992, and although it has lost 50% of its original surface, it still represents the most interesting coastal area in northern Spain from an ornithological point of view.

The Holocene sedimentary infilling of the Bidasoa estuary was studied using the IS1 and IS2 boreholes drilled in the lower estuarine area. The stratigraphical sequence of the IS1 borehole is represented by 7 m of sands and muds with a high content of calcareous biogenic components in some parts and abundant vegetal remains in other sections. The IS2 borehole is made of 26 m of sands and muddy sands with calcareous biogenic and vegetal remains.

The sedimentary evolution of the Bilbao estuary was studied by means of two boreholes taken from the middle and lower estuarine areas. The sequence of the EL-1 borehole is represented by 22 m of muds and sandy muds containing abundant vegetal organic matter and some calcareous bioclastic remains. The SR-8 borehole shows 26 m of sands, muds, muddy sands and gravels with vegetal matter and biogenic fragments in some units.

Finally, the sedimentary deposit of the Santoña estuary was analyzed with the S-CI and S-ST boreholes drilled in the lower estuary. The S-CI stratigraphical sequence is made of 31 m of sands, muds and muddy sands with bioclastic and vegetal material .The S-ST sequence contains 26 m of sands, muds, muddy sands and sandy muds with abundant calcareous bioclastic components and vegetal remains in some sections.

METHODS

Samples were taken at approximately 0.5 m intervals. Every sample was firstly dried up in an oven at 120 °C, secondly weighed (around 300 gr. of dried sediment) and, finally,washed with water to remove the clay in a 63 microns aperture sieve. After have been cleaned, the sediment of the sieve was dried again and weighed to determine the sand content in every sample. Then, the sample was concentrated in foraminifers using the flotation technique with trichloroethylene. In general, around 300 individuals were picked from each sample. All in all more than 300 samples and 96,000 foraminifers were studied for this work.

The study of the palaeoecology of benthic foraminifera is mainly based on the data gathered during the last 40 years on ecology and distribution of modern species, bearing in mind that most of these modern species appear in the Miocene period and accepting that their ecological requirements have not changed throughout time (Douglas, 1979).

In the modern estuarine environment benthic foraminiferal assemblages are basically constituted by an indigenous component made of species that live and reproduce within the estuary together with an exotic component of open marine species transported into the estuary from the inner shelf by tidal currents. Consequently, the degree of influence of normal saline waters from the open ocean on the estuarine environment will be indicated by both the number of stenohaline shelf species and the number of individuals present in the samples taken from the estuary. Conversely, the degree of saline stress generated as a consequence of the mixture of fresh and salt water in the estuary will be indicated by a decrease in the specific diversity and an increase in the number of individuals of the typically estuarine euryhaline foraminifera species. Thanks to the presence and abundance of these two categories of benthic species, it is possible to distinguish

different sub-environments within an estuary and to identify possible sea-level changes.

In each sample the obtained data were analyzed and compared by means of different indexes and parameters such as the relative abundance of each species (considering dominant species those representing more than 5% of the foraminiferal assemblage), the ratio between indigenous and exotic forms, the α index of species diversity and the chemical nature of the shells (agglutinated, porcelaineous or hyaline).

BIDASOA ESTUARY

As a whole, 98 different benthic foraminifera species were found in the Holocene sedimentary sequences of the two studied boreholes. The study of the vertical distribution and the relative abundance of the most significant species together with the variation of other micropalaeontological characteristics throughout the IS1 borehole have allowed the distinction of four different units in this sequence from top to bottom:

1. Assemblage 1 is formed by 1.4 m of sands with abundant vegetal organic matter followed by 0.6 m of muds containing a high vegetal component. It shows a moderate number of individuals, as well as a very low specific assemblage ($\alpha<1$) and 0.1% exotic content. This micropalaeontological assemblage is constituted by *Jadammina macrescens, Trochammina inflata* and *Arenoparrella mexicana* exclusively. Consequently, this unit has been interpreted as a very restricted middle/high marsh environment.

2. Assemblage 2 is made of 1.8 m of fine and medium sands with abundant vegetal organic matter. This unit is defined by an assemblage composed of *Cibicides lobatulus, Haynesina germanica, Elphidium williamsoni, Rosalina anomala* and *Ammonia beccarii* as main species. It contains a high number of individuals and species ($\alpha=6$) including 64.8% exotic forms. This assemblage suggests a sandy low tidal flat with vegetation, moderate salinity and a clear open ocean influence.

3. Assemblage 3 represents 2.1 m of fine and medium sands with a very low vegetal content. This unit exhibits a high number of individuals, a high specific diversity ($\alpha=6$) and 83.5% exotic individuals. The dominant species are *Cibicides lobatulus, Rosalina anomala* and *Elphidium williamsoni*. This foraminiferal assemblage indicates a subtidal sandy environment with normal marine salinity and a high open sea influence.

4. The final Assemblage 4 is composed of 0.8 m of muds with a very low vegetal matter content and it is characterized by a benthic foraminiferal assemblage basically made of *Haynesina germanica, Elphidium williamsoni, Elphidium oceanensis* and *Ammonia beccarii*. This unit presents a moderate number of individuals and a very low number of species ($\alpha<1$) together with 3% exotic tests. All this suggests a restricted muddy high tidal flat environment with very low salinity conditions.

Seven different benthic foraminiferal assemblages (units) have been distinguished from top to bottom in the IS2 borehole based on the vertical sedimentological and micro-palaeoentological variations detected (Fig. 2):

1. Assemblage 1 is formed by 2.1 m of muds with abundant plant remains, showing a microfaunal assemblage presenting a moderate number of individuals, a very low species diversity ($\alpha\leq1$) and 0% exotic elements. This assemblage is constituted almost exclusively by the agglutinated species *Jadammina macrescens, Trochammina inflata* and *Arenoparrella mexicana*, characterizing a middle/high marsh environment.

2. Assemblage 2 is represented by 5.5 m of sands, coarse in the first 2 m, containing abundant *Cibicides lobatulus, Rosalina irregularis* and *Rosalina anomala*. The number of individuals is high and the species diversity is also high ($\alpha=7$) showing 85% exotic foraminifera. Assemblage 2 is believed to represent a subtidal environment.

3. Assemblage 3 is made of 3.2 m of sands exhibiting an assemblage with *Ammonia beccarii, Haynesina germanica, Rosalina irregularis, Cibicides lobatulus* and *Rosalina anomala* as the main foraminiferal species, a high number of individuals and species diversity ($\alpha=6$), and 46% of exotic content, suggesting a low tidal flat environment.

4. Assemblage 4 is formed by 6 m of sands and muds, characterized by *Ammonia beccarii* and *Haynesina germanica*. It contains a moderate

number of individuals and species ($\alpha=4$) and 12% exotic tests, interpreted as a high tidal flat environment.

5. Assemblage 5 comprises 3.5 m of sands and muds with a microfauna represented by *Ammonia beccarii, Haynesina germanica* and *Quinqueloculina seminulum*. This assemblage contains a moderate number of individuals, a low species diversity ($\alpha=3$) and 8% exotic forms. It has been considered as deposited in a high tidal flat environment.

6. Assemblage 6 is composed of 4 m of sands increasing their mud content upwards, showing a moderate number of individuals and species ($\alpha=3.5$) as well as 7% exotic shells. It is dominated by the species *Ammonia beccarii* and *Haynesina germanica*, suggesting a high tidal flat environment of deposition.

7. Assemblage 7 is formed by 1 m of sands which contain a benthic foraminifera assemblage composed basically of *Cibicides lobatulus, Ammonia beccarii, Haynesina germanica* and *Rosalina irregularis*. This unit is also characterized by a high number of individuals and species ($\alpha=6$) and 65% of exotic elements. It has been interpreted as a low tidal flat environment.

BILBAO ESTUARY

Altogether 87 different benthic foraminifera species have been studied in the two boreholes. The vertical changes in the sedimentological and micropalaeontological characteristics allow the differentiation of, from top to bottom, several assemblages or units within the EL1 borehole (Fig. 3):

1. Assemblage 1 comprises 7.5 m of muds with abundant plant remains, showing a moderate and irregular number of individuals, a very low species diversity ($\alpha=1$) and 0.4% exotic elements. Assemblage 1 is basically formed by *Haynesina germanica, Ammonia beccarii, Trochammina inflata* and *Jadammnina macrescens*. It has been interpreted as a middle/high marsh environment.

2. Assemblage 2 comprises 3.5 m of muds with a benthic foraminifera assemblage dominated by *Haynesina germanica, Ammonia beccarii* and *Elphidium oceanensis*. This is characterized by a high number of individuals, a very low species diversity ($\alpha=1.5$) and 1.1% exotic forms. This microfaunal assemblage suggests a low marsh environment of deposition.

3. Assemblage 3 is formed by 6.5 m of muds with scarce sand and gravel defined by an assemblage composed basically of *Ammonia beccarii, Elphidium oceanensis* and *Haynesina germanica*. It also contains a high number of individuals and a moderate number of species ($\alpha=3$) and 7.5% exotic shells. This level has been identified as a high tidal flat environment.

4. Assemblage 4 is composed of 2 m of sandy muds showing a moderate number of individuals, a very low species diversity ($\alpha=1$) and 0.6% exotic content. The main species are *Elphidium oceanensis, Ammonia beccarii* and *Haynesina germanica*. Assemblage 4 is considered as indicative of a low marsh environment.

5. Assemblage 5 is represented by 0.75 m of sandy muds with scarce gravels, characterized by a benthic foraminifera assemblage basically made of *Elphidium oceanensis, Haynesina germanica* and *Ammonia beccarii*. This assemblage contains a high number of individuals and species ($\alpha=4$) and 6% exotic tests. It has been interpreted as a high tidal flat environment.

The analysis of the micropalaeontological content of the SR-8 borehole (Fig. 4) shows five units representing different sedimentary sub-environments throughout this borehole from top to bottom:

1. Assemblage 1 is made of 1.5 m of muddy sands with vegetal matter showing a moderate number of individuals and species ($\alpha=5$) and 17% exotic individuals. This benthic foraminiferal assemblage is dominated by *Haynesina germanica, Ammonia beccarii, Elphidium williamsoni* and *Cibicides lobatulus*. This unit is interpreted as deposited in a high tidal flat environment.

2. Assemblage 2 comprises 6.5 m of sands with abundant calcareous biogenic remains and vegetal organic matter and it is characterised by *Cibicides lobatulus, Ammonia beccarii* and *Haynesina germanica* representing the main benthic foraminifera species. The number of individuals and the species diversity are high ($\alpha=6$) and the exotic test content reaches 59%. This assemblage

is believed to represent a sandy, low tidal flat environment.

3. Assemblage 3 is formed by 8.0 m of muds with carbonate biogenic remains and vegetal material. It shows a moderate number of individuals, a low diversity (α=3.5) and a 16% exotic content. All this, together with a foraminiferal assemblage dominated by *Ammonia beccarii, Haynesina germanica, Elphidium oceanensis* and *Rosalina irregularis*, suggests a muddy high tidal flat environment.

4. Assemblage 4 is composed of 1.0 m of gravels with sandy matrix containing a foraminiferal assemblage characterized by a moderate number of individuals, a very low species diversity (α=2.5), a 20% exotic individuals. It is dominated by *Ammonia beccarii, Haynesina germanica, Cibicides lobatulus, Elphidium oceanensis* and *Elphidium williamoni*. These micropaleontological data characterize a gravy, low tidal flat environment.

5. Unit 5 is composed of 5.0 m with rounded gravels, sands and muds showing few individuals (average 10 tests/sample), not enough to carry out a foraminiferal analysis. This coarse unit is interpreted as deposited under a fluvial environment.

SANTOÑA ESTUARY

The analysis of the samples from the two boreholes taken in this estuary has shown 113 different species of benthic foraminifera. The vertical variation in the sedimentological and micropalaeontological content throughout the sequences obtained shows different foraminifera assemblages (units) in each borehole.

The study of the benthic foraminiferal assemblages obtained from the S-CI borehole shows six different units characterized by their micropalaeontological content that can be described from top to bottom as follows:

1. Assemblage 1 with 1.5 m of bioclastic sands and a low content in vegetal organic matter, is characterised by *Cibicides lobatulus, Jadammina macrescens* and *Trochammina inflata* as dominant species, a moderate number of individuals, a low species diversity (α=4) and a 69% exotic content. These data suggest a sandy low marsh strongly influenced by the open ocean.

2. Assemblage 2 is represented by 7.5 m of muddy sand with bioclastic and vegetal remains showing a foraminiferal content dominated by *Cibicides lobatulus, Ammonia beccarii, Haynesina germanica* and *Rosalina irregularis*, a moderate number of individuals, a high number of species (α=8) and 64% exotic tests. It has been interpreted as a low tidal flat environment.

3. Assemblage 3 is made of 10.0 m of muds with bioclastic and organic matter. This unit exhibits a very high number of individuals and species (α=10), 51% exotic tests and a foraminifera content characterized by *Rosalina irregularis, Haynesina germanica, Ammonia beccarii, Brizalina britannica* and *Quinqueloculina seminulum*. It has been considered as deposited in a low tidal flat environment.

4. Assemblage 4 is formed by 2.5 m of sands showing a micropalaeontological content dominated by *Cibicides lobatulus, Rosalina irregularis, Haynesina germanica, Ammonia beccarii* and *Quinqueloculina seminulum*, a moderate number of individuals, a high species diversity (α=9) and a 58% exotic content. This unit has been interpreted as a low tidal flat environment.

5. Assemblage 5 is represented by 7.0 m of muds with calcareous bioclastic remains and it contains abundant *Ammonia beccarii, Rosalina irregularis, Cibicides lobatulus, Aubignyna perlucida, Quinqueloculina seminulum* and *Haynesina germanica*. The number of individuals is high, the species diversity is also high (α=7) and it shows a 51% exotic component. This unit is believed to represent a high tidal flat environment.

6. Assemblage 6 represents the final 2.0 m of muddy sand with some gravels and bioclastic remains, containing a moderate number of individuals, a high number of species (α=7) and 61% exotic tests. This assemblage is dominated by *Ammonia beccarii, Cibicides lobatulus, Rosalina irregularis, Haynesina germanica* and *Aubignyna perlucida*. These data suggest a low tidal flat depositional environment.

The S-ST borehole has been divided in five different assemblages based on their benthic

foraminifera content (Figs. 5 and 6). They are as follows from top to bottom:

1. Assemblage 1 is formed by 2.4 m of sandy muds with bioclastic and vegetal organic remains containing a micropalaeontological assemblage characterized by the species *Haynesina germanica, Ammonia beccarii, Cibicides lobatulus, Elphidium williamsoni, Jadammina macrescens* and *Trochammina inflata*, a moderate number of individuals and species ($\alpha=6$) and a 30% exotic content. This unit has been interpreted as a sandy, low marsh environment.

2. Assemblage 2 is made of 13.2 m of muddy sands with bioclastic material and some small gravels in the lower half of this unit. The characteristic foraminifera assemblage is largely dominated by *Cibicides lobatulus, Ammonia beccarii* and *Haynesina germanica*. The number of individuals is high, the number of species is moderate ($\alpha=6$) and the exotic component represents 79%. These data seem to suggest a low tidal flat environment.

3. Assemblage 3 is composed of 4.6 m of sands with muds and small gravel with an abundant vegetal organic content and bioclastic remains. *Cibicides lobatulus, Haynesina germanica, Ammonia beccarii, Jadammina macrescens* and *Trochammina inflata* are the most abundant species. This assemblage shows a moderate number of individuals, a high number of species ($\alpha=8$) and 47% exotic tests. Its foraminiferal content indicates a sandy, low marsh environment of deposition.

4. Assemblage 4 is represented by 4.0 m of muds with some small gravels, bioclastic and vegetal organic matter. The number of individuals is high, the species diversity is low ($\alpha=3$) and the exotic content is 9%. The assemblage is dominated by *Haynesina germanica, Ammonia beccarii* and *Elphidium williamsoni*. All this indicates a high tidal flat environment.

5. Assemblage 5 is formed by 1.5 m of muddy yellowish sands with *Haynesina germanica, Ammonia beccarii, Elphidium oceanensis* and *Cibicides lobatulus* as main species. The number of individuals, the species diversity ($\alpha=4$) and the exotic component (9%) are low. This final unit is considered to represent a sandy high tidal flat environment.

DISCUSSION

All the benthic foraminifera species found in these boreholes are still present in the modern assemblages from the coastal areas in the Bay of Biscay. This fact permits conclusions of potential palaeoenvironmental application to be drawn from the study of the modern microfauna.

Different works on the recent assemblages from the Cantabrian estuaries (Cearreta, 1986; Pascual, 1990) and superficial samples taken in the Bidasoa estuary (Cearreta, 1994) have shown that these environments are characterized by living foraminiferal assemblages with a low species diversity. The most common species from these brackish environs are *Jadammina macrescens, Trochammina inflata* and *Arenoparrella mexicana* in the intertidal and supratidal marsh areas. *Ammonia beccarii, Haynesina germanica, Miliammina fusca, Quinqueloculina seminulum, Elphidium williamsoni* and *Elphidium oceanensis* are typical forms in sandy and muddy tidal flat areas. Whereas these same species together with *Fissurina lucida, Bolivina pseudoplicata* and *Brizalina britannica* are characteristic of deeper tidal and subtidal areas.

On the other hand, the dead (empty test) assemblages exhibit a large number of species, in general, due to transport of inner shelf marine species into the estuarine system. For this reason, these coastal assemblages are mainly composed of indigenous forms, which live and reproduce within the estuary and, consequently, that show a great variety of test sizes from juveniles to adults. Within these indigenous assemblages, it is possible to distinguish exotic forms that are never found living and whose characteristics change depending on the sediment type. Then, in muddy sediments it is possible to find a great variety of small sized, thin walled, perfectly preserved species which have been transported in suspension within the water column by the tidal currents, e.g., *Fissurina marginata, Brizalina variabilis, Bulimina gibba, Rosalina irregularis* and *Haynesina depressula*. On the other hand, in sandy sediments it is possible to find large, thick and sometimes badly preserved

tests transported as bed-load by the tidal currents, e.g., *Cibicides lobatulus, Rosalina anomala, Elphidium crispum, Quinqueloculina lata, Massilina secans, Gaudryina rudis* and *Spirorutilis wrightii*.

Based on the diagnostic presence of the above mentioned euryhaline indigenous species together with the exotic content, Murray & Hawkins (1976) recognised five sub-environments within an estuarine area: middle/high marsh characterized by its almost exclusive content of indigenous species with agglutinated tests; low marsh with an assemblage basically made of indigenous forms both hyaline and agglutinated with scarce exotic species; high tidal flat dominated by indigenous hyaline species and with up to 30% transported elements; low tidal flat with an indigenous assemblage similar to the latter but with a higher proportion of exotic forms (30-70%); and finally, the subtidal area where few hyaline and porcelaineous indigenous forms can be found and more than 70% transported exotic individuals are characteristic.

Furthermore, the specific diversity of a foraminiferal assemblage (α index of Fisher et al., 1943) is a parameter that also allows the distinction of different areas within the coastal zone. Following Murray (1991), estuarine assemblages exhibit a low diversity ($\alpha < 5$) whereas open sea assemblages are characterized by a high number of species and show an index $\alpha > 5$. Therefore, a high α index can be considered as indicative of mixed indigenous and exotic forms.

As a consequence of the low pH conditions common in most marsh areas, the characteristic species of these marginal environs show agglutinated tests that, consequently, do not suffer dissolution in these acid sediments. These species also appear in different assemblages closely related to height gradients (and therefore to salinity and temperature) from the average intertidal level (Scott & Medioli, 1986). It is possible to distinguish among a low marsh area where a mixture of hyaline and agglutinated tests exists, a middle marsh dominated by the agglutinated species *Trochammina inflata* and *Arenoparrella mexicana* and, finally, a high marsh with an assemblage composed mainly of *Jadammina macrescens* and *Trochamina inflata*. In the other estuarine sub-environments the assemblages are composed of calcareous hyaline species with a progressive increase in porcelaineous individuals towards the estuary mouth.

Considering all these micropalaeontological criteria and considering the data obtained from the analysis of these samples, it has been possible to recognise different depositional environments throughout the sedimentary sequence contained in the boreholes. Figs. 7 and 8 show the palaeoenvironmental interpretation of different assemblages defined in this work.

In the Bidasoa estuary, IS1 borehole begins at -5.6 m depth with 0.8 m of muds deposited in a high tidal flat (Assemblage 4) followed by 2.1 m of sands representing an environmental change towards deeper subtidal conditions (Assemblage 3). From here the sedimentary sequence tends to be shallower with 1.8 m of sands with vegetal organic matter (Assemblage 2) suggesting a low tidal flat followed by 2 m of sands and muds deposited in a middle/high marsh environment which is the culmination of this shallowing sequence.

IS2 borehole shows, at -25.5 m depth, a basal assemblage with 1 m of sands deposited in a low tidal flat environment (Assemblage 7) followed by 13.5 m of sands and muds with some vegetal remains representing a high tidal flat (Assemblage 6, Assemblage 5 and Assemblage 4) suggesting a decrease in the environmental depth as a consequence of the continuous sedimentary infilling of the estuarine basin. From -11 m the sequence is composed of 3 m of sands interpreted as a low tidal flat (Assemblage 3) which indicates a deepening process in the area that ends with the establishment of subtidal conditions represented by 5.5 m of sands (Assemblage 2). From -2.5 m depth a middle/high marsh with 2 m of muds and vegetal remains can be found (Assemblage 1).

In the Bilbao estuary, EL1 borehole begins at -20 m depth with 0.75 m of sandy muds and some gravels deposited in a high tidal flat environment (Assemblage 5) followed by 2 m of sandy muds representing a low marsh environment (Assemblage 4) so defining a first shallowing sequence in this area of the estuary. Then, from

-17 m, 6.5 m of muds with some small gravels and sands representing a new high tidal flat (Assemblage 3) are found and indicate deeper conditions. These are followed by 3.5 m of muds deposited in a low marsh environment (Assemblage 2) and 7.5 m of muds with abundant vegetal matter interpreted as a middle marsh (Assemblage 1) which completes this second shallowing sequence.

SR-8 borehole starts at -24.5 m depth with 5.0 m of gravels, sands and muds almost barren of foraminifera that is interpreted as a fluvial environment (Assemblage 5). These are followed by 1.0 m of gravels with a sand matrix representing a low tidal flat (Assemblage 4) and 8.0 m of muds with vegetal organic matter interpreted as a high tidal flat (Assemblage 3). Deeper conditions are shown by 6.5 m of bioclastic sands deposited in a low tidal flat environment (Assemblage 2). Finally 1.5 m of muddy sands represents a high tidal flat environment (Assemblage 1).

Finally, in the Santoña estuary S-CI borehole begins at -30.5 m depth with 2.0 m of muddy sands and small gravels interpreted as a low tidal flat environment (Assemblage 6) followed by 7.0 m of muds deposited in a high tidal flat environment (Assemblage 5). Deeper conditions are represented by 20.0 m of sands, muds and sandy muds representing low tidal flat environments (Assemblage 4, Assemblage 3 and Assemblage 2). This sedimentary sequence ends with 1.5 m of sands with some vegetal remains interpreted as a low marsh environment (Assemblage 1).

S-ST borehole commences at -25.7 m depth with 5.5 m of sands and muds representing high tidal flat environments (Assemblage 5 and Assemblage 4) which are followed by 4.6 m of muddy sands with vegetal organic matter interpreted as a low marsh environment (Assemblage 3) and representing the last unit of the first shallowing sequence. Deeper water conditions are represented by 13.2 m of bioclastic muddy sands and some small gravels interpreted as a low tidal flat environment (Assemblage 2). The final 2.4 m of sandy muds with vegetal remains are interpreted as a low marsh environment (Assemblage 1).

All these boreholes have been drilled in reclaimed areas and therefore an artificial filling is found covering the uppermost estuarine sediments.

The analysis of the micropalaeontological content of these six boreholes reveals the succession of different estuarine sub-environments suggesting changes in depth and salinity conditions as the sedimentary infilling of the estuary was taking place. Each stratigraphical sequence studied shows a diverse environmental development but all of them exhibit two different shallowing sequences with two different times of higher oceanic influence. The basal foraminiferal assemblages in every borehole are identified as the arrival of the sea to the modern Cantabrian coastline. This event has been dated by vegetal remains around 7,810 ± 130 years BP in Bidasoa. On the other hand, other group of different units in these boreholes (Assemblages 2 of IS2, Assemblage 3 of EL-1, Assemblage 2 of SR-8, Assemblage 3 of S-CI and Assemblage 2 of S-ST) seem to represent a second marine advance on the coast dated by vegetal material about 2740 ± 90 years BP in Bidasoa (Cearreta, 1992).

The sedimentological and micropalaeontological comparison of the analyzed sequences, even within the same estuarine area, does not allow interpretation of a clear model of sedimentary infilling as all the units change both vertically and laterally. This impossibility of a direct correlation between different boreholes was already noticed by Murray & Hawkins (1976) and Culver & Banner (1978). Furthermore it must be taken into account that these boreholes do not represent continuous sedimentary sequences but probably several units have been eroded during the evolutionary process of estuarine infilling. So, in the IS1 borehole apparently 4 m of sediments have been deposited in 5,000 years time (Assemblage 2 to Assemblage 4) whereas in the IS2 borehole 4 m seem to have been deposited only in 40 years (Assemblage 4 and Assemblage 5) (Fig. 8).

The multidisciplinary study of the Herriko-Barra coastal deposit, located close to the Bidasoa estuary and published by Altuna et al. (1993) has

also detected two transgressive episodes represented by sandy beach deposits separated by regressive fluvial and aeolian dune materials whose radiocarbon dates (from 5,810 ± 170 to 4,920 ± 100 years BP) agree with the estuarine data.

The aeolian deposit of Gorliz, situated close to the Bilbao estuary and studied by Cearreta and Pascual (1993), includes a regressive consolidated dune rock (aeolianite) dated 5,710 ± 50 to 6,020 ± 50 years BP. Furthermore, the submerged forest of Noja, close to the Santoña estuary, represents a regressive period with a deciduous forest development that has been radiocarbon dated between 4,070 ± 100 to 3,080 ± 100 years BP (Cearreta, 1993).

CONCLUSIONS

Consequently, all these data suggest a broad picture of sea-level and coastal changes in the southern Bay of Biscay during the Holocene. Two different transgressive episodes have been identified and they are dated around 8,000 years BP (Atlantic stage) and 2,500 years BP (Subatlantic stage) respectively with a relative regressive pulsation in between. Up to the present no sea-level curve has been published for this geographical area. The data presented differ from those obtained on the French Atlantic coast by other workers (Pirazzoli, 1991) where a continuous sea-level increase has been postulated. However on the southern Bay of Biscay an episodic general transgression seems to be observed. Possibly, neotectonics has played a substantial role in the regional sea-level changes but, unfortunately, nothing has been published on this matter.

ACKNOWLEDGEMENTS

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Fig. 1. Geographical location of the estuarine areas and the boreholes studied in the southern Bay of Biscay.

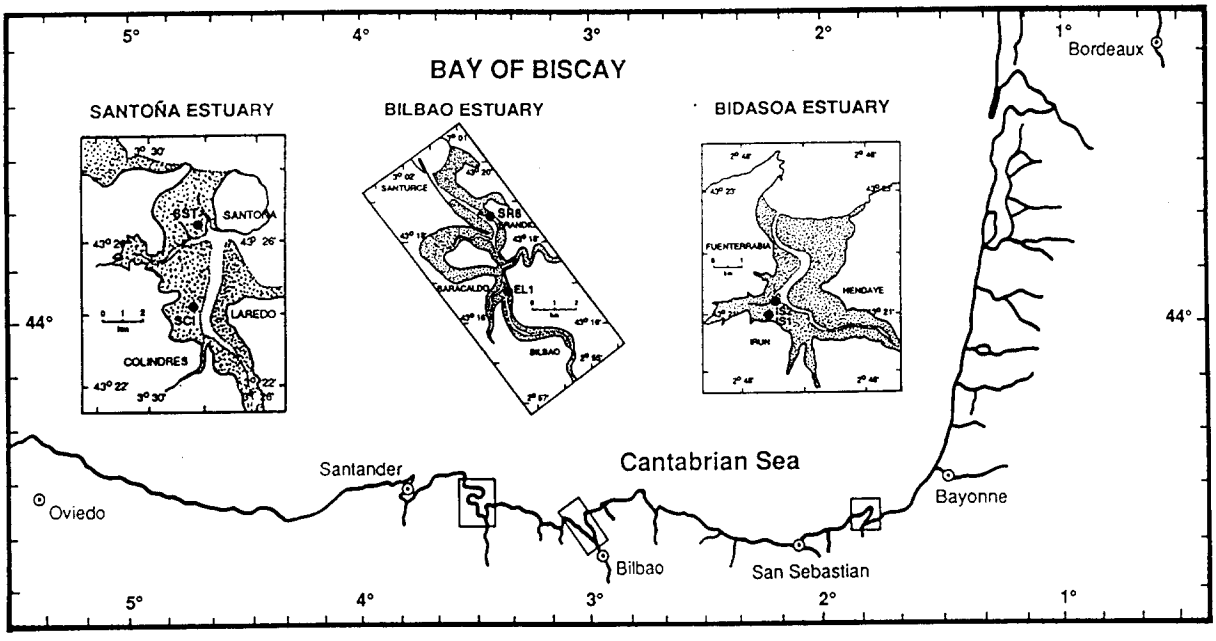


Fig. 2. Micropalaeontological analysis of the IS2 borehole, Bidasoa estuary (after Cearreta, 1992).

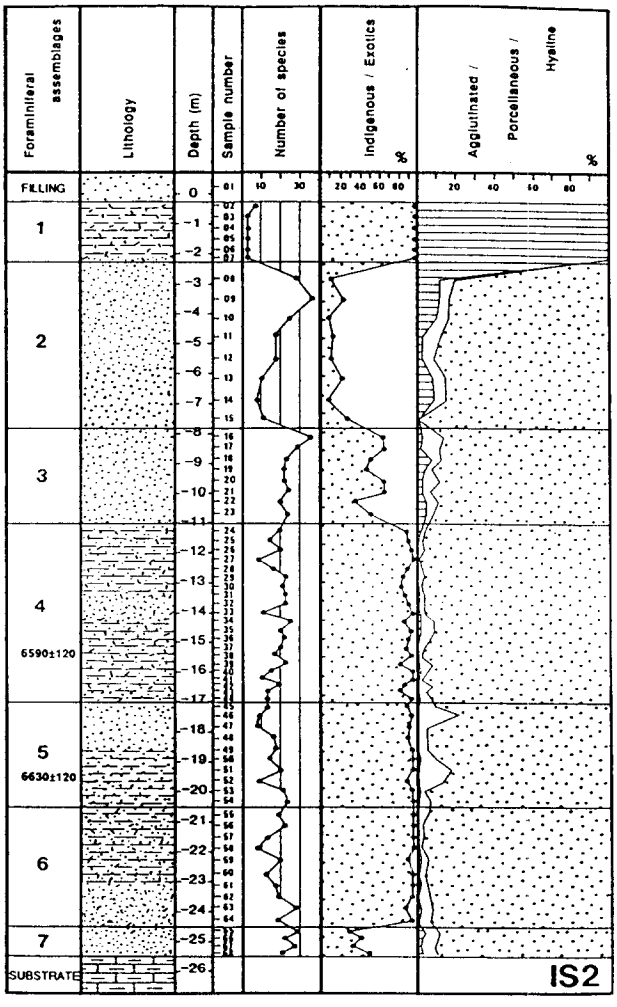


Fig. 3. Vertical distribution and abundance of the most important benthic foraminifera species throughout the EL1 borehole, Bilbao estuary (after Cearreta, 1992).

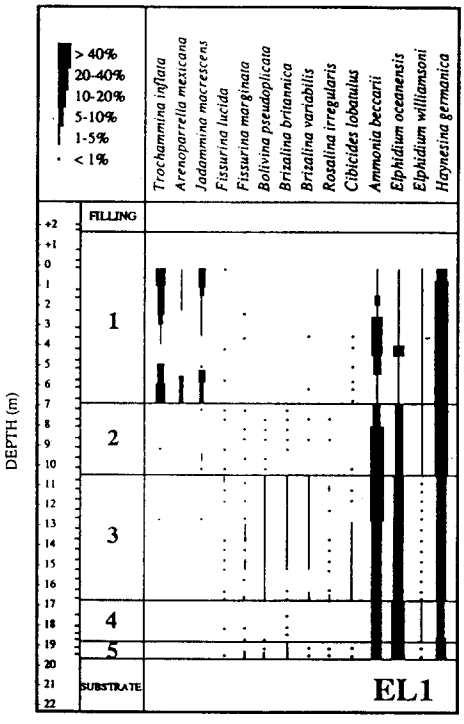


Fig. 4. Vertical distribution and abundance of the most important benthic foraminifera species throughout the SR-8 borehole, Bilbao estuary.

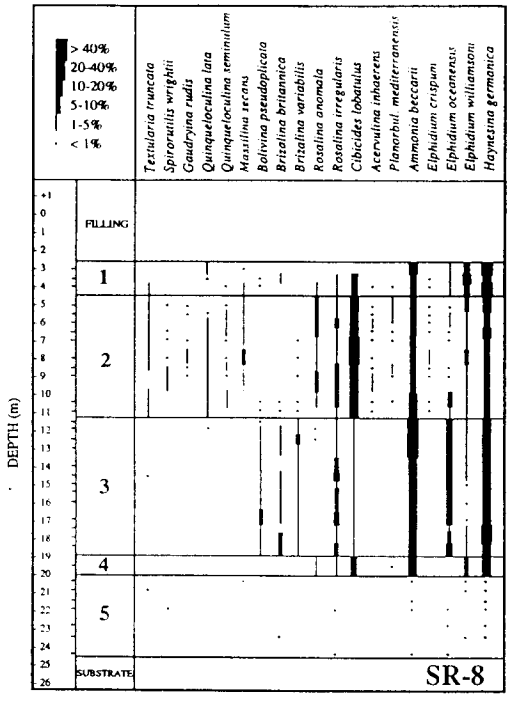


Fig. 5. Micropalaeontological analysis of the S-ST borehole, Santoña estuary.

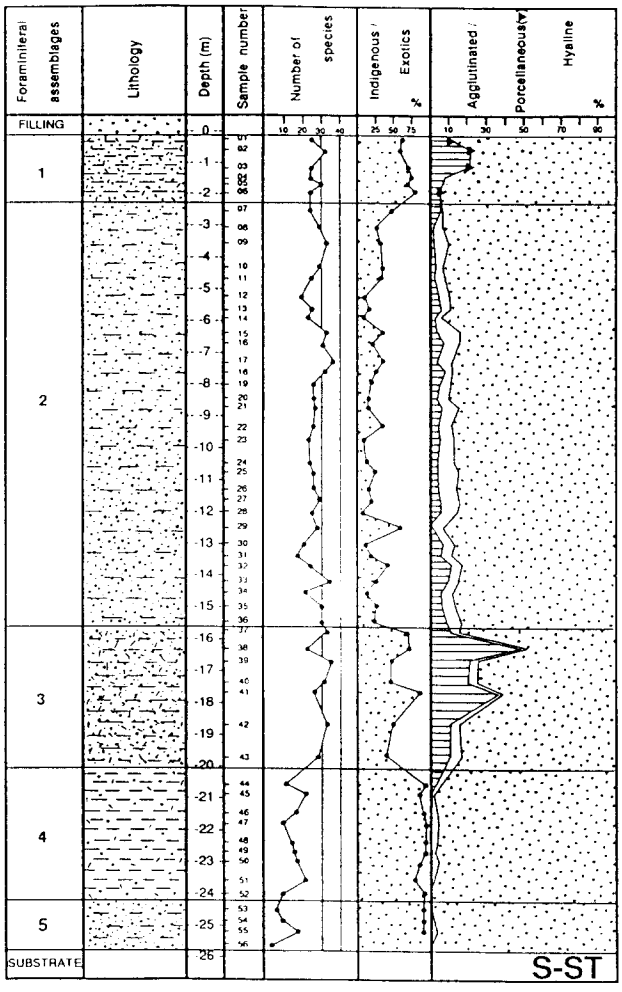


Fig. 6. Vertical distribution and abundance of the most important benthic foraminifera species throughout the S-ST borehole, Santoña estuary.

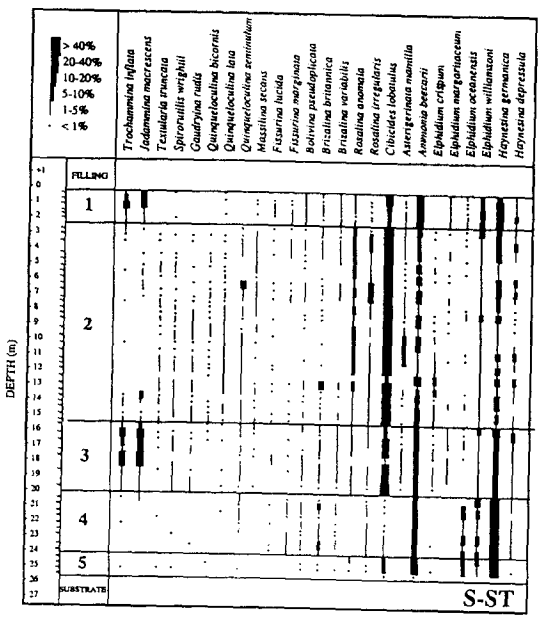
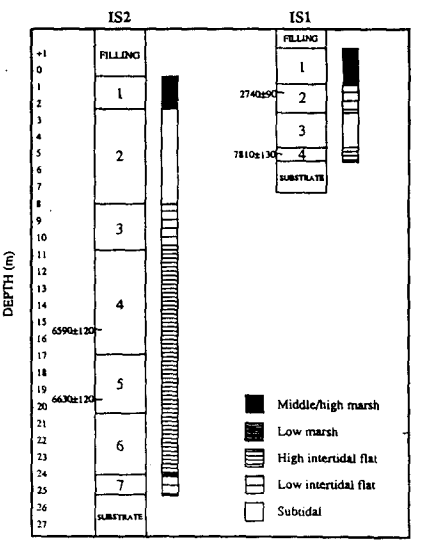


Fig. 7. Palaeoenvironmental interpretation of the benthic foraminifera assemblages found in the IS1 and IS2 boreholes, Bidasoa estuary (after Cearreta, 1994).



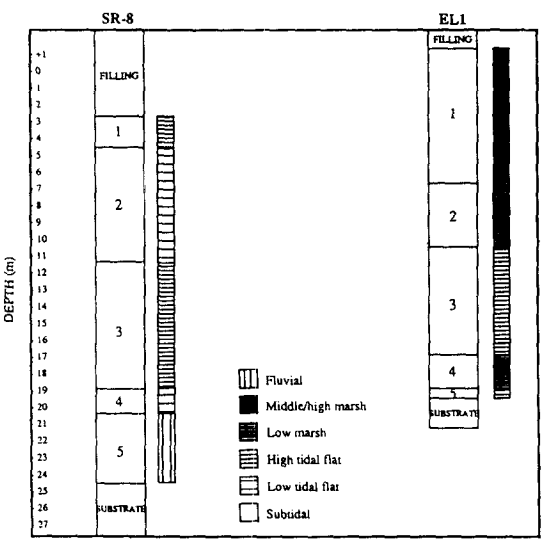


Fig. 8. Palaeoenvironmental int erpretation of the benthic foraminifera assemblages found in the EL1 and SR-8 boreholes, Bilbao estuary.

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ON COASTAL RELIEF CHANGE CONDITIONED BY SEA LEVEL OSCILLATIONS AND ITS INFLUENCES TO ECONOMIC ACTIVITY (AN EXAMPLE OF THE CASPIAN SEA)

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KEY WORDS Sea level fall and rise; shallow-water coast; shoreline progradation and retreat; sediment accretion; intensive shore erosion; bottom reclamation; land flooding; amount of sediment; sediment supply; economic activity; recreational area

ABSTRACT

During the fall of the Caspian sea level from 1929 to the beginning of the 1940's, a continuous shoreline progradation occurred, conditioned by steady sediment accretion and bottom reclamation. This caused an evident displacement of economic activities seawards. In 1978 a change to a sea level rise produced land flooding, penetration of subsoil waters in low-lying coastal areas and an increased shore erosion. The essential damage to the economy called for the necessity of urgent coastal defence and a radical change in economic plans. A prognosis of further coastal evolution and sea level fluctuations was required where data should be used of the World Ocean's Holocene transgressions.

INTRODUCTION

Sea level oscillations (i.e. relative coastal submergence and relative coastal emergence) depend considerably on the principal relief-forming coastal processes (marine erosion and sediment accretion), the total sediment budget in nearshore areas and shoreline evolution (Dolotov et al., 1964). As a result, the stability of the coastal land edge or, on the contrary, the radical changes in the shoreline position depend to a large extent on the sea-level fluctuations. The coasts of the Caspian Sea represent a real natural laboratory for the study of coastal evolution under conditions of sea level rise and fall at a dissimilar rate, since during its evolutionary history this marine basin has undergone repeated changes of sea level. From 1929 to the beginning of the 1940's, a rapid sea level fall of almost 2.0 m (Fig. 1) occurred. This was due to a decrease of receival water by the Caspian Sea basin, especially of river water discharge. In this period the average river-water discharge was 223.7 km^3/yr, which is 72.3 km^3/yr less than the normal value for 1880-1990. The loss by evaporation had been higher too, more than the normal value of 23 mm/yr.

The climatic change in the river basin (mainly of the Volga) and the marine aquatic system had been the principal factors affecting the sea level fluctuations during the last decades. Simultaneously the gradual increase of man's impact on water behaviour had taken place.

The major economic activities that exert the largest influence on the river discharge are as follows:

- the artificial irrigation of arid lands,
- the creation and exploitation of river-water reservoirs,
- the reclamation of swamps and boggy lands,
- the agri-forest-land-reclamation measures, and
- water supply for industrial and domestic purposes.

As a whole, the dynamic change in coastal areas depend on the rate of sea level fall (or decrease of depths in nearshore zone) and the amount of sediment load in coastal area (Dolotov, 1961 & 1982; Curray, 1964).

In sandy shallow-water coasts, which are the most widespread in the Caspian Sea, the relief-forming processes are mainly controlled by the bottom sediment landward transport and the strong influence of sea level fall (or relative coastal emergence), which is expressed in an intensive

reworking of the submarine shore slope profiles as a result of the disturbance of the former conditions of land-sea interaction boundary (Leontiev, 1949; Dolotov, 1958 & 1994). The reworking of profiles combine with the reclamation of the shallow-water nearshore bottom and, as a result of continuous coastal sediment accretion has occurred, accompanied by intensive shoreline progradation (Fig. 2a). This takes place with a greater sediment supply deriving from alongside, at a positive sediment budget during a prolonged period.

The reworking of submarine shore slopes largely depends on the dissipation of wave-energy and the character of the near-bottom wave velocity distribution in the nearshore marine area, which is controlled by the bottom surface gradient. A side effect is the nearshore bottom reclamation which causes, depending of its gradient, different mechanism and unequal magnitude of sediment accretion and of shallow-water coast progradation (Dolotov, 1958 & 1994). Besides it results in sediment supply shorewards and reclamation of the bottom surface (as the bottom surface gradient decreases the role of the latter factor increases). In the extreme shallow-water coasts, the advance of the shoreline represents a simple drying of the bottom surface at a high rate.

EVOLUTION AND COASTAL PROGRADATION

The evolution of the shallow-water coast under the conditions of continuous deposition and prolonged coastal progradation was considered by Johnson (1919) as the only possible evolutionary way under relative coastal emergence. However, on the basis of the author's and other investigators' observations of coasts of the Caspian Sea, the Barents Sea, the Sea of Japan and other seas (Dolotov, 1958, 1959 & 1994; Dolotov et al., 1964; Nikiforov, 1959; Leontiev, 1961), it was found that, in the course of evolution in some areas, characterized by a continuous accretionary beach, the sediment deficiency and accompanying shore erosion, may originate from the replacement of the positive sediment budget by a negative one (Fig. 2b). Such a process often occurs during the reworking of an insufficient thick bottom sediment blanket. In the course of erosion of bedrocks, the amount of erosional products is less than required for the continuation of the sediment accretion process. During the evolution, bottoms covered by mud may be included in the nearshore area. The other reason of sediment deficiency is a decrease, in the course of the reclamation process, of the bottom space covered by unconsolidated material. This may be caused by a decrease of sediment supply from the adjacent coastal areas. Thus, under the conditions of irregular sediment supply from the local bottom and nearby coastal areas, an alternation of coastal progradation and shoreline retreat had been characteristic (the second possible pattern of coastal evolution).

In some cases, under conditions of insufficient sediment supply, replacement of coastal erosion by a preservation of a sandy accretionary bodies may occur (Dolotov, 1958, 1959 & 1994; Dolotov et al., 1964) during complete cessation of direct wave attacks at the former coastline, due to a reclamation of the bedrock bottom surfaces (Fig. 2c). This takes place when the bottom surface, reworked by wave action, cannot keep pace with the sea level change. As a result a rapid reclamation of bottom areas covered by bedrock occurs (the third pattern of coastal evolution).

Nevertheless under conditions of falling level of the Caspian Sea, the most widespread coastal evolutionary pattern has been stable sediment accretion, bottom reclamation and continuous shoreline advance. As a result during the regression period in the western coast of the Caspian Sea, i.e. along the Daghestan coast, the younger low marine terraces (of 1929 and 1940) had been formed and are bordered by the wider contemporary sandy beaches (up to 150 m wide). In some areas of the western coast the subaerial part of modern terrace had reached a width of 600-700 m. Thus from 1929, the rate of land advance seawards had reached more than 25 m/yr (Dolotov, 1959). In the north-western coast such rates had been higher due to the reclamation of greater bottom space; for example, south of the Kislyar Bay, these rates became 60-100 m/yr, the coast of the Bay advanced 150-200 m/yr and north of it, 700-800 m/yr (Ignatov et al., 1993a).

The local coastal population adapted to these radical changes associated with the sea level fall. The occupation of the maritime territories and their economic assimilation had followed the retreating sea (Safianov et al., 1994). For example, in the deltaic areas of the Volga and the Ural rivers, the shoreline advanced seawards by tens or even hundreds of km. Since 1929 new roads and other economic and residential facilities have been constructed (Ignatov et al., 1993a).

PATTERN OF CASPIAN SEA EVOLUTION

The pattern of the Caspian Sea evolution had become the foundation of intensive economic assimilation of maritime territories, since the continuous sea level fall almost 180 years ago, beginning from the end of the XVIII century. Major specialists have predicted a further sea level fall and its following stabilization at the lower absolute marks, taking into account the increase of irretrievable withdrawal of river discharge for agricultural irrigation and other aims. It had caused coastal territories to move seawards and the removal of economic activities from original places in the same direction: an intensive building of settlements, of oil- and gas-pipe lines, recreational units, changing fishery, while road construction took place. The predicted further fall in sea level had conditioned the work plans and the creation of a vast recreational zone in the coast of the Daghestan and the Azerbaijan (Moltchanova, 1989). The recreational resources of the Caspian Sea coast have excelled in some regard those of the Caucasian coast of the Black Sea, because of their wide and lengthy sandy beaches, an abundant solar radiation and few days with precipitation during summer season (Veliev et al., 1987). On the Azerbaijan coast the construction of four recreational complexes for almost 800 thousands guests had been foreseen (Guseinov and Umudov, 1989). At the Daghestan coast, the erection of some recreational complexes had been planned too (Ignatov and Solovieva, 1990). Part of these outlined units are completed. In 1978 an unexpected and sharp sea level rise occurred (Fig. 1) and the subsequent average rate remained 14-15 cm/yr and sometimes reaching up to 30 cm/yr.

The rise of sea level, as its fall, is explained by a corresponding change in the Caspian Sea water budget. During 1978-1991 the river discharge was evaluated at 3O5 km^3/yr; in particular, that of the Volga had been 17 km^3/yr higher than its normal value. The layer of evaporating water had been less than 5-7 cm compared normal. The sea level rise would have been even higher, when there had not been an increased use of river water by economic activities (in 1990 this was evaluated at 41 km^3/yr). After 1972 a change of the atmospheric circulation could be noticed by an increasing frequency of its latitudal form and a decreasing meridional form. In particular a sharp climatic change occurred beginning 1976; the circulation activity increased by an average of 12% in comparison with the previous decade; the number of Atlantic cyclones increased by 48% and the West-European ones by 31%, under simultaneous enlargement of their moisture content by 35% and 18%, respectively. At the same time there was a rise of global temperature, an increase in cloudiness and precipitation, a corresponding increase of river discharge, and a decrease in evaporation.

A combined analysis of synoptical data concerning the river basins of the Caspian Sea and data relating to its sea level behaviour confirmed this correlation. During the periods of sea level rise the number of rainy seasons had significantly exceeded those of dry seasons, while during periods of sea level fall a decrease of rainfall had taken place. The analysis, however, does not explain the sharpness of the last changes from a sea level fall to a sharp rise (Fig. 1).

SEA LEVEL RISE AND FLOODING

The immediate effect of a sea level rise is flooding of low-lying coastal territories (for example of the vast coastal lowlands in the Kalmykia) and strong accelerated erosional processes in the nearshore zone. Its indirect impacts are expansion of the subsoil water penetration zone, the marshing of coastal territories, the salting of soils and the expansion of surge and dry areas. As a whole, radical changes of ecological conditions in the maritime

subaerial territories and the marine aquatories are noticed.

Sea level rise as a whole has promoted erosional process development, retreat of shorelines and displacement of the entire profile landwards (Johnson, 1919; Zenkovitch, 1962; Bruun, 1962; Dolotov, 1992). Coastal flooding has led to increased shore erosion and to the formation of active cliffs. For this reason the coastline of Daghestan has increased by a factor of 4, where 10% to 39% of the total shoreline retreated landwards at an average rate of 10-20 m/yr, embracing more than 70% of the formerly prograding areas, formed by unconsolidated material. In some coastal areas the shoreline retreat has reached a catastrophic level of 70-100 m/yr. In the traditionally erosional areas, formed by bedrock, the rate of erosion is about 2 m/yr. As a result of reworking and erosion of various type of deposits, the length of the coastline, subjected to intensive erosion, has at the present reached almost 40% (Badiukova et al., 1993).

Strong coastal erosion, flooding and bogging up of vast spaces, are typical for the coast of Daghestan (Ignatov and Solovieva, 1990). Intensive passive flooding takes place in the coasts with mud flats under nearshore bottom inclinations of about 0.0001. A rise of groundwater level, salinization and marsh development in the coastal lowlands are characteristic for the Azerbaijanian coast (Ignatov et al., 1993a).

Another coastal type is characterized by bar (or storm ridge) erosion and its migration landwards, accompanied by a crawling over lagoons or low-lying coastal territory. This type of shore is observed on the Daghestan coast (Badiukova et al., 1993). It has affected the limits of the Makhachkala territory, central and southern parts of the Derbent and its suburb, the external edge of the Sulak delta and in other areas. The strong shore erosion and flooding of the low-lying recreational areas, the beginning of threatened situations in the zones of the newly constructed and the erecting recreational objects and their destruction is evident. It seems not advisable to erect capital objects at the border of marine terraces; they must be sited at safe distance from erosional coastal areas, otherwise it is necessary to transfer them from one place to another. Some of them have been found in sea. At the Daghestan coast, due to the intensive erosion of the lower terraces of 1940 and 1929, a real threat endure the numerous rest bases and the capital constructions of youth camps; some of them on the beach are practically destroyed and partially submerged; in the Derbent region, areas with urban, suburban and recreational buildings, are subject to erosion. Unreasonable building on lower marine terraces, even on local authority initiative, has taken place, completely ignoring the natural phenomena and available scientific information. As a result and since 1978, in the southern part of Makhachkala about 200 ha of maritime land had been flooded; in Derbent more than 70 ha of coastal land was submerged (whole streets), in nearshore areas of the urban central part practically all buildings were destroyed. The rising of the ground water table embraced practically the complete southern part of Makhachkala, more than 300 ha of maritime urban territory of the Derbent, half of the urban space of Caspijsk and more than half of Chief Sulak (in the Sulak delta). The above mentioned data relate to some years ago and further changes have taken place.

In the Volga delta, pastures, roads and different constructions had been found submerged as well (Ignatov et al., 1993a). An essential correction of the planning and the realization of the early outlined recreational measures is necessary for these and the Azerbaijanian coasts (Leontiev et al., 1990). For the eastern coast many suburban settlements and lines of electro-transmission have been found under water (Ignatov et al., 1993b).

SEDIMENT ACCRETION AND SHORELINE

At the same time in some limited coastal areas sediment accretion and shoreline advance has been noticed, in spite of the sea level rise conditions. It takes place when the volume of supplied sediment exceeds the volume of unconsolidated material that becomes flooded in the course of sea level rise. Therefore especial attention must be paid to such areas, since they may give a unique opportunity for future economic use (first of all recreational), even

under condition of continuing sea level rise. In accordance with observations, the supply of finer material landwards due to surge effects, together with marine grass development, has promoted the progradation of shoreline. The barrier role of bedrocks as ridges takes place with sea level rise and facilitates the relative stability of such accretional coastal areas, but the presence of a great amount of sediment is necessary.

The scale of shoreline changes (and its trends), as a result of the Caspian Sea level prolonged oscillations is noticed on the map on the dynamics of the Caspian Sea coast of the Russian Federation, compiled by Geographical Faculty of Moscow University. Rates of coastal progradation and shoreline retreat have been calculated for some separate areas:

- from some 100 m/yr (in the Kalmykian coast and the Volga delta area)
- to 10 m/yr (in the southern and central parts of the Daghestan coast).

Observations along the Caspian Sea coasts under conditions of the current sea level rise have shown that coastal changes depend to a large extent on values of the submarine shore slope inclination (Beliajev et al., 1992).

For shallow-water coasts 4 types of shore processes had been determined. They are classified with for an increasing bottom inclination:

- the passive flooding of land;
- the emergence of a submarine ridge (bar) above sea level accompanied by the separation of a lagoon;
- the ridge migration landwards and its crawling over a lagoon;
- the cast of sediment ashore and its accretion on the bottom, lower than the breaker zone.

Almost the same evolutionary patterns have been distinguished at the east coast of the Caspian Sea by other researchers (Ignatov et al., 1993b). A more detailed model of coastal evolution, depending on inclination of the bottom profile surface has been supposed too (Ignatov et al., 1993a).

DISCUSSION OF FUTURE PROBLEMS AND TASKS

For decisions on problems related to the coastal evolution of the Caspian Sea it is necessary to use data from studies of World Ocean coasts evolution during irregular Holocene transgressions, for example of the Azov-Black sea basin. The latter has been described in detail by Nevessky (1958). It gives the opportunity to distinguish 3 main possible evolutionary patterns for the sandy accretional coast development under conditions of rising sea level, or relative coastal submergence (Dolotov, 1962, 1982, 1986 & 1992; Dolotov et al., 1964).

In the course of a rapid sea level rise, the rearrangement of bottom profiles due to hydrodynamical factors at depth changes (thereby ensuring the possibility of sediment migration landwards on the gently-inclined bottom profiles) "lags behind" in comparison with flooding of land (increase of depths); as a result inundation of nearshore accretional formations and maritime subaerial territories occur (Fig. 3a).

For sufficiently rapid sea level rise and a total exhaustion of the sediment reserves, the volume of supplied sediment does not compensate for the volume of eroded sediment in the course of flooding. The same situation occurs at slow sea level rise, but with an insufficient sediment amount. As a result, a substantial shore- and bottom sediment- erosion and shoreline retreat takes place (Fig. 3b).

During the slowing down of a sea level rise in the presence of abundant sediment reserves in coastal areas, long-term sediment accretion and continuous seaward coastal progradation is characteristic; in other words the volume of supplied sediment exceeds the volume of unconsolidated material that becomes flooded due to an intensive sediment migration shorewards in the course of rearrangement of the submarine shore slope (Fig. 3c).

The scheme, proposed by the author, referring to Zenkovitch (1962), supposes that for shallow-water coasts in the course of submarine shore profile rearrangement, under conditions of sea level rise, a landward sediment migration took place, although the literature holds the widely-held opinion, that according to the "Bruun Rule" (Bruun, 1962), sediment erodes in the upper part of the nearshore bottom profile and the accretion only occurs in the lower part of its profile.

As a whole, the character of the relief change, during rising sea level, is conditioned (Dolotov, 1992) by the rate of sea level rise, the character of the relief-forming environment dynamics (of the hydrodynamic action) and the sediment amount (its reserves and conditions of the replenishment). It depends on the relative role of the depth increase in the course of sea level rise and the amount of coastal sediment available (Dolotov, 1962, 1982 & 1986; Dolotov et al., 1964).

The present rates of the Caspian Sea level rise are very high and for this reason the whole coast undergoes an evolution of the first and the second pattern: the process of rapid flooding of land apparently exceeds submarine shore profile reworking, accompanied by bottom sediment supply shorewards, in spite of the abundant sediment reserves in many coastal areas. But in future, if again a decrease of the Caspian Sea level rise takes place, a third evolutionary pattern, accompanied by coastal progradation will be noticeable. This is especially important for economic development.

Taking into account the predicted rates of the World Ocean level rise, caused by the "green-house effect", of some mm/yr (Hoffman, 1984) and the rates during the Holocene transgression, one may suppose, that in different parts of the World Ocean the evolution of shallow-water coasts will be followed by the second and the third type described above, and the prediction must be based primarily on the evaluation of the sediment budget in concrete coastal areas (Dolotov, 1992). This should be taken into consideration when planning economic activities in coastal zones.

Dependence of possible patterns of coastal evolution under sea level rise upon the rate of the level fluctuations and the rate of the unconsolidated sediment supply have been considered and by Curray (1964).

As mentioned above, the sea level rise of more than 2 m has caused appreciable damage to the economy of coastal states of the Caspian region, including the territory of the Russian Federation, in its north-western part - the Daghestan, the Kalmykia, the Astrakhan province. Urgent measures are provided for the liquidation of the negative consequences of the catastrophic sea level rise in accordance with a Decree of the Council of Ministers of the Russian Federation *"On the urgent measures in 1993-1995 related to the prevention of flooding and subsoil water penetration of cities, settlements, industrial and non-industrial objects, agricultural and other valuable lands in nearshore areas of the Caspian Sea"* (Safianov et al., 1994). A large group of scientists and specialists of different disciplines from the Moscow University (Geographical and Geological faculties), institutions of the Russian Academy of Sciences (Institute of Water Problems and its Scientific Centre "Caspy", the Institute of Atmospheric Physics, Institute of Geography), the Russian Federal Survey on Hydrometeorology, the Russian Committee on Fish Economy and others have participated in the preparation of concrete measures as a solution to the problems. The author has taken part in the examination of such materials. The conditions of the current rapid sea level rise have dictated the urgent necessity of the installation of shore protective structures (Grebnev and Zhindarev, 1993).

The urgent measures on the defence of different objects and population from flooding, subsoil water penetration and erosion are classified as follows:

- the installation of permeable constructions (from reinforced concrete elements), containing wave chambers and
- the creation of an artificial beach and its periodic additional sediment nourishment (in the Makhachkala area);
- the installation of protective constructions, containing wave chambers of the pile-cell type (in the Derbent area);
- the creation of an artificial beach (in the Caspijsk area);
- the creation of an artificial subaerial territory at the settlement, accompanied by a change of river course to the former one (in the settlement Sulak area).

Coastal protective permeable constructions have been worked out in the Black Sea Division of the Marine Coastal Protective Constructions of the Central Building Research Institute, the Projecting-Prospecting Enterprise "Inzhzastchita"

of the Ministry of the Transport and Building and the Joint Scientific-Industrial Union "Baltberego-zastchita". Beginning in 1983 the construction of such types have been successfully used in the Baltic Sea, and from 1987 on in the Caspian Sea. The local coastal defence is considered for other, mainly low-lying coastal areas, based upon the local natural conditions, the value of the to be defended objects and the economic feasibility of the concrete measure as a whole. They are as follows: the formation of the artificial banks, accompanied by drainage and pumping of ground water and the installation of ring-shaped dikes.

It is necessary to emphasize, that the major difficulties in deciding the course of action on the coastal defence measures in the north-western region, were due to the absence of a real prognosis of the further sea level change, since the cause of the sharp change of the sea level in 1978 (the natural and anthropogenic ones) was not determined. Prognosis of further sea level fluctuations, undoubtedly must be based on an understanding of the major reason of the abrupt changes in water budget of the Caspian Sea, which occurred in the late 1970's. The knowledge of the regularities of sea level changes determines the choice of coastal defence systems. This is an urgent task for scientists and specialists.

These coastal problems are essentially related with the distribution of human population and its economic production. For this reason, the character and the scale of this catastrophic natural process and the unfavourable consequences on the economics and life of people depended to a large extent on the peculiarities of the relief structure and the dynamics of the sea level change.

An urgent task is the organization of a system of observation posts for the monitoring of the natural environmental parameters in the coastal areas, first of all, the sea level changes, and secondary the creation of a data bank. Effective regulation must be organized, banning of beach sediment mining, since even at present, for example on beaches of the Daghestan coast, everywhere evidence of sand and shell collection by excavators and bulldozers can be found. Vast sand-pits have been dredged through the beach for the exploitation of such material for building and agricultural needs. In the present situation this mining will lead to an intensification of shore erosion and retreat of the shoreline. These activities are absolutely inadmissible.

In the course of the preparation of the coastal defence concept, a complex approach had been used: plans for coastal protection are combined with the rational use of the maritime territories, such as a minimum constructions in the natural environment. The installation of permeable protective constructions has been combined with the building of a urban sea-front (quay). As a result the recreational beaches become wider. Artificial sediment accretion and additional sediment supply will allow the restoration of the former sediment budget and the use of part of its territory for recreational purposes, even at the unfavourable conditions of sea level rise.

Scientists and specialists have mapped the concrete measures in response to the strained situation to a catastrophic sea level rise such as observed during the last years, considering ecological and social-economic values.

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Fig. 1. Changes of the Caspian Sea level from 1929 to 1993, calculated by R.V. Nikolajeva on the base of data of 4 level-measuring observation posts (Baku, Mahachkala, Fort Shevtchenko and Krasnovodsk); average values.

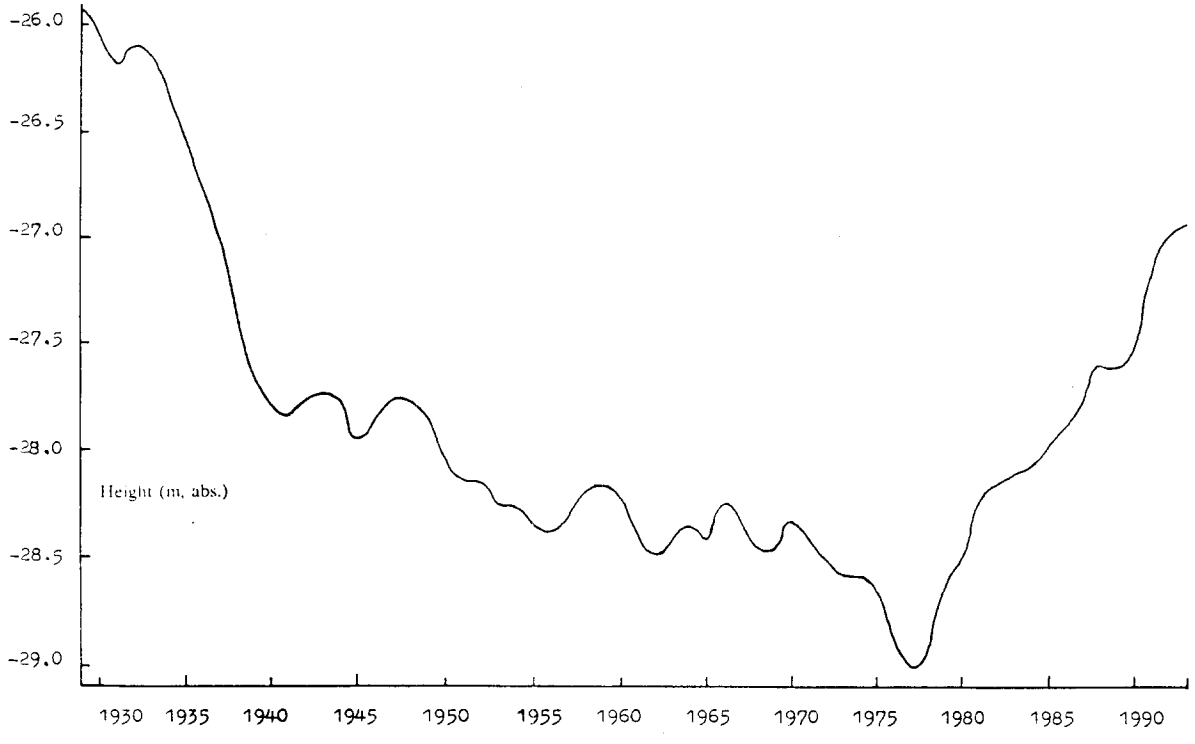
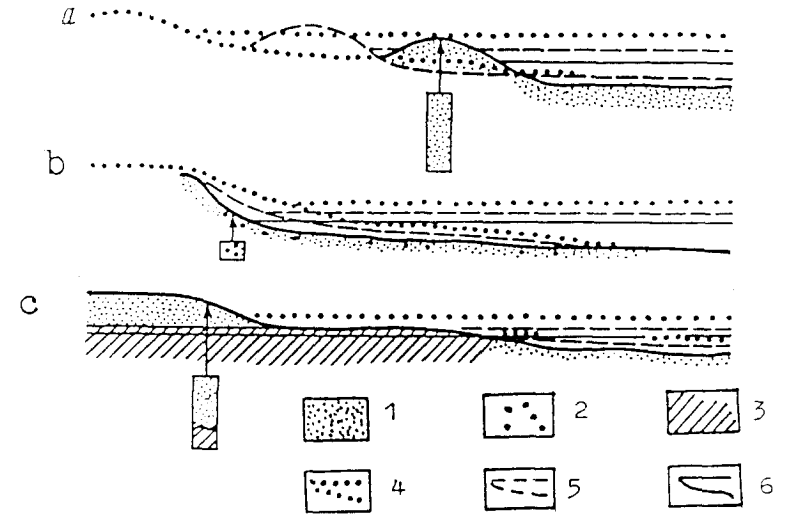


Fig. 2. Main patterns of the relief-forming and depositional processes in coastal shallow-water under conditions of sea-level fall, or coastal relative emergence (after Dolotov, 1989). a: continuous sediment accretion; b: erosion of external edge of accretional shore; c: preservation of sandy accretionary body 1-sand; 2-pebble; 3-bedrocks; 4, 5 and 6 -successive positions of sea level.



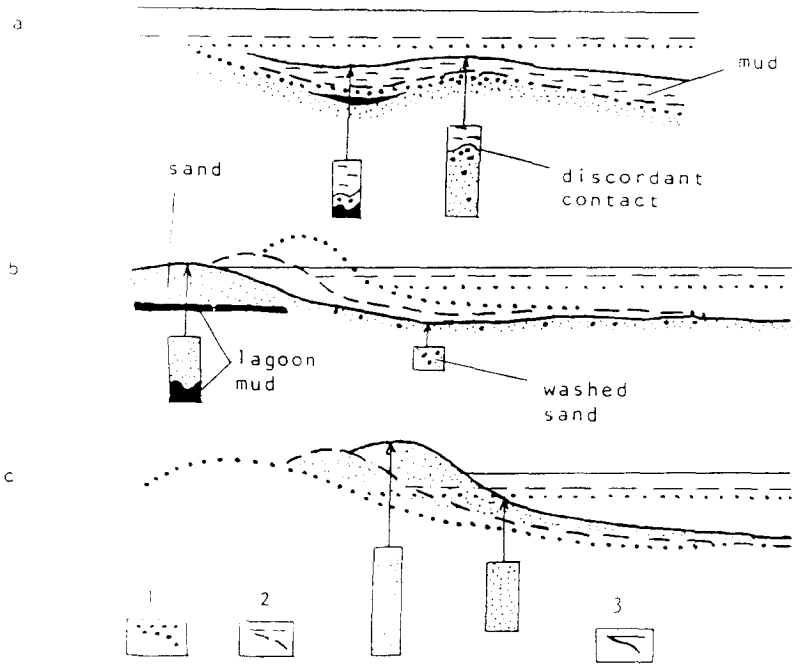


Fig. 3. Relief-forming and depositional processes in the shallow-water coast under conditions of sea level rise, or coastal relative submergence (after Dolotov, 1992). a: the flooding of the submarine accretional formations and coastal area; b: the shore- and the bottom sediment erosion accompanied by the shoreline retreat; c: long-term and continuous shoreline progradation; 1, 2, 3: the positions of the sea level and the resulting profile in the course of 3 stages of the successive sea level rise.

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GESTION PATRIMONIALE DU LITTORAL DUNAIRE AQUITAIN PAR L'OFFICE NATIONAL DES FORÊTS

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Longtemps considérées comme indomptables, les dunes littorales d'Aquitaine furent stabilisées au siècle dernier par reboisement. En bordure de l'océan a été édifiée une "dune bordière" non boisée à pente douce du côté exposé au vent. Les apports et les prélèvements de sable effectués par le vent et la mer modifient sans cesse ce fragile édifice et lui redonnent un grand degré de "naturalité".
C'est ainsi que sur un littoral aquitain à première vue très homogène on trouve une grande variété de types dunaires selon l'intensité de l'érosion marine, l'importance des transits sableux de l'estran à la dune, selon la végétation ... et bien sûr selon l'action de l'homme.

UN RÔLE DES DUNES EVOLUTIF AVEC LE CONTEXTE SOCIO-ECONOMIQUE

Les modes de gestion de ce milieu dépendent étroitement des rôles qui lui sont attribués, de là naît une première difficulté, en effet les attentes et les besoins évoluent avec le contexte économique et culturel.
La conception répandue indiquant que la dune "bordière" a été édifiée pour protéger les reboisements est source de confusion, il s'agissait plutôt pour les reboiseurs du siècle dernier d'éviter l'ensablement par les traînées sableuses des paraboliques subactuelles qui se déplaçaient alors loin du rivage. Ils eurent l'idée de créer un "piège à sable", stockage sédimentaire dont nous sommes les héritiers.
Un long débat a eu lieu sur le profil "idéal" à donner à ce cordon d'accumulation, la forme dite du "chien assis dos à la mer" l'a emporté c'est-à-dire la plus proche de celle des barkhanes, à pente faible du côté au vent. Mais dans la pratique ces formes artificielles évoluaient très vite en direction d'édifices plus complexes à inflexions longitudinales et transversales, une méthode unique ne pouvait s'adapter à 300 km de littoral soumis à des dynamiques diversifiées.
L'évolution des mentalités et des besoins (biodiversité, tourisme, paysage, ...) et une meilleure connaissance de la dynamique littorale ont amené l'O.N.F. principal gestionnaire du littoral aquitain à élargir ses objectifs et diversifier ses méthodes.
L'objectif unique du départ s'est complexifié en replaçant les systèmes dunaires dans les processus géomorphologiques et phytoécologiques globaux. Il s'agit tout à la fois de gérer un stock sédimentaire limité, de rechercher une diversité biologique maximale et de conserver des paysages et lieux de vie recherchés.
Parfois des arbitrages sont à faire entre objectifs contradictoires : comment conserver la beauté sauvage des étendues dénudées du Cap-Ferret et protéger la zone urbanisée contre l'envahissement du sable ?
En zone d'érosion, pour garder un cordon dunaire suffisamment large et résistant, est-il bon de le laisser reculer ou d'organiser son recul au dépens d'une lette grise de grand intérêt patrimonial ? Ne vaudrait il pas mieux repousser une partie du sable sur l'estran réalimentant ainsi la dérive littorale ?
C'est pourquoi après avoir clarifié l'objectif, il est nécessaire d'affiner les études préalables et d'établir un suivi des actions engagées. Des outils dans ce but ont été élaborés en collaboration avec l'Université de Bordeaux III: cartographie écodynamique à grande échelle, spiocartes ... Des missions photo-aériennes spéciales au 1/5000 sont effectuées régulièrement par l'O.N.F..

LA VEGETATION DUNAIRE FACTEUR DE L'EDIFICATION DUNAIRE EST AUSSI UN OUTIL DE DIAGNOSTIC ET UN ELEMENT FORT DE RICHESSE PATRIMONIALE

Organisée en bande parallèle finement liée à l'évolution stationnelle, la flore dunaire est un bio-indicateur de l'état du milieu (Fig. 1).

La plantation de végétaux est mise en oeuvre lors des travaux de restauration dunaire, ce n'est pas une fin en soi, l'objectif est plutôt d'aider la complexe mosaïque naturelle à se réinstaller. Les plantations sont plutôt à considérer comme un écosystème transitoire. Ces dernières années ont connu une amorce de diversification des végétaux utilisés, ainsi l'agropyrum remplace l'oyat en pied de glacis externe.

UNE GESTION MODULEE SELON LES SECTEURS

Dans tous les cas, il s'agit de concilier au mieux protection et activités économiques. Protection cela signifie contrôle contre l'ensablement et abri des milieux forestiers et urbanisés, mais aussi protection de l'écosystème original dune blanche-lette grise-manteau pré-forestier

Le degré de contrôle de la dynamique dunaire et les méthodes mises en oeuvre seront variables selon l'intérêt économique des zones à protéger, selon le secteur géographique et pour une même zone selon la phase du cycle sédimentaire.

On peut distinguer trois grands types de situation:

- les zones urbanisées et leur proximité
- les zones non urbanisées mais à vocation d'accueil forte
- les dunes "sauvages"

UN CONTRÔLE SOUPLE DES DUNES DOMANIALES "SAUVAGES"

Dans les zones où il n'existe pas d'implantation humaine lourde, il est possible de gérer l'écosystème dunaire en conservant tous ses aspects fonctionnels: lieu de stockage et de prélèvement de sédiments, amortisseur de l'énergie des houles, lieu de vie d'une faune et d'une flore spécifique, paysage original et attractif.

Le principe de ces travaux est de minorer les effets de l'érosion éolienne à l'aide de brise-vents, de couvertures de branchages ... Actions favorisant la reprise de la végétation naturelle qui à son tour assurera un contrôle du mouvement sableux. La dynamique du cordon dunaire est très étroitement dépendante de celle de l'estran qui connaît des alternances saisonnières, mais surtout des changements liés à la migration de "wagons" sédimentaires dans le sens de la dérive littorale de résultante Nord-Sud. Il s'en suit une alternance de phases d'érosion et de sédimentation.

En phase d'érosion marine, une organisation du recul.

Sur la côte Aquitaine, c'est l'érosion qui domine, il en résulte un recul inéluctable du trait de côte, cependant il est possible de contrôler la progression du sable vers l'intérieur des terres.

En phase d'érosion marine, l'avant dune est tronquée par une falaise vive, l'équilibre pénestable antérieur est rompu, il n'est temporairement plus possible d'agir sur la partie frontale (la lutte directe contre l'érosion marine est exclue de cette réflexion, elle est très coûteuse et pas toujours souhaitable car génératrice d'effets induits pervers). La compression frontale du vent génère un surcroît de transit sableux qu'il faut contrôler pour permettre aux groupements végétaux une translation vers l'arrière leur assurant la capacité de recolonisation lors de la phase de répit suivante.

Ce sable en transit est piégé sur la partie médiane et interne du cordon dunaire par pose de brisevents disposés perpendiculairement aux vents dominants dans les dépressions.

En front de dune après la phase de "coup de cuillère" marine, le profil de la falaise s'adoucit par éboulement puis éolisation, à ce stade on peut commencer un contrôle par dépôts de branchages dans les brèches et siffle-vents pour diminuer la déflation et éviter une trop forte irrégularité du nouveau glacis d'équilibre dynamique qui s'amorce.

En phase de répit de l'érosion marine, des entretiens ciblés pour aider la recolonisation végétale.

Si l'on a pu conserver une diversité végétale suffisante pendant la phase de recul, il suffira en

phase d'accalmie de créer des conditions favorables à l'essaimage de ces végétaux.
Il faut agir en priorité dans la zone frontale par couverture du sable ou pose de brise-vent en vue de retenir le sédiment à sa source et recréer progressivement un glacis externe aérodynamique. C'est la dynamique végétale naturelle qui aide à choisir le bon moment et la bonne situation pour déposer les brise-vents, les plaques embryonnaires à Agrogyrum caractérisent ces périodes (Fig. 2).
Les plaques de déflation du plateau et de l'arrière dune peuvent être couvertes de branchages de végétaux de densité variable selon l'importance de la déflation afin d'activer la recolonisation progressive de l'arrière dune par les végétaux de la lette grise.

DANS LES SECTEURS DE FORTE FREQUENTATION, des ENTRETIENS RENFORCES DANS LE CADRE DE PROGRAMMES COORDONNES d'ACCUEIL

Dans les zones à forte pression touristique, les travaux décrits précédemment doivent être renforcés, mais surtout s'intégrer dans des programmes concertés d'accueil touristique. Les "planplage" en Aquitaine ont prouvé qu'il est possible d'accueillir un public nombreux sans nuire au patrimoine. Cela nécessite des investissements adaptés (aires de stationnement, voies de secours, sentiers de guidages, caillebotis de traversée de dune, plages surveillées, ...), un entretien régulier, une surveillance et une information efficaces.

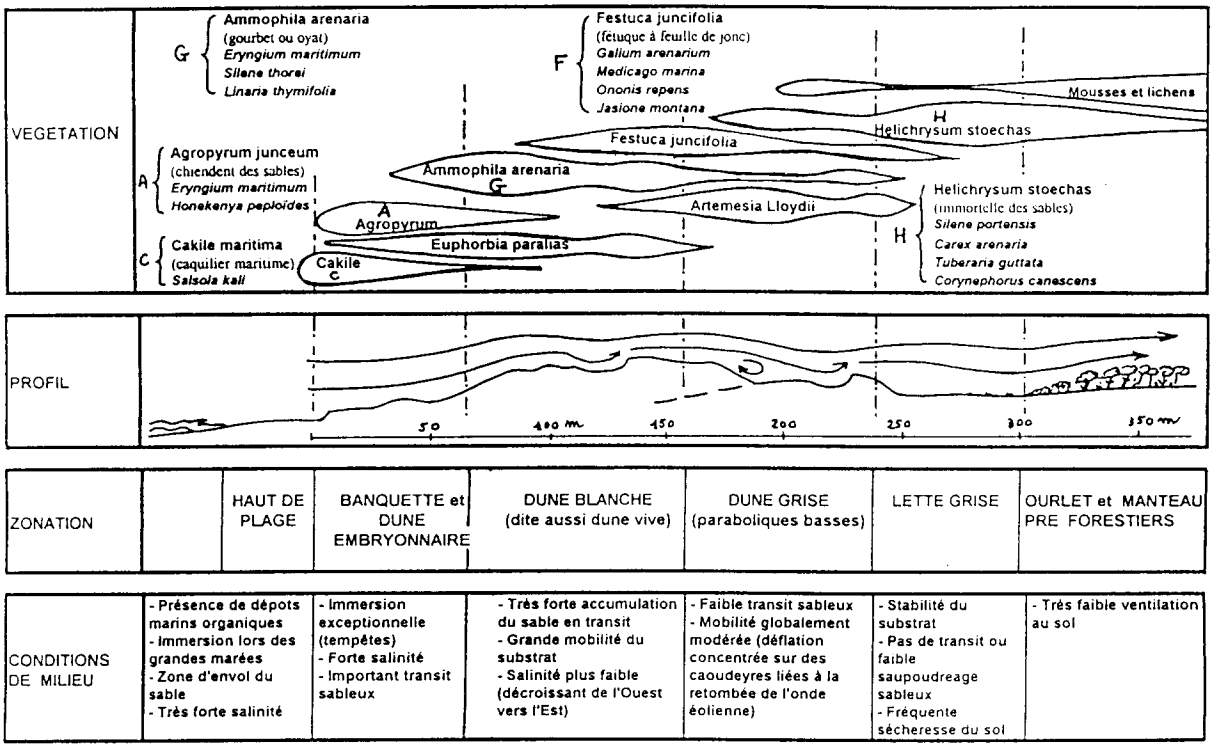
REHABILITATION LOURDE DES DUNES DEGRADEES EN ZONE A RISQUE

Le risque dunaire résulte presque toujours de constructions réalisées en position "aventurée" trop proche du rivage ou de l'absence d'entretiens réguliers et parfois des deux facteurs conjugués.
L'avancée dunaire est alors ressentie comme une menace et non plus comme un phénomène naturel prévisible. Faute de pouvoir reculer les équipements existants, on est alors contraint de recourir à des solutions "lourdes" qui nécessitent la mise en oeuvre de travaux de génie civil : remodelage généralisé, gros transfert de matériaux.
Lors des opérations de remodelage lourd, à l'aide d'engins de terrassement on reconstitue un cordon régulier de forme aérodynamique dont la coupe est proche de celle des barkhanes libres, glacis externe à pente de environ 20 % suivi d'un plateau très légèrement incliné vers l'Ouest (direction des vents dominants). Dès la fin du profilage, la totalité du sable est recouverte de branchages pour contrôler la déflation en attendant que les végétaux implantés jouent leur rôle.
Dans ces secteurs semi-urbains, les entretiens et le contrôle de la fréquentation doivent être particulièrement rigoureux. Par ailleurs, la possibilité de laisser à la dune un degré de liberté étant en général très faible ou sera obligé de repousser périodiquement le sable excédentaire ou bien (le plus souvent) à recharger le pied du glacis externe en cas d'érosion marine.

Pour conclure, rappelons deux aspects qui nous paraissent importants:

Dans les zones naturelles le contrôle souple de l'écosystème dunaire est le meilleur garant de la plurifonctionnalité du système. L'évolution des profils vers des formes de moindre résistance aérodynamique (parabolisation d'arrière dune) est une tendance à ne pas contrarier, en effet c'est cette zone de transition qui abrite les plus riches phytocénoses. A l'abri de cette dune semi-fixée la forêt trouve progressivement des conditions favorables à son implantation.
La collaboration praticiens-chercheurs a beaucoup apporté dans la compréhension des processus, la cartographie opérationnelle et l'adaptions des techniques aux diverses situations. Cette collaboration doit se poursuivre et s'intensifier, beaucoup reste à faire : détermination de bio-indicateurs fins de l'état du milieu, mise en place de placeaux de suivi permanent, place et rôles possibles de la dune dans les cycles sédimentaires côtier ... l'O.N.F. coordonne actuellement un programme européen de "biodiversité et protection dunaire" qui permettra des avancées dans ce sens, un colloque de présentation des acquis est prévu au début 1996 à Bordeaux.

Fig. 1. Schema des relations formes-vegetation dans les dunes littorales non boisées du centre Aquitain.



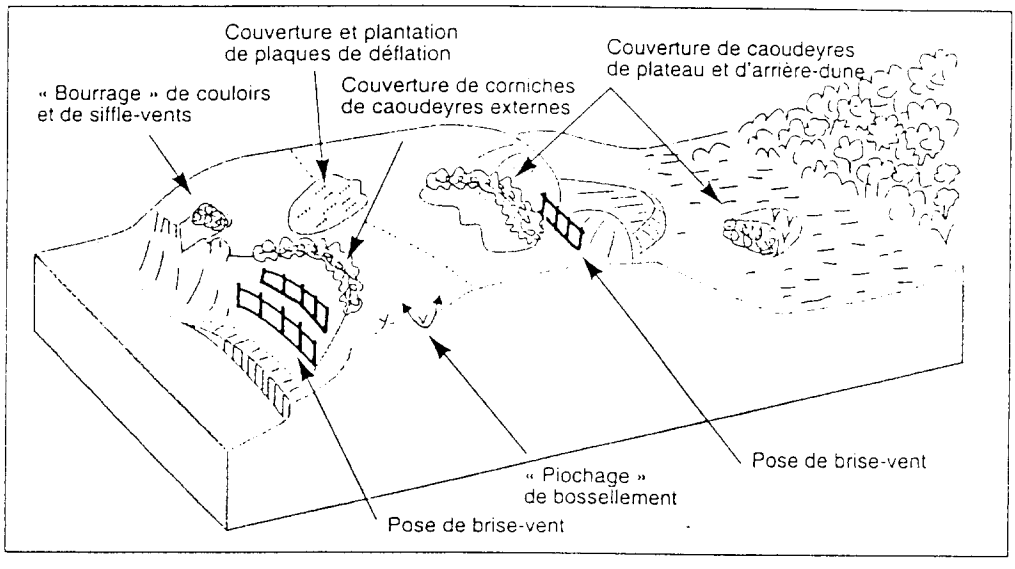


Fig. 2. Dynamique végétale naturelle qui aide à choisir le bon moment et la bonne situation pour déposer les brise-vents.

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GEOMORPHOLOGICAL AND PHYSICAL ASPECTS OF THE ROMANIAN COAST. ASSESSMENT OF COASTAL CHANGE

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KEY WORDS: Romanian Black Sea coast, wind climate, wave climate, shoreline monitoring, erosion, beach sediments, submarine relief, mans impact, coastal protection, coastal management.

ABSTRACT

The Romanian Black Sea coastline accommodates several geomorphological areas, grouped in two great zones: the delta of the Danube, consisting of alluvial sediments with extensive low-land marshes and lagoons, and a higher zone that consists mainly of cliffs, interrupted from place to place by short beaches. Excepting a small segment, the Romanian Black Sea coast is directed from north to south. In terms of this feature, winds from the north-east, east and south-east sector are dominant for wave generation and the sediment transport along the Romanian littoral.

Annual repeated surveys of beach profiles show an erosion up to 60%-70% of the shores at increasing erosion rates. In the coastal zone many activities such as industry, tourism, fisheries and agriculture are developing, but these are threatened by coastal erosion. A great number of coastal protection works have been built.

INTRODUCTION

The Romanian Black Sea coastline, which extends over about 250 km, consists of several geomorphologic areas (Cotet, 1973, Trufas et al., 1967; Gistescu, 1986), grouped in two great zones:

- the limitrophe shore to the Danube Delta, consisting of alluvial sediments with extensive low-land marshes and lagoons, mostly between 0.5 and 0.8 m, and
- a higher zone which consists mainly of cliffs, interrupted by short beaches. Other authors consider three zones: Sulina - Cap Midia, Navodari - Constanta (transition zone) and Constanta - Vama Veche. From an engineering point of view we defined a new classification that, besides their mineralogical and structural criteria, considers, for each beach sector the degree of exposure to waves action. Thus, five or even six divisions could be considered:
- Sulina - Sahalin,
- Sahalin - Periteasca,
- Periteasca - Cap Midia,
- Navodari - Constanta,
- Agigea - Vama Veche (Agigea - Tuzla and
- Tuzla - Vama Veche; Fig. 1).

The sea bottom consists of sand deposits in the northern part and of hard ground in the southern part. Here, cliffs are extended seaward as submarine promontories which separate littoral cells. These cells have particular dynamics (Postolache, 1992).

Under the influence of natural forces the shoreline is moving; advancing at one location, receding at another.

This is specific in the case of the first zone. In the second zone, except some parts, where there are a few beaches, the coastal processes are irreversible; cliffs are destroyed by gravitational breakdown. The patterns of the coastal processes (accretion and erosion) are now well known.

Some coastal protection works have been built in selected areas, but they are not all completed. Important nature reserves are lost and other interests, including recreational, residential, agricultural and industrial functions on the beach, are endangered.

COASTAL MONITORING AND DEVELOPMENT

Since 1978 the position of the shoreline along the Romanian Black Sea coast has been annually

measured. In the southern zone, these measurements have been carried out in spring and autumn along defined sections, each marked by a landmark. In the case of the largest beach (Mamaia) the measurements were done monthly. The place and the height of these landmarks are known precisely. These landmarks are present on the beaches along the entire Romanian Black Sea coast, from Sulina in the north, to Vama Veche in the south, with an interval of 2 to 3 km in the northern section and of 200 to 500 m in the southern section. Thus height/depth values are determined up to a sea depth of about 1 m. Periodically, the profiles are extended to sea depths of about 15-20 m. The results of the coastal measurements are stored on data files. In the same period, when bathymetric measurements have been carried out, sediment samples have been taken with a Van Veen grab sampler.

Sediment samples are chemically and granulometrically analyzed. These data have been statistically treated (Spiegel, 1972) and the correlation between terrigenous and organogenic component determined.

The landmark base was established in the northern sector in 1962 and in the southern sector in 1977. In 1978, when the annual measurements started, 50% of the landmarks were lost by coastal erosion. The National Council for Water replaced the landmarks 1985. Where erosion was largest, some landmarks were lost again. Using the results of coastal measurements, the development of the coast can be followed from year to year. In this way it can be seen whether the beach is becoming narrower, whether a particular bed contour has moved to the shore or offshore, and how much sand is lost from the coastal system. Considering this information, a reasonable prediction for the coastline development in coming years can be made and the sections that require protection measures specified.

COASTAL ENVIRONMENT

Wind Climate

Except for a small section, the Romanian Black Sea coast is directed from north to south. Hence, winds from north-east, east and south-east are the most important for wave generation and the sediment transport at the Romanian littoral. They represent annually 55.6%. The results of an hourly wind value analysis show that, at the Romanian coast, the prevailing shoreward wind directions are from the north and northeast. Along these directions, highest wind intensities are also reached. The wind intensities are obviously higher during the cold season as compared to those in the warm season (Besleaga, 1976).

Wave Climate (1971 - 1994)

The wind climate has great variability. Consequently the wave climate causes significant annual and inter-annual changes. The annual evolution of the wave patterns during calm periods is cyclic, as well as the ratio between waves and swell. Calm periods occur chiefly in May (66.5%) and scarcely in February (52.1%).

The wave frequencies vary between 20.3% (in May) and 39.4 % (in October) and of swell between 13.1 % (in June) and 20.6 % (in November). The ratio between these two types of waves, has a value of 1.2 in November and of 2.2 in October. This means that the November storms occur offshore and those of October are generated in the western coastal zone.

Maximum monthly values of wave height, period and length were recorded in January (height: 1.3 m; period: 5.2 s; length: 35 m). The lowest values were determined in June (height: 0.8 m, period: 4.2 s; length: 21 m).

Dominant northern winds determine a maximum frequency of waves from the north-east sector (41.2 % for the waves from northeast - east sector) and 16.2 % swell from the east (refraction effect).

Beach Sediments

Beach sediments consist of terrigenous, organogenic and calcareous sand. The terrigenous sand is brought by the Danube into the sea and is predominantly found in the northern sector, up to 87% on the beach and up to 95% in the nearshore zone. It is of mineral origin, fine and grey coloured.

Organogenic and calcareous sand is found in the southern zone, up to 98% on the beach and up to 80% in the nearshore zone (Postolache, 1990).

This sand is less fine and yellowish coloured. Calcareous sand is typical within this zone and originates from cliff erosion. Mollusc shells of *Corbula, Cardium, Mya* in the northern zone, and *Mytilus* in the southern zone, are the sources for organogenic sand. Besides, limestone fragments and limestone pebbles are found in this zone.

In the first sector (N1+ N2+ N3+ M4, see Fig 1) the grain size ranges from shell fragments to clay, but predominantly fine and very fine sand. Along the shore the grains are distributed within parallel alternate strips in which there are different contributions of the grain size. The foreshore zone predominantly contains shell fragments, coarse and very coarse sand. The fine sand is found in a small quantity, predominantly from 0.5 m to 10.0 m depth. The coarse sediments are found for 10% to 90% in the inshore region of sector two (S5+ S6). On the whole, medium grains decreases in % as we advance offshore, reaching 0.15 - 0.10 mm (Diaconeasa et al., 1992).

The sediments from the Romanian littoral have been studied by numerous Romanian scientists, but not the entire coastal area was considered. The main results are given below. Bondar et al. (1972) studied the marine sediments in front of the Danube Delta. In the nearshore zone, he found that sediments with medium grain size larger than +4.43 ϕ (ϕ is the mesh size, where 10ϕ, 9ϕ, 8ϕ, 7ϕ,..., 4ϕ, 3ϕ, 2ϕ & 1ϕ reflect respectively 1μm, 2μm, 4μm, 8μm,..., 64μm, 125μm, 250μm & 500μm) are prevailing. Generally speaking, medium grain-sized particles increase to the southern limit of zone A, where they exceed the value of +3.33 ϕ. The seaward limit of the coarser material (> +4.33 ϕ) is located approximately along the 15 m contour line.

Gomoiu (1969) concluded a range from 0.03 ϕ to 3.84 ϕ for the mean grain sized sediments, for the Romanian coastal area that there exist two main types of sediments, namely: fine quartz sand of fluvial origin, generally situated in the first sector (N1+N2+N3+M4); in the deeper zone occurs coarse and mean-coarse, calcareous, conchiferous sand of biogenic origin, generally placed in the second sector (S5+ S6) of the Romanian littoral and especially in the meso-littoral.

Caraivan (1981) studied the textural features of sediments for Portita-Tuzla area. He also found longshore stripes of fine mineral sands from nearshore zones to 15-20 m depth, with values of mean grain sizes ranging from 2.94 ϕ to 3.44 ϕ. There were additionally sandy residual coarse deposits seaward of rocky type shores.

Panin (1974, 1989) studied the sedimentology and the evolution and genesis of Danube Delta, assuming two basic types of marine littoral deposits:

- type "a", deposits formed by littoral drift from the north (from the mouth of the rivers Bug, Dniestr and Dniepr), consisting of quartz sands with very high silica contents (86-95%) and particularly reduced alumina (average value 1.5%) and iron oxide (mean value 0.12%). The heavy mineral content is very small (0.1-0.3%), while the characteristic mineral assemblage contains minerals highly resistant to transport and environmental change: garnets (50-60%), imenite (12-18%), tourmaline (6-10%);
- type "b", deposits of Danubian origin, represented by fine grained sand with a lower SiO_2 content (60-85%) and a higher Al_2O_3 (1.7-8.0%), Fe_2O_3 (0.3 - 3.3%) and TiO_2 (0.1-1.6%) content. The heavy mineral content is significant (2-3%), the characteristic assemblage includes amphiboles (15-35%), garnets (5-35%), opaque minerals, especially illuminate (5-15%) and epidote (9-12%). He mentions two subtypes:

-- subtype "b1", of littoral diffusion, marked by a mixing with type "a" material, and

-- subtype "b2", of normal littoral transfer, preserving obvious characteristics of the Danube derived sediment. He also noted a subfacies of present-day or fossil marine erosion, displayed deposits enriched in heavy fraction residue (reaching 35%), as well as a subfacies related to terrigenous matter deficit, in which the terrigenous material is partly replaced by shell debris ($CaCO_3$ to 45-50%).

A more complete data set regarding actual sediments from the superficial layer has been obtained by the authors by their investigations on the entire littoral since 1986.

The littoral sediments of the studied area consists mainly of sand (1 ϕ to +4 ϕ) containing

frequently shells debris, rocky gravels and mud (clay, silt, sand mixture). Coarser sediments are found in a narrow band in front of the beach. The most significant amounts (> 90 %) of fine and very fine sediments (2.5 ϕ to 3.5 ϕ) occur in the inshore and offshore environments of N1, N2, N3, M4 segments (1.0 m to 15 m depth) and offshore environment (5.0 to 21 m, depth) of the S5 and S6 segments. Shell debris predominantly appear in the foreshore of the entire Romanian coast. In the S5 and S6 segments there is specifically rocky gravel of a residual nature (nearby Sarmatian limestone source). Also, we collected samples of shells from 7-20 m depth interval with actual or relict fauna (palimpsest deposits).

Mud is seen over 6-7 m depth of N2, 13-15 m depth on M4 (clay >10%) and between 15-20 m depth on S5 and S6 areas (clay >10%). Generally the percentage of clay increases over 15 m depth.

Submarine Relief

A classification in two sectors can be considered for the submarine zone. Singol Cape represents the point which divides the northern littoral, exclusively sandy, from the southern one, generally rocky. Nevertheless, the rocky part alternates with a sandy one. The former is in fact a continuation of the shore areas where beaches exist.

Northward of Singol Cape the submarine beach profile displays reduced slopes, the only morphological 'accidents' being the submerged longitudinal bars, whose number varies from one profile to another.

Between north of Portita and Vadu a submarine 'wave' was identified by the authors. It starts from 9 m depth and intersects the 15 m isobath right in the Vadu section. This reaches a height of 2.1 m and is formed of fossil, coarse sediments, reddish-brick coloured. Some information about the existence of similar sedimentary deposits with the mentioned features has been given by Gomoiu (1969), referring to distant points at the depth 12 and 14 m respective.

South of Singol Cape, the profiles have a much more complex character, the slopes are steeper with important differences of depths, which emphasizes rocky submarine platforms. A special situation occurs between Eforie Sud and Tuzla. Here, depths increase at distances of only 500 - 600 m, from 10 m to 24 m and 30 m respectively. Profiles similar to those from A sector are specific for shore sectors with beaches.

Some data concerning profile slopes give the possibility of differentiating between zones, sectors or beach areas with different characteristics. Slopes, given in Table 1, refer to depths of 5 m and 10 m as a function of distance from the shore (for 500, 1000 and 2000 m).

Analysis of these slope clearly confirms the differences between the sectors A + B and C. For the sectors A and B, especially, the evolution in slopes, emphasizes a submarine relief behaviour with respect to distance to sediment sources and certain particularities of sediment transport. A clear-cut separation exists between the segments N1 (represented by profiles E1 - E3), N2 + N3 (represented by profiles E4 - E6), south of the segment N3 (profile E7), and M4 (profiles E8 - E10). The separation is evident between the northern sector (represented by profiles E1 - E10) and the southern sector (represented by profiles E11 - E16; see Table 1).

MAN'S IMPACT

At present the contribution of sand by various sources has decreased as a consequence of a number of factors, of which man's impact is the greatest during the last decades (Spataru, 1979; Postolache, 1990). Man's impact has influenced both terrigenous and organogenic sediment sources. This has caused a decrease of sand carried to the sea by the Danube, a change of shore contour and the death of molluscs. The diminution of terrigenous sand quantity has taken place due to hydrotechnical works, realized for the management of hydrographic basins (e.g. stopping of soil erosion, irrigation and a hydro-electric works).

The shore contour changed as a consequence of navigational and port works (i.e. Sulina channel, Midia and Constanta Harbour).

The prolongation into the sea of the Sulina branch, as a 9 km long channel, favoured spreading of sand offshore and retaining sand, carried to the sea by the Chilia branch. A

secondary delta was formed. Moreover, the Sulina channel has favoured a particular current climate south of it, which acted as a sand trap (Nae et al., 1978; Spataru, 1979) extending Sulina beach, concomitant with depth reduction in the near-shore zone. Marine pollution has determined the increase of the death rate of the mollusc population.

CONSEQUENCE OF THE MAN'S IMPACT AND OF THE INFLUENCE OF THE FORCES OF NATURE

Between the two branches, Sulina and Sf. Gheorghe, the shore has been strongly eroded and the sea comes in direct contact with the deltaic vegetation. There is a similar situation in the south of the Sf. Gheorghe branch. The erosion process has almost extended to the north of the Midia Harbour.

Annually repeated surveys along beach profiles between Sulina and Vama Veche, show an increased erosion up to 60% - 70% of the shore length and increasing erosion rates. The northern part (Sulina-Vadu) of the coastal zone lost more than about 2200 ha (that is 77 ha/yr) from 1962 to 1991. The shoreline retreated up to 340 m in the last three decades, though mostly about 200 m. At the same time, the accumulation amounted to only to 169 ha, which is 6 ha/yr. In periods of storm, where the shore is lower, the coastal barrier is often broken or covered by waves, and sea water flows into the fresh-water lakes, jeopardizing their ecosystems. On other parts, where the shore is higher, sand layers with thickness up to 80 - 100 cm are removed. From Constanta to Vama Veche, where the high shore is prevalent, the breakdown of the high shore has taken place discontinuously. A single breakdown causes the shore to retreat more than 15 m.

COASTAL PROTECTION

We have previously presented the two large subdivisions of the Romanian littoral from a geomorphologic point of view and genetic characteristics. Their particularities have been already emphasized. We must add the touristic interest being very important in the southern area. This is because of access facilities and not in the least place the wish to protect Danube Delta, this real paradise of nature. Consequently, the protection works have been especially directed to the touristic regions. For the other areas, works have been carried out to facilitate navigation and much later to protect the sea coast.

Mamaia beach, is situated on the littoral belt which separates the sea from Siutghiol Lake. It is remarkable for its high quality sand, mainly of terrigenous origin. After a favourable evolution in the past, with the sand discharged into the sea by the Danube's branches and the development of Midia and Constanta harbours, the greatest part of the beach face an absence of necessary sediments for maintaining an equilibrium. The negative effect of sediment starvation due to hydrodynamical factors, is already felt in a restricted area in the southern end, which imposes urgent protection works. Firstly, a longitudinal dam was built at the shoreline. This dam consisted of plastic tubes but this had no beneficial effects. After two strong storms, recorded in 1976 and 1977, urgent measures were needed and which has been carried out in the winter of 1977-1978 by a hydrotechnical construction parallel to the beach with artificial nourishment of about 2700 m^3 sand. A short time afterwards, the effects became only but visible locally, because erosion continued, extending the danger northward to another area. Over a length of 300 m the beach was completely destroyed (Fig. 2). Estimates, made by Tanase (1992) show that between 1966 and 1988 over a length of 1.5 km, the beach surface decreased from 135,600 m^2 to 46,700 m^2, with a 59.2 m reduction of the width. Considering a requirement of 8 m^2 beach per individual tourist, this results in a reduction of recreation capacity of 11,100 places for this sector. This situation became much more serious after the exceptional storms recorded in 1979, 1981 and 1988 (Postolache et al., 1989). In 1976 an extensive research began to find protection solutions. This was assigned to two institutions, specialized in planning and design, where more than one variant were analyzed (Fig. 3).

Among these, variant V4 (see Fig. 3) was accepted as the best. The following aspects were taken into consideration:

1. Reduction of wave-destructive action by partial energy dissipation;
2. Regeneration of the last beach sectors with artificial sand supply from Siutghiol lake;
3. Ensuring the stability of protection constructions;
4. Securing the attractable aspects (which was less carried out);
5. Regeneration of ecological values of the area;
Previously, in winter, at the inner limit of the beach, reed was planted in order to withhold sand from being blown away due to strong wind action.

Constanta - Eforie South sector.
In Constanta area, 9 protective seawalls were realized, parallel to the shore over a total length of 3.93 km protecting 90,000 m^2 of beach. In order to protect the beach between the localities Eforie North and Eforie South, over a length of 6 km, 19 seawalls have been constructed with a total length of 2.67 km.

Eforie South - Vama Veche sector.
The sector concerns an area with beaches and some cliffs, accompanied by touristic accommodations (hotels, water pools and so on), whose capacity exceeds the beach sustainability, thus requiring the application of some dual purpose technical solutions: shore protection and the use of sanding neetheads in order to create new beach surfaces. In this part of the littoral, the seaward constructions are usually linked to the shore in the form of jetties with different shapes (Y, T, 1/2Y, 1/2T, so on).
In order to protect the cliffs in the area of the touristic resorts, hard works like embankments to reinforce the cliffs and the drainage of underground waters has been done. The high shore, to be protected, had a length of 7.4 km.
After 1990, some of the hydrotechnical works have been stopped because of lack of financial support.

COASTAL MANAGEMENT IN ROMANIA

A new era has started for marine and coastal management, because 70% of the world's population lives in coastal zones. Because of these large population concentrations and their related human activities, all issues are closely interconnected. The lack of the national policy for integration of sectoral plans and environment protection has caused a number of conflicts concerning the use of coastal resources. These conflicts are more complex in this period of transition to a market economy. Clearly, a management program is very necessary to save the coastal ecosystems and their resources. We are trying to develop an action plan in connection with the GEF Program for Environmental Management and Protection of the Black Sea. Annex 1 shows the schematic diagram of an ICZM institutional mechanism for the integrated management of the Romanian coastal zone.

CONCLUSIONS

From the above mentioned data it is very clear that erosion is a great problem for the Romanian coast. In addition, the lack of financial resources and a proper legal framework are elements which restrict finding proper solutions for coastal problems.
Erosion will become more and more important in case of climate change and sea level rise, at least for the low lands of the northern sector, with as a consequence that ecosystems of the littoral lakes will be destroyed and many natural, man-made and human components will be lost.

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Annex 1. Schematic diagram of ICZM (Integrated Coastal Zone Management) institutional mechanisms in Romania (project).

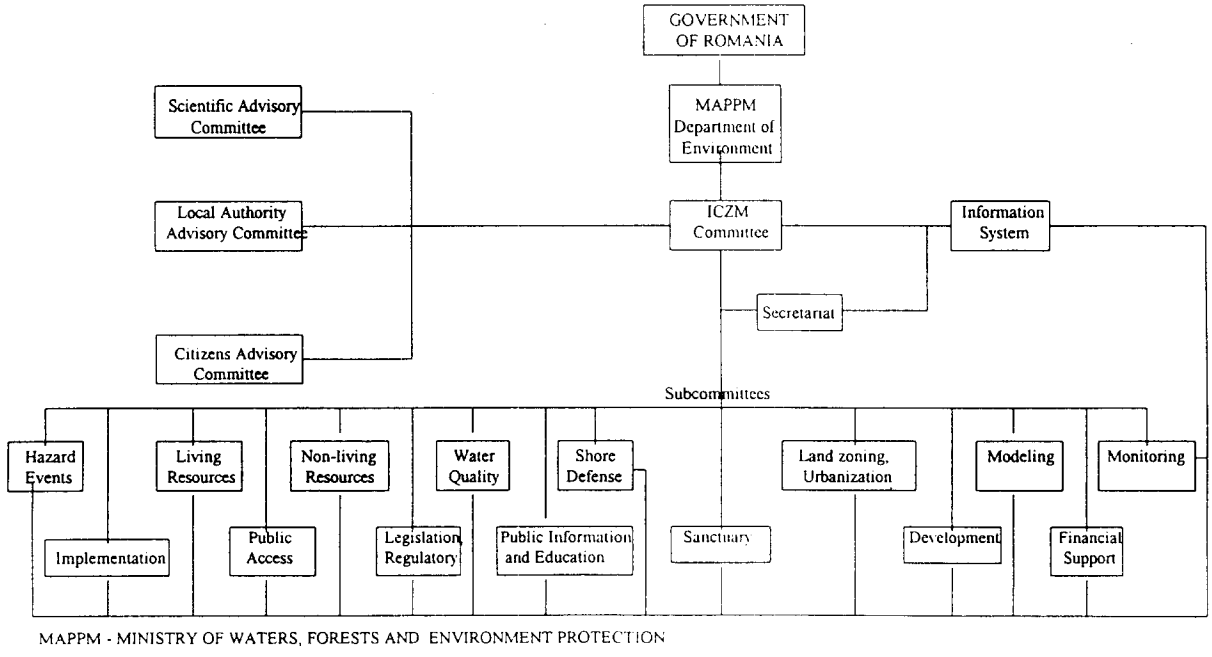


Fig. 1. Geomorphologic subunits of the Romanian littoral.

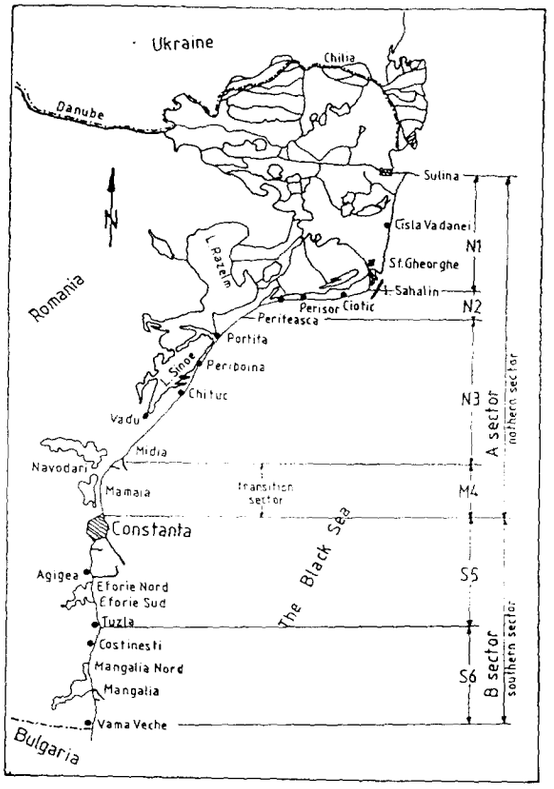
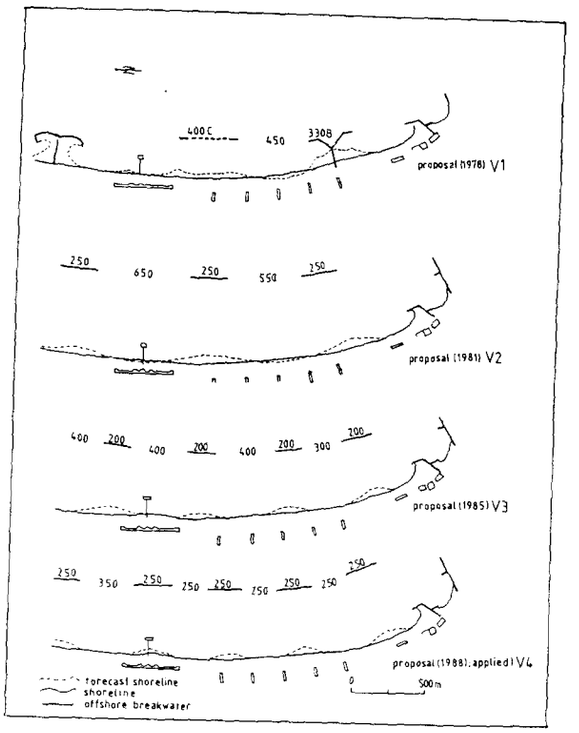


Fig. 3. Variants investigated for Mamaia beach protection.



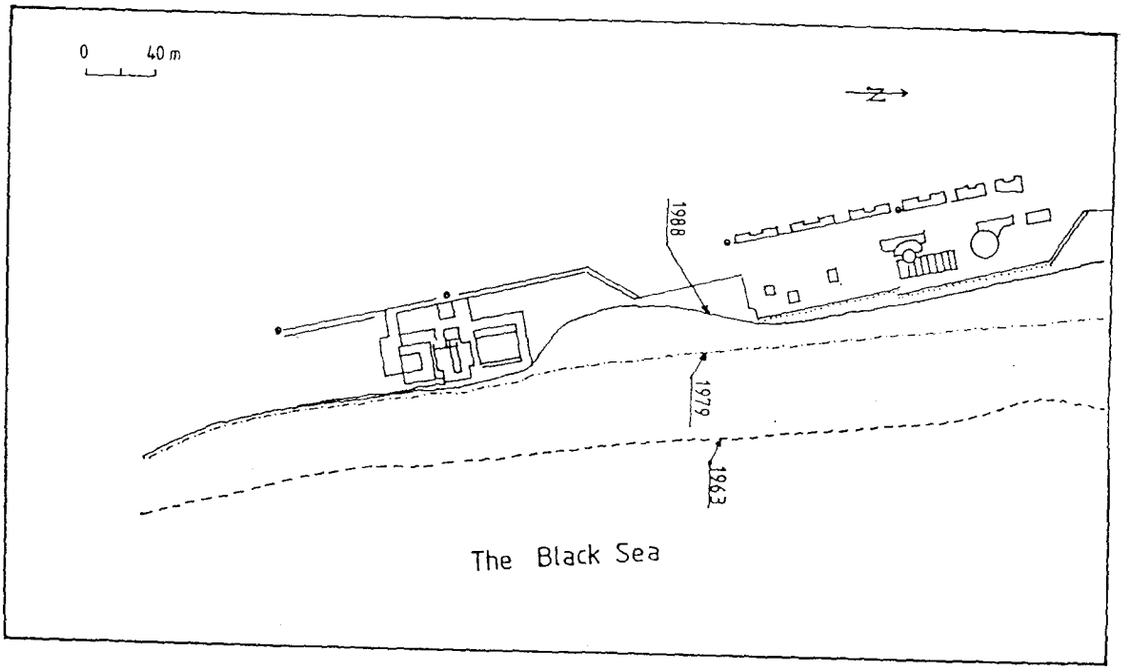


Fig. 2. Dramatic state of a part of Mamaia beach.

SESSION VI

Short-Term Mechanisms, Processes & Modelling

Session VI-a
Mechanism & Processes

Chairman: J.C. Pernetta & A. Héquette
Rapporteur: S. Gao

Proc. Int. Conf. 'Coastal Change 95' Bordomer-IOC, Bordeaux, 1995, p. 521 only

THE HIGH-FREQUENCY IN SITU MEASUREMENT OF COASTAL ZONE PROCESSES

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The understanding of coastal zone processes has been approached (by oceanographers, geologists and engineers) on a variety of scales, both temporally and spatially. Hence, on the one hand, beach stability constitutes part of an overall sediment transport system incorporating: riverine inputs, sometimes ephemeral; the onshore-offshore transport of material; and the loss of sediment through submarine canyons, intercepting the adjacent continental shelf or shoreline. At the same time, there is a need to understand the response of beach profiles to extreme events such as short-term effects. Such process-response mechanism, on the basis of scale extrapolation, control the evolution and development of the associated coastal morphology.

Sediment transport mechanism, at various scales, have been investigated using a variety of techniques including field measurements and (1D, 2D and 3D) numerical modelling. In some cases, conventional instrumentation and modelling has been used; in others, specifically-designed experimentation or "instrumentation has been utilised.

Against a background of the development of regional course-grain (conceptual) sediment transport model for a section of the coastline and inner continental shelf of southern England, a bottom-mounted tripod system (TOSCA) has been developed. The system was designed to examine the movement of shingle, under combined wave and current activity, in water depths of up to 20 m. Hydrodynamic conditions were monitored using electromagnetic meters (currents) and pressure sensors (waves). Movements of the sediment particles was detected using SGN self-generated noise), caused by inter-particle collision. For comparison, regional patterns of movement were identified on the basis of:

- sea bed sampling;
- geophysical (side-scan sonar) surveying; and
- the numerical modelling of hydrodynamic conditions.

A high-frequency monitoring system, similar to TOSCA, has been used on adjacent sandy beaches. The resuspension of sand has been related here to the presence of "wave groups" and, in comparable laboratory studies, to pore pressure fluctuations.

Following the description of integrated fieldwork, modelling and laboratory programmes, designed to understand processes and parametise the boundary conditions for models, consideration will be given to:

(i) the utilisation of site-specific measurements to large-scale sections of the coastline;
and
(ii) extrapolation of short-term measurements of extreme events to long-term coastal evolution.

The scientific objectives described affect utilisation of the coastal zone with particular reference to the artificial replenishment of beaches and dredging activities.

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IMPORTANCE OF FIELD MEASUREMENTS[1]

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Concern was expressed about the importance of field measurements. It is argued that in many cases models are not necessary; a good observation system will solve many problems. An example was presented from Australia, by looking into the Holocene evolution of an estuarine-coastal system.

[1] Additional presentation, see for detailed information Dr. Chappell's keynote address, given in Session II-b.

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COASTAL SAND TRANSPORT, EROSION AND DEPOSITION USING NATURAL RADIOACTIVITY IN HEAVY MINERALS

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KEY WORDS: sand transport, heavy minerals, shore erosion, longshore transport, barrier islands. Coastal Sand Transport, Erosion and Deposition

ABSTRACT

Research on the properties of naturally radiogenic heavy mineral sands has led to the development of techniques for using such particles as tools for monitoring coastal sand movement over both large and small scales. Additionally, heavy mineral radiometry has proven to be a quite useful indicator of regional sources of detrital sand to the coastal zone. Work on the North Sea coast of the Netherlands, Germany and Denmark, has found radiometric "fingerprinting" to be a reliable method for determining the source of sand to the modern coast. The method has been used to discriminate among sediment sources in the glaciated terranes of Scandinavia, the Elbe River watershed and the Rhine River system. The effects of tidal inlets and prevailing longshore currents on sand movement are also evident in the results. An additional aspect of radiometric analyses of coastal sands is the ability to estimate the relative percentage of heavy minerals in a sand body.

INTRODUCTION

Heavy minerals are detrital particles with high specific gravity greater than that of quartz. They are commonly found in trace amounts in most beach and nearshore sediments. At certain locations and under certain hydrodynamic conditions heavy minerals may constitute a significant proportion of the sandy deposits of the coastal zone.

Besides being denser than common quartz sand, some heavy minerals incorporate small amounts of natural radioelements, uranium, thorium and potassium, in their crystal structure. Their higher density and radiogenic properties enable us to exploit heavy minerals for monitoring coastal erosion, deposition and sand transport. Moreover, because radioactivity is a function of mineralogy and mineralogy is a product of source area, the radioactive signature of a coastal heavy mineral deposit is a potential indicator of the provenance, or source, of the coastal sand.

The procedure by which such particles are utilized for monitoring sand transport in the coastal zone begins with density separation. Minerals are gravimetrically split into two or more density groups. Additional separations may also be made, based on differences in magnetic susceptibility. Mineral sub-groups are then analyzed by high-resolution gamma spectrometry to quantify the radioelement concentration for each group. These concentrations provide a "signature" for sands from different sources.

Our work with radiogenic heavy minerals over the past decade has led to the development of such minerals as tools for monitoring coastal sand movement over both large and small scales. Moreover, heavy mineral radiometry has proven to be a quite useful indicator of sand provenance on a regional scale. Our recent work in the coastal zone of the North Sea has in addition suggested a potential benefit in utilizing radiogenic heavy minerals in beach renourishment projects and offshore mineral exploration.

Investigations on the North Sea coast of the Netherlands, Germany and Denmark, has found radiometric fingerprinting to be a reliable method

for determining the source of sand to the modern coast. The method has been used to discriminate among sediment sources in the glaciated terranes of Scandinavia, the Elbe River watershed, and the Rhine River system. The effects of tidal inlets and prevailing longshore currents on sand movement are also evident in the results.

Another practical aspect of radiometric analyses of coastal sands is the ability to estimate the relative percentage of heavy minerals in a sand body. Coastal and nearshore sand deposits of recent and earlier geologic epochs have been utilized in many parts of the world as sources of economic heavy minerals. Such minerals include ilmenite ($FeTiO_3$), rutile (TiO_2), and zircon ($ZrSiO_4$). By rapidly detecting the presence and approximate concentration of economic heavy minerals in nearshore sand deposits, the radiometric fingerprinting method suggests the possibility of a dual use for nearshore sand deposits. When dredged and pumped onshore, such deposits could be used both for beach renourishment to build up the profile of an eroding coastline, and for recovery of valuable heavy mineral resources.

Radiometry of heavy mineral sands is an investigative tool that has proven to be quite useful in coastal research. The method continues to evolve. It has much potential for use in assessing and monitoring coastal sediments in transport, deposition and erosion. As such, it is a potentially valuable tool for resolving some of the management problems associated with the complex physical interactions that occur in the coastal zone.

AREA OF INVESTIGATION

The primary area in which we been developing the radiogenic tracer techniques is the North Sea coasts of the Netherlands, Germany and Denmark (Fig. 1). The geologic history of these coasts is a diverse one, with sandy sediments being derived from a variety of sources. Different source areas have been active at different times in response to glacial advances and retreats. As a result, it is a complex problem to determine the source area of the deposits of the modern coast.

The geologic development of these coasts is a history of glacial and periglacial processes. The most recent glaciers, of Weichsellian age, moved from the north across the present west coast of Denmark, covering earlier Saalian glacial materials with till and outwash almost to the German border. Weichsellian glacial sediments occur extensively along the present-day Danish coast. South of the Weichsellian outwash plain, the coastal sediments of northwest Germany are composed of older Saalian-age deposits, which were transported from the Baltic region (Ehlers, 1988).

The Frisian Islands are also the product of late Quaternary glacial advances. The Frisian island of Texel, for example is developed on a line of till deposits laid down by Saalian glaciers (Zagwijn, 1974). These glacial sands, eroded from the Baltic shield, include the heavy minerals garnet, epidote, hornblende, tourmaline, muscovite and saussurite, with traces of kyanite and staurolite (Weenstra and Winkelmolen, 1976; Eisma, 1968).

A different sand source, supplied the coastal sediments to the Netherlands coast south of Bergen. These sands were transported by the Rhine and Meuse Rivers during the Holocene. Their heavy mineral suite contains saussurite from the Swiss Alps and augite from the Eifel.

During the mid- to late Holocene the volume of sand supplied by the Rhine and Meuse to the south coast of the Netherlands was sufficient to allow seaward progradation of the coast at average rates of 2-3 m yr^{-1}. This situation persisted until about 2,000 yrs ago, when the Rhine mouth migrated southward. Since that time the southern Netherlands coast has been erosional. At present the Rhine supplies essentially no sand to the Dutch coastal zone (Roep, 1984).

At present, these shorelines are characterized as highly energetic, with large volumes of sand in transport, and heavy erosion in many places. Erosion has been accentuated by sea-level rise. Sea level rose rapidly following the Weichsellian glacial maximum about 20,000 years ago. The rate of sea level rise slowed about 5,000 years ago but continues up to the present (Jelgersma, 1979).

As an example of modern erosion rates, the island of Ameland (Fig. 1) has retreated 900 m since 1809 with a rate of 5 m yr^{-1}. Tidal currents carry much of the eroded sediment into and out of inlets between the islands. Large ebb deltas have formed off many inlet mouths, trapping coarser sediments (Veenstra and Winkelmolen, 1976). The combination of island retreat and tidal current transport fill the Wadden Sea at an estimated rate of 8-20 million tons of sediment per year (Wiersma and van Alphen, 1988).

On dynamic coasts such as those of the North Sea basin, where large amounts of sand are in transport, it is of great benefit to have the means to determine such factors as: the source area of the sands, the locations on the coast where sand is significantly eroding or collecting, and the mineralogic composition of the sand. Radiogenic analysis provides some insight into each of these factors.

RADIOACTIVE MINERAL TRACER INVESTIGATIONS

Erosion and Accretion Studies

The original driving force behind this research was the belief that naturally radioactive heavy minerals, which are relatively common in coastal sediments, ought to be an effective tracer for sand transport along the coast. Our initial experiments with radiogenic sand were designed to examine the hypothesis that changes in the profile of a beach (erosion or accretion) ought to be discernible as a change in the radioactive "signature" of the beach, as detected by field surveys with a gamma monitor.

A number of surveys and experiments were carried out on various coasts over a period of years, at gradually increasing scales. (de Meijer et al., 1987, 1989, 1991; Donoghue and Greenfield, 1991; Greenfield et al., 1989, 1991). It was found that, for beaches with typical proportions of heavy minerals in the sand, erosion and accretion of the beach profile results in measurable changes in the gross radioactivity of the beach, as determined from field gamma monitors.

In a simple case, deposition of a layer of low-activity quartz sand on top of a heavy mineral deposit results in a raising of the beach profile and a diminishment of the activity at the beach surface. Activity measurements, in this case, can provide a reasonable approximation of change in beach elevation. An example from the island of Texel, the Netherlands, is shown in Fig. 2.

More complex geometries, such as multiple episodes of heavy mineral deposition, result in more complex responses. But the observed correlation between the presence of heavy minerals and the level of radioactivity opened new avenues of investigation.

Radiometric "Fingerprinting"

The research has evolved along a number of discrete paths, all related to the original thesis. First, we have developed a radiometric "signature" method for discriminating among multiple sources of sediment to the coast. This has been accomplished by means of field surveys throughout the North Sea basin, the South Island of New Zealand, Australia, and parts of the coast of South Africa. These diverse geologic terraces have yielded consistent results. We have observed that the radiometry of coastal sediments is imprinted with a pattern that is imparted by the source area for those sediments (de Meijer et al, 1988; de Meijer et al, 1990; de Meijer and Donoghue, in press).

The method for characterizing sand by radiometric fingerprinting was demonstrated first for sand samples collected from beaches and dunes along the North Sea coast in the Netherlands (Fig. 4; De Meijer et al., 1990). In that project an initial sample from the island of Texel was separated into a heavy and light fraction by the heavy-liquid method. Subsequently for each fraction the specific activity was determined by means of gamma-ray spectroscopy. The result of this measurement was then used as a "calibration" for a radiometric method to determine the heavy-mineral mass percentage, α. For a given sample the radiometrically-determined value of α, α_{rad}, follows from a linear interpolation of the measured activity concentration, A, between values for the specific activity of the light and heavy-mineral fractions, A_L and A_H, respectively:

$$A = \alpha_{rad} A_H + (1 - \alpha_{rad}) A_L \quad (1)$$

Next, for a number of samples the mass fraction determined from heavy-liquid separation (α_{grav}) was compared with that determined radiometrically. If the activity concentration in the reference sample is representative for a certain region (sand province), then a plot of α_{rad} versus α_{grav} will yield a straight line with slope 1. The results for some Netherlands coastal samples are given in Fig. 3 (de Meijer et al., 1990). From the figure one notices that samples taken at the Dutch Frisian Islands (labelled "north") correspond very well with the expectation; for samples collected to the south, on the Dutch mainland coast (labelled "south"), the results indicate that $\alpha_{rad} \approx 0.5\ \alpha_{grav}$. The border between these two regions is a large tidal inlet, Marsdiep as shown in Fig. 4.

Further analysis confirmed that the two regions differ in provenance; the southern region corresponding to Rhine River deposits, and the northern one most likely sediments weathered from the Erz Mountains. The latter conclusion was based on fission track dating results on individual zircon grains. Fission-track ages of zircons from the northern province fall in the range 225 - 275 Ma, consistent with the age of emplacement of granitic rocks in the Erz mountains (Andriessen, 1988).

To investigate further the latter conclusion and to test whether the method is more widely applicable, a suite of sand samples was collected in 1990 from beaches and dunes of the Frisian Islands of the Netherlands and Germany (at that time FRG), from an island and peninsula near Sleswig-Holstein (Germany), from the coast of Jylland (West Denmark) and from the coast near Travemünde on the Baltic coast of Germany (see Fig. 4). No samples could be collected from the upper part of the Elbe River due to the fact that the river constituted the border between the Federal and Democratic Republics of Germany at the time of sampling. We briefly summarize here the radiometric analytical method and the results of that investigation (de Meijer and Donoghue, in press).

Sample collection and heavy-mineral analysis

Sand samples of approximately 2 kg were collected from surface exposures in the field area. In locations where there was the potential for reworking of glacial or fluvial deposits by atmospheric processes, samples were collected by trenching. In the laboratory the samples were washed in distilled water, allowed to settle and repeatedly decanted to remove any salts and mud. They were then oven-dried at 60 °C and sieved at -1 phi (2 mm diameter) to remove any gravel and shell fragments that might be present.

The samples were then weighed for heavy-mineral analysis, and split to approximately 50 g using a mechanical splitter. The splitting was done carefully so as to avoid sorting due to density and grain size differences. Subsamples were then placed in a separatory funnel filled with tetrabromoethane (sp. dens. 2.97) for heavy-mineral separation using standard methods (Carver, 1971). This method separates quartz, feldspars and calcite from accessory (heavy) minerals. After gravity settling both the light and heavy fractions were oven-dried and weighed to determine the percentage of total heavy minerals present.

Sample replicates were analyzed to assess the analytical uncertainty introduced by these methods. It was determined that, even with careful splitting and heavy liquid separation, the procedure introduces a potential uncertainty of approximately $\pm$ 25%. This uncertainty is included in the data presented here. In more recently collected samples we have eliminated sample splitting by separating the entire sample and have in addition determined the specific-activity concentration for both the heavy- and light-mineral fraction of each sample.

Radiometric analysis

After drying and weighing, sand samples were placed in a Marinelli beaker on a large-volume hyperpure Germanium detector. The detector and sample were surrounded by 10 cm of "old" lead to suppress cosmic and room background. The gamma radiation emitted by ^{40}K and nuclei belonging to the decay series of ^{232}Th, ^{235}U and ^{238}U gives rise to peaks in the spectra collected with the detector. From the content of these peaks the specific activities may be derived. In the decay of ^{238}U, ^{222}Rn occurs as an inert gas with an

appreciable half-life (3.8 days), and may escape from the sample. Because gamma-rays are mainly emitted by the radon progeny ^{214}Bi and ^{214}Po, ^{214}Bi instead of ^{238}U concentrations will be presented.
As shown previously (de Meijer et al., 1990) the specific activity of various mineral susceptibility groups may also be determined. De Meijer et al. (1990) present specific activities of groups of minerals separated primarily by a Frantz isodynamic separator. It should be stressed that only rarely are the susceptibility groups purely one mineral. If the specific activities of all mineral susceptibility groups are determined, the specific activity of nuclide j, A_j, in a sample is given by:

$$A_j = E\ \Sigma_i\ m_i A_{ij} \quad (2)$$

where m_i is the relative mass of susceptibility group i with specific activity A_{ij} for nuclide j (note that j = Bi, Th or K). It can be seen that equation (2) implicitly contains the relation:

$$\Sigma_i\ m_i = 1 \quad (3)$$

Of the four activities mentioned, the relative intensity of ^{235}U and ^{238}U are likely to be given by the isotopic abundance. Therefore, each analysis reveals three independent quantities: A_K, A_{Bi} and A_{Th}. If for all mineral groups the quantities A_{ij} (j = K, Bi or Th) were determined, from each measurement equation (2) may be formulated for each nuclide leading to three equations with the relative masses, m_i, as unknowns. Using equation (3), in principle the relative mass of four mass groups may be derived.
The four equations, then are:

$$\begin{aligned} &m_a A_a^{Bi} + m_b A_b^{Bi} + m_c A_c^{Bi} + m_d A_d^{Bi} = A_{tot}^{Bi} \\ &m_a A_a^{Th} + m_b A_b^{Th} + m_c A_c^{Th} + m_d A_d^{Th} = A_{tot}^{Th} \\ &m_a A_a^{K} + m_b A_b^{K} + m_c A_c^{K} + m_d A_d^{K} = A_{tot}^{K} \\ &m_a + m_b + m_c + m_d = 1 \qquad (4) \end{aligned}$$

In practice, however, the A_{ij} are not determined. Moreover A_K is mainly determined by the light minerals, as noted in a more limited study by Greenfield et al. (1989). So in the application of the technique one restricts oneself to a "reference" sample from which the specific activities of Bi and Th are determined for both the light- and heavy-mineral fraction. With these specific activities α_{rad} (Bi) and α_{rad} (Th) are calculated for the samples to be analyzed. Another possibility is to calculate α_{rad} (Bi) and use the activity concentration ratio, R, of Bi/Th, as a second quantity. In this investigation we have chosen the latter option.

"Fingerprinting" Results

Analytical results are listed in Table 1. For the specific activities of the reference samples we used the values 581 $\pm$ 10 and 595 $\pm$ 17 Bq kg^{-1} for Bi and Th in the heavy-mineral fraction, and 2.87 $\pm$ 0.10 and 3.15 $\pm$ 0.18 Bq kg^{-1} for Bi and Th in the light-mineral fraction, respectively. These values correspond to the values obtained for a reference sample from the Island of Texel (de Meijer et al., 1990).
The locations along the Dutch mainland coast have been indicated in Fig. 4 and Table 1 with letters A (Egmond) and B (Bergen), to indicate their difference from the other samples. They differ in the sense that they were collected from a freshly renourished beach. In both cases sand was pumped on shore from a location about 20 km west-northwest from the sampling site. The renourishment sand could be distinguished from the original beach sand by its pink colour.
From the values in the table one notices that both samples have the signature of the source area II, whereas from the work of De Meijer (1990) sand deposits of the Dutch main-land were identified as belonging to Region I. From the present finding we may conclude that the renourishment "contaminates" the beach with sand having provenance that differs from "natural" sand. This contamination could potentially be monitored over time to measure erosion and deposition processes.
From the table one notices that sand collected in the region from Ameland to Eiderstedt yields similar values for α_{rad} (Bi) and α_{grav} and has a Bi/Th activity ratio of about 1.1. Sand collected on Sylt (Fig. 4) on the North Sea side and at Travemünde at the Baltic Sea side of Germany is characterized by α_{rad} (Bi) $\approx$ 0.6 α_{grav} and Bi/Th $\approx$ 0.6. Moreover the K content of the sand seems to be somewhat lower than in the previous group. In the last group extending from Römö northwards α_{rad} (Bi) $\approx$ 0.5 α_{grav} and Bi/Th $\approx$ 1.1. For this group one notices a tendency of a northward decrease in activity ratio.

Utility of the Fingerprinting Process

In an earlier investigation (de Meijer et al., 1990) it was found that beach and dune sands along the Dutch coast may be divided into two source regions. Sand along the mainland coast (Region I) originates in the Rhine watershed. Sand on the Frisian Islands (Region II) originates most likely in the Erz Mountains. The Erz Mountain sand suite extends to Eiderstedt, Germany, north of the mouth of the river Elbe (Fig. 4).

North of Eiderstedt, the Island of Sylt has a radiometric fingerprint (Region III) that is also found in the beach sand of Travemünde along the Baltic Coast of Germany, about 150 km southeast of Sylt. To the north of Sylt a tidal inlet, Lyster Dyb, separates that island from the Danish island of Römö. Sand on Römö, on the Danish west coast of Jylland, has a radiometric fingerprint which differs from Region III in the Bi/Th activity ratio. This area is indicated as Region IV in Fig. 4. The borderline between Region III and IV corresponds with the known areal extent of glacial ice during the Weichsellian (Anonymous, 1988).

In view of this correspondence and the previously obtained results, we suggest the following provenance for the sediments in the investigated regions:

- Region III represents the older glacial sediments, originating from deposits laid down during the Saalian Ice age (about 150 ka BP), or perhaps to a mixture of Saalian and younger deposits. To the north these sands are covered with Weichsellian tills (> 20 ka) deposited in Region IV. The decreasing Bi/Th activity ratio moving northwards may indicate that the thickness of this layer decreases.
- South of Sylt the Saalian deposits are covered with sand originating in Middle Europe and transported to the present North Sea by rivers like the Elbe (Region II).
- From a few samples (inland near Amsterdam and on the North Sea coast near Bergen) evidence was found that, along part of the mainland coast of Holland (Region I), Rhine deposits overlie "Elbe" deposits.

Another observation is that the regions are separated by narrow tidal inlets: Marsdiep, between the Dutch mainland and Texel (Regions I and II) and Lyster Dyb, between Sylt and Römö (Regions III and IV). From these observations one may conclude that these inlets are apparently natural barriers for littoral transport of heavy minerals and have been so for a rather long period of time (several thousands of years). This is qualitatively understood in terms of a simplified sediment-transport model (Tanczos, unpublished data), as bottom velocities in the tidal channels exceed the threshold for eroding and transporting both light and heavy minerals. Littoral sand reaching the inlets will therefore be removed from the longshore system, to be transported out to sea or into the estuaries and will not be allowed to cross these channels.

Additional Studies

The radiometric fingerprinting studies led to a related finding is that the radiometric spectrum (obtained by high-resolution gamma counting) of the sediment of a particular area can be used to develop a reasonable estimate of the minerals present and their approximate quantities. This makes the technique a potentially useful exploration tool, because many of the minerals involved are of economic value.

Additionally, we have recently extended our on-shore investigations to the inner continental shelf. At the KVI a large scintillation gamma-ray detector in a waterproof casing has been developed. When towed along the sea floor, the detector can measure the natural gamma radiation being emitted from the near-bottom sediments, sensing minerals down to a sub-bottom depth of approximately 0.5 m.

Similarly, natural radioactivity of radiogenic minerals may be used to study density-related aspects of transport processes in laboratory conditions. In a recent investigation (de Meijer et al., submitted) some initial results of *in situ* and laboratory studies are presented.

Because the nearshore sea floor is simply a recently-drowned coastal area, the same techniques applicable to the coast should be useful on the inner-shelf. It has been found that sand enriched in heavy minerals can be detected by gamma surveying and analyzed with an approximately 10% accuracy for each nuclide. The

new prototype detector recently underwent successful testing in cooperation with the British Geological Survey. The investigation, in the North Sea off the Netherlands, proved the utility of the process and located a large area of seafloor that is enhanced in heavy minerals. Over the next several years the goal is to refine its capabilities for sedimentological research in the nearshore.

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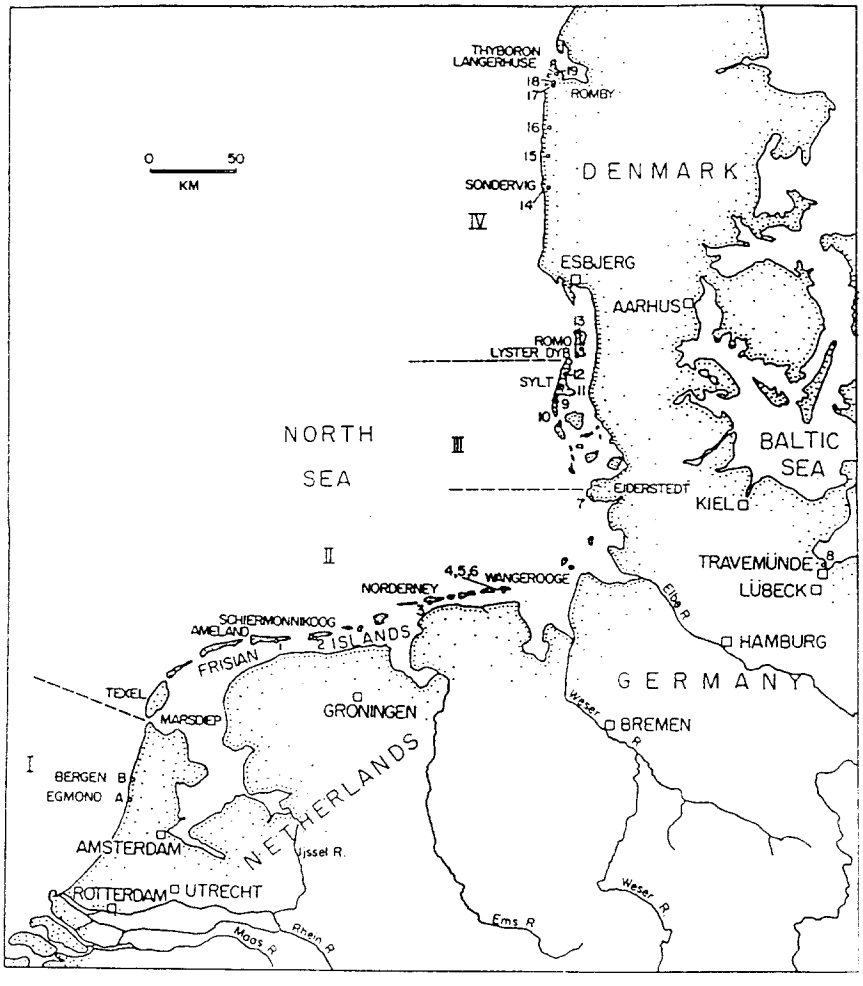


Fig. 1. North Sea coast of the Netherlands, Germany and Denmark.

Table 1. Activity concentrations of Bi, Th & K and heavy-mineral concentrations based on Bi activity concentrations, gravimetrically determined heavy-mineral concentration and the Bi/Th activity ratio. The samples are listed from south to north. Sample locations are shown in Fig. 1.

Sample	Location	Bi* (Bq/kg)	Th (Bq/kg)	K (Bq/kg)	α_{rad} (Bi) (%)	α_{grav}** (%)	Bi/Th (%)
A	Egmond***	5.5(0.1)	6.0(0.3)	271.4(1.6)	0.46(0.03)	0.3	91(5)
B	Bergen***	286(10)	369(15)	161(18)	52(6)	60	77(4)
1	Ameland	9.3(0.2)	9.4(0.5)	172.5(1.3)	1.11(0.05)	1.5	99(6)
2	Schiermonnikoog	5.0(0.2)	5.2(0.3)	212(6)	0.37(0.04)	0.5	97(6)
3	Norderney	93(2)	76(4)	120.5(1.2)	15.5(0.5)	17	122(7)
4	Wangerooge-W	46.3(1.6)	51.7(2.4)	137(6)	7.5(0.3)	7.5	90(5)
5	Wangerooge-C	6.2(0.2)	5.6(0.3)	221(2)	0.58(0.03)	0.13	111(6)
6	Wangerooge-E	210(5)	168(9)	55(4)	35.9(1.1)	48	125(7)
7	Eiderstedt	3.1(0.3)	3.0(2.0)	156.8(1.3)	<0.1	0.29	100(70)
8	Travemünde	175(4)	323(14)	159(11)	29.8(0.8)	47	54(3)
9	Sylt-S	32.7(0.8)	54(3)	76.7(0.6)	5.15(0.16)	8.7	60(3)
10	Sylt-S	168(3)	361(16)	81(13)	28.5(0.8)	42	46(2)
11	Sylt-C	7.8(0.2)	11.2(0.5)	146.9(1.1)	0.86(0.4)	1.1	70(4)
12	Sylt-N	77.3(2.0)	155(7)	58(6)	12.9(0.4)	25	50(3)
13	Römö	4.10(0.10)	3.01(0.10)	256.9(1.5)	0.13(0.11)	2	137(5)
14	Sondervig	37.6(0.8)	28.9(1.4)	87(4)	6.01(0.17)	15	130(7)
15	Torsminde	148(4)	123(7)	75(10)	25.1(0.8	51	120(8)
16	Tomby****	10.3(0.3)	11.5(0.6)	285.2(1.5)	1.28(0.05)	1.0	90(5)
17	Langerhuse	257(6)	244(11)	49(5)	43.9(1.3)	84	105(5)
18	langerhuse	183(3)	154(6)	50(6)	31.2(0.8)	51	119(5)
19	Thyborön	64.5(1.6)	66(3)	145(5)	10.7(0.3)	27	98(6)

Notes

* ^{214}Bi activity is given in lieu of ^{238}U as described in text.

** α_{grav}, the gravimetrically determined weight percentage of heavy minerals is obtained by means of heavy liquid separation. These values have a systematic uncertainty on the order of 25% due sample splitting and subsampling.

*** Beach renourishment sand. Sand was pumped from seafloor about 20 km west of sample location.

**** Romby sampling site is 30 km inland from Langerhuse.

Fig. 2. Correlation between change in beach elevation (upper left, in cm) and total gamma radioactivity (upper right, in counts/sec) over a one-month period on the island of Texel, the Netherlands (from de Meijer et al., 1991). Plot of the change in beach elevation (H) versus the log of the effective count rate (I) is shown at bottom.

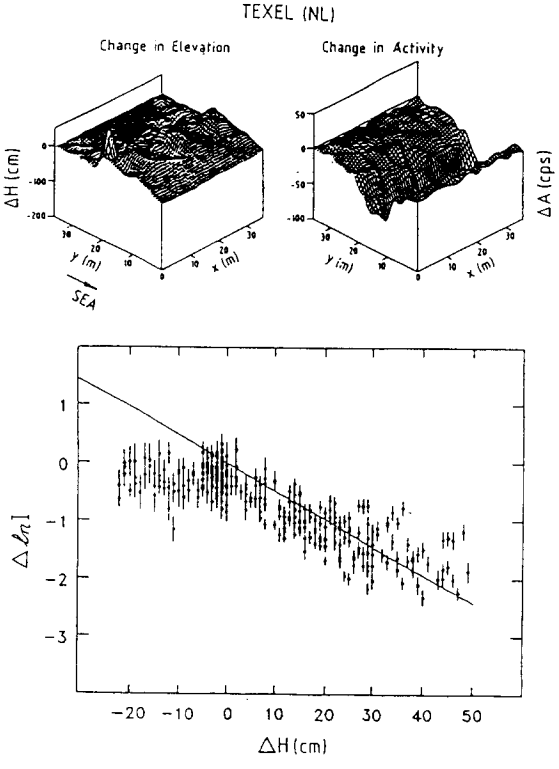


Fig. 3. Comparison of the values of the heavy-mineral mass fraction (percent) determined radiometrically (α_{rad}) and those determined by heavy-liquid separation (α_{grav}). The samples labelled "north" are from the Dutch Frisian Islands. The samples labelled "south" are from the Dutch mainland (de Meijer et al., 1990).

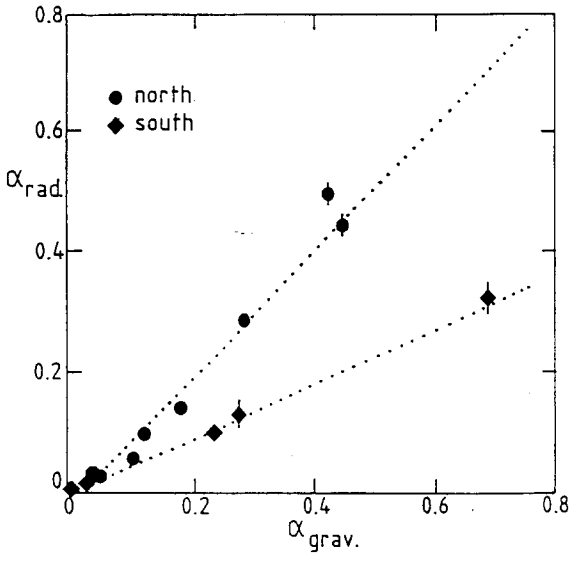
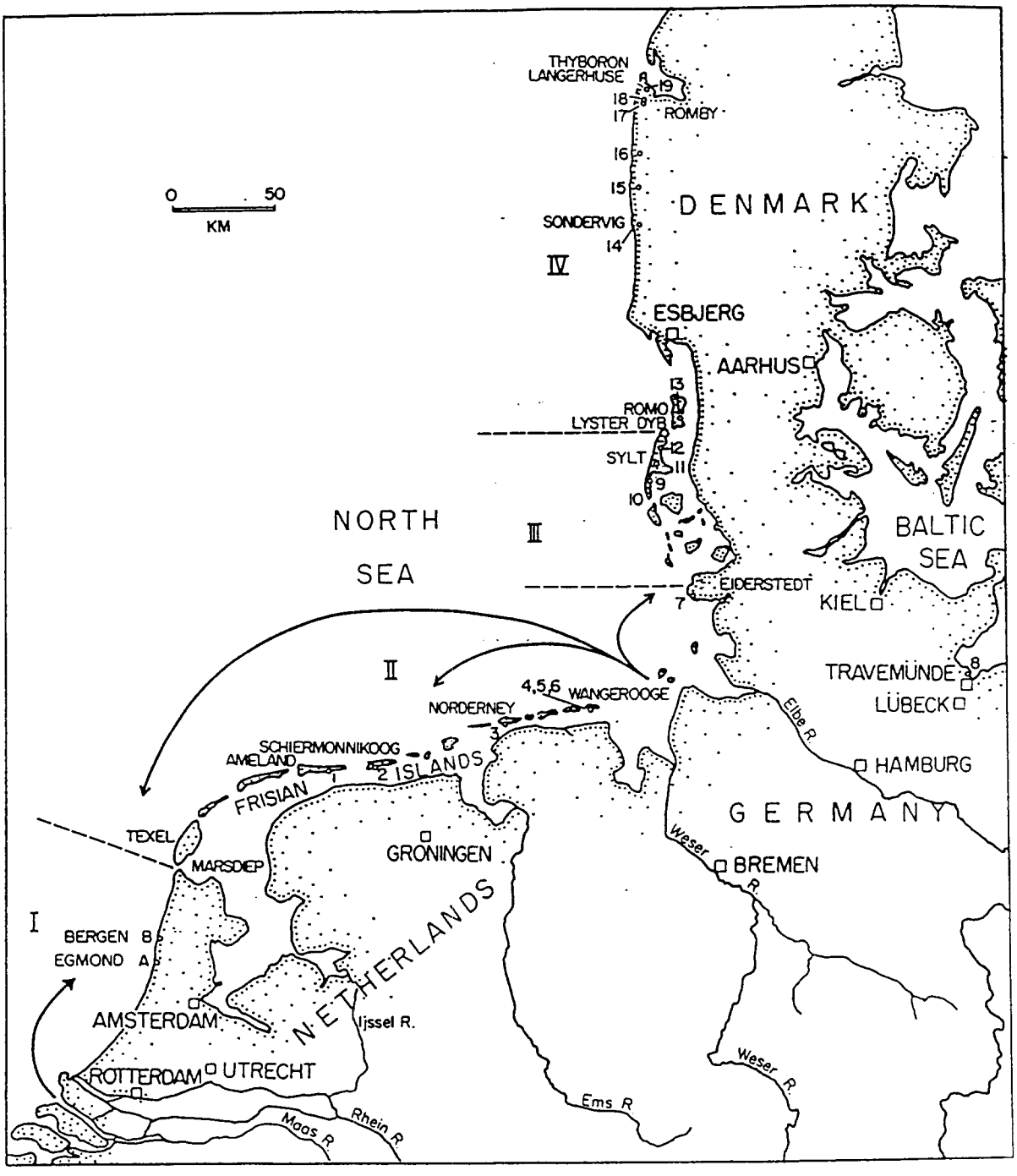


Fig. 4. North Sea coast, indicating schematically the four discrete suites (indicated by Roman numerals) of beach and dune sands identified by radiometric methods. The arrows suggest possible transport routes for Rhine and Erz Mountain sediments.



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AN EVALUATION OF THE IMPACTS AND DIRECT EFFECTS OF OFFSHORE DREDGING ACTIVITIES ON BENTHIC ORGANISMS

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KEYWORDS: Marine minerals, dredging, benthic organisms, repopulation

ABSTRACT
In April 1992, the Minerals Management Service's Office of International Activities and Marine Minerals initiated a field study to evaluate the extent of marine benthic organism repopulation in a dredged area. Through coordination with the U.S. Army Corps of Engineers, four dredge sites off the west coast of Florida, south of St. Petersburg, were selected for study. The study's instrumentation and sampling involved box coring, otter trawling, and using a towed sled carrying a video camera and a sidescan sonar device. The baseline collection phase of the study began in mid-July 1992, before the actual dredging of the sites. Subsequent post-dredging cruises occurred over a period of 22 months. Preliminary evaluation of the data indicates that repopulation occurred very quickly and that, apart from some dredge holes that are still evident in some areas, there appears to be little overall impact from the dredging operations.

STUDY BACKGROUND

The Minerals Management Service's (MMS) Office of International Activities and Marine Minerals (INTERMAR) is the office responsible for the coordination of potential marine mineral leasing and development activities on the United States Federal Outer Continental Shelf (OCS). Currently, INTERMAR is overseeing several generic and site-specific studies to obtain environmental information to support future mineral leasing decisions.

During the last several years, the main focus of offshore investigations has been on marine minerals most likely to be commercially developed in the near future. Sand resources in several areas of the OCS are being evaluated as a source of material for beach nourishment efforts and projects. Marine sand and gravel deposits may represent future sources of construction aggregate, and many are known to contain various amounts of industrially important minerals such as ilmenite and rutile. These resources are likely to be harvested using traditional offshore dredging techniques and vessels.

The immediate consequences of dredging for such minerals will likely involve some degree of destruction or disruption to the habitat of benthic invertebrates or other seabed organisms that lie within the path of the mining operation; sessile or slow-moving organisms may be especially susceptible to impact. This population is generally a source of food for many water column-dwelling species. Also at risk, due to operations that disrupt the seafloor sediments, are changes to the spawning grounds for fish or other marine species and long-term changes in the sea-bottom population due to major changes in the character of the bottom substrate or modifications in bottom sediment grain sizes.

A survey of the existing literature indicates that, of the studies intended to detail the environmental effects of offshore dredging and mining, a small percentage have focused on the seafloor impacts to the mining site itself. Existing studies have concentrated on the extent and character of sediment resuspension induced by the mining operation, the impacts of turbidity plumes induced by surface discharges from the mining vessel, and the influence of these materials on local pelagic fish populations or the benthic communities found in the areas adjacent to the area being dredged or

mined. Little information appears to exist regarding the degree to which direct contact with the mining operation or possible changes in seabottom substrates induced by a mining activity affects benthic communities and their ability to repopulate in the wake of a mining or dredging venture.

Beginning in fiscal year 1992, INTERMAR developed a statement of work and began a study to evaluate and gain insight into the long-term effects of seabed mining operations, specifically to determine the degree to which benthic organisms may repopulate the seabed or the bottom population may change after mining occurs in a coastal or shallow open-ocean area. The details of the project and a preliminary evaluation of the data are described in the following sections.

STUDY AREA AND LOGISTICAL DETAILS

Once funding was secured for the study, personnel from the U.S. Army Corps of Engineers' Dredging Research Group at the Waterways Experiment Station in Vicksburg, Mississippi surveyed their District offices to identify an area which would undergo dredging in fiscal year 1992. Several sites on the continental shelf area off the west coast of Florida, south of St. Petersburg, were subsequently selected for study since they were composed mainly of sandy substrate similar to conditions in OCS areas likely to undergo mining for sand and gravel resources. These sites were being used to renourish the adjacent beach areas. Fig. 1 shows the general location of the study area.

After establishing the study area, the MMS signed a cooperative agreement with the University of South Florida's Department of Marine Science in St. Petersburg to conduct the study. The Florida Institute of Oceanography provided overall program management, research vessels, and equipment; under a subcontract, Mote Marine (Mote Marine) Laboratory in Sarasota, Florida, to undertook the sorting, processing, and faunal identification of the benthic samples.

At an initial meeting in April 1992 of all involved groups, decisions were made to monitor three distinct dredge sites (Egmont Key, Sarasota Beach, Venice Beach/Manasota Key) instead of one, and to compare and note any variability in pre- and post-dredging conditions in the three areas. Water depths in all of the areas range from 7 to 10 m. Although dredging had already begun at the Egmont Key site, the area to be dredged was considered sufficiently large to allow for the collection of pre-dredging samples. Later in the project, a fourth area, Longboat Key, was added in order to assess possible differences in impacts due to differing dredging techniques. Dredging in the Longboat Key borrow site used a new type of dustpan dredge specifically modified and developed for beach restoration work; the other sites were dredged using clamshell and hopper dredges. Fig. 2 shows the location of all four study areas and their assigned study area numbers.

STUDY METHODOLOGY

Before field work began, maps obtained from the U. S. Army Corps of Engineers showing the exact location and extent of each sand borrow area were reviewed. Fig. 3 represents an example of the map for the Egmont Key area. The map coordinates, based on a State coordinate system, were converted into latitude and longitude using a computer conversion program. Two points within and one point outside each of the dredged areas were identified. The points within the dredged areas serve as the impact zones, while the points outside serve as control areas, one mile removed from the limits of the borrow area, but in a sediment environment similar to the dredge areas.

A baseline cruise to determine pre-dredging physical conditions and benthic populations at each of the sample sites at Study Areas 1, 2, and 3 was conducted in July 1992. Post-dredging cruises were held in January 1993, September 1993, and May 1994. Although dredging had already begun in Study Area 4, Longboat Key, Mote Marine had obtained some baseline benthic information prior to dredging. The first sampling was in October 1993. The main components of the sampling program are individually described below. The gear array layout for the surveys is shown in Fig. 4. Up to 12 nautical miles of high-resolution seismic reflection profiling, sidescan sonar data, and continuous video tape of

the bottom were collected simultaneously. Line spacing was adjusted in order to pass over actual dredged areas during the post-dredging surveys, which were conducted at a speed of 2 knots. During the post-dredging surveys, the profiler and sidescan information was used to identify with certainty the actual dredged areas. Precision depth recorder records were obtained using a system with a hull- mounted transducer.

Geophysical components

High-Resolution Seismic Reflection Profiling

Seismic reflection data were collected using an ORE Geopulse profiling system consisting of an ORE power supply, acoustic source, 20 element hydrophone array, receiver/filter/amplifier, and an EPC 1650 graphic recorder. The seismic profiles were recorded using a 62- ms sweep with band pass filters set for 700-3000 Hz settings, which were deemed optimal for the west Florida shelf based on prior experience. These profiles were run in each of the sampling areas before the benthic sampling events.

Sidescan Sonar Survey

Sidescan sonar records were obtained using an EG&G Sea Floor Mapping System with automatic slant correction. Sonographs were recorded with a horizontal range of 75 m on a side (150 m total swath).

Benthic community surveys

Video Camera System

A video camera mounted on a PHANTOM 500 Remotely Operated Vehicle was towed a few feet above the seabed and the output was recorded on VCR tape. Observations of bottom type and biology were logged in real time every 10 minutes, or as specific features or changes in bottom type or epibenthos were encountered. Onboard observations of epibenthos included the presence of dominant epifaunal species such as bottom fish, crabs, sponges, corals, and shellfish as well as major attached and rolling algae. A LORAN fix was taken at the time of each log entry. Upon return to the laboratory, the video tapes were reduced to a slower speed and any species encountered was verified with the results of the epibenthic trawl samples.

Box Coring Program

The three points at each of the dredge sites (two in the dredge area and one outside) were sampled by box corer. Each box core consists of a sediment plug measuring on the order of 21.3 cm x 30.5 cm in surface dimensions with a maximum penetration depth of 43.2 cm. Previous sampling in the study area had shown that nine cores at each station were required to obtain a statistically valid description of the benthic macroinfauna community at each sample site. A tenth core at each station was obtained as a backup.

As each box core was brought aboard the ship, it was subsampled; the subsamples were retained for later sediment size analysis. The top 15 cm in each of the box cores was sieved using a 0.5-mm sieve, placed in cloth bags, preserved and stained with rose bengal, and provided to Mote Marine for analysis. Due to some fragmentation of fauna during sieving on the baseline cruise, a float-off technique was used on subsequent cruises to separate the fauna from the sediment. About 330 box cores have been obtained from all of the cruises.

Otter Trawl

After each video camera/sidescan/seismic/box core survey, three 30-foot otter trawls were taken for epibenthic species verification. The location of each 20-minute trawl depended upon the onboard video camera observations. The individuals collected in each trawl sample were counted, and representative individuals were preserved and returned to the laboratory for analysis to the lowest possible taxon. The results of this analysis are being used with the video tape to describe the epibenthic assemblages observed during each survey of each site.

Laboratory analysis and data reduction

Geophysical Data

Sequence boundaries at each sample site were mapped from the high resolution seismic reflection data. Isopach maps of the sequences present, including the sand body to be mined, are present-

ly being constructed for each sampling period. The sidescan data were analyzed for topographic changes, bedform character, and sediment textural variation. Seismic and sidescan records were correlated with bathymetry and with the observations taken from the video data. Epibenthos was characterized for each site from the file records, and variations in all parameters due to dredging have been emphasized.

Sediment Analysis

The sediment samples have been analyzed for texture, carbonate content, and total organic carbon. Differences in grain sizes and overall texture due to dredging are being noted.

Benthic Infauna Community Analysis

After removal of the organisms from the sediment, rough sorting, and identification of the organisms to species, the following parameters were or are presently being measured:

- Species diversity,
- Species evenness,
- Species richness,
- Definition of community assemblages based on classification and ordination analysis procedures, such as cluster analysis,
- Association of assemblages with substratum variables by discriminate multivariate analysis,
- Analysis of distribution of fauna by species and numbers among majorfaunal groups. (The loss of a particular type of organism representing a particular functional morphology often indicates an alteration of the habitat structure.)

LOGISTICAL PROBLEMS

Several logistical problems were encountered during the conduct of this study. Dredge schedules and the decision as to whose beach gets renourished and when are often based on political circumstances and occurrences outside the realm and influence of the scientific community. Therefore, the established dredging schedule was often subject to change during the sampling period of this project. Study Area 1 - Egmont Key was dredged as expected; however, dredging and beach renourishment work relevant to Study Areas 2 and 3 was delayed until Summer 1994. The Longboat Key area in the meantime had been subsequently moved ahead in the schedule. As mentioned above, because Mote Marine had baseline information for the Longboat Key borrow area and a new kind of dredge expressly designed for beach restoration work was being used, Longboat Key was added to the project as Study Area 4. Sampling in Study Area 2 - Sarasota Beach was discontinued after the January 1993 cruise; sampling in Study Area 3 - Venice Beach was discontinued after the initial baseline cruise. These areas may be revisited after dredging commences, funds permitting. As a result of these logistical problems, the main area of study, at least in terms of benthic repopulation, is the Egmont Key site (Fig. 5). The available baseline information and the post-dredging data collected for the Longboat Key area are being used to the maximum extent possible for comparison purposes.

In addition, the funds and budget allotted for the project were not sufficient to allow for the placement of current meters or other instrumentation. Available current and sediment transport information is being used when possible to aid in data interpretation. Similarly, the MMS could not schedule enough cruises to allow for seasonal samplings and existing seasonal information is being used to the maximum extent possible.

PRELIMINARY CONCLUSIONS AND OBSERVATIONS

Physical parameters

Analysis of the sediment samples, sidescan, and seismic data has been completed for all four cruises. The sidescan and seismic data show no major changes attributable to dredging, and there are no significant changes in grain size, carbonate content, or mineralogy at any of the study sites. Both the control sites and the dredge sites at the study areas show a large degree of grain size variation, pre-and post-dredging. In addition, there appears to have been no influx of fines at any of the sites.

Over the full sampling period, there has been little overall change in bottom topography at any of the study areas. The precision depth recorder data at several of the dredge sites show dredge holes that have still not completely filled in, even

after the passage of a major storm. This is particularly true at Study Area 1 - Egmont Key where a clamshell dredge was used. At the ebb-tide shoal at Study Area 4 - Longboat Key, the Bean Dredging Corporation's Beachbuilder dredge was used. Bean has claimed that the Beachbuilder's dustpan design, combined with an advanced computer positioning system, allows the dredge to skim thin, precise layers of sand from the bottom, thereby avoiding the excavation of deep holes, as is evident at the other dredge sites. The data collected as a result of this project confirm this claim. The bottom at the Longboat Key site shows very little residual physical changes due to the dredging and there are no pits or holes evident. This type of dredging, therefore, should help to preserve the natural contours of areas to be dredged, thereby precluding any potential adverse long-term effects on the resident marine organisms and habitats.

Biological Parameters

All of the video transects have been reviewed. Basically, they show a bare sand bottom with an occasional worm tube and balls or mats of the alga *Laurentia*. No hard ground was observed. The benthic trawls confirmed the results of the video transects. A few crabs were collected, but the epibenthic communities for all sites and all cruises were comprised of fewer than 25 species. The infaunal analyses have been completed for the baseline and first two post-dredging cruises. Summary information from these analyses concerning the number of individual species identified thus far is presented in Table 1 and Fig. 6. Over 500 taxonomic groups have been identified, representing a far larger number of biological species than initially anticipated. The high diversity in these samples makes determining similarity between samples or effects of dredging difficult. Possible explanations for the high diversity are that this is a very dynamic environment and in this region there is a mix of estuarine and Gulf of Mexico species. These factors may allow for rapid recovery of the infaunal community after disturbance. At the Egmont Key area, there was some evidence of significant population decline at one of the sites within the dredging area for the first post-dredging sampling, but population decline was also evident at the control site, although not so pronounced (Fig. 6). In terms of species numbers and individuals, there is no immediate evidence of pronounced dredging impacts on the benthic epi- or infauna. Infauna analyses for the last post-dredging cruise is ongoing. Mote Marine will be examining the pre-dredging samples from near the Longboat Key site and comparing the data to the collected post-dredging data. Also ongoing is an analysis of species dominance to ascertain any differences in species type or the actual benthic community structure between pre- and post-dredging samples.

SUMMARY

The MMS has been examining the physical and biological effects of dredging within four study sites located on the continental shelf off the west coast of Florida. Of particular interest is the degree of benthic repopulation in the actual dredged areas. A baseline pre-dredging cruise and three post-dredging cruises have been conducted thus far. Preliminary observations of the collected physical data have shown no overall change in grain size, mineralogy, or bathymetry. However, precision depth recorder records indicate that traditional dredging methods (clamshell and possibly hopper dredges) may leave deep pits or holes in the seabed, which could result in benthic community or sediment changes in the long term. Newer, more innovative dredging techniques do not appear to create these types of features. The infaunal analyses are continuing, but there does not appear to be any significant changes to the benthic community, at least in terms of shear numbers of individuals. An examination of possible differences in species dominance and benthic community structure between pre- and post-dredging samples is ongoing. A final report for the study is due to be completed in August 1995.

Table 1. Summary statistics of benthic fauna for July 1992, January 1993, September 1993 and October 1993 samplings.

Date	Station	No. of Taxa	Number of Individuals	Individuals per m2	Shannon logE	Shannon log10	Shannon log2	Pielou	Margalef	Simpson	Gini
Jul-92	I1	101	1839	3144	3.16	1.37	4.56	.68	13.30	.081	.919
Jul-92	I2	51	679	1161	2.37	1.03	3.42	.60	7.67	.179	.821
Jul-92	I3	87	1539	2631	1.97	.86	2.84	.44	11.72	.409	.591
Jul-92	II1	94	597	1021	3.59	1.56	5.18	.79	14.55	.052	.948
Jul-92	II2	105	1548	2646	2.87	1.25	4.14	.62	14.16	.184	.816
Jul-92	II3	111	1105	1889	3.21	1.39	4.63	.68	15.70	.143	.857
Jul-92	III1	125	1349	2306	3.68	1.60	5.31	.76	17.21	.055	.945
Jul-92	III2	177	2468	4219	4.03	1.75	5.82	.78	22.53	.031	.969
Jul-92	III3	136	2693	4603	3.39	1.47	4.89	.69	17.09	.064	.936
Jan-93	I1	97	1624	2776	3.13	1.36	4.52	.68	12.99	.087	.913
Jan-93	I2	111	1180	2017	3.15	1.37	4.54	.67	15.55	.130	.870
Jan-93	I3	36	566	968	2.03	.88	2.93	.57	5.52	.286	.714
Jan-93	II1	169	1245	2128	4.47	1.94	6.45	.87	23.57	.017	.983
Jan-93	II2	115	1524	2605	3.58	1.55	5.16	.75	15.55	.055	.945
Jan-93	II3	134	1444	2468	4.00	1.74	5.77	.82	18.28	.030	.970
Sep-93	I1	126	3261	5574	3.15	1.37	4.55	.65	15.45	.083	.917
Sep-93	I2	151	1569	2682	3.64	1.58	5.25	.73	20.39	.066	.934
Sep-93	I3	67	466	797	3.09	1.34	4.46	.74	10.74	.085	.915
Oct-93	IV1	106	741	1267	3.83	1.66	5.53	.82	15.89	.037	.963
Oct-93	IV2	99	3784	6468	2.48	1.08	3.58	.54	11.90	.186	.814
Oct-93	IV3	109	1228	2099	3.50	1.52	5.05	.75	15.18	.056	.944

I = Egmont Key, II = Sarasota Beach, III = Venice Beach/Manasota Key, IV = Longboat Key.
Site number 1 at each study area represents the control site.

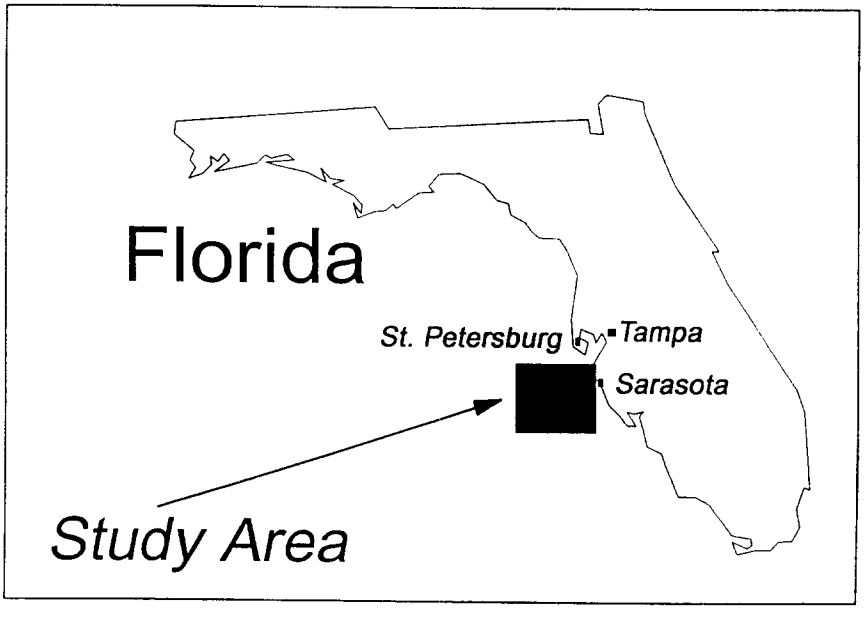
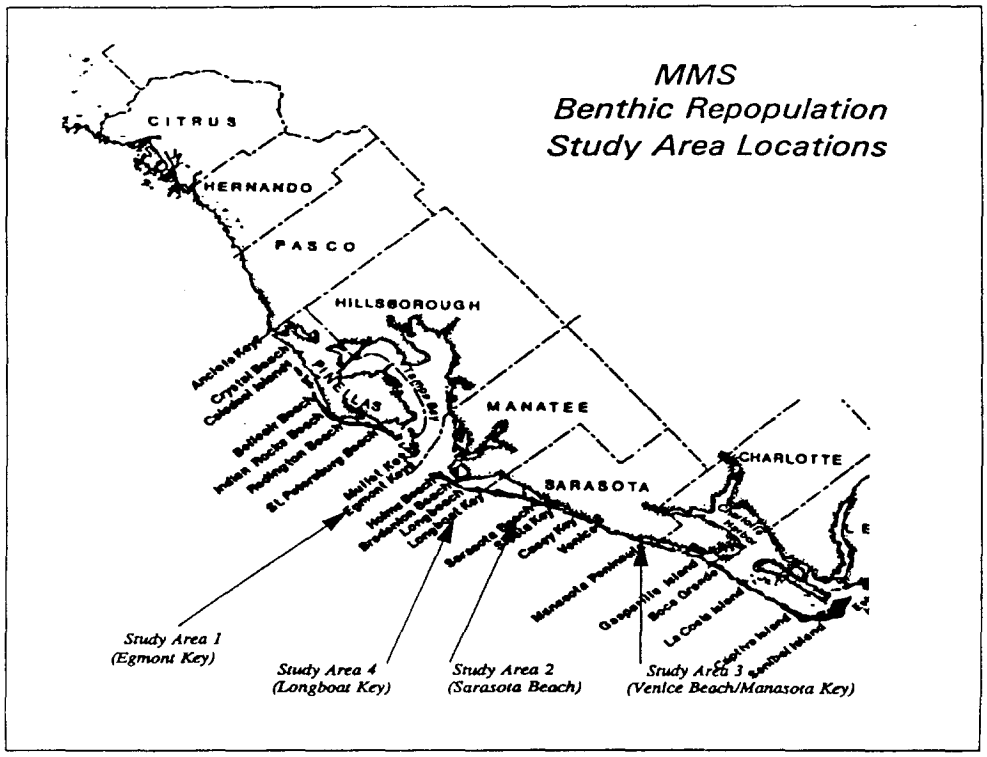


Fig. 1. General location of MMS benthic repopulation study.

Fig. 2. Four benthic repopulation study area locations.



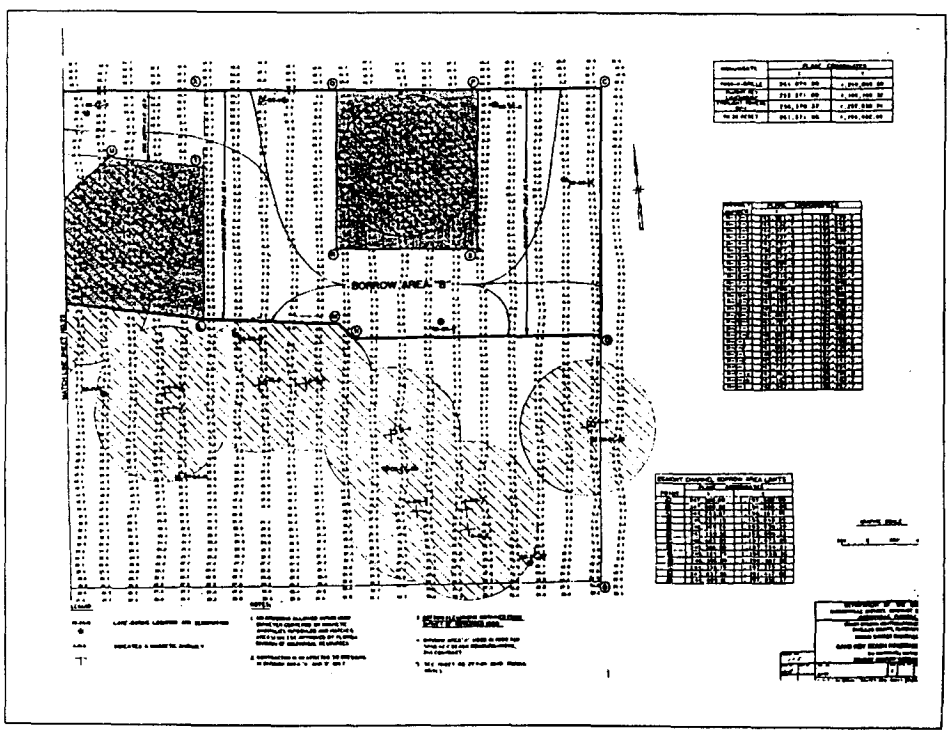


Fig. 3. Map obtained from US Army Corps of Engineers, showing extent of Egmont Key sand borrow area.

Fig. 4. A: Towing configuration for geophysical and video surveys. B: ROV towing system.

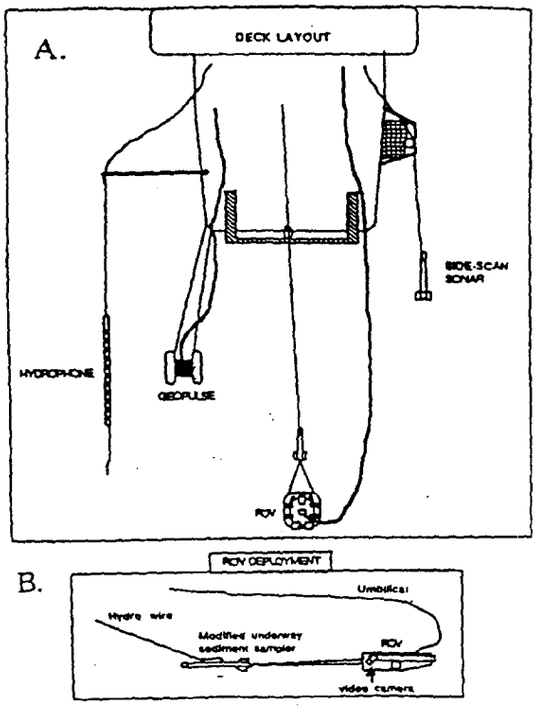
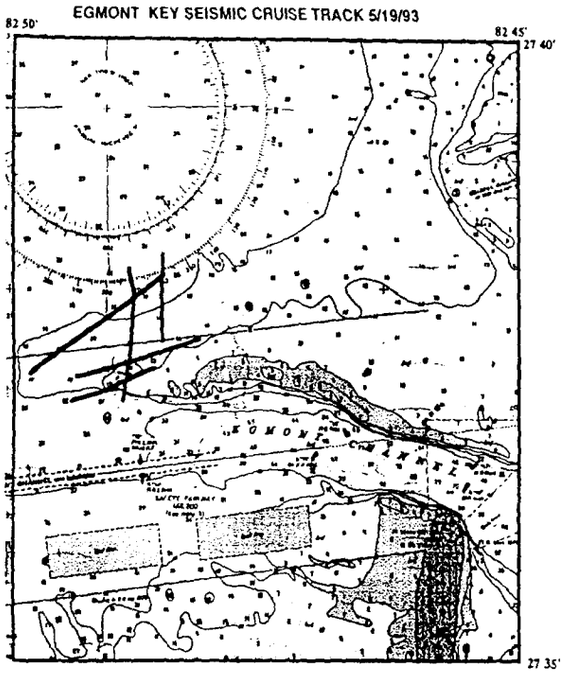


Fig. 5. Detailed location map of study area 1-Egmont Key. Map shows seismic cruise tracks for May 1993 post-dredging cruise



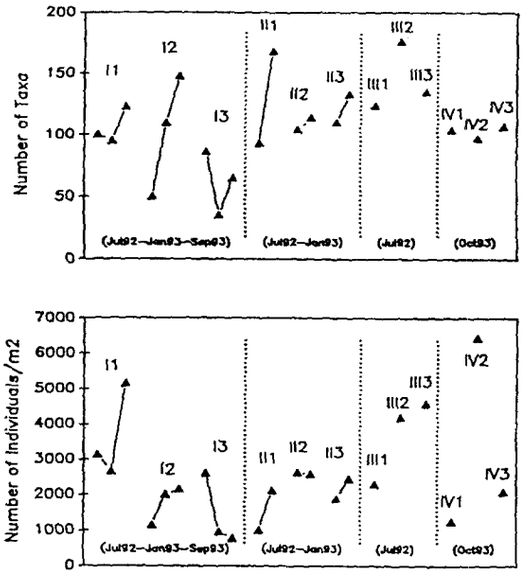


Fig. 6. Number of taxa (top) and number of individuals (bottom) collected from four area locations. I = Egmont Key; II = Sarasota Beach; III = Venice Beach/Manasota Key; IV = Longboat Key. (Note: Site number 1 at each of the study areas represents the control site.)

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STABILITY OF NATURAL SYSTEMS AS A CRITERION IN COASTAL MANAGEMENT

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KEY WORDS: Coastal management, physical criterion, English coasts

ABSTRACT

"Design with nature" is one of the principles in coastal management practice. We suggest here that the stability of natural systems can be used as a criterion in implementing the physical aspects of such a principle. The criterion implies two requirements: (1) for any characteristics associated with equilibrium, human activities should not damage the mechanisms which maintain the equilibrium state; and (2) for the characteristics which change constantly within the coastal system, the rate of changes introduced by artificial activities, in addition to the natural changes, should be of the same order of magnitude as the original, long-term natural rate of evolution. Two examples are described, to demonstrate how these criteria are used. For a quay reconstruction scheme, associated with a tidal inlet system, an analysis shows that the planned changes will not disturb the equilibrium state and the magnitude of the changes will be much smaller than that introduced by natural processes. For the dredging of sandbanks within an estuarine system, a maximum feasible output for sand extraction on the sandbanks is defined. Thus, intended aggregate outputs should be considered against such limits.

INTRODUCTION

Coastal areas are characterised by intensive human activities (eg. sea transport, coast erosion control, manufacturing industries, power stations, recreational activities, and seabed mining). Such activities exsert heavy pressure on the natural environment. In order to avoid damage to the environment, therefore, any developments in coastal areas should be planned carefully, taking various factors into account. For example, some sections of the coastal zone may not be suitable for development, because of their ecological importance.

For any coastal area considered for economic development, the problem remains with regard to environmental quality. Human activities over the coastal areas are so diversified that conflicts among these activities are inevitable. From past experiences, it has been realised that modifications to the coastal zone should be introduced with caution, to reduce the risk of economical losses and negative influences on the environment. Thus, it has been proposed that any coastal engineering work should be undertaken on the basis of a sufficient understanding of the physical processes and within the bounds of acceptable coastal impact (CERC, 1984).

"Optimisation" is important in coastal engineering practices, but this principle is insufficient, since an optimised design always exists even if the environment is already damaged significantly. From an environmental point of view, "the bounds of acceptable coastal impact" implies another principle that man must design with, rather than against, nature (Coats, 1976). To implement such a principle in coastal management, some specific criteria are needed. The purpose of the present study is to use the stability of natural coastal systems as a criterion for the physical aspects of the "design with nature" principle.

STABILITY AS A PHYSICAL CRITERION

Any human activities in the coastal environment interfere inevitably with the prevailing natural processes. Hence, as far as the physical aspects of human activities within the coastal areas are concerned, the principle of "design with nature" does not imply that the coastal system cannot be

modified artificially. Rather, it means that the rates of evolution of the coastal regions remain and the system behaviour be retained, even if some physical changes are introduced by human activities.

The behaviour of any coastal system is controlled by a number of natural factors, causing a number of mechanisms (including various positive and negative feedbacks) within the system. As a result, in terms of the physical environment, some physical characteristics of a coastal system may approach a state of dynamic equilibrium, whereas the other undergo continuous evolution. In order to protect the physical environment, these different behaviours must be taken into account. For the implementation of the "design with nature" principle, therefore, the stability which reflects the system behaviour under natural conditions could be used as a criterion. According to this criterion, the physical environment will not be damaged as long as the natural stability is not changed significantly. It implies two specific requirements. First, for the physical characteristics associated with dynamic equilibrium, human activities should not interfere with the mechanisms which maintain the equilibrium state (although the equilibrium point may be modified slightly). Second, for the characteristics which change constantly within the system, the rate of changes introduced by artificial activities, in addition to the natural changes, should be of the same order of magnitude as the original, long-term natural rate of evolution. In this manner, any modification to the natural environment will be reduced to an acceptable level. For example, changes in the area intertidal flats occur naturally, but birds living on them have had to cope with such changes. Likewise, if such changes are introduced artificially (eg. reclamation of saltmarshes for farming purposes) and they are not more rapid than the original natural changes, then the birds may be able to survive under the new conditions.

The criterion described above represents a *sufficient* condition for protecting the physical coastal environment. Under certain conditions, such a criterion can be used with some flexibility. For example, if the changes due to human activities has only a localised scale compared with the dimension of the natural environment, then they may not "damage" the environment (although at present this situation has become very rare). If some *sufficient* criteria in terms of chemical and biological changes and *necessary* criteria for all the aspects can be identified in the future, then some general criteria, which lie between the sufficient and necessary criteria, may be established to protect our coastal environments.

Two examples are provided below to demonstrate the application of the criterion outlined above. The first example is concerned with a proposed reconstruction scheme for a quay located within a tidal inlet system. The second example involves a plan to extract a large quantity of sand (used as building materials) from sandbanks formed within an estuarine system.

EXAMPLE 1: QUAY RECONSTRUCTION IN A TIDAL INLET

Christchurch Harbour (Fig. 1), southern England, which is a small tidal inlet system, has been used by local people as a fishing harbour. Using the northern side of the entrance to the tidal basin and a section of nearby shoreline, a quay was constructed previously. Since that time, the quay has been used for the mooring of fishing boats and recreational purposes. The eastern part of the quay is used as a car park. It is planned that the quay should be extended a further 2 m towards the sea, through the use of infill, in order to provide more space. The section for the proposed project is located to the seaward side of the harbour, close to the entrance (Fig. 2). Hence, the feasibility of undertaking such an engineering project needs to be examined.

Equilibrium of Tidal Inlets

Under any hydrodynamic and sediment dynamical conditions, a tidal inlet will evolve towards a state of a dynamic equilibrium in terms of the cross-sectional area at the entrance. The equilibrium state can be related to hydrodynamic and sediment dynamic conditions. On the basis of an analysis of the interrelationships between these factors, the cross-sectional area in equilibrium

(A_E) can be determined using the following equations (Gao and Collins, 1994):

$$T_f U_f A_E + T_f Q_F = P \quad (1)$$

$$T_e U_e A_E + T_e Q_F = - P \quad (2)$$

and

$$T_f B q_{sf} + T_e B q_{se} + T k q_l = 0 \quad (3)$$

where T_f is the flood tide duration, T_e is the ebb tide duration, U_f is the current speed averaged over the cross-section during the flood phases, U_e is the current speed during the ebb phases, Q_F is freshwater discharge, P is the mean tidal prism, B is the width of the entrance channel, q_{sf} is the sediment transport rate caused by the flood currents, q_{se} is the transport rate on the ebb, and kq_l is the rate of sediment supply into the channel by longshore currents (q_l being the longshore sediment flux and k a coefficient between 0 and 1). These parameters have been derived for Christchurch Harbour (Table 1).

Implications of the Results

Of the equilibrium parameters listed in Table 1, seven (i.e. B, U_e, U_f, q_{sf}, q_{se}, k and A_E) are dependent variables. Other parameters are independent variables, which are controlled by regional hydrodynamic and geological-geomorphological conditions.

The durations of the flood and ebb tidal phases are a result of the general tidal system of the English Channel. Thus, they cannot be modified to any extent by any highly localised morphological changes. Likewise, the freshwater discharge is determined by the regional climatic and drainage basin conditions, independent of the entrance morphology. The tidal prism is a function of the tidal range and the morphology of the tidal basin; a small change at the entrance will not result in, therefore, any observable modification to the tidal prism. Finally, the longshore sediment transport rate is determined by the wave climate, which is relatively stable on a regional basis.

In terms of the dependent variables, the entrance width has been stable for the past 20 years (Gao and Collins, 1994). However, the position of the tidal channel seaward of the entrance has shifted from time to time (Robinson, 1955). The energy used for the transport of sediment within the entrance and during flood and ebb phases is provided by the tidal prism and freshwater input. Under equilibrium conditions, the transport capacity reaches a maximum, to maintain the entrance open against siltation (from sediment supplied by longshore transport). These conditions associated with sediment movement within the entrance (i.e. B, U_e, U_f, q_{sf}, q_{se} and k) can be predicted. Hence, according to Equations (1), (2) and (3), the equilibrium cross-sectional area will also be maintained.

If the equilibrium conditions at the entrance are maintained, then the impact of the project on the inlet system will be localised. For example, shortly after the extension of the quay, some scouring may occur on the side opposite to the quay wall; this could cause a slight migration of the channel towards the sea, reducing the width (measured at low water on springs) of the ebb tidal delta by less than 5 m (because the seaward side of the delta has a slope of around 1/50-1/100 and the slope of the offshore seabed is of the order of 1/250). The magnitude of such migration is small compared with the natural changes in the position of the southern spit of the inlet system and the ebb tidal delta. Over the period between 1785 and 1938, there had been several cyclical changes, with the difference in the width of the intertidal part of the ebb tidal delta being of the order of 100 m over the period (Robinson, 1955). Hence, the second requirement of the criterion is satisfied for the scale of the proposed quay extension scheme. On the basis of the stability criterion, the project is considered as environmentally feasible.

EXAMPLE 2: DREDGING IN A SANDBANK AREA

Dredging of marine aggregates is an important industry, supplying a large percent of building material used in Britain (Fox, 1993). The Severn Estuary and Bristol Channel (Fig. 1) is one of the places where deposits of good quality have been found. For example, on the Charston and Dun Sands (Fig. 3), high quality sand aggregate resources exist; it has been proposed recently to increase the dredging output from the banks.

Environmental concerns arise, however, with regard to possible coastal erosion and the influence of dredging activity on sea birds. Therefore, an "acceptable" annual output of aggregates needs to be defined. For this purpose, an investigation into the impact of dredging activities on physical changes of the sandbanks has been undertaken.

Sediment Transport Patterns

Coarse-grained sediments in the Severn Estuary, which form the sandbanks, are derived from seabed and coastal erosion, input from the rivers, the reworking of the glacial tills, and input from the Celtic Sea.

On the basis of the evidence provided by bedform orientations (Kenyon and Stride, 1970), grain size trends (McLaren *et al.*, 1993) and sediment transport calculations (Keiller, 1987), the bed-load transport is directed to the bay-head area of the Severn Estuary. In quantitative terms, longitudinal variations in the potential overall transport of sediment have been investigated by Keiller (1987). The results (Fig. 4) show that the discharge is predominately eastward to the east of Minehead. According to this particular study, there is a landward net bed-load discharge of 6.0×10^6 t yr^{-1} across the boundary between the Bristol Channel and Severn Estuary (Fig. 1).

In response to such sediment discharge, large deposits have formed within the Severn Estuary. On the basis of the published data on sediment type, combined with information on thickness (Evans, 1982), it is estimated that around 320×10^6 m^3 of gravel, 2400×10^6 m^3 of sand and 550×10^6 m^3 of mud have been deposited within the estuarine system.

For the Charston and Dun Sands, the area measured above Chart Datum (-6.5 m O. D. Newlyn) are estimated to be 0.34 and 1.69 km^2, respectively, based upon a 1985 Admiralty Chart. The thickness of sediment on the Charston and Dun Sands has been estimated on the basis of information presented in published papers, historical charts, and vibrocorer surveys, the thickness of sediment is estimated to be 10 m. Hence, the Charston and Dun Sands have sand volumes of 3.4×10^6 m^3 and 17×10^6 m^3, respectively.

Historical Sandbank Changes

In order to evaluate the historical changes in sediment volumes and sand bank elevations, a number of charts and maps have been examined. The mean elevation (H_{mean}) of a sandbank has been estimated on the basis of:

$$H_{mean} = \sum_{i=1}^{N} \frac{H_i}{N} \quad (4)$$

where H_i is a depth value at a point and N is the total number of depth values within the sandbank area. It has been pointed out elsewhere that, in order to obtain representative H_{mean} values, the number of the depth values per km ("point density") should be sufficiently large (Bowyer, 1992). For the Charts used, the point density data listed in Table 1 range between 100 and 820 depth readings per km^2; such a magnitude of point density is adequate for a comparison between newer and older charts.

The volume of sand (V), stored in the bank above -6.5 m O.D. Newlyn, was determined then by:

$$V = H_{mean} A \quad (5)$$

where A is the area of the bank above -6.5 m O. D. Newlyn. The data obtained in this way are listed in Table 2. The mean elevation of the Charston Sands has increased between 1849 and 1926/27 (at an accretion rate of 3.0 cm yr^{-1}), but its area decreased during the same period (at a rate of 2.2×10^3 m^2yr^{-1}). Overall, the sand volume increased by 4.2×10^5 m^3 during this period (i.e. 5.5×10^3 m^3yr^{-1}). Between 1926/27 and 1957, however, both its mean elevation and area were

reduced; this resulted in an erosion rate of 0.7 cm yr^{-1} in terms of mean elevation, and 6.7×10^3 m^3yr^{-1} in terms of sand volume. From 1957 to 1962, accretion had taken place on the bank, with an accretion rate of 2.0 cm yr^{-1} in terms of mean elevation and 2.4×10^4 m^3 in terms of sand volume.

In general, both the mean elevation and area of the Dun Sands have reduced since 1849, although there was a slight increase in the sand bank area between 1926 and 1962. The erosion rate in terms of elevation was 0.3 cm yr^{-1}, between 1849 and 1926; it was 0.8 cm yr^{-1} between 1926 and 1962. Hence, the sand volume in the bank has decreased since 1849, at a rate of around 1.0×10^4 m^3yr^{-1}.

The above observations should be considered within the context of "regional" patterns of sand movement. For example, erosion has taken place over the Dun Sands, compared with an overall accretion in the Severn Estuary (due to sediment input from the inner Bristol Channel and the rivers). Such an erosion event should represent a localised process, rather than the evolutionary direction of the Estuary as a whole. These changes in the sandbanks represent "natural" processes of estuarine evolution.

Environmental Impact of the Dredging Activities

The sand banks belong to an evolutionary type. As described previously, if any trends are to be considered as not being "against nature", then human activities should not introduce any rates of change which are considerably greater than the rate of natural (sedimentary) evolution. Hence, rate of changes in area and volume of the sandbanks, introduced by sand extraction, should be compared with those associated with natural processes.

On a regional basis, the rate of sand extraction from the estuarine deposits over the region was approximately 2.0×10^6 t yr^{-1} (i.e. 1.0×10^6 m^3yr^{-1}) in the early 1980s (Parker and Kirby, 1982); this is smaller than the total amount of the annual sediment input to the Severn Estuary from the Inner Bristol Channel (i.e. 2.5×10^6 m^3) (Keiller, 1987). At present, therefore, the dredging has not caused any reverse in the evolution of the estuarine system as a whole.

On a localised basis, since alternating accretion and erosion has taken place historically, with an accretion/erosion rate of around 0.3 to 2.0 cm yr^{-1}, the amount for sand extraction should be less than 1.4×10^4 t yr^{-1} for the Charston Sands and 6.8×10^4 t yr^{-1} for the Dun Sands (these values are equivalent to an "erosion" rate of 2 cm yr^{-1}, without reducing the bank area). Furthermore, these maximum quantities should be understood as being valid within a generally accretional (rather than erosional) environment. Such limits imply relatively slow changes in the geomorphological and sedimentological features. Thus, the rate of the changes in the physical environment is of the same order of that observed in the natural environment. Any greater dredging output than the limits would change the physical environment too rapidly.

CONCLUSION

A criterion on the basis of the historical, long-term stability can be used for the implementation of the principle of "design with nature" in terms of physical characteristics. The criterion has two requirements: (i) for any characteristics associated with equilibrium, human activities should not damage the mechanisms which maintain the equilibrium state; and (ii) for the characteristics which change constantly within the coastal system, the rate of changes introduced by artificial activities, in addition to the natural changes, should be of the same order of magnitude as the original, long-term natural rate of evolution.

Two examples from England demonstrate the use of the stability criterion. For a quay reconstruction scheme, because the proposed engineering work is not likely to introduce any alterations to the equilibrium state, and/or to cause greater morphological changes than those occurring naturally over the past 200 years, it is concluded that such a project is environmentally feasible.

For an assessment of dredging activities over two sandbanks, the information on the rates of natural change, in combination with the patterns of sediment movement within the estuary and existing dredging quantities, enables a maximum feasible output for sand extraction on each of the sandbanks to be defined. Thus, any proposed

output exceeding such a limit may be considered unjustified.

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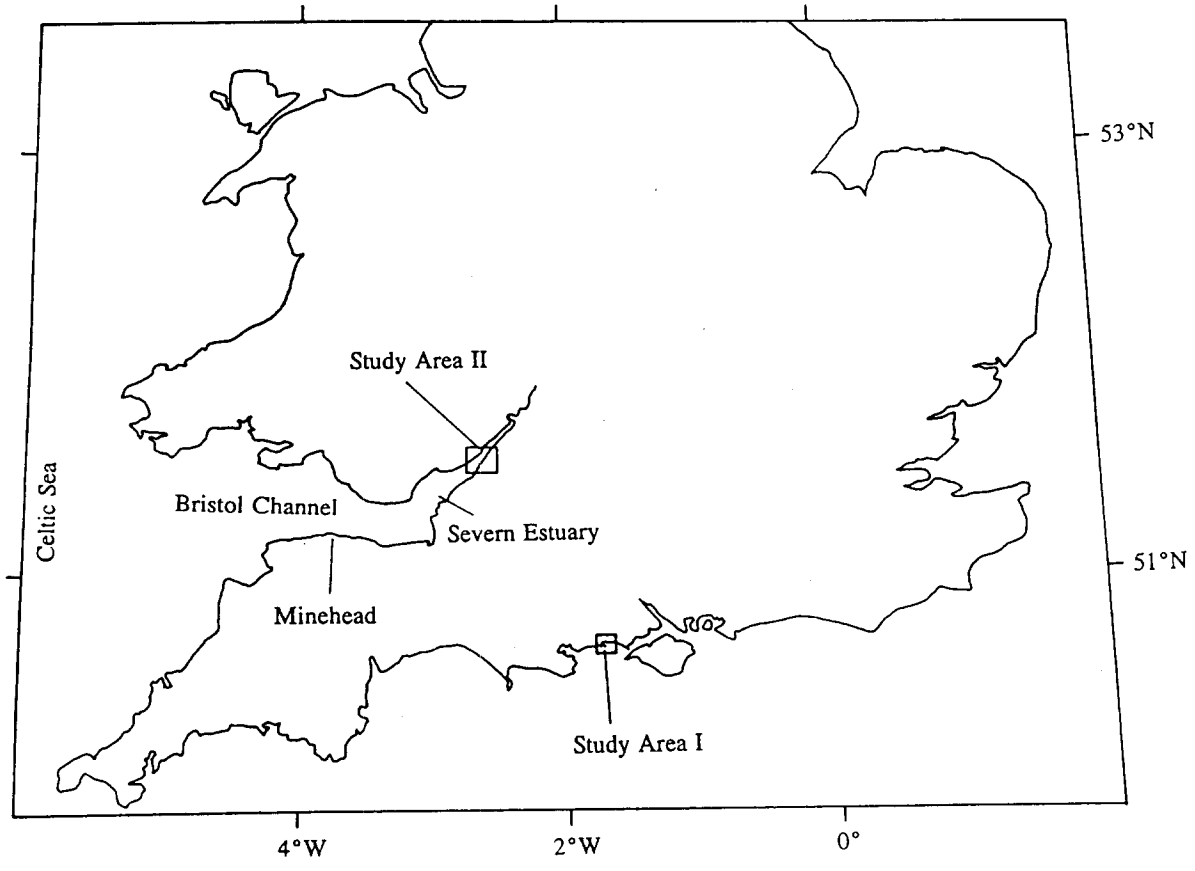
Table 1. Christchurch Harbour: the estimated parameters representative of equilibrium conditions.

Parameter	Quantity
B	47 m
P	1.06×10^{6} m^3
T_f	6.40 hr
T_e	6.01 hr
Q_F	26.9 m^3 s^{-1}
U_f	0.165 m s^{-1}
U_e	0.556 m s^{-1}
q_{ll}	5.3×10^{4} m^3yr^{-1} (Nicholls and Wright, 1991)
q_{sf}	0.92×10^{-6} ~ 1.18×10^{-6} $m^3m^{-1}s^{-1}$
q_{se}	16.4×10^{-6} ~ 41.7×10^{-6} $m^3m^{-1}s^{-1}$.
k	0.21 ~ 0.55
A_E	136 m^2

Table 2. Estimated elevation, area and sand volume (above -6.5 m O.D. Newlyn) data for the Charston and Dun Sands.

Location	Year	H_{max} (m O.D.)	H_{mean} (m O.D.)	A (km^2)	V_a (10^6 m^3)
Charston	1849	-1.8	-4.3	0.51	1.12
	1926/27	1.3	-2.1	0.35	1.54
	1957	0.9	-2.3	0.32	1.34
	1962	0.6	-2.2	0.34	1.46
Dun	1849	-1.7	-4.7	1.87	3.37
	1926/27	-2.3	-4.9	1.59	2.54
	1962	-2.5	-5.2	1.69	2.20

Fig. 1. Locations of Christchurch Harbour and the Severn Estuary, southern UK.



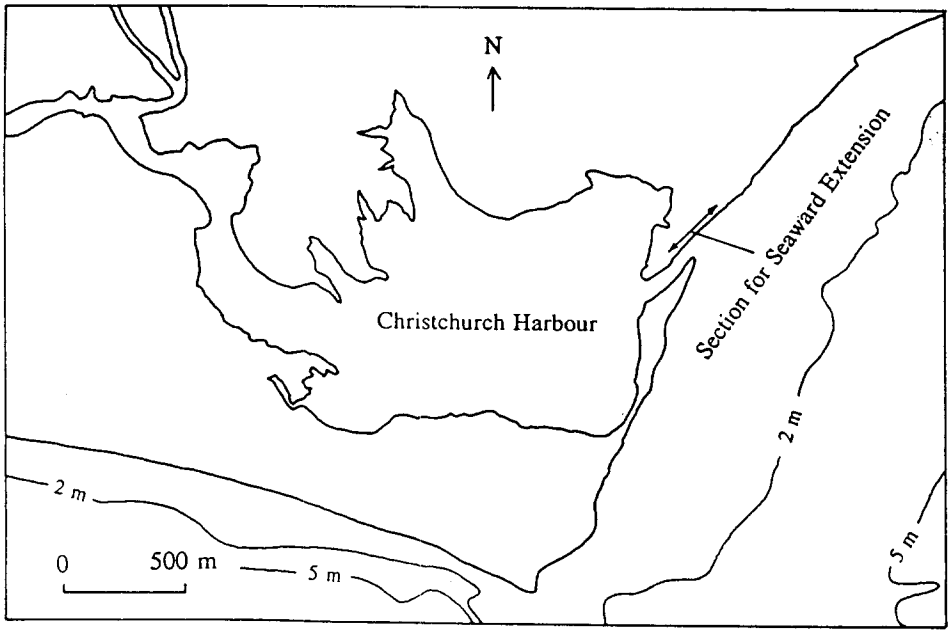
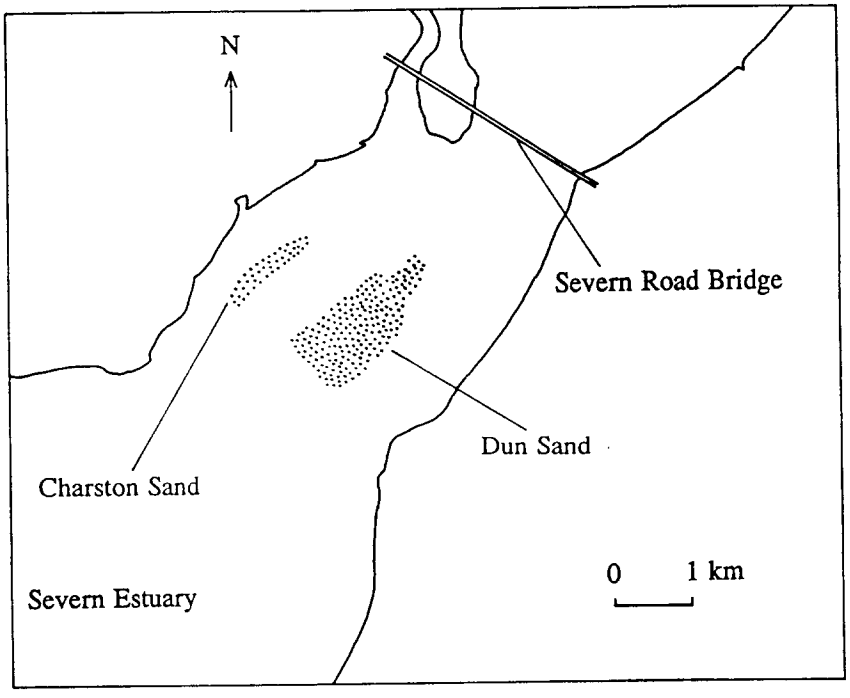


Fig. 2. Geomorphological and sedimentological features of the Christchurch Harbour area (Study Area I on Fig. 1).

Fig. 3. Location map of the Charston and Dun Sands, Severn Estuary (Study Area II on Fig. 1).



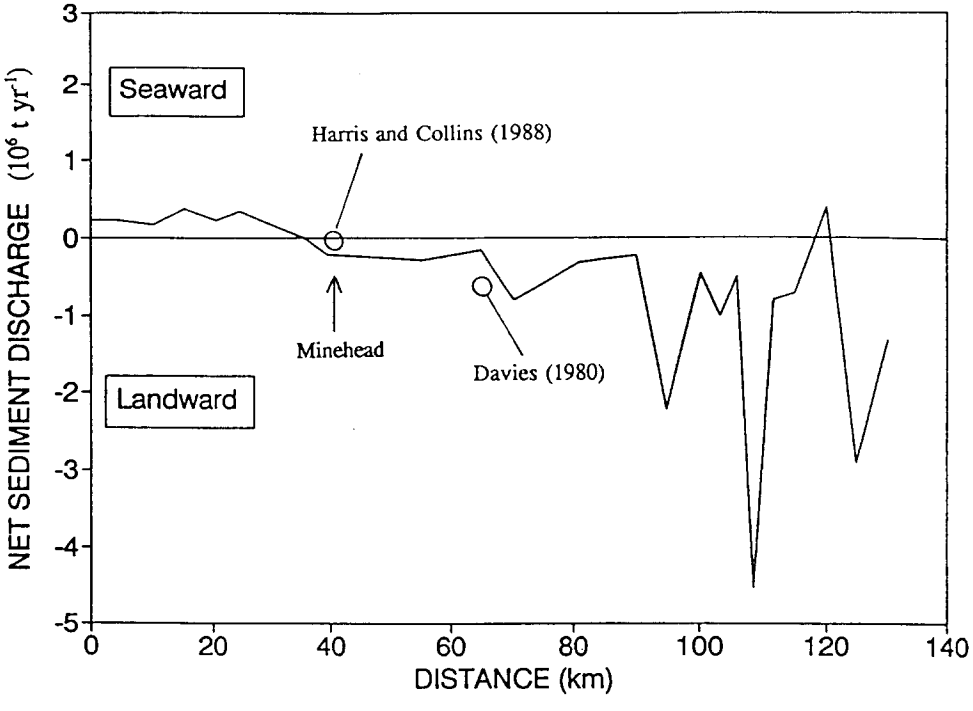


Fig. 4. Longitudinal variations of net potential sand discharge in the Bristol Channel (after Keiller 1987). Observed values for some locations, from Davies (1980) and Harris and Collins (1988), are also shown.

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RESPONSES TO COASTAL CHANGE IMPACTS ON WETLAND PROTECTION ON THE CALIFORNIA COAST

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KEY WORDS: Coastal impacts, Wetlands, Estuaries, Wetland restoration, Fish and wildlife habitat, Riparian habitat, Watershed planning, Dredged material, Pollution, Erosion, Sedimentation, Flooding, Water diversions, Land stewardship, Public access, Non-governmental organizations, Model projects, California, San Francisco Estuary.

ABSTRACT

This paper briefly describes several projects designed to address urban development, agriculture, tourism, and maritime impacts on California coast and San Francisco Estuary wetlands. These impacts are increasingly felt as population growth, harbour expansion, and human use of coastal natural resources continue. The issues concerned are typical of many wetland and estuarine situations in Europe and elsewhere. They include erosion, sedimentation, flooding, pollution, fresh water diversions, and impacts of public works construction, dredged material disposal and public access. The innovative project methods summarized are applicable outside California, suitably adapted. They are based on recent advances in scientific knowledge of wetland and estuarine ecosystems and hydrological functioning, which have enable much progress in wetland restoration.

INTRODUCTION

Coastal and bay wetlands,estuaries, and related fish and wildlife habitats are increasingly subject to physical impacts of urban development, intensive agriculture, shipping and harbour expansion, and tourism. These activities have economic implications numbering in the billions of dollars and hundreds of thousands of jobs. While the economic importance of coastal wetlands is only just beginning to be recognized as very substantial, prevailing attitudes among coastal policy-makers and decision-makers tend to devalue wetlands in favour of new development, cultivation, and direct human use, to the detriment of wetlands and their habitats.

Concurrent with this disturbing trend, however, has been the increase in scientific knowledge of wetland and estuarine ecosystems and hydrological functioning over the past decade or two. This growth in understanding has enabled significant progress to be made in testing and using improved methods of wetland and estuarine protection, restoration, and enhancement, even as efforts continue to expand our knowledge. This paper briefly describes several case examples of projects designed to address a variety of development, agriculture, and maritime impacts on California coast and San Francisco Estuary wetlands. The issues concerned are typical of many other wetland and estuarine situations in Europe and other locations. The innovative project approaches and methods summarized also have broad applicability outside California, suitably adapted, by virtue of their flexibility in design and application to a variety of physical, political, institutional, and socio-economic circumstances.

The projects concern: use of non-traditional engineering approaches to combat urban development-induced erosion, sedimentation, and flooding impacts on a coastal lagoon and its watershed in a three-city area of San Diego County on California's south coast; use of an innovative, bi-national approach to demonstrate a low cost method of sewage treatment and re-use to address pollution problems in the Tijuana River Estuary, generated by rapid urban growth in the Mexican border city of Tijuana; in southern Napa County on the San

Francisco Estuary, development of voluntary land stewardship methods among wine grape growers and cooperative watershed planning with government agencies to demonstrate economically and environmentally sound viticulture techniques, designed to prevent further impacts of pesticide runoff, soil erosion, and fresh water diversions on publicly owned tidal marsh waterfowl and riparian habitat, also home to an endangered species of freshwater shrimp; cooperation among multiple public agencies, local government, and a non-governmental organization (NGO) to resolve problems of potential road construction and flood control impacts on wetland restoration in a southern California coastal city; use of uncontaminated harbour dredged material to help restore tidal marsh in the San Francisco Estuary as an alternative to bay and ocean disposal, thereby enabling both a vitally needed shipping channel deepening project and a major wetland restoration effort to proceed; and design and management of public access as part of restoration and enhancement of urban wetlands in several northern and central coast cities to avoid disruption of waterfowl feeding and breeding activities.

These projects are being implemented by an unusual California government agency, the State Coastal Conservancy, in cooperation with other state and federal agencies, local government and other special districts, NGOs, private land owners, and community groups. They provide models for inter-governmental and public-private cooperation, use of new techniques and methods of technical assistance, and successful design of multi-purpose wetland projects that support fish and wildlife habitat protection while also responding to economic and social concerns.

PROJECT CASES

Flood Management in the Buena Vista Lagoon and Watershed

Buena Vista Creek, in southern California's San Diego County, drains a twenty square mile watershed into a 300 acre coastal freshwater lagoon The lagoon was created by damming the creek's original tidal outflow to the sea to enhance adjacent residents' scenic quality by providing an open water view. The watershed lies within the boundaries of three cities, Oceanside, Carlsbad, and the upstream community of Vista.

Extensive urban development of the watershed lands for housing and commercial building often involved major grading of hillsides above the creek. The creek was confined in a narrow concrete flood control channel and riprap along much of its length, and tributaries were run through underground pipes and drains. The results of this activity were acceleration of storm water flows, massive hillside and creek bank erosion, destruction of watershed habitat and scenic quality, and sedimentation of the downstream lagoon, which led eventually to a $1 million dredging of the degraded lagoon by the State Department of Fish and Game and the likelihood of future dredging.

In the 1980's, the State Coastal Conservancy, a multi-purpose, non-regulatory state government agency, then studied the lagoon and watershed as a single unit, using computer models to seek solutions to these problems. The project's goals were:

(1) control sedimentation of the lagoon by decreasing the volume and acceleration of storm water flows;

(2) prevent flooding in areas surrounding the lagoon and upstream in central Vista;

(3) restore and enhance riparian habitat; and

(4) provide an attractive visual amenity in the center of the City of Vista.

Two main conflicts surfaced early in the project. First, local opposition arose to using alternative methods of flood management in place of traditional "hard edged" concrete or riprap channels and piped storm drains, even though the engineering analyses showed that "soft edged" approaches could work. Second, Vista was initially uninterested in addressing the lagoon sedimentation, flooding, and amenity problems of the two downstream cities.

The Coastal Conservancy, with additional aid from the State Water Resources Control Board (a regulatory agency for water quality), funded preparation of the engineering studies and computer models of the watershed and a full enhancement plan. It also helped organize the three cities into a joint powers committee to cooperate in solving the several problems of the creek, its watershed, and the lagoon. Specifically, a long term, comprehensive

solution for the entire watershed was devised. Its principal elements were construction of storm water detention basins to reduce the volume and rate of storm water flows, and restoration of sections of the remaining natural creek as enhanced flood management channel with riparian vegetation and small drop structures to reduce flow velocities. Most of the improvements were built in the City of Vista, the source of most of the sedimentation and storm water flows, and were financed by the Coastal Conservancy.

Several important lessons were learned from the Buena Vista Creek Watershed project that has made it a model for many subsequent watershed projects. First, parties which initially are opposed to a solution can become solid supporters given adequate information and understanding about the benefits to their own interests. Second, this change of outlook can be facilitated by a combination of well-reasoned regulatory positions together with physically and economically feasible alternatives. Third, less conventional alternatives to traditional flood management measures can work effectively while also enhancing wetland and riparian habitat values, thereby achieving multiple objectives which often have been in conflict. Fourth, perseverance is necessary to overcome initial opposition or hesitation regarding new technical alternatives, and to cooperative approaches to comprehensive problem solving that addresses issues beyond an individual party's immediate interest. Finally, availability of funds for planning and implementation is a powerful incentive to elicit cooperation from initially unenthusiastic participants.

Low Cost Wastewater Reuse for the Tijuana River Valley: Ecoparque

The overall area of concern of this Coastal Conservancy project was the Tijuana River basin's watershed area of approximately 1,700 square miles, with 455 in the United States and 1,245 in Mexico. The Mexican City of Tijuana has a population of approximately 1.2 million, and has grown over the past two decades at an annual rate of over 5%. Within the lower reaches of the watershed lay the immediate project focus: the 2,531 acre Tijuana River National Estuarine Research Reserve, located within the United States. The actual site for the Ecoparque demonstration low cost wastewater treatment and reuse project was originally in the United States, and later shifted to a 23 acre parcel in the City of Tijuana.

The critical problem was wastewater pollution in the form of sewage from Tijuana's very rapid development flowing into the Estuary Research Reserve and out of the river mouth, causing damage to the estuarine habitat and health problems in the estuary and along nearby beaches. Cost estimates of a full scale bi-national treatment and disposal solution were around $729 million.

The Southwest Wetlands Interpretive Association (SWIA), a non-profit, non-governmental organization, initiated the project in 1984 with two main goals: overall, to protect the Tijuana River Estuary ecosystem; second, to demonstrate that wastewater should and can be seen as a bi-national resource and economic asset; and third, that beneficial reuse of treated wastewater can be the basis for an international perspective on watershed management that is essential to resolving this issue in the bi-cultural border zone.

Bi-national conflicts existed as to what technical solution to the main sewage treatment and disposal problem was most feasible and acceptable, and how to share costs. In addition, different groups and factions were critical of potential solutions with regard to their own interests, which included private land owners, gravel mining interests, equestrian interests, those concerned with border security, local government concerns with fiscal impacts, and various environmental groups.

With respect to the demonstration project itself, a change of leadership in the International Boundary and Water Commission (IBWC) resulted in the loss of the project's lease on its United States site after the project's first phase was successfully completed, and a lengthy delay ensued while a new site was located in Tijuana for the second phase.

With Coastal Conservancy funding (approximately $500,000) and technical assistance, SWIA got assistance to build and operate the project's first phase of primary treatment from consultants and El Colegio de la Frontera Norte (COLEF), a Mexican applied research institute. The second phase, built and operated in Mexico, was a collaboration of the

Coastal Conservancy, COLEF, and another NGO, the Environmental Defense Fund (EDF). This phase was funded mostly by the Conservancy and EDF, with additional Mexican assistance.

The project design concept was to use low cost, alternative technology that already existed and was simple in design and operation, to make available treated wastewater for several different uses rather than just to dispose of it in a sewer outfall. The principal initial reuse was for landscape irrigation to create new urban park area, which was sorely needed in Tijuana. Potential future uses included wetland creation and selected industrial and commercial uses.

First phase technology components consisted of a stainless steel screen to separate solids, and a plastic biological filter to which bacteria adhere to dissolve organic materials and reduce biological oxygen demand (BOD). The second phase, located on the 23 acre Tijuana site, consisted of the same two components plus a settling basin and a composting unit, and space for a wetland to be funded later. The project was named Ecoparque.

The Ecoparque demonstration project was a technical and organizational success in both phases, and continues to operate at its Tijuana location on a permanent basis. The project and its technology were never conceived as the total solution to the entire watershed's vast sewage treatment problem. Rather, they were designed:

(1) to illustrate a new approach to managing wastewater as an asset instead of a liability and thus contribute to an overall solution to the problem, and this was borne out in practice;

(2) to demonstrate a fiscally modest and physically flexible method of addressing the treatment and reuse issue that could be replicated extensively in Tijuana and elsewhere along the Mexican/United States border, and which in fact has adaptive potential in a variety of other situations around the world; and

(3) to show how bi-lateral (and, potentially, multi-lateral) cooperation is essential to solving complex economic and environmental problems that transcend political boundaries.

Agricultural Land Stewardship in the Huichica Creek Watershed

Huichica Creek drains a scenic 4,500 acre watershed in the Carneros region of southern Napa County, on the northern shore of the San Francisco Estuary. The creek empties into the state-owned Napa Marshes, the largest remaining wetland area on the San Pablo Bay/San Francisco Bay shoreline and one of the few remaining waterfowl nesting areas in the entire San Francisco Estuary region. The creek also provides instream habitat for the endangered California fresh water shrimp. Much of the watershed's rolling hills have been converted over the past two or three decades from grazing and dairy farms to vineyards, which provide grapes for the well-known Carneros pinot noir, chardonnay, and sparkling wines.

The project's demonstration site, which was acquired by the Napa County Resource Conservation District (a local public agency with a major interest in agriculture-related soil and water conservation) with funding from the Coastal Conservancy and the State Wildlife Conservation Board, is 84 acres, of which 21 consists of 16 acres of vineyard and five acres of wetland; the balance, all wetland, was incorporated into the state-owned Napa Marsh area.

Rapid conversion of grazing land to vineyards, land preparation for which is very capital-intensive, has resulted in hillside soil erosion, fresh water diversions from the creek, and high levels of pesticide use, with consequent negative impacts on riparian and wetland wildlife and habitats. These impacts affect both private lands and state-owned wetlands, which represent a significant public investment.

The Resource Conservation District's overall goal was to develop and nurture voluntary land stewardship as a different approach to land management -- an ethic, not a program, based on cooperative use of assets and interests of land owners, public agencies, and other interested parties. With the Coastal Conservancy's broad emphasis on the watershed and marshes, the District's initial focus on chemical-based water quality problems was broadened to a more comprehensive approach.

Specifically, the effort aimed to:
(1) Develop and extend voluntary land stewardship by local land owners;
(2) Eliminate negative impacts on creek, watershed, and downstream marsh fish and wildlife habitat (including one endangered species of fresh water shrimp) of pesticide runoff, soil erosion, and excessive fresh water diversions caused by viticulture; and
(3) Develop alternative methods that will enable accomplishment of goal 2 in an economically viable manner and thus to shift viticulture to an ecologically sound and economically sustainable basis.
Conventional viticulture methods and their negative environmental impacts were at odds with state and federal environmental regulations. Additionally, many land owners and growers were distrustful of and opposed to governmental requirements, procedures and environmental aims. Faced with this initial anxiety and opposition, the District undertook to build a solid base of voluntary participation by the land owners. This process, which took over two years, required the District to bring together land owners, growers, and other concerned parties including university extension, federal, state, and local government agency staff, environmental interests and NGOs into a stewardship group The District then worked with the land owners and growers to obtain voluntary support for, and participation in, preparing a watershed plan, financed by the Coastal Conservancy as part of the stewardship effort, that included identification of a set of specific demonstrations and field experiments to address the negative impacts of viticulture practices. These actions were to be implemented on (a) a demonstration vineyard site owned by the District and purchased with Coastal Conservancy funds, and
(b) on private lands voluntarily by the land owners.
Lastly, the stewardship group devised a detailed monitoring program to assess the environmental effectiveness and economic viability of the new viticulture methods.
The demonstrations and experiments are focused on three specific problems: pesticide runoff, soil erosion, and fresh water diversions. Alternative methods include new techniques for land preparation and vine cultivation, planting of vegetation which supports natural insect predators and will also test the effectiveness of vegetative diversity and cover crops on insect pest control, and more water-conserving irrigation methods.
The project is still in process, so experimental results are not yet available. However, one big lesson learned is that with the proper approach that emphasizes "bottom up", voluntary participation and assumption of responsibility rather than a "top down", command-based approach characteristic of more traditional government programs, land owners and growers will voluntarily cooperate to achieve environmental goals that are in the broader society's, as well as their own, interests.

Public Works Mitigation in the Huntington Beach Wetlands

This project site is a 147 acre marsh remnant of over 2,000 acres of wetlands in southern California's Orange County, now mostly filled and developed. It is located within the jurisdiction of the City of Huntington Beach at the mouth of the Santa Ana River and is bounded by the coast highway, a county flood control channel, and urban development. The area is subject to flooding.
In the late 1980s, this degraded salt marsh area was considered of no value by private land owners and the city government except for urban development, which had occurred on most of the surrounding vicinity. In the dry season it was used for informal parking by beach goers, but it was inundated during the winter. In fact, the whole area, lying in a flood plain at the most of a river, was subject to flooding. The city wanted the land developed, but the Coastal Commission and local environmentally concerned citizens considered the wetland important enough to be saved and restored. The citizens organized themselves in a new non-governmental organization, the Huntington Beach Wetlands Conservancy.
The Coastal Conservancy was asked by the city to help resolve this impasse. In addition, the public works agencies were uncertain as to how to mitigate (i. e., financially and physically compensate for) the wetland losses resulting from their road widening and flood control projects. Besides resolving the use conflict and finding mitigation solutions, the project also aimed to restore the wetland's biological health

and functioning, provide public access to the area, and provide improved flood protection.

The project that evolved out of the Coastal Conservancy's efforts, working cooperatively with the Huntington Beach Wetlands Conservancy, involved:

(1) preparation of a plan for wetland restoration that met Coastal Commission requirements, and which included mitigation for wetland losses that would be caused by state highway department road widening and county flood control projects, costs for which would be borne by these agencies;

(2) purchase of highway department land by the NGO with Conservancy grant funds that was needed for plan implementation;

(3) plan implementation to restore tidal and salt marsh vegetation, provide public access to the site, and increase flood protection for the adjacent area; and

(4) formulation of an approach to resolve land owner concerns about land value and development on private land (which unfortunately was not accepted by the land owners).

An essential element of the project was the mechanism for assuring the mitigation: an eight party agreement that was crafted by the Coastal Conservancy and entered into by the city, state and federal regulatory and wildlife advisory agencies, the NGO, and the Coastal Conservancy. Several key principles underlay the agreement that embodied current federal and state regulatory policies regarding wetland mitigation. First, mitigation, to be acceptable, had to be "in kind", i. e., species and habitat lost had to be replaced by the same or very similar species and habitat. For example, loss of salt marsh habitat could note be satisfactorily compensated for by restoration of fresh water or upstream riparian habitat.

Second, mitigation had to provide at least equal area of restored habitat as measured in acres. Usually, regulatory agencies required more than a 1:1 ratio of replacement to provide a larger "comfort margin" of likely mitigation success in view of the considerable uncertainties that attend wetland restoration; no specific criterion exists at this point, however, and decision-making occurs on a case by case basis.

Third, simply providing sufficient acreage of restorable marsh habitat, whether purchased or donated, would not satisfy the mitigation requirement. In other words, a shift in ownership of the physical area did not itself provide necessary improvement of the actual habitat. A site had to be provided, but it had to contain degraded wetland habitat whose restoration would actually provide a significant improvement to the quality of that habitat, as measured along specific dimensions by federal and state wildlife agencies.

Fourth, the permit applicant(s) (i. e., the project developer who would be causing the negative impact) -- who in this case would be the state highway department and the county flood control district -- were responsible for paying the entire cost of any required mitigation, i. e., the costs of planning and implementing the actual restoration.

These were the main concerns of mitigation generally and specifically for this project, although there were others as well.

Several important lessons were learned from this complex project. Realistic wetland preservation incentives can be devised and gain support of regulatory agencies, but they must take into account the site's physical constraints, development restrictions, and land ownership characteristics. Land owner participation is useful in developing solutions that local government and regulatory agencies consider reasonable. Close coordination between all parties concerned is necessary to enable understanding of different viewpoints and engender a constructive atmosphere. Nevertheless, some land owners may not be persuaded to cooperate, even if offers made seem reasonable to other parties. Finally, local citizens who advocate wetland protection can achieve significant results, even against great resistance.

Beneficial Use of Dredged Materials at Sonoma Baylands

Located on the northern shore of San Pablo Bay within the San Francisco Estuary, this 322 acre site was formerly tidal marsh which was converted to hayfields. It was part of an 830 acre ranch divided by highway and railroad embankments along a potential urban development corridor.

This path-breaking project began as a fairly straightforward tidal marsh restoration. After purchase in 1986 and initial planning by the Coastal Conservancy and the Sonoma Land Trust, a local NGO, the site was considered as a potential disposal site for uncontaminated dredged material from the Port of Oakland's harbour. The Port had a critical need to deepen its channel in order to serve the current generation of container vessels. Other possible disposal sites had either been eliminated (within San Francisco Bay) or had not yet been approved by the federal government (offshore ocean disposal). Time was critical, as the Port's economic viability and many thousands of jobs were at stake; and major regional economic and employment impacts loomed as well.

The Sonoma Baylands project thus had two major goals:

(1) To accomplish a significant tidal marsh restoration in an area that had been designated by public agencies and NGOs as the top priority wetland protection location in the Estuary; and

(2) To provide a solution for the Port of Oakland's dredge material disposal problem so its vitally needed channel deepening could proceed. A third goal, a natural outgrowth of the basic project concept, was to demonstrate the beneficial use of dredged material for wetland restoration as a model for other similar projects elsewhere.

Three principal conflicts emerged that had to be resolved before the project could be approved by federal and state regulatory agencies and endorsed by environmentally concerned NGOs:

(1) Could dredged material be safely used to restore marshes?

(2) Would this "upland" disposal method be more cost-effective, or at least competitive with, traditional methods of deep water disposal? And

(3) Could all fish and wildlife habitat resources at the site be successfully accommodated in the project design?

The project as finally designed -- it is now under construction -- has several main features:

(1) Clean, uncontaminated dredged material is used along with onsite material to raise the site level to that appropriate for tidal marsh functioning, and to help create upland habitat to support several endangered species.

(2) The plan for the project provides for restored marsh several decades sooner than if natural forces alone were relied upon. Briefly, the design calls for: (a) Deposition of just enough dredged material to a level sufficient to enable marsh vegetation to re-establish itself, rather than relying upon natural tidal action to "prepare" the site. The Port's need for disposal was not the criterion used for how much dredged material to place on site. Study of several early experiments in the Bay Area of tidal marsh restoration using artificially placed material showed that the level, or height, of the deposited material was a key variable in the success of restoring wetland vegetation; in some cases, the material was too high to enable tidal marsh vegetation to thrive. The other major design element was:

(b) Construction of peninsula-like berms to dampen wind-driven wave action during the initial phases of marsh restoration to enable marsh vegetation to sustain itself. In addition, an extensive monitoring program will observe whether natural scouring of the inflow channel from the bay is adequate to enable the inner portions of the restored marsh to flourish.

(3) The project's use of the dredged material is cost-competitive with alternative methods of deep ocean disposal. This was a major concern for the U. S. Army Corps of Engineers, the federal agency with regulatory and funding authority over such dredging-related projects. In addition to its regulatory function over "waters of the United States" (which in this case included San Pablo Bay and the Oakland harbour), the Corps also may provide funds for dredging projects which are matched by a 25 percent "local" contribution (i. e., port, city, and/or state government); the Corps does detailed cost benefit analyses to determine whether a project is worthy of federal support. After much discussion over its potential merits, the Sonoma Baylands project was deemed cost-effective by the Corps. In effect, the Port of Oakland and other Bay Area ports now have another option for future disposal needs, because other potentially restorable tidal marsh sites exist elsewhere within the Estuary.

(4) Lastly, seasonal wetland habitat will be provided on another part of the 830 acre ranch property in addition to the tidal marsh restoration, in order to address the habitat needs of all species that

currently use the site. This component was not initially part of the project design, but the U. S. Fish and Wildlife Service, a federal wildlife agency that is advisory to the Corps of Engineers, considered this addition to be necessary so it was added in.

This innovative project is still in process, but already wide recognition exists that considerable dredged material can be available, following adequate testing by the water quality regulatory agency, for marsh restoration, and that this approach is indeed feasible. From the institutional point of view, two other profound lessons are evident: first, obtaining full organizational support for new methods (in this case, especially from higher levels of the U. S. Army Corps of Engineers, which resisted approval of this approach for some time) can be extremely difficult and time-consuming, and requires intensive energy and perseverance, but it can be achieved.

Second, coalitions of environmental and business interests can be forged effectively when respective goals can be joined and articulated adequately. In this latter respect, environmental interests such as the Save San Francisco Bay Association and the Sierra Club, both non-profit NGOs, were very concerned at first about the potential ill effects of placing harbour dredged materials on a wetland site and called for intensive testing by government water quality agencies. Once this was done and testing proved that much of the material was uncontaminated and thus suitable for upland disposal, i. e., for marsh restoration, the NGOs became strong supporters of the project. For their part, the Port of Oakland, other Bay Area port administrations, and business interests, who had organized themselves into the Bay Area Dredging Action Coalition to promote a solution to the dredge disposal issue, were ready backers of the Sonoma Baylands approach because of the great uncertainty regarding when the federal government might approve a deep ocean disposal site.

Public Access at North Coast and San Francisco Bay Wetlands

Public access is increasingly provided for in many wetland enhancement projects, especially those in urban areas. Urban wetlands in particular often are among the few readily accessible places for recreation, education, and "breathing space" for urban populations. Relatively little is known, however, about the real affects of human activities on wetland wildlife. The Coastal Conservancy, which has funded many such wetland enhancement projects, financed a study in 1988 to begin to bring together information on this important question.

The Conservancy contracted with San Francisco State University's Romberg Tiburon Center for Marine Studies to do the work. The scientists reviewed scientific literature, surveyed several hundred park and wildlife managers, and carried out field studies of a number of wetland projects where public access had been provided. The projects were located around San Francisco Bay primarily, but a few northern coast projects also were examined.

Two of the study's main findings were these: Public access typically was provided in the form of footpaths, and occasionally boardwalks. The most effective barriers between humans and wildlife in the marshes are channels and high vegetation.

More significantly, however, the study concluded that public access to, through, or around wetlands adversely affect wildlife such as birds, although such impacts may be difficult to observe during short periods of time. For example, the field studies indicated that, on the one hand, birds in wetlands that experienced the highest levels of human activity, such as walking and bird watching, were less frequently disturbed by it than birds in less well-used areas, suggesting that they became used to it; but such high human activity areas had much lower overall bird use. Short term affects tended to be increased flight; over the long term, there are suggestions that the trampling of vegetation can lead to reduction in breeding success.

More studies of long term impacts of human activity are needed, especially in wetland locations where public access is growing. In addition, planning for public access to wetlands needs to be done on a case by case basis, involving careful consideration of buffer distances and methods, and possibly precluding access in situations where the impacts will be too severe.

CONCLUSIONS

The projects described in this paper exhibit a variety of innovative technical and institutional measures to

address impacts to coastal resources. Several common themes run through them, however, that can help provide a basis for more enlightened and effective stewardship of these resources as they come under greater pressures of population and exploitation.

First, the resolution of multi-interest resource and coastal land use conflicts should be an integral and top priority part of any coastal management framework. This vital task must be based on the recognition that economic and environmental concerns are inextricably intertwined. Long term economic and environmental health will be assured only to the degree that these two concerns are addressed together. In most cases they can be dealt with most effectively through non-confrontational methods involving all of the concerned interests. The Sonoma Baylands project is an excellent example of this commonality of interests joined through cooperative communication. This objective was only partially reached in the Huntington Beach case, for example, as the private land owners and the public agencies could not agree on appropriate land values; hence a portion of the project site remains both unrestored and undeveloped. Yet a significant success was achieved through the complex mitigation agreement covering the public works projects, and most of the Huntington Beach wetland has since been restored to biological health and public enjoyment while the needed public works projects were enabled to proceed.

Second, coastal resource management should be grounded in an ecosystemic foundation, rather than on traditional sectoral, administrative, or jurisdictional lines. Watershed-based planning, now becoming increasingly widespread, exemplifies this approach. The Buena Vista Creek and Huichica Creek projects illustrate how this outlook can be implemented successfully. At Buena Vista, the use of "soft edged" engineering solutions, while originally resisted during planning, were effective during recent storms in addressing the flooding problem at the source. At Huichica, the results of the technical experiments are still to come, but the establishment of the voluntary-based Stewardship structure has generated a solid base for long term prevention of resource impacts. This is evidenced by the high level of voluntary land owner and grower commitments of money, land, and energy to the demonstration project.

For larger watersheds, consideration must be given to the full range of fish and wildlife habitats, the spatial limits of their viability, and their interactions, the key economic activities such as fishing, forestry, riverbed mining, tourism, urban development and transportation and their impacts, typifies this approach. This naturally requires new methods of institutional functioning that stress greater cooperative activity and flexibility of the concerned public agencies based on mutual understanding of different needs, priorities, and constraints; possibly some structural changes may be needed as well. Multi-interest, multi-agency watershed planning committees are one approach that shows promise at least in the California context.

Third, public policies that create financial and other incentives that stimulate resource development and land use investment decisions need to be re-examined and altered to provide new incentives that foster sustainable use of coastal resources. Regulation alone cannot adequately protect those sensitive and threatened resources that need it. Non-regulatory methods, such as new incentive systems that generate new bases for individual, household, business and governmental financial, technological, and spatial choices, are more powerful means for achieving wiser and more socially responsible resource actions.

On the project level of action, the methods exemplified by the Coastal Conservancy-assisted projects reviewed in these paragraphs provide working models for how to bring diverse and often contentious interests together to reach mutually satisfactory solutions for addressing coastal change impacts. Ability to identify common or complementary interests and goals is the key to success, as shown especially in such projects as the Huichica Watershed, Sonoma Baylands, and Tijuana cases, and also by the Huntington Beach mitigation agreement.

Fourth, coastal resource management must consider land-based impacts on marine resources, and thus should be viewed as a geographical continuum from inland to a nation's seaward limits. For example, upstream impacts on shoreline and nearshore resources such as estuarine habitats, which are so

vital to a broad spectrum of marine life, must be addressed within the scope of coastal resource management policy and administration. The Coastal Conservancy, by virtue of its jurisdictional ability to operate outside the coastal zone boundary of coastal regulation, was thus able to successfully implement projects like the Tijuana Ecoparque, Huichica Creek Watershed, and Buena Vista Creek projects. How might these methods of dispute resolution, project planning and priority setting, and resource management as used by the Coastal Conservancy be transferred to coastal situations outside of California? To answer this question, we must first consider the principal factors behind the Conservancy's success, and the likely obstacles to adaptation and extension of its methods elsewhere.

The California State Coastal Conservancy was created specifically to address numerous population, development, and natural impacts that the existing regulatory system, as administered by the Coastal Commission, could not adequately handle, and to do so in a non-regulatory way. It was established by an act of the California Legislature in 1976 at a time of high public environmental consciousness and concern, which provided a strong incentive for positive action. More directly, the Conservancy was conceived at the time as a means to reduce or eliminate the onerous affects of regulation on coastal development and land use. Thus, its formation was supported by a broad range of development and business interests as well as environmentalists.

The Conservancy was given an extraordinary range of authority and great flexibility of action. Administratively, its program-based budget (as distinct from the conventional line item budgets other departments had) enabled it to set priorities for both long range and crisis response-based action. This also gave the agency more flexibility in negotiating project agreements with public and private sector interests. In addition, the Conservancy was able to act more rapidly on a number of issues including land acquisition and disposition and project planning, and to assist other government departments which were hampered by existing administrative constraints. This ability was particularly useful when dealing with opportunity purchases of land or needs to take immediate action on behalf of other agencies to respond to particular resource issues. The Conservancy also operated on a multi-disciplinary basis, and was thus able to address complex problems in a comprehensive, non-sectoral manner. Finally, it had the ability to try innovative solutions to problems, both technological as at Tijuana, Sonoma Baylands, and Buena Vista Creek, or institutional as at Huichica Creek and Huntington Beach.

A third major success factor was money. The Conservancy had funds made available to it through general obligation bond acts voted by the electorate in state elections every four years from 1976 to 1988. While much of its negotiating, conflict resolution, and planning activity did not require great amounts of money, the agency was able to bring a large incentive to the bargaining table through its ability to fund significant portions, if not all, of a project's public outlays.

Fourth, much of the Conservancy's success, especially in its early years, could be traced to the existence of the Coastal Commission's regulatory back-up. The Conservancy had been created largely to reduce or eliminate the onerous affects of regulation, and the knowledge that the control-based structure remained in the background if the Conservancy's non-regulatory efforts were unsuccessful, often proved to be a useful incentive for reaching accommodations without regulatory or legal confrontations. In later years, however, the Conservancy continued to be effective even though the impact of the Commission lessened somewhat. This was in great measure a consequence of the Conservancy's ability to work cooperatively with diverse interests to find solutions that met both environmental and economic objectives.

A final factor of major importance was the continued support the Conservancy received from the California Legislature. Legislators saw the agency as more effective, less bureaucratic, and more responsive to both overall issues and constituency concerns than some conventional government departments. The Legislature thus provided increased administrative flexibility for Conservancy operations; expanded its jurisdiction (first, in 1980, to include the nine county San Francisco Bay area, and two years later, to enable it to operate in coastal watersheds outside the

coastal zone); and increased its programmatic responsibilities by designating it the state's lead agency for urban waterfront development, authorizing it to work with and support land trusts and other non-governmental organizations, and to address problems of the commercial fishing industry, among several other new concerns.

In other contexts, several constraints may limit possibilities for adapting Coastal Conservancy-type methods for coastal resource management. Clearly, a lack of an active public constituency would dampen institutional inclinations to adopt innovative approaches. More directly, political opposition to either new government programs or creation of new agencies or divisions could reduce the chances further. Such opposition could arise from development pressures that may view any attempt to strengthen coastal management as a threat, or from other segments of government which may see a new departure as bureaucratic competition for scarce funds or a threat to existing departmental control. Other interests, both within and outside government, may fear competition with other issues held to be more important, all competing for public and institutional attention and funding. Less well established traditions of inter-organizational cooperation may also present a constraint. In some situations, lack of an adequate assessment of trends, issues, and opportunities may lessen official willingness to try a new approach in the absence of a compelling reason for it. Lastly, funding shortages could result in reduced enthusiasm for a new effort as well, even at a modest initial level.

Nevertheless, the potential exists for promoting improved approaches to the handling of coastal change impacts along the lines described in this paper. The demonstration effect of successful projects can be a powerful influence for constructive change. Modest beginnings with a fairly high probability of success provide a solid basis for building a strong constituency for change. Heightened attention to linking major coastal resource management priorities with other critical issues, especially the inter-relationships of specific economic activities with environmental concerns in particular geographic areas, can also help reduce the propensity for confrontation and competition for resources in coastal problem-solving. Improved information on critical coastal problems -- what was called the Issue Identification in the California Coastal Plan of 1975 -- and its timely communication in readily understandable form to policy-makers, coastal decision-makers, and the general public, is yet another path to increased awareness of both the need for more constructive action to deal with coastal change impacts and opportunities for it to occur. Lastly, increasing and spreading negative impacts may finally force adequate attention to be given to adopting new ways of addressing these problems before catastrophic results ensue. It remains to be seen whether this optimistic outcome will happen.

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THE ROLE OF SHORELINE CONFIGURATION AND COASTAL MORPHOLOGY ON NEARSHORE SEDIMENT TRANSPORT UNDER STORM COMBINED FLOWS, CANADIAN BEAUFORT SEA.

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KEYWORDS: Sediment transport, combined flows, storm surges, nearshore zone, Beaufort Sea.

ABSTRACT
Potential sediment transport during storm surges was estimated at two nearshore sites of the Canadian Beaufort Sea using a numerical model for combined flow conditions (Li and Amos, 1993). The first site is a sandy beach backed by a low bluff, while the second site consists of low-lying sand spits. Several storm surges occurred during the field experiments, leading to a downwelling circulation and offshore sediment transport. Numerical modelling suggests that offshore sediment transport is more significant where the beach is backed by a bluff acting as a natural barrier.

INTRODUCTION

A good understanding of sediment transport processes in the nearshore zone is important for scientists and managers working in the coastal zone. The nearshore zone is a highly energetic environment affected by surface gravity waves and mean currents, and is the site of complex interactions between fluid processes and substrate response. The nearshore environment is also a transition zone characterized by on-offshore sediment transport between the surf zone (i.e., inshore of the breaker line) and the offshore zone. The exchange of sand between the inshore and offshore environments plays a major role on coastal evolution and shoreline stability (Stanley and Swift, 1976; NRC, 1990).

This paper is not concerned with sediment transport processes in the surf zone which is dominated by the action of longshore currents driven by the energy of breaking waves (Komar, 1976), but rather by sediment transport processes on the shoreface, seaward of the surf zone, where surface wind stress, internal pressure gradients, and tides are major factors forcing mean currents. Although these forces are significant factors controlling nearshore circulation, oscillatory flows associated with wave orbital motions represent the most important source of bottom sediment remobilization in that zone of shoaling but non-breaking waves (Swift et al., 1985; Vincent et al., 1983; Niedoroda et al., 1984; Wright et al., 1991). Because wave orbital currents and mean flows commonly interact in nearshore environments, the direction and magnitude of nearshore sediment transport result from the combined action of unidirectional steady currents and oscillatory flows in the bottom boundary layer (Fig. 1). As shown by Grant and Madsen (1979), unidirectional currents and wave-induced oscillatory flows interact in a non-linear fashion causing a total bottom shear stress of greater magnitude than the stress produced by wave motion alone. Consequently, combined flows induce sediment motion at lower current velocities than wave oscillatory currents alone.

The aim of this paper is to present the results of wave and current measurements carried out at two nearshore sites of the Canadian Beaufort Sea (Fig. 2), and of potential sediment transport according to a numerical model for combined flow conditions (Li and Amos, 1993).

STUDY SITES

Both study sites are located on the Tuktoyaktuk Peninsula, in the southeastern Canadian Beaufort (Fig. 2). The coast of the Tuktoyaktuk Peninsula consists of low bluffs (< 10 m) of unconsolidated Quaternary sediments and of beaches, spits and barrier islands undergoing rapid retreat (Forbes and Frobel, 1985; Héquette and Ruz, 1991). Most of the high energy waves originate from the west and northwest in response to storm winds. The Canadian Beaufort Sea is a microtidal environment, the mean tide ranging from 0.3 to 0.5 m. In addition to tide-induced water level fluctuations, storm surges may raise coastal water levels up to 2.4 m above mean sea level (Harper et al., 1988) in Kugmallit Bay (Fig. 2).

The first study site is the nearshore zone of Tibjak Beach, located near the mouth of Kugmallit Bay, a wide and shallow embayment of less than 10 m water depth (Fig. 2). Tibjak Beach is a 2.5 km long beach of medium-grained sands, characterized by a steep foreshore backed by a low bluff (Fig. 3). Bottom sediment in the nearshore zone consists of well-sorted sand having a mean diameter of 0.25 mm. The second study site is the nearshore zone seaward of Atkinson Point, a small sandy promontory from which two spits of fine to medium sand developed (Fig. 4). Both spits are wide and low-lying coastal features (< 1 m above mean sea level) that are extensively overwashed during storm surges. Mean grain-size in the nearshore zone is 0.20 mm. Both study sites are facing the northwest which corresponds to the dominant storm wave approach, but the Atkinson Point site is more exposed to high energy waves compared to the Tibjak Beach site which is partly protected from westerlies by a headland.

METHODS

Directional wave and current data were obtained at Tibjak Beach in August and September 1987, using a Sea Data model 621 wave and current meter deployed in 3.4 m water depth (Fig. 3). At Atkinson Point, wave and current measurements were carried in 1992 and 1993, using InterOcean S4 current meters. Two current meters were deployed in 3.0 m water depth in July and August 1992, while one current meter was moored in 5.0 m water depth in August 1993 (Fig. 4). Spectral analyses of the raw data yielded values of wave direction, significant wave height, and peak period. Mean sea-surface elevation above the bottom and mean current velocity and direction were also obtained for every burst. All these instruments were located in the lower part of the water column, at heights of 0.8 to 1 m above the seabed, so the mean current components correspond to the time-averaged residual near-bottom flows.

These data were then used to compute potential sediment transport using a numerical model developed by Li and Amos (1993) for wave and current combined-flows over a non-cohesive bed. The threshold for sediment motion adopted in this model is the critical shear velocity of Grant and Madsen (1979). The rate of sediment transport per unit width of bed (q_s) was also calculated using a modified Engelund and Hansen (1967) total load equation:

$$q_s = 0.05 D u_{100} r^2 u_*^3 / D\ [(r_s - r)]^2 \quad (1)$$

where D is the grain diameter of the sediment, u_{100} is the mean current velocity at 1 m above seabed, g is the acceleration of gravity, and *rho* and rho_s are the fluid and sediment density respectively.

RESULTS

Nearshore sediment transport at Tibjak Beach

Five intense wind events occurred during the period of the field experiment during which winds were predominantly from the northwest. These storms resulted in significant wave heights of more than 0.9 m in 3.4 m water depth, reaching a maximum of 1.3 m on August 28 (Fig. 5). High water levels were observed at Tibjak Beach during these storms due to wind-induced set-up of the sea surface against the shore. Several positive surges in excess of 0.7 m above mean sea level were measured at the study site, with a maximum storm surge of 0.96 m above mean sea level recorded on August 31 (Fig. 5).

The directional distribution of mean near-bottom currents showed that alongshore flows dominated at all measurement sites during fairweather conditions, setting either to the north-northeast or south-southwest (Héquette and Hill, 1993). During storms, however, the distribution of mean near-bottom currents was significantly different and high-velocity offshore-directed currents (NNW to NW) were recorded during northwesterly storms (Fig. 5). Mean offshore current speeds of 0.25 to 0.35 m/s were recorded during those events, but a maximum of 0.50 m/s was recorded during the September 5 storm (Fig. 5). The seaward-directed currents varied in duration from one event to another, but were generally persistent during each storm once they began to develop. During most of the storms, near-bottom currents were directed offshore for periods of at least 6 to 9 consecutive hours, and on 13 September, seaward currents occurred continuously for more than 18 hours.

These storm-generated currents were strongly controlled by wind forcing and by the pressure field associated with the set-up of the mean sea surface against the coast. Onshore-blowing winds induced a landward water transport at the surface which was compensated by coastal downwelling and offshore bottom flow (Fig. 6). During storm surges, small but important slopes of the sea surface develop in the nearshore zone, extending down from the coast. Such sea level slopes cause seaward-directed horizontal pressure gradients that drive offshore-directed mean bottom currents (Swift et al., 1985).

High wave-orbital velocities (> 1.0 m/s) were recorded during the storms (Fig. 5) which, according to the numerical model used in this study, contributed to significant sediment remobilization. The model suggests that up to 0.037 kg/m/s were transported during these events and that most of the sediment load was directed offshore (Fig. 7) in response to combined wave oscillatory currents and mean flows. Once waves have supplied power to remobilize sediment, the direction and rate of the resulting sediment transport is strongly affected by the steady flow component over the seafloor, so the sediment load was probably directed offshore because of the downwelling circulation that was taking place during northwesterly storms.

Nearshore sediment transport at Atkinson Point

Northwesterly to westerly storms also occurred at Atkinson Point during the periods of wave and current measurements in the summers of 1992 and 1993. As a result, significant storm surges were observed in the coastal zone (Fig. 8) in response to shoreward surficial water transport induced by onshore winds. The nearshore circulation during the storm surges was similar to the circulation observed at Tibjak Beach during northwesterly storms. Surface currents were onshore at the surface and downwelling near-bottom currents developed on the shoreface. Although a downwelling circulation took place at Atkinson Point during storm surges, mean currents showed a less pronounced offshore component compared to the currents observed seaward of Tibjak Beach.

Computation of potential sediment transport based on the numerical model of Li and Amos (1993) suggests that sediment transport in the nearshore zone of Atkinson Point is mainly directed alongshore or obliquely offshore during storm surges(Figs. 9 & 10). According to the analyses of the wave and current data collected in 1992, sediment was mainly transported obliquely offshore to the northeast in 3.0 m water depth (Fig. 9). The threshold of sediment motion was only exceeded during three storms of moderate magnitude during which the potential sediment transport rate was always less than 0.015 kg/m/s. In 1993, two significant storms occurred during the period of the field measurements. Potential sediment transport rates in response to combined flows reached more than 0.04 kg/m/s for each of these storms (Fig. 10). Again, the direction of sediment transport was dominated by alongshore and offshore components.

DISCUSSION

According to the numerical model used in this study, the potential sediment transport due to combined flows on the shoreface during northwesterly and westerly storms is characterized by a more pronounced offshore component at Tibjak Beach than at Atkinson

Point. This is believed to be mainly due to the differences in shoreline configuration and in coastal morphology between the two sites.

Due to its location at the mouth of Kugmallit Bay, Tibjak Beach is affected by more significant storm surges because the set-up of the sea surface is increased in coastal embayments (Harper et al., 1988). This results in a significant horizontal pressure field driving offshore-directed near-bottom barotropic currents (Héquette and Hill, 1993). The set-up of coastal waters is more restricted at Atkinson Point because the shoreline configuration is more linear, and because the water level can be raised above the low sandy spit. Consequently, the magnitude of storm surges and of horizontal pressure gradients is limited along such low coastal accumulation landforms that are easily submerged. Numerical modelling suggests that longshore sediment transport is more significant than offshore transport in the nearshore zone of Atkinson Point during northwesterly storms.

CONCLUSION

This study suggests that sediment transport due to the combined action of waves and currents may vary significantly from a nearshore site to another during episodic storm events, leading to variable offshore sediment dispersal along the shoreface. Shoreline evolution may thus be very different along the coast as increased offshore sediment transport at certain locations may lead to a loss of material for the coastal zone and contribute to enhance coastal erosion problems. These results have implications for coastal managers and decision-makers who have to plan future development in the coastal zone, as it shows that potential loss of material to the offshore zone may be increased during storm surges in coastal areas backed by an artificial or a natural barrier such as a bluff.

ACKNOWLEDGMENTS

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Fig. 1. Schematic representation of the interaction of wave orbital currents and mean flow on sediment transport in the nearshore zone.

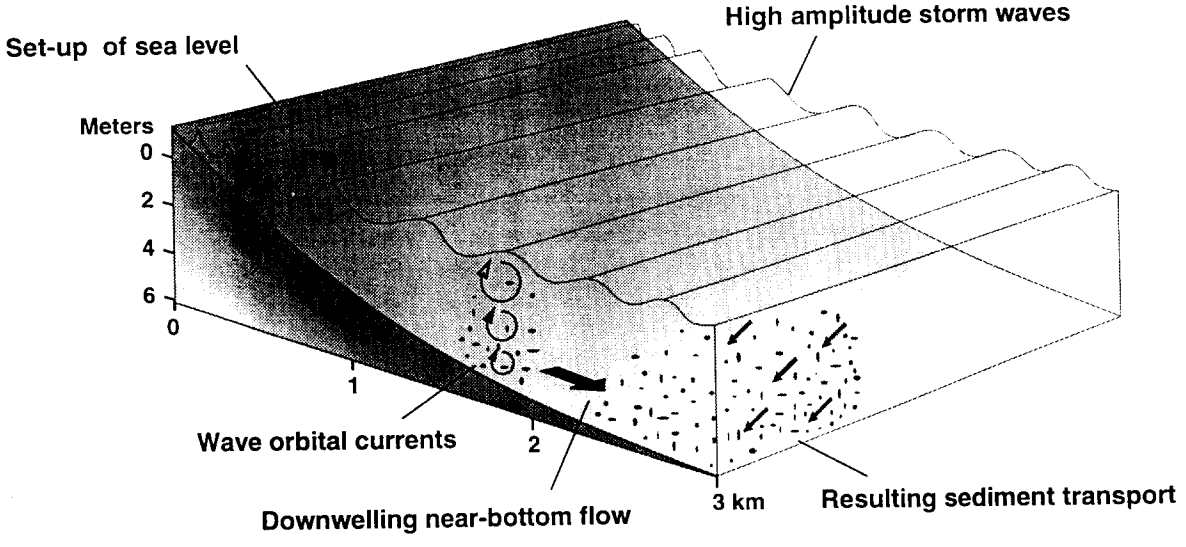


Fig. 2. Location map of the Canadian Beaufort Sea.

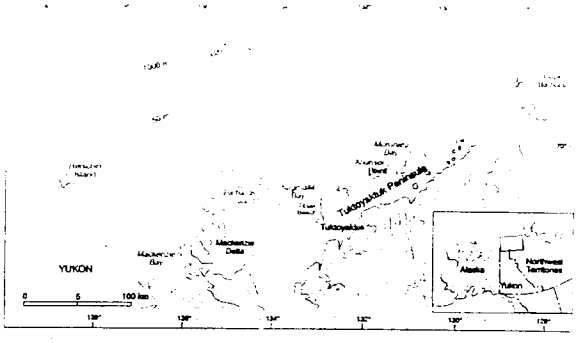
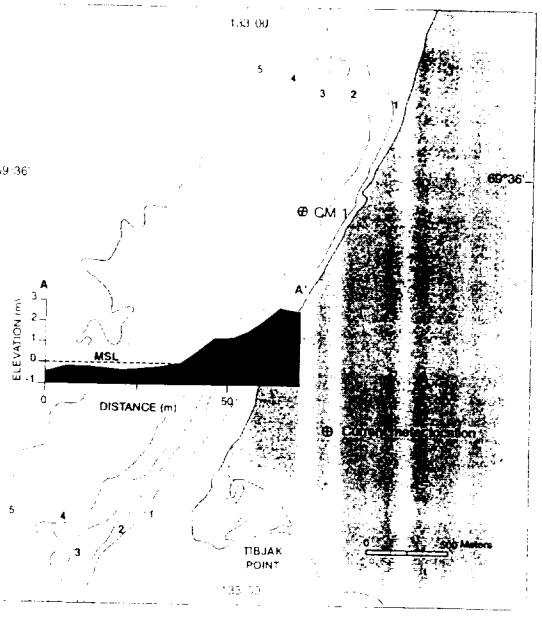


Fig. 3. Beach morphology and current meter location at the Tibjak Beach study site, 1987.



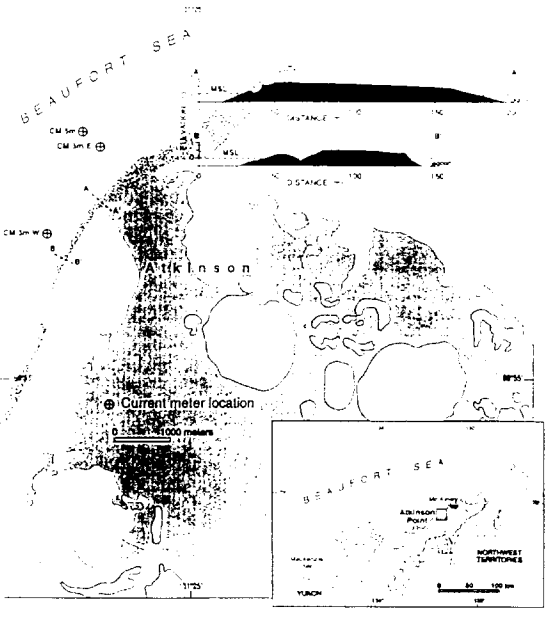


Fig. 4. Beach morphology and current meters location at the Atkinson Point study site, 1992 and 1993.

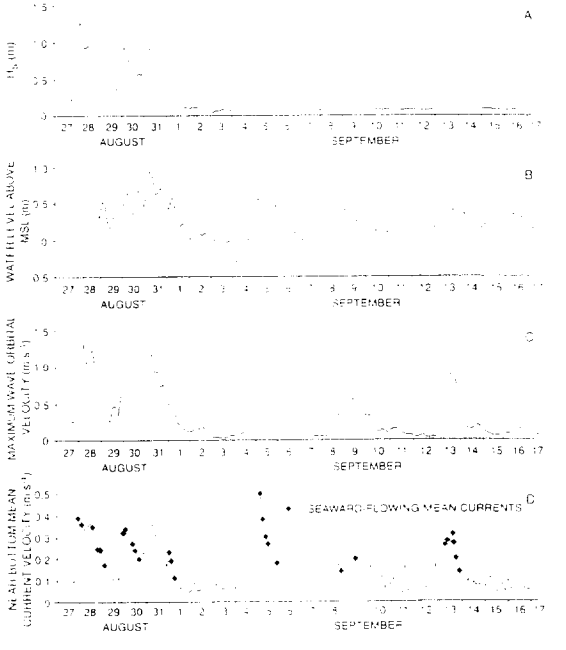


Fig. 5. Time series of A) significant wave height (H_s), B) water-level fluctuations relative to mean sea level, C) maximum wave-orbital current velocity (u_m), and D) near-bottom mean current velocity recorded in 3.4 m water depth (relative to mean sea level), seaward of Tibjak Beach. Chart datum is approximately 0.4 m below mean sea level.

Fig. 6. Shoreface circulation at Tibjak Beach during set-up of sea level at the coast.

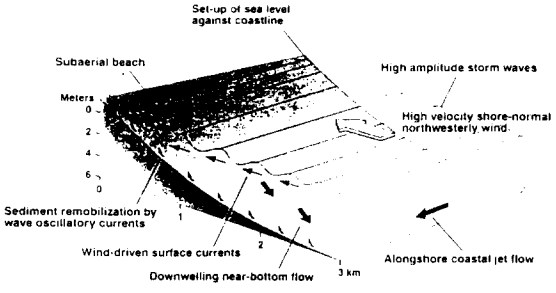
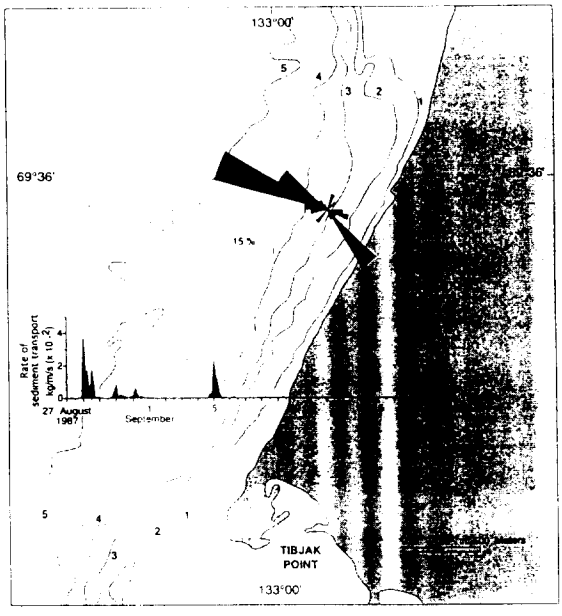


Fig. 7. Rate and direction of sediment transport at Tibjak Beach (computations based on the numerical model of Li and Amos, 1993).



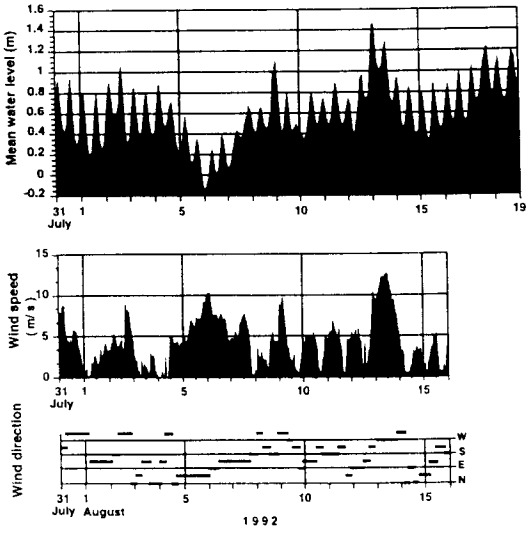


Fig. 8. Wind speeds and directions and water levels at Atkinson Point, summer 1992.

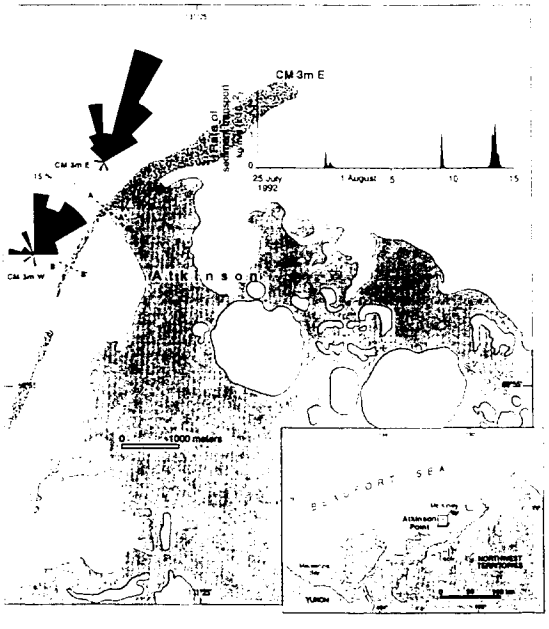


Fig. 9. Rate and direction of sediment transport at Atkinson Point in 1992 (computations based on the numerical model of Li and Amos, 1993).

Fig. 10. Rate and direction of sediment transport at Atkinson Point in 1993 (computations based on the numerical model of Li and Amos, 1993).

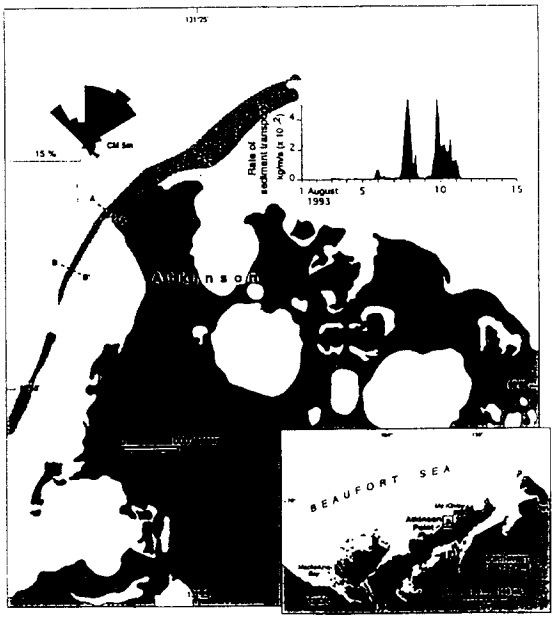
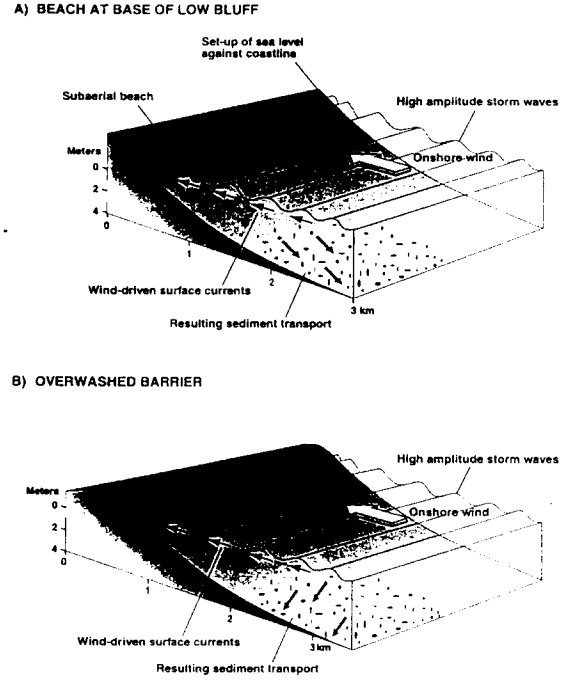


Fig. 11. Conceptual model of nearshore sediment transport during storm surges seaward of (A) a beach backed by a low bluff, and (B) a low-lying spit or barrier beach.



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BLUFF BASE AND BEACH PROTECTION; THE COASTAL CELL METHOD

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Data for the protection of sedimentary coasts can be organized in the following manner: There is no even repartition of sand on sandy shorelines and forebeaches. To the contrary there are sand pockets which are often referred to as coastal cells where beach profiles are healthy and keep the wave energy away from bluffs.

Coasts are seen and said to be eroding in between cells. A cell can be classified according to the length of the coastline which is entrapped within its boundaries: micro-cells (less than 50 m long), meso-cells (between 50 m and 1000 m long), and macro-cells (longer than 1000 m). Coastal replenishment is assured by littoral transit. Because of irregular coastal cells, there is no even, parallel spreading of sediments along the coastlines (re. studies by Carter, 1988). Indeed, the cell morphology determines two kinds of transits: within the cell, and between cells. There is little or no transit between cells under established wind and sea conditions. In this case the only noticeable transit is within the cell against the cell limits abutment, but there is no escape beyond the cell downstream boundary.

Transit between cells is generated when changes in wind and sea conditions reverse abutments. This frees some sediments from the cell attraction. The problem is that this loose sediment will pass by eroded areas only to accumulate in the next cell.

Action against erosion must thus address this natural uneven sand budget by a coast-smoothing device. In the best of cases this is achieved by creating artificial coastal cells that will Integrate the eroded area with the inter-cell and intra-cell transit. These artificial coastal cells are obtained from Artificial Ripple Systems (Fig. 2) some of them made out of easily installed hollow modular careens. Those artificial ripples aim at undulating the beach and forebeach in order to stabilize it and to cause stable sand bumps generating natural sandbank responses.

The service offered by the installer comprises a cartography of existing coastal cells with blimps, prior to deciding whether and where to install patented low profile artificial ripples. The blimp comprises a video-photographic platform which will allow a specialized team of geologists to monitor the shoreline in real time at low cost with state-of-the art electronic equipment.

Fig. 1. Sand-cell mapping

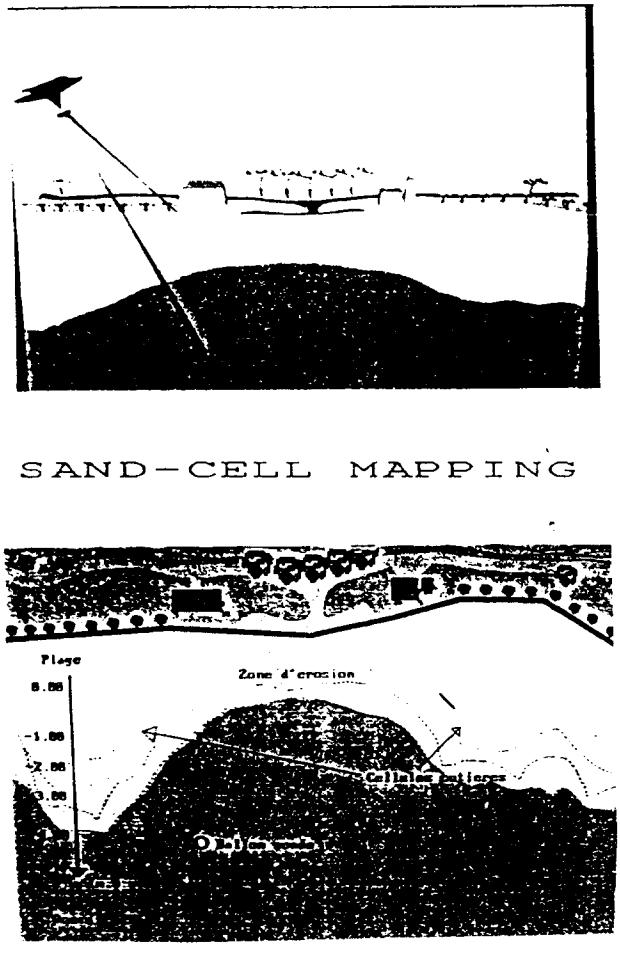


Fig. 2. Artificial ripple system

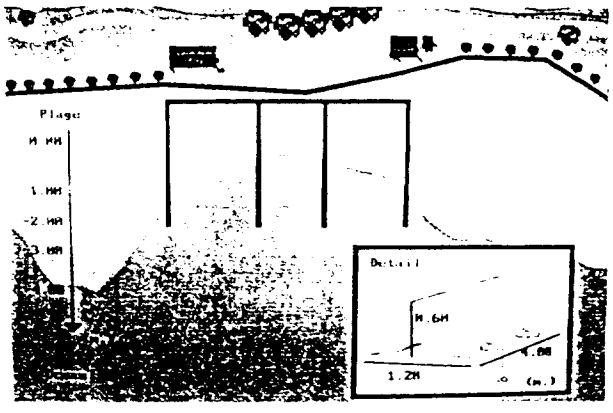
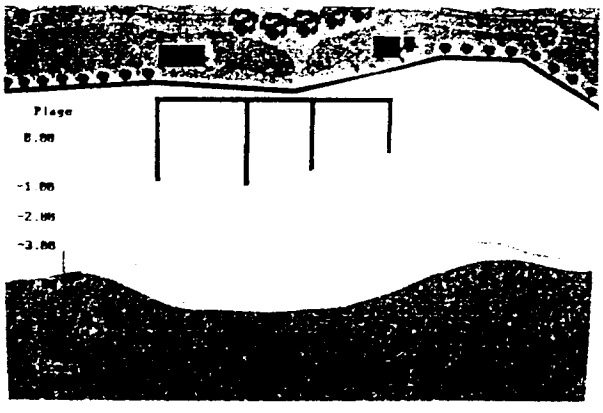


Fig. 3. Site evolution



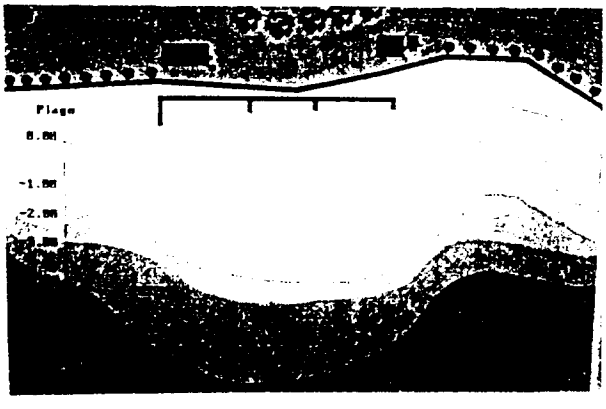
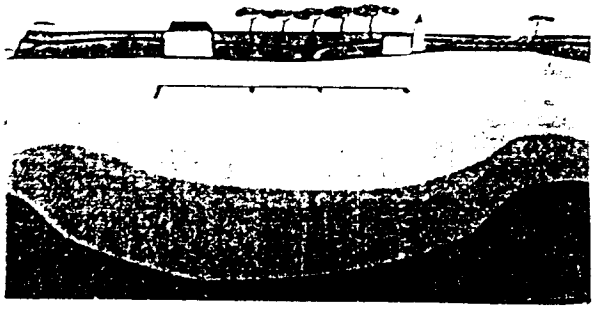


Fig. 4. Stabilito.



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THE INFLUENCE OF THE ANTHROPOGENIC FACTOR ON THE COASTAL-SEA SEDIMENT STRUCTURE

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ABSTRACT

Certain data on the coastal zone dynamics of the southern-eastern Black Sea are discussed. As a result of anthropogenic disturbance of the material and energy fluxes, many processes occur under conditions that differ from natural ones. The accumulative processes have changed and beaches have lost their old sources of nourishment and are eroding. The regime of the nearshore sedimentation has changed too. In the surf zone various sediment layers exist that have been formed under different geological conditions. Unconsolidated old layers are eroding rapidly under the influence of waves and streams and by physical and biochemical weathering. Owing to this process, the rate of coastal retreat is increasing.

INTRODUCTION

Since the moment of a relative stabilization of the World ocean level (5-6 thousand years ago) abrasion and accumulation in coastal zones have reached a dynamic equilibrium. This has manifest itself in a certain profile, geological structure, dynamic processes and evolution. Mankind has disturbed this balance for several decades. At the end of the 20th century, many forms of anthropogenic impacts on sea coasts became obvious and are sometimes disastrous. The increasing economic activity in coastal regions has resulted in a considerable change of the natural features of the eastern Black Sea coast. In fact there are almost no more natural beaches and the coast itself has been turned into a complex of ferro-concrete constructions.

The mass removal of sand and gravel from the beaches and river beds, the construction of dams for hydroelectrical power stations and the increase of a general water intake, the building of port jetties and the local systems of coastal protection have greatly worsened the balance of the beach and bottom sediments. This has resulted in a general increase of the original coast and bottom outwash, of slope erosion and of the rock-slides (Zenkovich, 1985; Peshkov, 1993). The decrease in suspended sediment flow has entailed the exhaustion of loose sedimentary cover on the submerged slope. On the bottom rocks became visible which gave quite different physico-mechanical characteristics to the bottom than the recent sediments. As a result of a direct contact between sea water and soft sediments (clays, peats, ancient deltaic silts, etc.) the latter are rapidly disintegrated. When the original bedding becomes to composed of loose sediments, these begin to shift to the deep-sea under the influence of currents and gravity. The increase of depth in the surf zone generally amplifies the wave effect upon the coast and accelerates its erosion. These processes together become a key factor for the modern evolution of accumulative forms on the eastern Black Sea coast (Menshikov, 1981; Peshkov, 1993). Coastal erosion often becomes a disastrous phenomenon when the structure of the coastal-sea deposits is broken with an impact on the coastal evolutionary process.

Before the construction of the port of Sochi (1935-1937), sandy gravel beaches were 30-40 m wide. Their relatively shallow submerged slope (0.02-0.03) was covered with a sand layer of 0.4-0.5 m thick. An intensive downstream erosion began as a result of the overlapping of the north-western sedimentary flux by the port jetties (the average flux was 30 thousand cubic meters per year). By the middle of 1940s an active cliff was formed on a long coast section. The sea broke through the less resistant cliff materials and the

coastline obtained a twisting profile. The rate of the retreat of the shore, composed of clay marls, was 4 m/y; on some coast sections almost vertical cliffs came down directly in water to the depth of 2-3 m. Landsliding has sharply intensified. The beach erosion was rapidly spreading in the south-eastern direction. At the same time the original beach was retreating with the rate of 0.5 km/y. According to repeated observations, the rate of bench lowering in the surf zone was determined to be 3-5 cm/y. Marine burrowers played an important role in this process. For example, *Barnea candida* turns the clay marls into a surface that looks like honeycomb (some hundred holes per one cubic meter). This mollusc makes its passages to 12-15 cm down in the bottom and hastens the loosening of the bed rocks (Zenkovich, 1967).

The observations show that the bottom roughness increases when the density of some organisms is high. As a consequence the turbulence of near bottom streams increases and the shift of loose sediment shift increases too.

At the end of 1940s, coastal and nearshore bottom erosion became disastrous near Sochi. To protect the town area and communications, a construction of baffle plates, groins and submerged breakwaters started. In the end, the coastal protective constructions had to be erected over a length of 30 km, i.e. up to the end of the lithodynamic system. In spite of these large efforts, coastal protection in Sochi remains an unresolved problem. A deficiency of beach and bottom sediments exists and the original bench continues to be eroded. The beaches between groins are largely exhausted, and in some places absent. The coastal protective constructions themselves are in unsatisfactory state.

The practice shows that the problem of the coastal protection can be solved only by the elimination of the main reason of its erosion, i.e. the general deficiency of sediments, a process provoked by man's meddling. To create a balanced sediment budget, a large recharge of sandy-gravel material is necessary with additional nourishment of the whole lithodynamic system. In other words man must carry a work which otherwise was done by nature.

At present the Scientific Industrial Association KRASNODARBEREGOZASHITA has begun a series of measures aimed at beach restoration in Sochi town, and the first positive results have been already obtained.

A similar situation of coastal erosion occurred in Western Georgia, after the construction of the port in Ochimchire town. The downstream outwash has spread almost 6 km to the south of the port (Fig. 1). At first it eroded the beach and subsequently a high clay terrace of the Quaternary age. By the middle of the 1960s the sea had cut a belt of land 150 m wide (at an average rate of about 5 m/y), and the height of the eroded cliff was 10 m. According to the data of repeated surveys between 1933 and 1959, the total loss of coastal land was 30 hectares. The surface of the submerged slope had changed completely. It turned to a clay bench with insignificant accumulation of sandy deposits. Outcrops of poorly compacted finely dispersed sediments accelerated their disintegration. The vital activity of marine borrowers (mud-eaters, drillers) played an important role. The exhaustion of the beaches provoked the intensification of the erosion of underlying clays. During storms, small gravel deposits began to make pits of 0.5 m deep with across several meters. Due to these processes, the surface of the bench lowered at an average rate of 3-5 cm/y (Yesin et al., 1980).

A comparison of maps shows that south of the port of Ochamchire the volume of the original coast erosion was about 2 million m^3, which was much more than the sand and gravel accumulation on the windward side (about 200 thousand m^3). The reason of such a disparity is a high content of the fine-grained particles in the sediments of the original shore. Those particles are completely transported to the deep sea, and are excluded from the sediment budget in the coastal zone. Early in 1960 the building of the baffle-plates and groins started for coastal protection in this region. This construction, however, has not resulted in the stabilization of the shore because there exists a sediment deficiency due to the blocking of the north-western sedimentary flux. In the 1980s the Scientific-Industrial Association GRUZBEREG-

OZASHCHITA started artificial beach restoration (Kiknadze et al., 1990).

As a result of the mass removal of beach sediments and the meddling into the evolution of the river bed, the coastal erosion between the Myuser Hills and Eshera (to the south-west of Sukhumi) was noticeably accelerated. On the submerged slope Neogene conglomerates and Pleistocene alluvial-diluvial deposits appeared. On the sections where landsliding occurred, Majkop suit clays became visible. To obtain quantitative data about the rate of erosion of the original shores and benches composed of Majkop clay, bench marks were installed for repeated investigation. Similar bench marks were installed on the analogous (according to geological structure) coastal sections with narrow gravel beaches. During 5 years (1986-1990) the average rate of the clay sediment erosion at depths of 2-3 m, was 8-10 cm/y. The retreat of the shoreline was about 1.5 m/y (Fig. 2). On the bench sections composed of clay and beaches were absent, the rate of the bench erosion turned to be considerably higher to a value of 20 cm/y, owing to physical and biochemical weathering. The retreat of the shore cliff was about 3.5 m/y.

This phenomenon can be explained in the following way. Exposed clay surfaces experience a constant influence of the sea water, especially under the intensive water exchange in the surf zone. Biological weathering and cavitation make an additional contribution to the erosion of these clay deposits (Fig. 3). Although the critical velocity for such a process should be above 15 m/sec., cavitation happened also when the speed is lower (Yesin et al., 1980). Water motion can be created when there is a thrust against a vertical obstacle, such as a cliff. Besides, in a turbulent flow there are many air bubbles, which are the 'seeds' of cavitation. Cracks and a rough bottom serve as cells for formation of cavities.

Analysis of the modern coastal evolution in the region of Gudauta and Novy Afon has shown that the total loss of coastal land for the last 30 years was about 200 hectares due to the abrasion and weathering of the clay bench. The share of these processes was 90 %, and only 10% of the coastal retreat was due to the deficiency of beach sediments. The abrasion and biochemical weathering of Pliocene conglomerates and of the Majkop clays is the main reason for the coastal retreat between the Tolsty Cape and the Souk-Su Cape (Fig. 4).

An exceptionally high rate was observed after the change of the coastal-sea sediment composition in the region near Gagra town. The building of the comb of groins and submerged breakwaters resulted in the complete rupture of the north-western sedimentary flux (an average capacity was 30-35 thousand m^3/yr). In contrast previous beach washing proceeded only at a slow pace. The total loss of beach sediments between 1959 and 1968 was 40 thousand m^3, but from 1968 to 1982 (the period of the groin construction) the volume of the outwash increased to 900 thousand m^3. The maximum rate of the coastal retreat was in the period when clays and peats of lake-lagoonal origin began to be exposed in the surf zone (their age was about 4-4.5 thousand yrs). During the period of accumulation of this coastal section, they were covered from the sea side with sandy gravel, namely with a bar. The thickness of these superincumbent sediments exceeded the active wave influenced layer. Therefore the relic sedimentary layers did not (yet) participate in the lithodynamic processes of the coastal zone. The erosion of the sandy gravel cover has entailed a disastrous breaking of the original coastline (Fig. 5).

During the winter storm season in 1981-1982 an average rate of retreat of the coastal section of 3 km long was 20 m with extremes of 30-35 m (Peshkov, 1993).

In the case of being ruptured, the sandy bar, a vast low-lying area, the height of which is close to mean sea level, could be under threat of inundation. Here we see an example of an extremely quick coastal evolution when quantitative changes turn to qualitative ones. Subsequently the coastal accumulative genesis becomes typically abrasive, with all characteristic elements in its dynamics and structure. In the original natural regime, this process takes many hundred years and it is brought about by large-scale changes in climate and related sediment discharge, wave action and sea-level regimes, etc.

According to paleogeographical reconstructions of the eastern Black Sea coast, such changes are characteristic for transgressions, when due to changing river flow the amount of sediment discharge is sharply reduced and the period of general erosion of beaches and accumulative forms starts.

Detailed investigations of the large mountain rivers in the eastern Black Sea indicate a general degradation of the deltas and adjacent beaches. Among the reasons for the changing erosion of those accumulative forms we can mention the exhaustion of the loose sedimentary cover on the submerged coastal slopes (Menshikov, 1981). According to the data obtained by divers and core sampling, large areas of the nearshore bottom are covered with sand (0.3-0.5 m). In many places ancient deltaic silts and clays exist (Fig. 6). Here they undergo, as mentioned earlier, a quick disintegration due to the action of marine burrowers. Disintegrated loose sediments are resuspended by waves and are transported to the deep sea. The landsliding processes, which are observed when the bottom slope is 0.03, are rather intensive too (Fig. 7).

We should dwell on the reasons for the bed rocks being exposed in the tops of submerged canyons. These forms of bottom relief are widespread on the shelf of the eastern Black Sea coast (Leont'ev & Safjanov, 1973). They cut Holocene weakly consolidated sedimentary strata in their upper parts. Some canyons are formed at a distance of 40-50 m from the shore (at the depth of 6-8 m) and they cross the zone of the beach and bottom sediment migration. According to the data obtained by divers, the thickness of the loose sediments on the tops of some canyons is not large. The outcrops of the sediments from tough silt to compact silty sandstones are often observed on the frontal and side slopes of the canyons. These deposits mark an original bed of the canyons and their position under the strata of more recent sediments. Usually the original rocks are seen at the bench terraces and at cliffs of 10 m height (Figs. 8-9). The cones of crumbling large blocks of sediments can be observed near the foot of the steep walls. They are the products of erosion of the upper part of the slope. Repeated diving has revealed that the shift of the loose masses to larger depths occurs with a rather high speed. In any case, there remains practically no sign of the slides and falls two months later.

In the course of the research between 1970 and 1990, it was revealed that the disintegration of the sediments, which were composed of the original bed, played an important role in the modern evolution of submarine canyons. Being disintegrated, those sediments have a tendency for sliding and falling. The loss of resistance of the steep slopes sometimes results in the fall of large blocks of rocks (several thousand m^3; Zenkovich et al., 1974). Wave action, motion of the water masses, streams and turbidity currents of a low density contribute to loose sediment transport to greater depth. The high geomorphological efficiency of gravity and hydraulic factors is ensured by the steepness of the canyon beds.

When the original bed of the canyon is eroded in its head part, the submerged canyons may move towards the shore. For example, during the last 20 years the canyon Novy (between Mzymta and Psou Rivers) advanced towards the coast with the rate of 0.5-0.7 m/y. Thus, it really has an increasing influence on the sediment balance in the coastal zone. This is confirmed by the formation of typical erosion hollows in the zone under the influence of the canyon.

The causes of modern canyon cutting are not yet clear. One can suppose that this process intensifies when the conditions of sedimentation in the coastal zone and on the shelf change. The steepness of the shelf is rather high on the Caucasian coast and therefore material, brought from the shore, is constantly washed away to the deep sea. As to canyons, they ensure the transit of this terrigenous material as a localized flow. When the flow of sediments entering the coastal zone is reduced, the original relief begins to outcrop in the top parts of the canyons. Then the process that provokes the canyon moving towards the land comes into effect.

The dependence of the canyon evolution on the regime of the coastal-sea sedimentation is probably one of the reasons of their burial during regressions. During such periods the volume of sediment discharge increases greatly at the Black

Sea coast. During transgressions the sweeping of the loose sediments to the depths becomes a predominant process because of the general decrease of the discharge. Thus, a modern stage of canyon cutting coincides with the natural preconditions that may be considered as a consequence of the technological impact on the regime of the coastal sea sedimentation.

CONCLUSIONS

The interdependence and the dynamics of coastal processes determine the sensitivity of coastal zone to any non-natural influence. Recently the anthropogenic one has become a dominant factor, which can be compared with geological factors, and sometimes it is more important than the latter. The anthropogenic influence on a small scale and intensity can cause rather strong reciprocal reactions. The artificial nature of such an impact can be one of the reasons of this effect. The further intensification of economic activity and the actual rise of the World Ocean level demands the determination of the permissible limits of technological interference. The practice has shown that it is rather easier to disturb the relative sediment balance in the coastal zone than to return it to its initial state. This is confirmed by many examples, including those described in this paper. Under the influence of the technological stress, the coastal zone strives for a new balance or a steady state close to it. The consequences of breaking the coastal sediment regime results in such a tendency. Under unfavourable geological conditions, coastal erosion sometimes becomes an irreversible process and affects more and more coastal sections. At the same time the processes that have not been influenced earlier, now become affected and can determine further coastal evolution. The processes involved are abrasion, biochemical weathering and slope erosion. The influence of the bottom biota on the physical-mechanical properties of the relic sedimentary series at outcrop can be so important, that it is not possible to predict the evolution, not only of the bottom relief but also of the coastal zone as a whole.

Thus, the task of the study of the modern dynamics of the sea coast under the anthropogenic stress should include not only the determination of the limits of the technological impact, but also the evolution of those boundaries in time and space. It is additionally important to take into account the possibility of the increasing impacts due to the unforeseen reactions.

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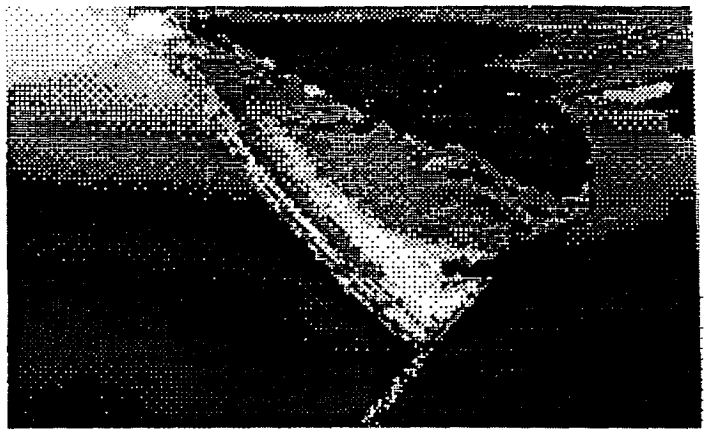
Fig. 1. General character of the coastal change after the construction of the port of Ochamchire. Above: Accretion behind the pier of the Mokva River mouth. Capacity of beach sediments is 12-15,000 m^3/yr.



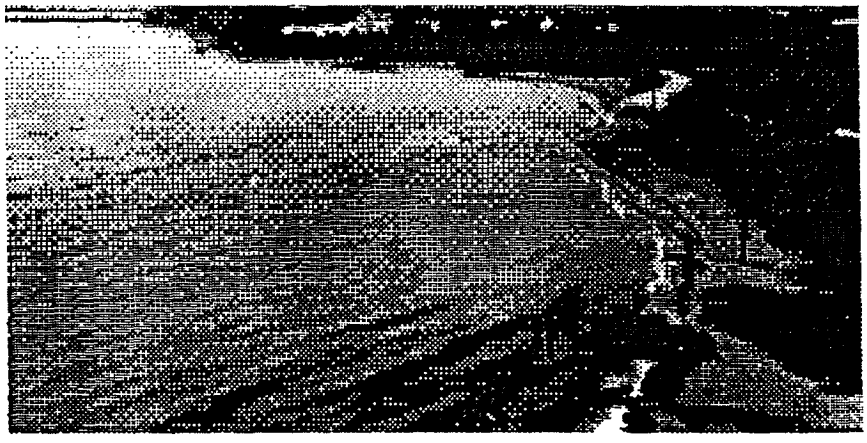
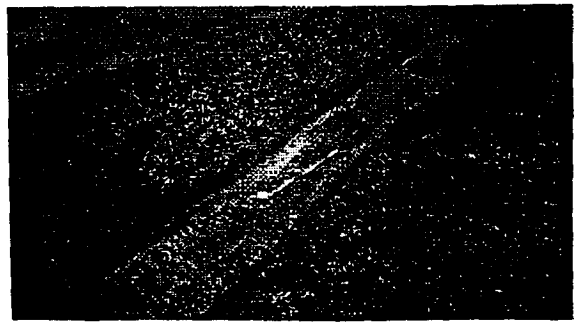
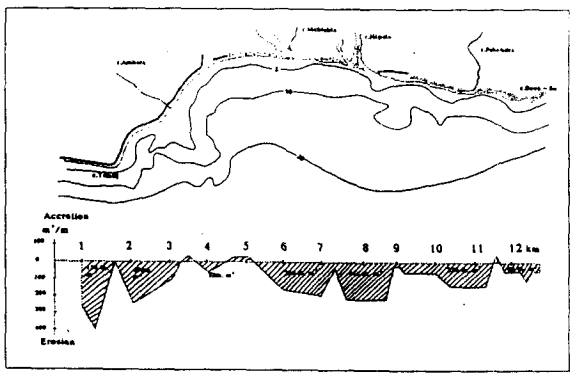


Fig. 2. During a strong storm the whole mass of the beach sediments begin to move and cause abrasion of the underlying layers composed of Majkop clays. Under such a process the original coast can retreat with a rate of several m/yr. One can inhibit this erosion only by full restoration of the beach.

Fig. 3. The exposed surface of the Majkop clays experiences an intensive physical and biochemical weathering (depth is 4-5 m). On the clay's surface the furrows are seen, they have been made by gravel shifting along the bottom during storm.





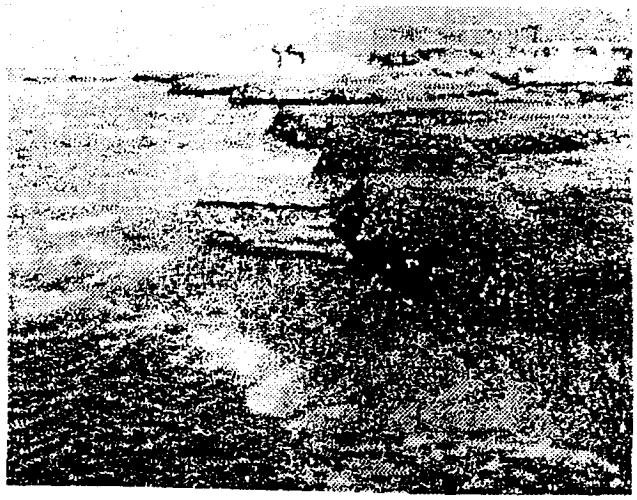


Fig. 4. The volume of the original shore corrasion between Tolsty Cape and Souk-Su Cape due to corrasion and weathering of the Majkop clays and Pleiocene conglomerates was $1.2 \times 10^6 m^3$ from 1968 to 1982. Any attempts to protect this coast by means of hydrotechnical erections are doomed to fail, since this process is irreversible, and concerns covered a wide belt of the bench to the depth of 4-5 m. An appropriate solution of this problem is possible by the restoration of beaches and maintenance of an active sediment balance in the coastal zone.

Fig. 5. A general view of the coast in the southern outskirts of Gagra town in March, 1982. Only several years ago there was a wide sandy-gravel beach. After its outwash, peat became uncovered in the surf zone (the upper black layer) on clays with the thickness of 11 m.

Fig. 6. Outcrops of weakly compacted clays on the near issue section of the large mountain river (the depth is 7-8 m; Photo of V. Menshikov).

Fig.7. As a result of disintegration, weakly compacted clays became disposed to slide and fall. The bottom section at the depth of 8 m (slope is 0.03) is shown. (Photo of V. Menshikov).

Fig. 8. A fragment of a steep slope of the submarine canyon in the south-eastern Black Sea. The depth is 15 m. (Photo of V. Menshikov).

Fig. 9. Planes of teared off of sliding masses at the top of one of nearby canyons in the eastern Black Sea coast. (The depth is about 15 m). After the disintegration a loose mass is shifting as a gravity flow (Photo of V Menshikov).

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SESSION VI

Short-Term Mechanisms, Processes & Modelling

Session VI-b
Modelling

Chairman: C. Wu & A.Y. Le Roux
Rapporteur: R.D. Kos'yan

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CALCULATION OF LONGSHORE SEDIMENT TRANSPORT RATE

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KEYWORDS: Sediment transport, wave elements, longshore current, beach development, coastal engineering.

ABSTRACT
By adopting M.S. Longuet-Higgins and P.D. Komar's research on the determination of the velocity field and based on the conception of sediment motion under wave and current action, equations on the capacity of sediment transport were set up. According to the different composition of wave and current actions, the calculation of the longshore sediment transport rate is gradually carried on. These are combined and compared with E.W. Bijker's, Xie Shileng-Liu Defu's and the American Coastal Engineering Research Centre (CERC)'s calculation achievements, and applied to field data of the Nouakchott coast, Mauritania and the Golden Sand Beach of the Bulgarian Black Sea. A preliminary verification is carried out. It appears that the theory and the method of calculation of longshore sediment transport rate in this paper is feasible.

1. THE CALCULATING MODELLING OF LONGSHORE SEDIMENT TRANSPORT RATE

The general calculating equation for longshore sediment transport rate may be written as

$$q_T = \int_0^h cu\,dz \tag{1}$$

where, q_T = the longshore sediment transport rate per unit width;

c, u = sediment concentration and longshore velocity on the arbitrary point of z respectively (Fig.1);

h = water depth.

These hydraulic factors mentioned above are all the mean value in time being much bigger than the wave period T.

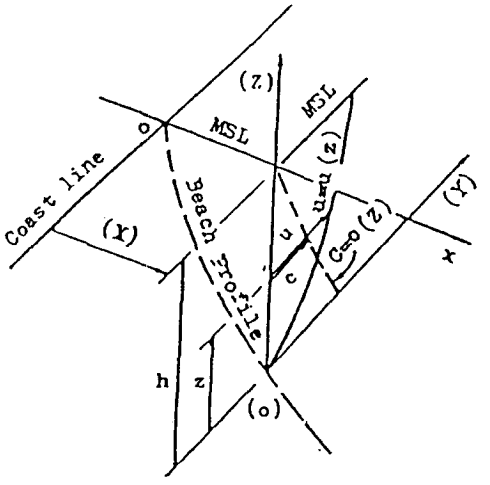

Fig. 1 The Illustration of Calculation Modelling

2. CROSSWISE DISTRIBUTION OF THE LONGSHORE MEAN VELOCITY

Based on radiative stress theory, M.S. Longuet–Higgins under the condition of no consideration of increased water effect of wave, the equation from reference (5) as follows:

$$\overline{V}=\begin{cases} B_1\overline{X}^{P_1}+A\overline{X}, & \overline{X}\leqslant 1; \\ B_2\overline{X}^{P_2}, & \overline{X}>1. \end{cases} \tag{2}$$

where, $\overline{V},\overline{X}$ = dimensionless variables;

$\overline{V}=v/v_0;\overline{X}=x/x_b$;

v = mean longshore velocity along the water depth;

$v_0=\frac{5\pi}{16}\cdot\frac{r}{f}(gh_b)^{1/2}(tg\beta\cdot sin\theta_b)$;

x = the crosswise coordinate;

x_b = the width position of breaker line far from the shore line;

r = H / h;

H = wave height;

h = water depth;

f = friction coefficient of bed surface which may be taken at the place of stronger wave from reference (6) as follows:

$$f=\begin{cases} exp[-5.77+5.213\left(\frac{a_b}{r_s}\right)-0.104] & 1.47<a_b/r_s<3000; \\ 0.32 & a_b/r_s\leqslant 1.47 \end{cases} \tag{2a}$$

$a_b=\frac{H}{2}\cdot\frac{1}{sh\frac{2\pi h}{L}}$, wave amplitude near the bed surface; (2b)

$r_s=120d_{50}$ suggested by Nielson and Green[6];

g = gravity acceleration;

h_b = breaker water depth;

β = sea bed slope angle;

θ = incident angle of breaker;

$B_1=\frac{P_2-1}{P_1-P_2}A$;

$B_2=\frac{P_1-1}{P_1-P_2}A$;

$P_{1,2}=-\frac{3}{4}\pm\left(\frac{9}{16}+\frac{1}{P}\right)^{\frac{1}{2}}$

$A=\left(1-\frac{5}{2}P\right)^{-1}$

$P=\frac{\pi N tg\beta}{rf}$ *crosswise mixing coefficent*;

N = a parameter.

Due to the value of N is not a definite parameter, so, the value of P is also a coefficient undecided. The Figure 2 taken from reference (5) expresses the different value of P corresponding to crosswise distribution of longshore mean velocity.

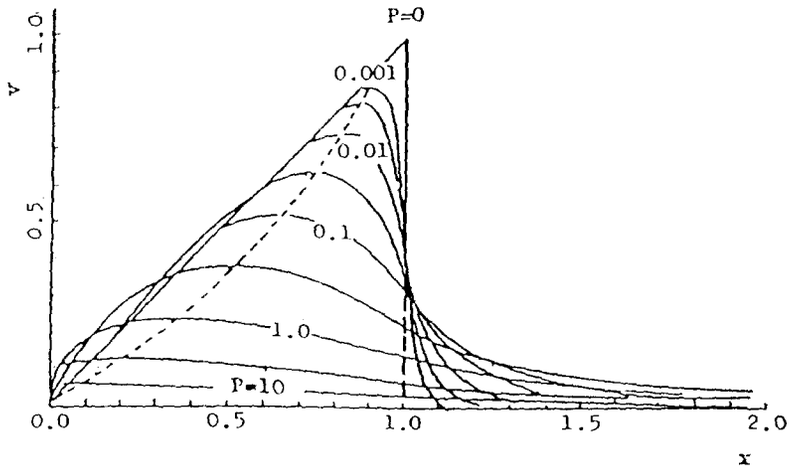

Fig. 2 Theoretiacl Solution of Longshore Velocity Field in Different Value of P by Longuet–Higgins

3. THE VELOCITY DISTRIBUTION ALONG THE WATER DEPTH

In calculation, we assume that according to the accomplishment from reference (9), the velocity distribution along water depth may be writen:

$$u = v + \frac{u_*}{K}\left(1 + 2.3lg\frac{z}{h}\right) \tag{3}$$

where, u = longshore velocity on the arbitrary point of z (calculating upward from the bed surface);

$u_* = \sqrt{\frac{\tau_c}{\rho}} = \sqrt{ghJ}$, shearing velocity or called "moving sediment factor"[7,10]; (3a)

$\tau_c = \bar{\gamma}hJ$, shearing stress acted on the bed surface; (3b)

$\bar{\gamma} = \bar{\rho}g$, mean value of the specific gravity of turbid water; (3c)

$\bar{\rho}$ = mean value of density of turbid water;

J = hydraulic grdient;

$k = \left[\frac{1}{k} + 1.14\frac{(\gamma_s - \gamma_w)(\bar{w} - vJ)}{\gamma_w u_* J}\bar{C}\right]^{-1}$ Karman constant[9]; (3d)

$K_w = F\left(\frac{v}{u_*}, C_\delta\right)$, (3e)

the partial variation of Karman constant due to the bottom condition of sediment–laden flow;

C_δ = sediment concentration on the surface of bed layer by volume ratio;

$\delta = h \times 10^{-\frac{1}{2.3}\left(\frac{1}{2}\frac{v}{u_*}k+1\right)}$, thickness of the bed layer (3f)

γ_s, γ_w = specific gravity of sediment and clear water respectivesly;

$\bar{W}$ = mean value of settling velocity of sediment along the water depth;

$\bar{C}$ = mean sediment concentration of suspended load (by valume ratio).

The definition of the rest of symbols is as mentioned above.

4. THE DISTRIBUTION OF SEDIMENT CONCENTRATION ALONG THE WATER DEPTH

According to the analytical results of the sediment diffusion theory the distibution of sediment concentration along the water depth may be written as follows:

$$\frac{C_z}{C_\delta} = \left[\frac{\delta}{h-\delta}\frac{h-z}{z}\right]^{\frac{w}{Ku_*}_T} \tag{4}$$

where, C_z = sediment concentration on the arbitrary point of z (by volume ratio);

C_δ = sediment concentration on the suface of bed layer ($z = \delta$) which may be determined according to the equation (5n);

w = the settling velocity of sediment particle;

$$u_{*T} = \left[\left(\frac{u_{**}}{u_*}\right)^2 + \frac{f}{2}\left(\frac{U_0}{u_*}\right)^2\right]^{1/2} u_*,$$

shearing velocity, or called "sediment carrying factor" in this paper[10]; (4a)

f = friction coefficient of bed surface (equation 2a)

$$u_{**} = \left[1 + \alpha_0\left(\frac{h}{2u_*^2}\left|\frac{\partial v^2}{\partial x}\right| + \frac{h}{u_*^2}\left|\frac{\partial v}{\partial t}\right|\right)\right]^{1/2} u_* \tag{4b}$$

α_0 = one coefficient;

$U_0 = \pi H / Tsh\frac{2\pi h}{L}$, the maximum orbital velocity of wave near the bottom;

H = wave height;

T = wave period;

L = wave length.

The significance of rest symbols is as mentioned above.

5. THE EQUATION OF LONGSHORE SEDIMENT TRANSPORT RATE [9,10]

The general equation of longshore sediment transport rate may be written as follows:

$$q_T = q_s + q_b = \int_\delta^h cudz + \int_0^\delta cudz \tag{5}$$

where, $q_T = \int_0^h$ cudz, sediment transport rate per unit width; by volume (5a)

$q_s = \int_\delta^h cudz$,

transport rate of suspended load per unit width by volume; (5b)

$q_b = \int_0^\delta cudz$,

transport rate of bottom sediment per unit width by volume; (5c)

Substituting the equation (3) and (4) into (5b), the transport rate of suspended load may be derived as follows:

$$q_s = \alpha u_* c_b \cdot \delta\left[4.62\left(2 + \frac{1}{\alpha K}\right)I_{1T} + \frac{4.62}{\alpha K} I_{2T}\right]; \tag{5d}$$

where, $\alpha = \frac{1}{2}\frac{\nu}{u_*}$

$$I_{1T} = 0.216\frac{A^{z_{*T}-1}}{(1-A)^{z_{*T}}}\int_A^1\left(\frac{1-z}{z}\right)^{z_{*T}} dz; \tag{5e}$$

$$I_{2T} = 0.216\frac{A^{z_{*T}-1}}{(1-A)^{z_{*T}}}\int_A^1\left(\frac{1-z}{z}\right)^{z_{*T}} lnzdz; \tag{5f}$$

$A = \delta / h$; (5g)

$z_{*T} = \frac{w}{Ku_{*T}}$; (5h)

Assuming that the speed of sediment motion in bed layer is the same with its surrounding water and the vertical distribution of longshore velocity and sediment concentration are changed by linearity in the bed layer, the transport rate of bed load will be derived as follows [10]:

$$q_b = \int_0^\delta cudz = \frac{S_*}{6}\alpha u_* C_b \delta \tag{5i}$$

where, $S_* = 0.033 d_{50}^{-0.603}$, ($d_{50}$—mm); correct coefficient of bed load derived from the Einstein's results and the experimental data from Tianjin New Harbour, Tianjin, China [10].

$$C_b = \begin{cases} = \dfrac{-0.0064 + \sqrt{4.1 \times 10^{-5} + 0.39\tau_{bT}}}{0.196} \\ \leqslant C_m = 0.755 + 0.222 lg d_{50}, d_{50} \geqslant 0.02mm, \\ \text{bed suface concentration of sediment;} \\ \leqslant C_K = 15.4 d_{50} + 0.07, d_{50} < 0.02\text{mm, by volume ratio} \end{cases} \tag{5k}$$

$\tau_{bT} = \bar{\rho} u^2_{*T}$, shearing stress on the bed surface due to wave and current; (5l)

and $\bar{\rho}$ = mean density of turbid water.

Substituting (6d), (6i), into (6), the equation of sediment transport rate may be written into partial accumulation form as follows:

$$q_T = \sum_{i=1}^{n} q_{Ti} = \alpha u_* \delta \sum_{i=1}^{n} q_{Ti} \{[4.62(2 + \frac{1}{\alpha K}) I_{1Ti} + \frac{4.62}{\alpha K} I_{2Ti}] + \frac{S_{*i}}{6} C_{bi}\} \tag{5m}$$

The above equation is the longshore sediment transport rate per unit width in coast zone.

$$in \text{ which, } C_{\delta i} = i_b C_b f\left(\frac{w_i}{u_{*T}}\right) \tag{5n}$$

i_b = proportion of sediment with settling velocity w_i in the composition of bed materials. The diagram of equation (5n) is shown in Fig.3 [8,9]

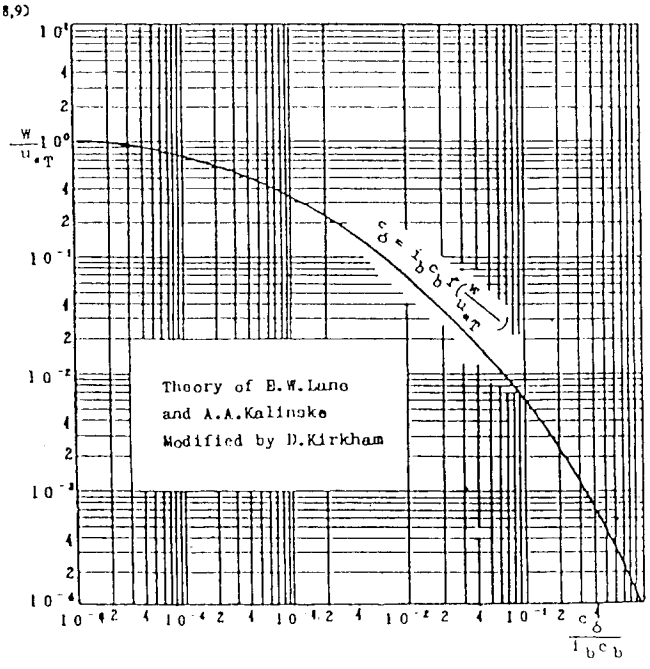

Fig.3 The Calculating Diagram of C_δ on the Surface of Bed Layer

6. ANALYTICAL CONTRAST WITH THE RESULTS FROM E.W. BIJKER

Bijker carried out the checking for the following data under several conditions [2]. The beach profile belongs to a sand coast; the mid diameter of the bed material d_{50} = 0.2mm; wave height of deep water H_0 = 2.0 m and wave period T = 7.0s as well as the uniform slope 1 / 100.

(1) The Fig.4 shows the velocity field of longshore current under 6 kinds of different calculation modelling. The results of checking calculation of longshore sediment transport rate by Bijker Modelling as shown in Fig.5.

(2) Corresponding to the above 6 kinds of different calculation modelling, the checking results of longshore sediment transport rate calculated in this paper is shown in Fig.6.

(3) Fig.6A–6F showing the calculation comparison between the results of longshore velocity and the crosswise distribution of sediment transport rate per unit width in this paper and Bijker respectively.

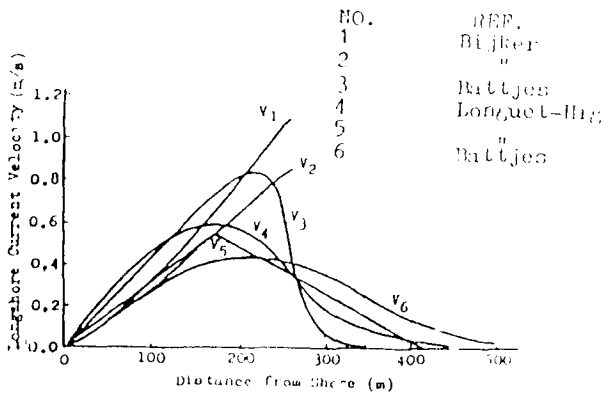

Fig.4 Velocity Field of Longshore Current under 6 Kinds of Different Calculation Modelling

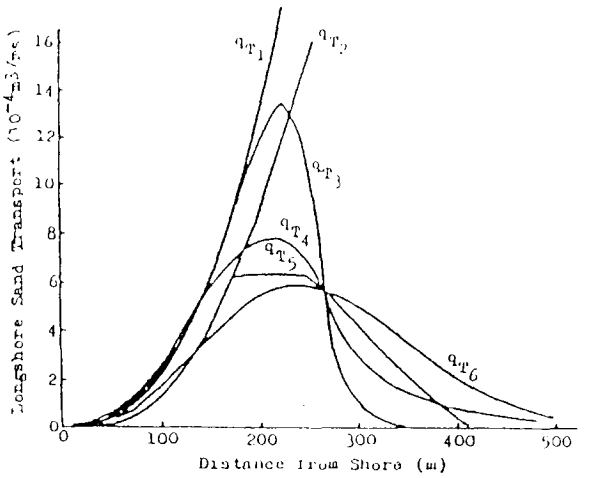

Fig.5 The Checking Calculation Results of Corresponding 6 Kinds of Velocity Field and Longshore Sediment Transport Rate per Unit Width by E. W. Bijker

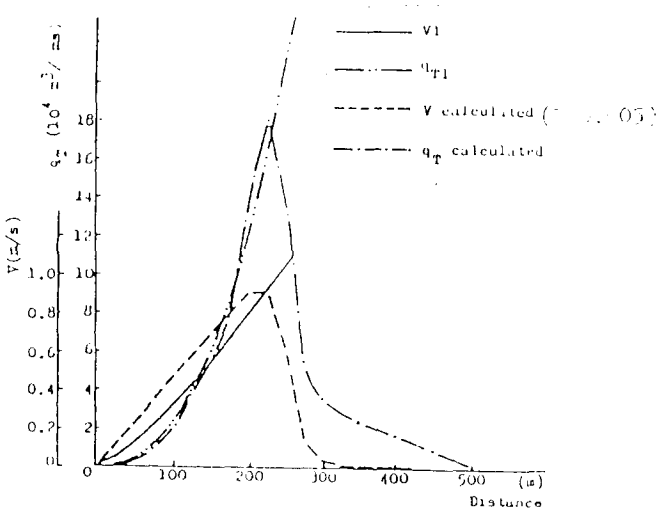

Fig.6A Condition I Comparison between the Results of Calculation in this paper and from Bijker

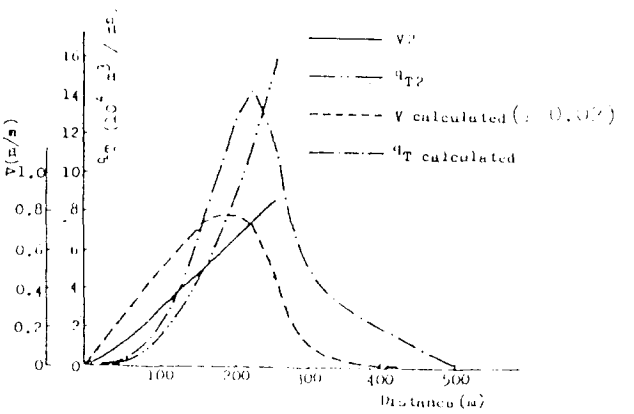

Fig.6B Condition II Comparison between the Results of Calculation in this paper and from Bijker

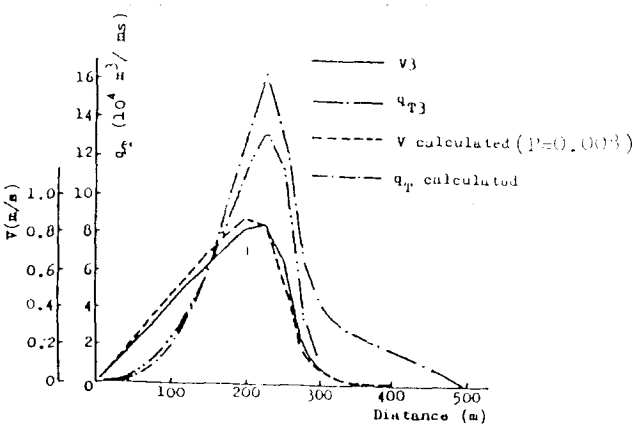

Fig.6C Condition III Comparison between the Results of Calculation in this paper and from Bijker

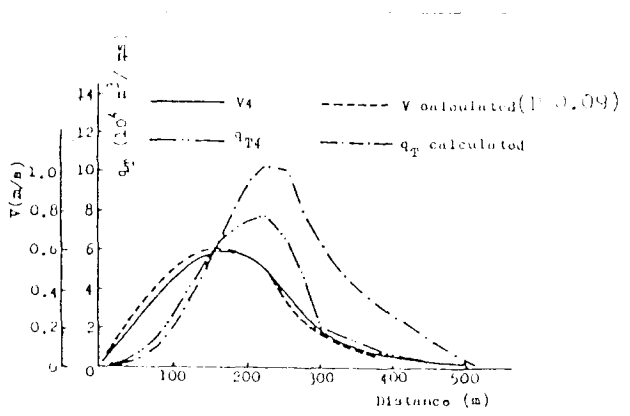

Fig.6D Condition IV Comparison between the Results of Calculation in this paper and from Bijker

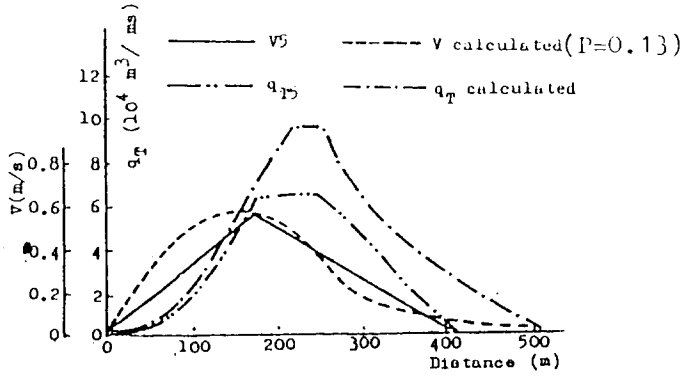

Fig.6E Condition V Comparison between the Results of Calculation in this paper and from Bijker

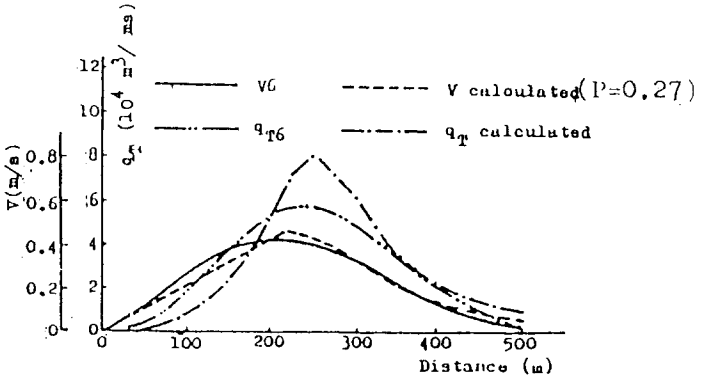

Fig.6F Condition VI Comparison between the Results of Calculation in this paper and from Bijker

(4) Table 1 illustrates the comparison between the longshore sediment transport rate calculated in this paper under the various conditions and from Bijker.

Table 1 Comparison of the Results of Longshore Sediment Transport Rate Calculated by Some Ways (m^3 / s)

	Bijker	This Paper	CERC	Xic
1	0.179	0.229	0.314, $K_0=0.036$;[2]	0.238 $r_*=0.04$
2	0.123	0.224		
3	0.132	0.228		
4	0.159	0.211		
5	0.143	0.204		
6	0.146	0.154		

7. COMPARISON BETWEEN THE RESULTS OF THE EQUATION OF AMERICAN COASTAL ENGINEERING RESEARCH CENTRE (CERC) AND THE RESULTS IN THIS PAPER

The calculating equation of longshore sediment transport rate is shown as follows. [2]

(1) $$Q_T = K_0 H_0^2 C_0^2 K_{rbr}^2 \sin\varphi_{br} \cdot \cos\varphi_{br} \tag{6}$$

where, Q_T = longshore sediment transport per year by volume (m^3 / year)

C_0 = wave velocity (m / s);

K_{rbr} = refractive coefficient of breaker line;

φ_{br} = incident angle of breaker;

K_0 = empirical coefficient;

and H_0 = wave height in deep water.

(2) The comparison results of the equation (6) for the value of $K_0=0.036$ illustrated in the Table 1.

8. COMPARISON BETWEEN THE XIE–LIU'S ACHIEVEMENTS [13] AND THE RESULTS IN THIS PAPER

(1) The equation adopted by Xie–Liu

The equation of longshore sediment transport rate may by obtained from the reference [13] as follows:

$$q_T = 1.83 q_* \{[I_1 \ln\left(\frac{33h}{r_*}\right) + I_2] + 1\} \tag{7}$$

$$where, q_b = 5 d_{50} \frac{v}{C} g^{1/2} exp\left\{ \frac{-0.27 \Delta d_{50} \rho g}{\mu \tau_c [1 + \frac{1}{2}(\zeta \frac{u_0}{v})^2]} \right\} \tag{7a}$$

longshore sediment transport rate of bed load per unit width;

$$C = 18 lg\left(\frac{12h}{r_a}\right) \tag{7b}$$

$$\Delta = \frac{\rho_s - \rho}{\rho} \tag{7c}$$

$\rho_s \rho$ = density of sediment and clear water respectively;

$$u = (C / C')^{3/2} \tag{7d}$$

$$C' = 18 lg\left(\frac{12h}{d_{90}}\right) \tag{7e}$$

I_1, I_2 = H.A.Einstein's integrals;

$$\xi = C\left(\frac{f}{2g}\right)^{\frac{1}{2}} \tag{7f}$$

and the definition of rest symbols is the same with above mentioned. The relationship between the parameter r and longshore sediment transport rate q in equation (7) was shown in the Fig.7.

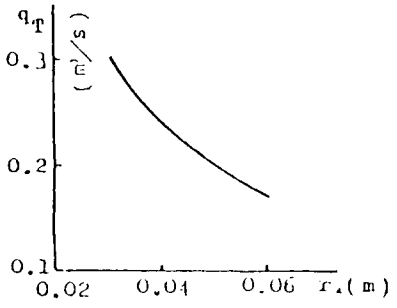

Fig.7 The Relationship between the Parameter r_a and Longshore Sediment transport Rate q_T

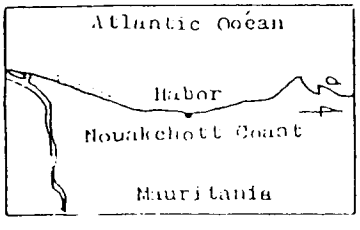

Fig.8a Sketch of the Geographical Location of the Nouakchott Coast, Mauritania (Befer Eng'g in 1976,1977)

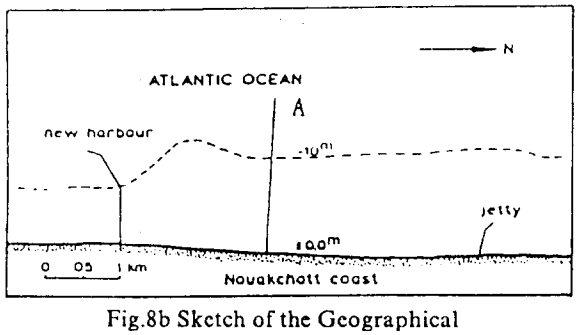

Fig.8b Sketch of the Geographical Location of the Nouakchott Coast, Mauritania (After Eng'g in 1986)

(2) The contrast result of corresponding calculation illustrated in the Table 1.

Basing on the results as mentioned above, it may be found out as follows:

(a) The difference of current field to the variation of crosswise distribution of sediment transport rate is comparatively apparent, the influence of longshore sediment transport rate is maximum up to 21.8% by Bijker and by the modelling in this paper is maximum up to 25.9%;

(b) In the Table 1, the longshore sediment transport rate 0.229 m^3/s calculated in this paper is near to Xie's results 0.238 m^3/s, but biger than Bijker's results;

(c) Under the six kinds in different conditions, the calculation results of this paper are at the middle between Bijker and CERC ($Q_T = 0.314$, $K_0 = 0.036$ [2]).

9. LIVING EXAMPLE CALCULATION

(I) Nouakchott Coast of Mauritania

(1) Description of the Coast Outline

Nouakchott coast belongs to a stable alluvial coast, the coast line is horizontally straight; the water area is wide; That the bed contour line is basically parallel with coast line is approximately toward north and south and the beach profile is as shown in the Fig.12 . There is a coastal submarine sand bar and trough under the water near the coast.

Nouakchott coast is acted by intense wave longshore current with the direction from the north toward the south. The Fig.9, 10 and 11 are the diagram of wave roses observed at−9m contour by the methed of wave Measuring Pole in 1976, 1977 and 1986 respectively. It may be seen that the wave direction concentrates between NNW−W, among them the frequency of NW is the highest occupying one half of the total approximately, the coast is giving the priority to the action of wave and the tide action is smaller. Based on the field measurement, it is expressed that at the place of contour line of equal depth−9m the maximum velocity of tide current is about 0.18m / sec, which the longshore velocity will be several times smaller than it due to the broken wave in surf zone.

The mid diameter of sediment d_{50} of beach profile in surf zone is approximately 0.2 mm and there has been the yearly drift moving from the north to the south. The sediment mobile zone is limited within the−8m contour line.

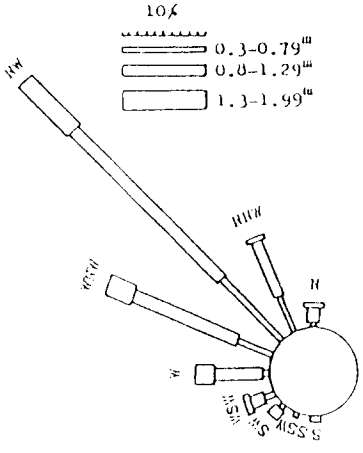

Fig.9 The Diagram of Wave Rose at Nouakchott Coast in 1976 (measured at−9m)

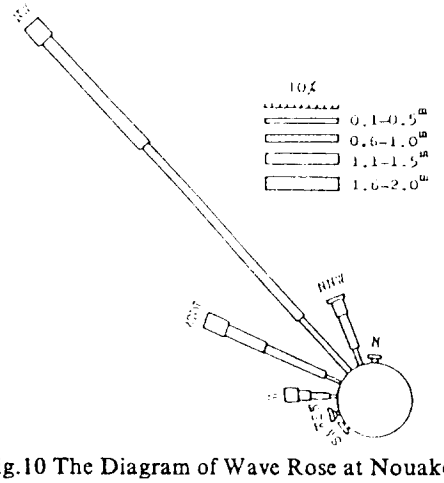

Fig.10 The Diagram of Wave Rose at Nouakchott Coast in 1977 (measured at−9m)

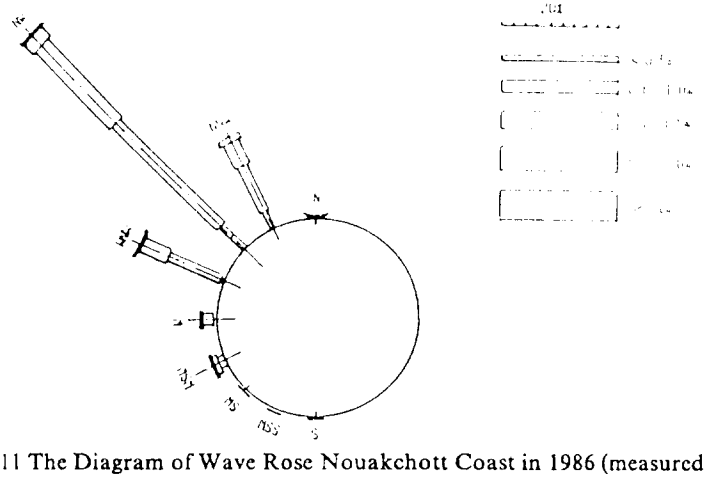

Fig.11 The Diagram of Wave Rose Nouakchott Coast in 1986 (measured at−9m)

At the sea bed outside the−8m contour is composed of pebbles and shells coated with mud, which give rise to

black colour and offensive odour and is generally not liabl to be moved. Inside the place−8m contour especially the surf zone, the bed material is clear sand particle, the sediment motion is intense. So we may deem that the place of−8m contour is the bounds of sediment motion.

At the Friendship Harbor located at the Nouakchott Coast, there has been the carrying on of a series of federal observation to the wave, the current velocity, sediment concentration, beach profile, ect.

In the design of the New Harbor Nouakchott that the longshore sediment transport rate adopted 60−90 ten thousand cubic meters per year which was determined from the field data in 1976 by means of the geomorphological method and the result calculated by the equation of the American Coastal Engineering Research Center (CERC) as well as the method of synthetic analysis.

After the coast engineering as shown in the Fig.8b, the breakwater with 1550 m long was completed in 1986. Measuring results of the configuration development for two times from Jan to Dec. of 1986, we obtained the sediment deposition between the construction and the section A shown in Fig.8b being 360000 m^3.

We choose section A to carry on the longshore sediment transport calculation on the beach profile of section A with a mean slope of 1 / 23, there is no sand bar and trough under the surface of the mean sea level, which is different from the condition of 1976 and 1977 befer engineering.

(2) The Resistance Coefficient f of Bed Surface, the Bed Roughness r_a and the Index γ_b of Breaker.

From the mid diameter of bed material $d_{50}=0.2$ mm, the bed roughness is [6], $r_a=120d_{50}=120\times0.2=0.024$m.

The wave is much more stronger than the tide current, so the resistance coefficient may adopt equation (2a).

Based on the characteristics and position of the broken wave in Nouakchott coast and referred to the documents concerned, we take the index of breaker agreed well with recent value in the USA as follows:

$$\gamma_b=H_b/h_b=0.80$$

(3) The Crosswise Mixed Coefficient P.

During the determination of the crosswide mixed coefficient P, we adopted the statistical data from the observation of the longshore current velocity on the Nouakchott coast (as Fig.12). The incident angle of wave is chiefly at 45° including ± 22.5° and T = 5−8 second. When the principle of least square method to determine the value of P is adopted, we used four kinds of characteristic wave height, namely: $H_{\frac{1}{10}}$, the meanvolue of $\frac{1}{10}$ bigger wave height; $H_{\frac{1}{3}}$, the effective wave height and mean wave height $\overline{H}$ as well as the mean square root wave height H_r.

Basing on the comparison between the calculating velocity and the field data, we adopt $H_{\frac{1}{10}}$ as the characteristic wave in calculation, and according to the accomplishment suggested by Goda [3], we make its period being $T_a=1.1\overline{T}$ which is the mean value of wave period.

In calculation, we have the wave height divided into three grades and the following have been taken separately:

$H_1=0.8$ m (0.6 − 1.0 m);

$H_2=1.3$ m (1.1 − 1.5 m);

$H_3=1.8$ m (1.6 − 2.0 m).

The statistical results of observation data expressed that the mean period of wave $\overline{T}=7.32$ sec. So, the period of the characteristic wave $T_a=1.1\times7.32=8.05$ s.

Based on the observation data of wave, we take the incident angle of wave measurement from the station as $\theta=45°$.

As shown in the Fig.12, the beach profile is modelled. Combining the testing calculation, the mean value of the crosswise mixing coefficient P may be obtained as shown in Fig.12, P = (0.08+0.13+0.11) / 3 = 0.1067.

(4) The Elements of Breaker and Crossiwse Distribution of Longshore Velocity

Based on the results as mentioned above, the calculation of breaker elements and the crossiwse distribtions of longshore velocity as in the Table 2 and Fig. 13 are carried out.

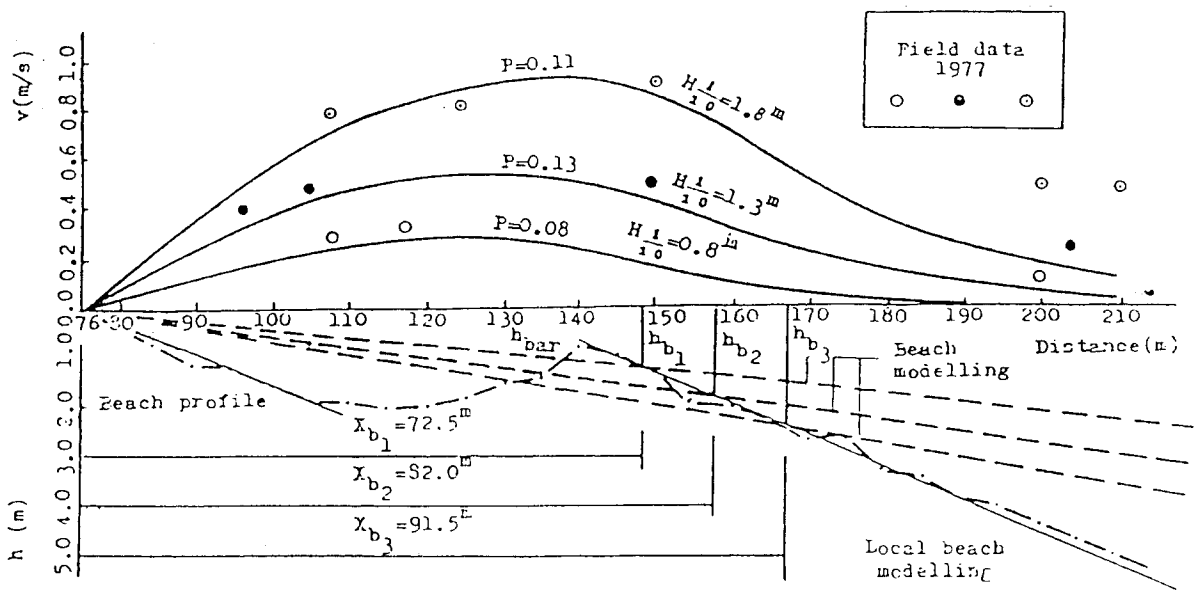

Fig.12 The Modelling of Beach Profile and the Determination of the Value of P at the Nouakchott Coast

Table 2 The calculating Results of Breaker Elemennts

Incident Wave $H_{\frac{1}{10}}$ (m)	X_b (m)	h_b (m)	θ_b (Degree)
0.8	148.5	1.25	16.32
1.3	158.0	1.85	19.83
1.8	167.5	2.44	22.80
L_b (m)	C_b (m / sec)	H_b (m)	n_b
27.83	3.46	1.00	0.974
33.58	4.17	1.50	0.962
38.36	4.77	1.98	0.951

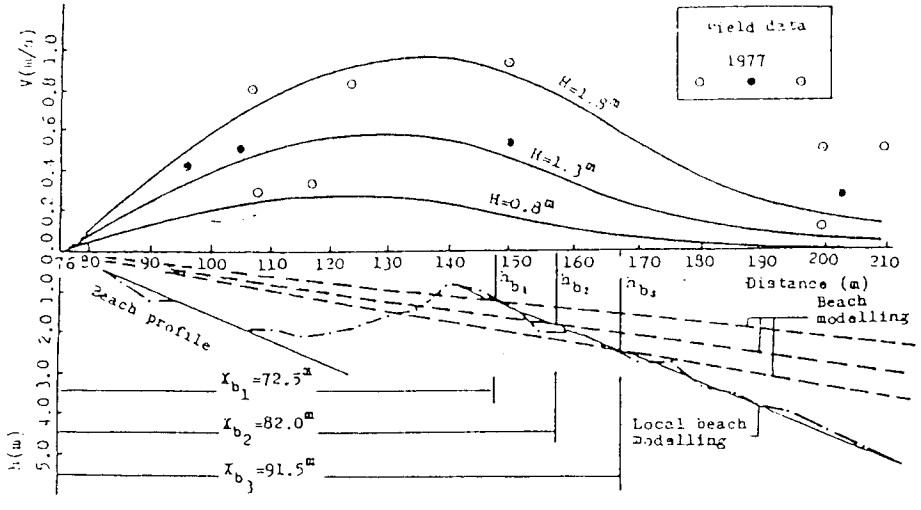

Fig. 13 When at P = 0.1067, the Calculation Results of Crosswise Distribution of Longshore Current Velocity

(5) The Crosswise Distribution of Longshore Sediment Transport Rate per Unit Width.

We may obtain the crosswise distribution of longshore sediment transport rate per unit width under the conditions of the different wave height and the incident angle of wave. As an example, the calculation results were obtained as shown in Fig.14 at the condition of P = 0.167, T_s = 8.05 sec and θ = 45° as well as the incident wave height H = 0.8 m, H = 1.3 m and H = 1.8 m respectively.

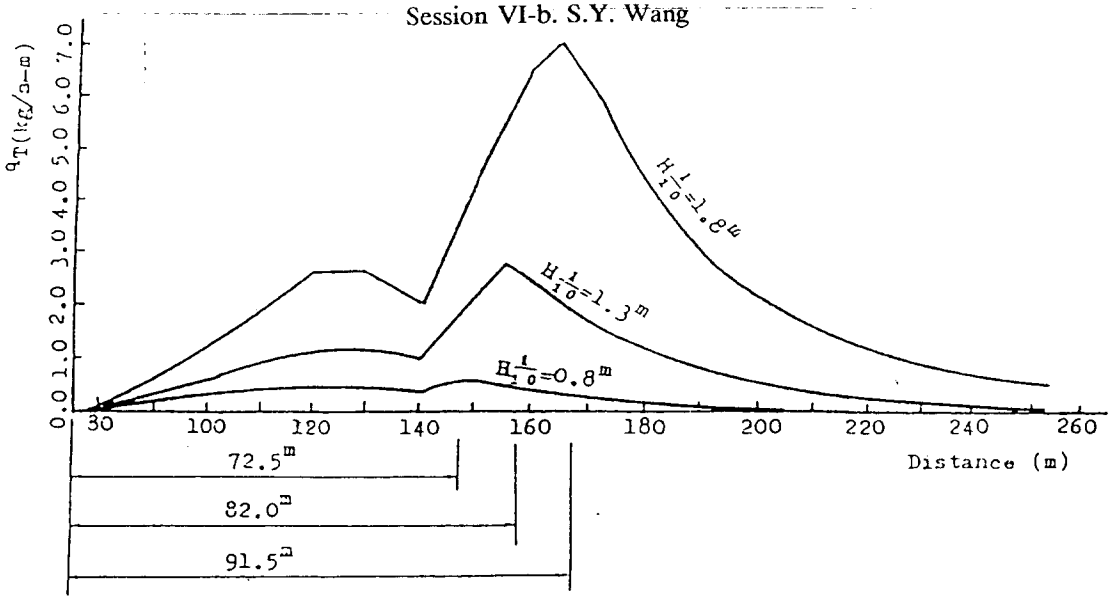

Fig.14 Crosswise Distribution of Longshore sediment Transport Rate per Unit Width shown as an Example

(6) The Verification of the Crosswise Distribution of Sediment Concentration.

The comparison between the calculating result and field data processed in Reference (15) is shown in Fig.15.

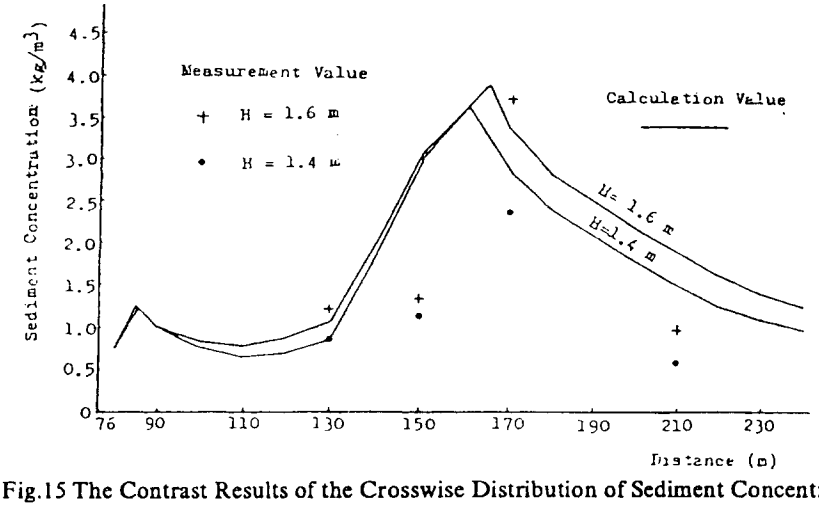

Fig.15 The Contrast Results of the Crosswise Distribution of Sediment Concentration

(7) Discharge of Longshore Sediment Transportation in 1977

We have the wave data of 1977 divided into sixteen directions and four grades. According to the distribution of wave elements, we can obtain the longshore sediment transportation as shown in Table 3.

(8) Discharge of Longshore Sediment Transportation in 1976

The value of crosswise mixing coefficient P=0.1067 tested in the data of 1977 is still adopted. In calculation, it is different that $T_s = 1.1\ \bar{T} = 1.1 \times 9.8 = 10.78$ sec and the distribution of the wave rose diagram as shown in Fig.9. In the same way mentioned above, we can have the discharge of longshore sediment transportation as shown in Table 4.

(9) Discharge of Longshore Sediment Transportation in 1986

The crosswise mixed coefficient of longshore current in calculation is still taking P=0.1067, the wave period $T = 1.1 \times \bar{T} = 1.1 \times 6.795 = 7.475$(s) and the diagram of wave rose is shown in the Fif.11. The calculation results of the crosswise longshore velocity distribution and the sediment transportation per unit width as shown in the Fig.16, Fig.17 and Table 5 are corresponding to the wave direction NW and wave height H=0.8, 1.3, 1.8 and 2.0(m) respectively.

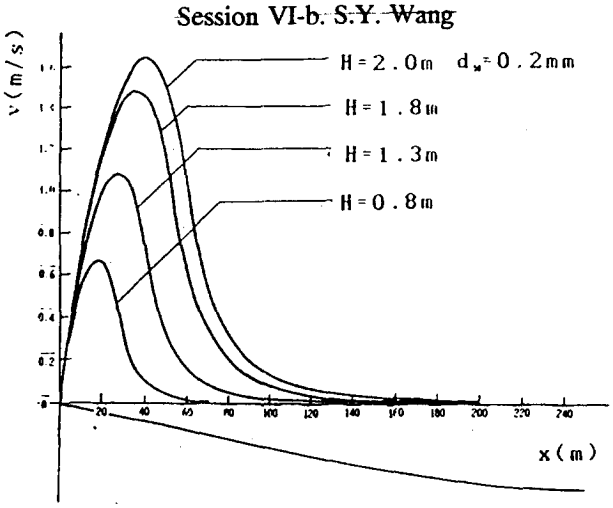

Fig.16 Crosswise Distribution of Longshore Current Velocity in 1986 for a Special Case

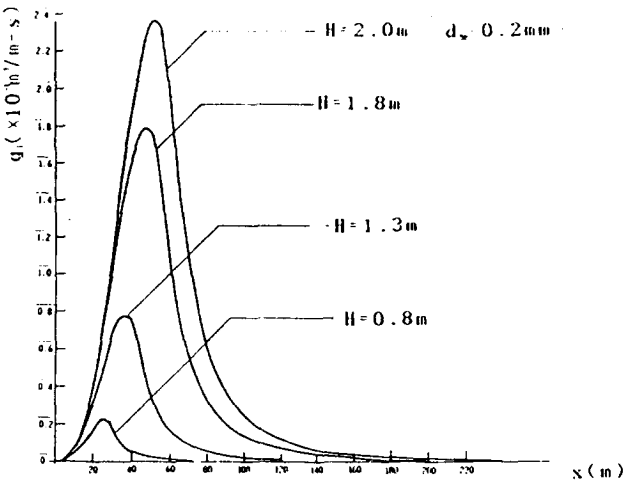

Fig.17 Crosswise Distribution of Longshore Sediment Transportation per unit width in 1986 for a Special Case

(10) Throught the Calculation Results in Table 3, Table 4 and Table 5, we can sum up as Follows:

(a) Based on the beach modelling and the field data, adopting the least square method, the mixing coefficient P is 0.1067.

(b) Using the four kinds of characteristic wave height $H_{\frac{1}{10}}$, $H_{\frac{1}{3}}$, $\overline{H}$ *and* H_r to carry out the calculation of longshore current, the results expresses that it is much more approximate to the measurement field data and the value of P is also comparatively stable (as the Fig.12), when the value of $H_{\frac{1}{10}}$ was used.

Table 3 The Calculating Results of Longshore Sediment Transportation in 1977

	Q_s $(10^4 m^3/yr)$	Q_b $(10^4 m^3/yr)$	(Q_s+Q_b) $(10^4 m^3/yr)$	$\frac{Q_b}{(Q_s+Q_b)}$
Q_{s0}	83.62	9.79	93.41	10.48%
Q_{n0}	3.27	0.34	3.61	9.42%
$Q_{s0}+Q_{n0}$	86.89	10.13	97.02	10.44%
$Q_{s0}-Q_{n0}$	80.35	9.45	89.80	10.52%
$\frac{Q_{s0}}{Q_{s0}+Q_{n0}}$	96.24%	96.64%	96.28%	

Note: Q_{s0}— Sediment transport rate from the north to the south;

Q_{n0}— Sediment transport rate from the south to the north;

Table 4 The Calculating Results of Longshore Sediment Transportation in 1976

	Q_s ($10^4 m^3/yr$)	Q_b ($10^4 m^3/yr$)	(Q_s+Q_b) ($10^4 m^3/yr$)	$\frac{Q_b}{(Q_s+Q_b)}$
Q_{s0}	73.61	10.00	83.61	11.96%
Q_{n0}	8.84	1.15	9.99	11.51%
$Q_{s0}+Q_{n0}$	82.45	11.15	93.60	11.91%
$Q_{s0}-Q_{n0}$	64.77	8.85	73.62	12.02%
$\frac{Q_{s0}}{Q_{s0}+Q_{n0}}$	89.28%	89.69%	89.33%	

(c) It may be known from Table 2 that the mean incident angle of breaker is about 20 ° or so.

(d) It may be known from the Fig.14 that the maximum value of longshore sediment transport rate per unit width is appearing near the breaker line and declining its value rapidly outside the breaker line. The longshore sediment transportation appears mainly within the level of beach profile−4 m, especially the surf zone. Outside the −8m contour, the value of longshore sediment transport rate per unit width is very small and may be ignored in consideration.

(e) It may be known from the Table 3 and 4, the value of longshore sediment movement from the north to the south occupying over 90% and the bottom sediment movement occupies 9% − 12% of the total.

(f) The comparison between the results from the Field data and the calculation is set up. We can see that from the above contrast results, the discharge of longshore sediment transportation as shown in Table 6.

Table 5

	Q_s $10^4 m^3/yr$	Q_b $10^4 m^3/yr$	(Q_s+Q_b) $10^4 m^3/yr$	$\frac{Q_b}{Q_s+Q_b}$
Calculated	27.25	4.34	31.86	13.61%
Measured			36.00	

Table 6 The Contrast Results of Calculation from References (14,15) and this Paper

Year	1976	1977	1986
Referece (14) Q_T ($\times 10^4 m^3/yr$)	69.1	96.9	
Referece (15) Q_T ($\times 10^4 m^3/yr$)	70.0		
This Paper Q_T ($\times 10^4 m^3/yr$)	73.6	89.8	31.9
Field data Q_T ($\times 10^4 m^3/yr$)	60-90		36.0

The net quantity in 1976 is $Q_{s0}- Q_{b0}=73.6\times 10^4$ m^3 which is 4.5×10^4 m^3 bigger than the result 69.1×10^4 m^3 from reference (14) and is 3.6×10^4 m^3 bigger than 70.4×10^4 m^3 from reference (15). The net quantity in 1977 is 89.8×10^4 m^3 which is 7.1×10^4 m^3 less than the result 96.9×10^4 m^3 from reference (14). Thst in the engineering design of Nouakchott, Mauritania to determine the longshore yearly sediment transportation is $60-90\times 10^4$ m^3 derived is chiefly based on the field measurement data of 1976 by means of hydrological section method and the calculation reasult from the Eq. 6 of CERC as well as combined with the comprehensive analysis of geomorphological investigation. It may be found out that the results of this paper and the predecessors' data as well as estimated results are basically identical.

(II) Golden Sands Beach of the Bulgarian Black Sea [12]

(1) Description of the Coast Outline

The Golden Sands Beach is situated at the eastern part of Varna Municipality of Bulgaria, the coast line is flat and straight, the water region is broad. The beach is nearly equilibrium condition before structure building "Γ" (see the Fig.18) and the slope of coast beach near the section 18A is approximately 1 / 18. After the structure building "Γ", the equilibrium condition near the structure "Γ" district is disturbed.

The Golden Sands Bench mainly suffered the wave action without tide influence. The Fig.19 is the average wave rose diagram of five years (1978 – 1983). The maximum wave height is up to 2.4 m on NE direction and the wave distribution between NE–S may be found out. The middle diameter of the sediment particle of the Golden Sands Beach profile d_{50} distributing between the place of 20 m and 200 m along the crosswise x is 0.24 mm and 0.165 mm separately as shown in the Fig.20.

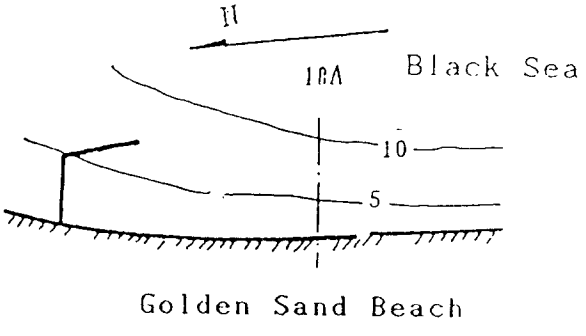

Fig.18 Sketch of the topographical map of Golden Sand Beach, Bulgaria

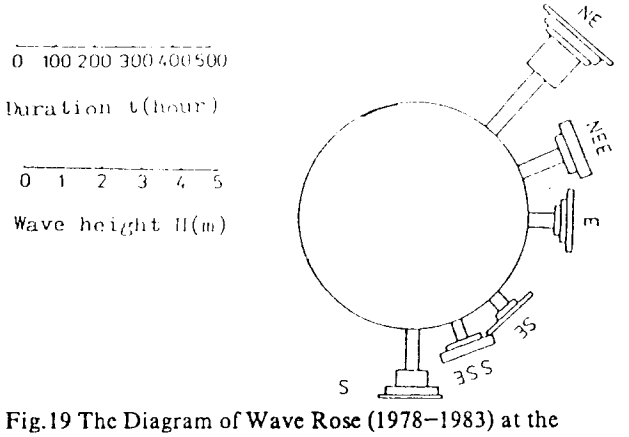

Fig.19 The Diagram of Wave Rose (1978–1983) at the Golden Sands Beach Bulgarian Black Sea

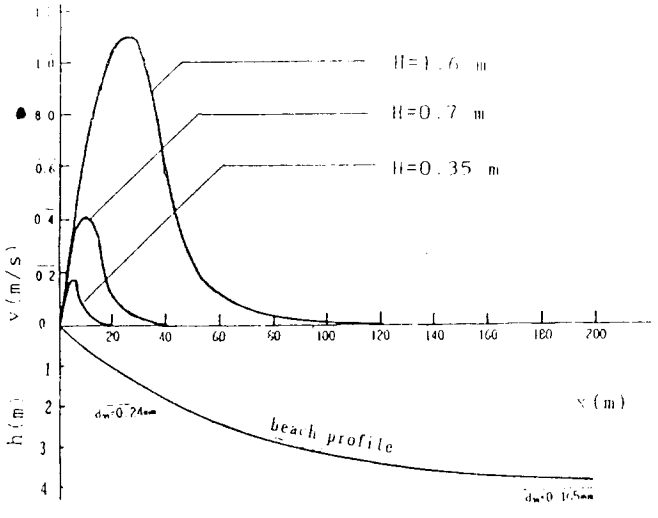

Fig.20 The Beach Profile and the Crosswise Distribution of Longshore Current Velocity (as an example)

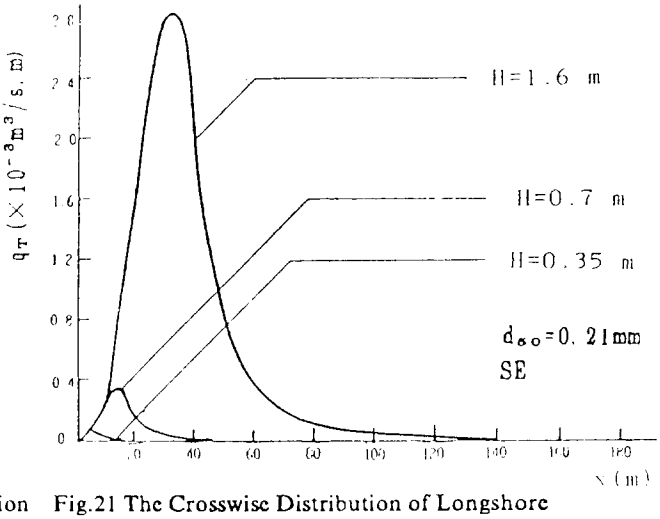

Fig.21 The Crosswise Distribution of Longshore Sediment Transport Rate per Unit Width at the Golden Sand Beach, Bulgarian Black Sea

(2) Determination of Related Parameters

(a) In calculation, taking mean middle diameter of the beach profile d_{50} = 0.21 mm;

(b) Adopting equation (2a) to calculate the friction coefficient of beach profile f corresponding to different wave direction and wave height, the value of f derived from calculation is in the scope of 0.0250 – 0.0697;

(c) The bed roughness of beach profile r_a is determined by the following equation suggested by Nielson and Green. [6]

$r_a = 120 d_{50} = 0.0252$ m

(d) Due to the lack of field data, we find no way to determine the value of crosswise mixing coefficient p directly.

Based on past experiences and the characteristics of the Golden Sands Beach Profile, we take p=0.10.

(3) The Elements of Breaker and the Crosswise Distribution of Longshore Current Velocity

Based on linear wave theory and Longuet-Higgins' calculation modelling of longshore current, the breaker elements and crosswise distribution of longshore current velocity under the different wave conditions are carried out. As an example, the partial results for section 18A are shown in the Table 7 and Fig.20 respectively.

Table 7 The Calculated Results of Breaker Elements

H_0 (m)	θ_0 (Degree)	H_b (m)	h_b (m)	Q_b (Degree)	C_b (m / s)	X_b (m)
0.35	30.0	0.369	0.458	12.33	2.05	8.25
0.70	30.0	0.768	0.944	12.73	2.94	17.00
1.60	30.0	1.805	2.208	15.81	4.48	39.75

(4) The Crosswise Distribution of Longshore Sediment Transport Rate per Unit Width

We may obtain the crosswise distribution of longshore sediment transport rate per unit width under the different wave condition. As an example, the calculation results for section 18A are obtained as shown in the Fig.21 at the condition of P=0.10, $\theta_0=30°$, $H_0=0.35$ m, 0.70 m and 1.60 m. respectively.

(5) Longshore Sediment Transportation for the Period of Five Years (1978–1983)

From the wave rose diagram (Fig.19), we may carry out the calculation to the different wave characteristics and the sediment composition. From the above results we can obtain the net quantity of longshore sediment transportation passing through the section 18A and depositing in the region of 18A-"Γ" for five years as shown in the Table 8.

Table 8 Results of Longshore Sediment Transportation for the Period of Five years (1978–1983)

	Q_s (m^3 / 5 yrs)	Q_b (m^3 / 5 yrs)	Q_s+Q_b) (m^3 / 5 yrs)	$\frac{Q_b}{Q_s+Q_b}$ (%)
Calcalated	74006	7357	81363	9
Measmed			78500	

(6) Results Analysis

(a) From Fig.21, it may be found out that the maximum value of longshore sediment transport rate per unit width appears at the region between the breaker line and the point of maximum longshore current, and it will rapidly diminish outside the surf zone. The longshore sediment transportation mainly appears within the geographical contour line between 0–4 m. Outside the zone with limit h=7.0 m, its value is very small, which may be ignored to be calculated.

(b) From the Table 8, it may be found out that the bottom sediment transportation occupies 9% of the whole sediment or so.

(c) With reference to the period of 5 years (1978–1983) total measured aggradation is 78500 m^3 and the calculated value is 81363 m^3 (see the Table 8), these value are approximate to each other.

(Ⅲ) M-P BEACH OF SHAN-DONG PROVINCE, CHINA [13]

(1) Brief Introduction to the M-P Beach

As illustrated in the Fig.22, the P-M Beach, facing the Bo-Hai (Sea), west contiguous to YanTai Harbour and east adjacent to the Wei Hai City, is located at the north side of the Shan-dong Penisula, China, and the Yang-Ma-Island, natural protective screen exists north and there are broad regions abundant in natural resources near south.

As shown in Fig.22, the M-P Beach is basically belonging to stable sand beaach. The shallow beach profile is composed by the sands with middle diameter $d_{50}=0.3$ mm, near the surf zone the slope is approximate to 1 / 50. Under water, -6 m approximately forming a comparatively stable contiguous district with fine sand ($d_{50}=0.02$ mm) and clay ($d_{50}=0.006$ mm). See Fig.22.

(2) Hydraulic Condition under Wave and Current

(a) The velocity field of M-P Beach is shown in Fig.23 as follows:

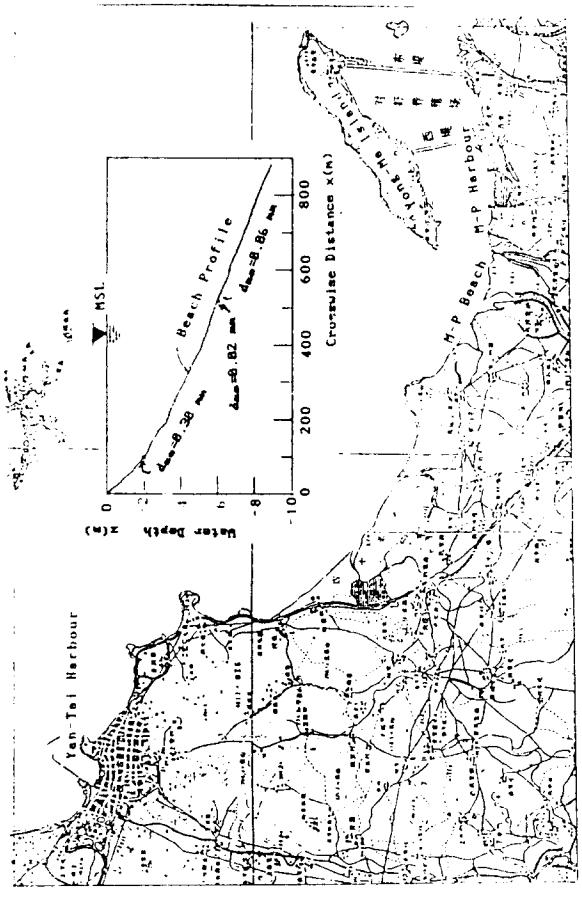

Fig.22 Sketch of M–P Beach and Its Description

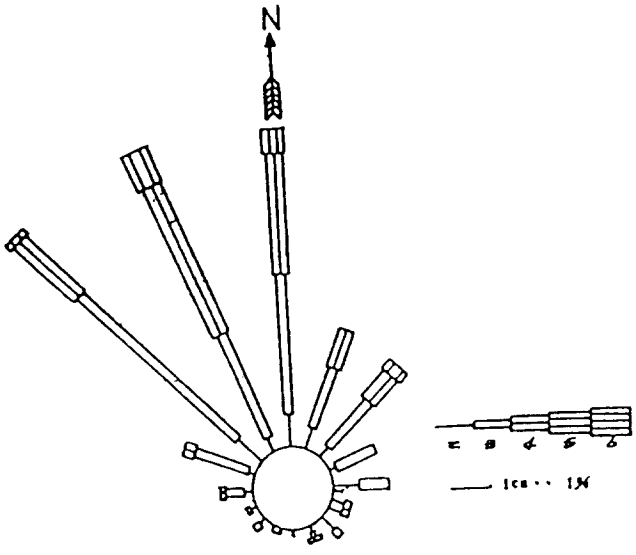

Fig.24 The Dragram of Wave Rose of M–P Beach

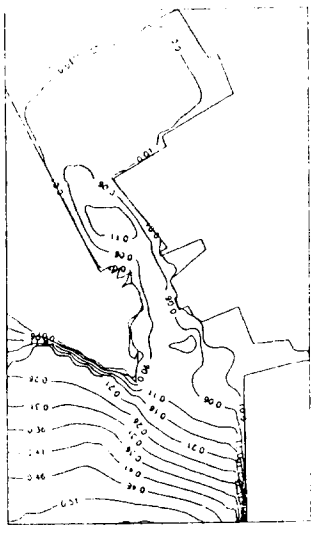

Fig.23b The Contour Line of Instantaneous strom Current Velocity of Spring–Tide

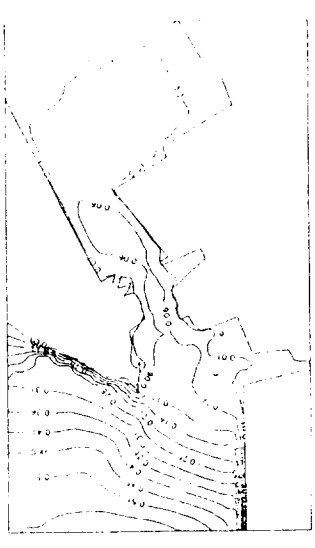

Fig.23a The Contour Line of Instantaneous Current Velocity of Ebb–Tide

(b) The Diagram of Wave Rose of M–P Beach is Shown in Fig.24 as follows:

(3) Calculation Results and Its Verification

So far as the function of hydraulic conditions under wave and current of the M–P Beach shown in the Fig.23 and Fig.24 is considered, the calculation result of the yearly net longshore sediment transportation from west to east of the M–P beach is 2.40×10^4 m^3 being approximately to the field living measureed value 2.47×10^4 m^3.

10. CONCLUSION

Adopting M.S. Longuet–Higgins' and P.D. Komar's theory together with the adjustment of parameter P. simulating the flow field of the nature longshore current, the author, basing on the conception of sediment transportation sets up the capacity of sediment transport equation under wave and current [7,8], and suggests a theoretical modelling of a calculated longshore sediment transport rate as well as a set of its corresponding calculation method. It is certified, through preliminary practice, that to be a research approach on analytical mechanics to explore the numerical calculation of longshore sediment transport rate is feasible.

In this paper, checking computation is made to E.W. Bijker's theoretical research achievements[2] and contrast is made with the computation results of the formula proposed by the Coast Engineering Research Centre (CERC), U. S. A.. The results derived in the paper is between the two results mentioned above (see Table 1).

So far as the field measured data from the Nouakchott coast, Mauritania and the Golden Sands Beach of the Bulgarian Black Sea as well as the M–P Beach, China are concerned, the checking computation is further made in this paper, the results derived are basically identical with field data and near to Xie–Liu's and Zhou's research achievements.

Incompleteness in the aspect of calculating theoretical modelling still exists, such as, the deformation of wave elements in shallow water regions, irregular wave motion as well as a series of more difficult problems of sediment motion mechanism under wave, etc. need be further explored.

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Appendix II–Notation

The following symbols are used in this paper:

$A = \frac{\delta}{h}$, relative value of the bed layer;

a_b = wave amplitude near the bed surface;

$B_1 = \frac{P_2 - 1}{P_1 - P_2}A$;

$B_2 = \frac{P_2 - 1}{P_1 - P_2}A$;

C_z = sediment concentration on arbitrary point of z by volume ratio;

C_b = bed surface concentration of sediment by volume ratio;

$C_m = 0.755+0.222\lg d_{50}$;

C_0 = wave velocity;

$\overline{C}$ = mean concentration of suspended load by volume ratio;

C_δ = sediment concentration on the surface of bed layer by volume ratio;

d_{50} = middle diameter of sediment particle;

f = friction coefficient of bed surface;

g = gravity acceleration;

h = water depth;

h_b = water depth at the breaker line;

h_{bar} = water depth at the top of sand bar;

H = wave height;

H_b = wave height at the breaker line;

H_{bar} = wave height at the top of sand bar;

H_0 = wave height in deep water;

H_r = root–mean–square wave height;

$H_{\frac{1}{3}}$ = effective wave height;

$H_{\frac{1}{10}} = \frac{1}{10}$ bigger wave height;

$\overline{H}$ = mean wave height;

i_b = proportion of sediment with settling velocity w_i in the composition of bed material;

I_1, I_2 = two Einstein's integrals;

J = hydraulic gradient;

K = Karman constant;

K_0 = empirical cofficient;

K_r, K_s = refractive coefficient and shallow water coefficient respectively;

K_w = partial variation of Karman constant due to the bottom condition of sediment–laden flow;

L = wave length;

L_0 = wave length in deep water;

N = a parameter;

n, n_0 = shallow water and deep water refractive rate respectively;

n_b = incident rate of breaker;

P = crosswise mixing coefficient;

$$P_{1,2} = -\frac{3}{4} \pm \left(\frac{9}{16} + \frac{1}{P}\right)^{1/2}$$

q_b, q_s = transportation of bed load and suspended load per unit width by volume respectively;

q_T = sediment transport rate per unit width by volume;

Q_T = longshore sediment transport rate by volume;

$r_* = 120 d_{50}$;

$S_* = 0.033 d_{50}^{-0.603}$, ($d_{50}$–mm);

T = wave period;

$\overline{T}$ = mean wave period;

u = longshore velocity on the arbitrary point of z;

u_* = shearing velocity or called "moving sediment factor";

u_{**} = combination shearing velocity;

u_{*T} = combination shearing velocity under common action of wave and current;

$U_0 = \dfrac{\pi H}{Tsh\dfrac{2\pi h}{L}}$, the maximum velocity of wave point near the bottom;

v = longshore mean velocity along the depth;

$$v_0 = \frac{5\pi r}{16f}(gh_b)^{1/2}(tg\beta \cdot sin\theta_b)$$

w = settling velocity of sediment particle;

$\overline{w}$ = mean settling velocity of sediment partcle along the water depth;

x = crosswise coordinate;

x_b = position of breaker line far from the shore line;

$$z_{*T} = \frac{w}{Ku_{*T}}$$

$$\alpha = \frac{1}{2}\frac{v}{u_*}$$

α_0 = a constant;

β = sea bed slope angle;

r = H / h;

γ_b = index of breaker;

γ_s, γ_w = specific weight of sediment particle and clear waer respectively;

$\overline{\gamma}$ = mean value of the specific gravity of turbid water;

δ = thickness of bed layer;

θ_0, θ = incident angle of wave in deep water and shallow water respectively;

θ_b = incident angle of breaker;

ρ = the density of turbid water;

$\overline{\rho}$ = mean density of turbid water;

$\tau_C = \overline{\gamma}$ hJ, shearing stress on the bed surface;

$\tau_{bT} = \overline{\rho} u_{*T}^2$, shearing stress on the bed surface due to wave and current.

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ARTIFICIAL BEACHES ALONG THE KUWAIT WATER FRONT, KUWAIT

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KEYWORDS: Artificial shoreline, grain size distribution, beach profile, hydrodynamics, accretion and erosion, Kuwait.

ABSTRACT

The artificial shoreline between Doha Marina and the Kuwait Towers (12 km) which represents the Waterfront project (Phase I and II), has been monitored during this study which covers the period from 1989 to 1993. The study includes coastal process measurements (waves, winds, longshore currents), beach profile measurements in order to monitor the morphological changes along 10 chosen locations, and the grain size distribution along each profile, which was studied using different parameters of grain size analysis of 66 sediment samples. Available data from previous studies (1977 and 1985) were used for comparison. The changes in observed beach profiles were acceptable except for some locations where high amounts of sediment eroded with time. The grain size distribution shows that in general the artificial beaches along the waterfront project are stable.

Wave dynamics are weak and affected by the presence of Green Island and the hook at Kuwait towers. The presence of wave cut platforms at some locations tends to reduce the wave energy. The design of the whole project with extended groins is useful in protecting artificial beaches and causes wave diffraction. The longshore current velocity depends on the wave energy and direction adjacent to the location, whether exposed or hidden. At exposed locations, longshore sediment transport can be high while at hidden places it is low. After twelve years of beach nourishment, a maintenance is needed for some locations that shows severe erosion.

INTRODUCTION

Kuwait is located at the head of the Arabian Gulf, in the northeastern corner of the Arabian Peninsula, and has a surface area of about 17,818 km^2. The climate, in general, is dry and hot. Kuwait has a flat, slightly undulating surface that gently slopes towards the northeast. The coast is characterized by extensive intertidal flats which are muddy in the north and sandy in the south.

The study area is located at the waterfront project (Phase I and II), between Kuwait Towers and Doha Marina (Fig. 1). The project is considered to be one of the most important recreational beaches on the coast of Kuwait Bay. The project is initiated by the Kuwait Municipality in 1976 with the objective to improve about 20 km of the waterfront along Kuwait City. The first two phases (study area) include the construction of artificial beaches, service centres, swimming clubs, marina, launching ramps, yacht club and an extensively planted attached artificial island of 400 m in diameter.

Field surveys took place at ten chosen locations, which were studied over the last twenty years. The surveys include beach profiles, coastal processes and grain size analysis.

OBJECTIVES

The objectives of the study are:

1. Identification of historical changes of the present shoreline.
2. Study of coastal geomorphological features and grain size distribution.

3. Comparison of beach profiles to identify seasonal variations (1976-1993).
4. Identification hydrodynamic variables (waves and littoral drifts) that influence the changes in shoreline configuration.
5. Identification of accretional and erosional areas.

METHODOLOGY

Grain Size Distribution

Sediment samples were collected from several stations along the beach profiles. Before the grain size analysis were carried out, the samples were dried and disaggregated. A sieve set, ranging from (-2.00ϕ) to (<5.0ϕ) with 0.5ϕ interval, was used for the grain size analysis. The cumulative weight percentages were calculated. Land cumulative curves were plotted. Mean size, standard deviation, median, skewness and kurtosis were the main grain size parameters used in describing the sediments. All formulae used in the following calculations are those given by Folk and Ward (1957).

Wave Dynamics

Three stations were monitored for a continuous 10-days period in order to study the coastal processes during high tide. The following parameters were determined:
1. Breaking wave height (H_b), which is the average wave height between the trough and crest. These were measured for at least 100 waves using a graduated staff held in place at the breaker line.
2. Average wave period (T_b), which was measured as the time when a number of consecutive wave crests pass a fixed point near the breaker line. The wave period, given in seconds, was the average of a three times repeated exercise.
3. Breaker type (spilling, plunging, collapsing or surging), following the standard classification of CERC (1977).
4. Breaker angle (α_b) (the acute angle between the shoreline and breaker line), which was measured in degrees using a hand-held compass aligned with the shoreline and breaking crest.
5. Longshore current velocity (V), which was measured between the line of breakers and shoreline using plastic floats moving from fixed point for certain distance at a fixed time. This process was repeated for three times and the average was calculated. The gross longshore sediment transport, given in m^3/month, was calculated according to the formula by CERC (1984):

$$Q_d = 3.54 \times 10^{-7} P_{ls}$$

$$Pls = 2.78 \times 10^{10} H_b^{5/2} \sin 2\alpha_b$$

where Q_d is the longshore sediment transport amount, P is the energy flux, H_b is the wave breaker height in meters and α_b is the wave breaker angle in degrees.

Beach Profiles

The beach profiles were surveyed at low tide, using an engineer's level theodolite and a stadia. The beach levels were measured relative to a known datum (bench mark) to a distance reach 300 to 400 meters away from the starting point. The data collected were reduced to Kuwait Land Datum (KLD), and the final elevation, distance data were plotted.

BEACH PROFILES

Beach profiling is a useful tool to identify the physical characteristics of beaches in order to monitor the changes in beach morphology and to determine the amount of sediment transport due to the effect of longshore currents along the beach. In this study, beach profile measurements were carried out seasonally and for three years. Additional available data covering the last 17 years were also used. Measurements done for 10 selected stations along the project that were previously surveyed (Figs. 2, 3, 4, 5). These measurements include the distance from the starting fixed point and the elevation, which is measured according to arbitrary data at each location (Kuwait Land Datum, KLD). These data were used in drawing the profiles. Volumetric changes along beach profiles were carried out, based on the comparison between the first field survey (Oct. 1989) and the last ones (July, 1993). Volumetric variations of acceptable nature of erosion or deposition of sediments in each station concern: maximum loss of sediment to 61.8 m^3/m,

while maximum gain is 26.96 m^3/m. In general the beach profile study showed that sediments are shifting from one end to the other due to waves and tidal currents.

BEACH MORPHOLOGY

The beach morphology of Kuwait is influenced by wave energy, tidal range and currents. In Kuwait Bay, waves reach heights of 1.5 meters with 3-5 s interval. The general direction of the littoral drift is anti-clockwise and the bay is mainly characterized by a low wave energy. The tidal range along the Kuwait shorelines varies from 2.5 m near the southern border to more than 3.5 m near the west end of Kuwait Bay. Before the construction of the artificial beach started, the shoreline of the study area was in the form of a broad arc, (Fig. 6).

Eight artificial pocket beaches were created along the Kuwait Waterfront Project (Fig. 7). The sediments, used for beach nourishment of those beaches, are fine to medium clean sand. These beaches were retained by extended outfall promenades, which worked as groins in order to protect these pocket beaches from wave action. The orientation of these beaches were designed to align with the dominant wave approach (from the northwest). Rock revetments were used in order to protect the construction behind the beaches. In some locations, beach rocks are present acting as wave-cut platforms. Sand bars are also present with ridge and runnel features. Berms developed in some locations where a sufficient quantity of sand was present as a result of tidal action.

According to the grain size analysis, there is a systematic variation in grain size in the longshore direction as well as across the profile. The progressive change in particle size is due to variations in wave energy and changes in the beach slope.

COASTAL PROCESSES

The seasonal variation of the hydrodynamics along the shoreline of the study area is the major cause of changes. These changes are due to waves, currents and tides. During this study, the parameters wave breaker height (H_b), wave period (T_m), wave angle (α_b) and wave type were studied. Two types of beach profiles were produced to understand seasonal variations in waves along the waterfront project. A storm profile was formed during winter when waves of larger height occur, whereas a swell profile was formed during summer season, when wave heights are low. The longshore-current velocity (V_m) was measured along the study area, and it varies from 1.0 to 100 cm/s. Longshore sediment transport (Φ_d) was calculated according to the formulae suggested by CERC (1984). Values of (Φ_d) varied depending on the wind direction and wind speed. The tidal action contributes to the changes in beach profile and may cause erosion and accretion depending on the size of the material and the degree of protection of such profile.

CONCLUSION AND RECOMMENDATIONS

The comparison between four beach profile surveys (Oct. 89, Feb. 90, May 90 and July 93) indicates that a relative beach stability exist, except for some locations where severe erosion can be noticed, indicated by erosional scarp and scattered rocks that fall down from the revetment, and the formation of sand bars in the intertidal flat area.

Sediment samples along the waterfront project have different mean grain size and are sorted according to the level of wave energy acting on them. Coarser and poorly sorted samples are found in places of high wave energy, while finer, better sorted can be found at lower wave energy levels.

Waves and tidal currents play a major role along the study area. From this survey of coastal processes, it becomes obvious that there are seasonal effects as well as long-term effects, depending on the wave characteristics and direction.

The presence of the protection structures tends to minimize wave action at some locations.

It is recommended that an immediate maintenance is needed for some locations that show severe erosion. The detailed studies should continue for the purpose of monitoring possible changes in beach stability.

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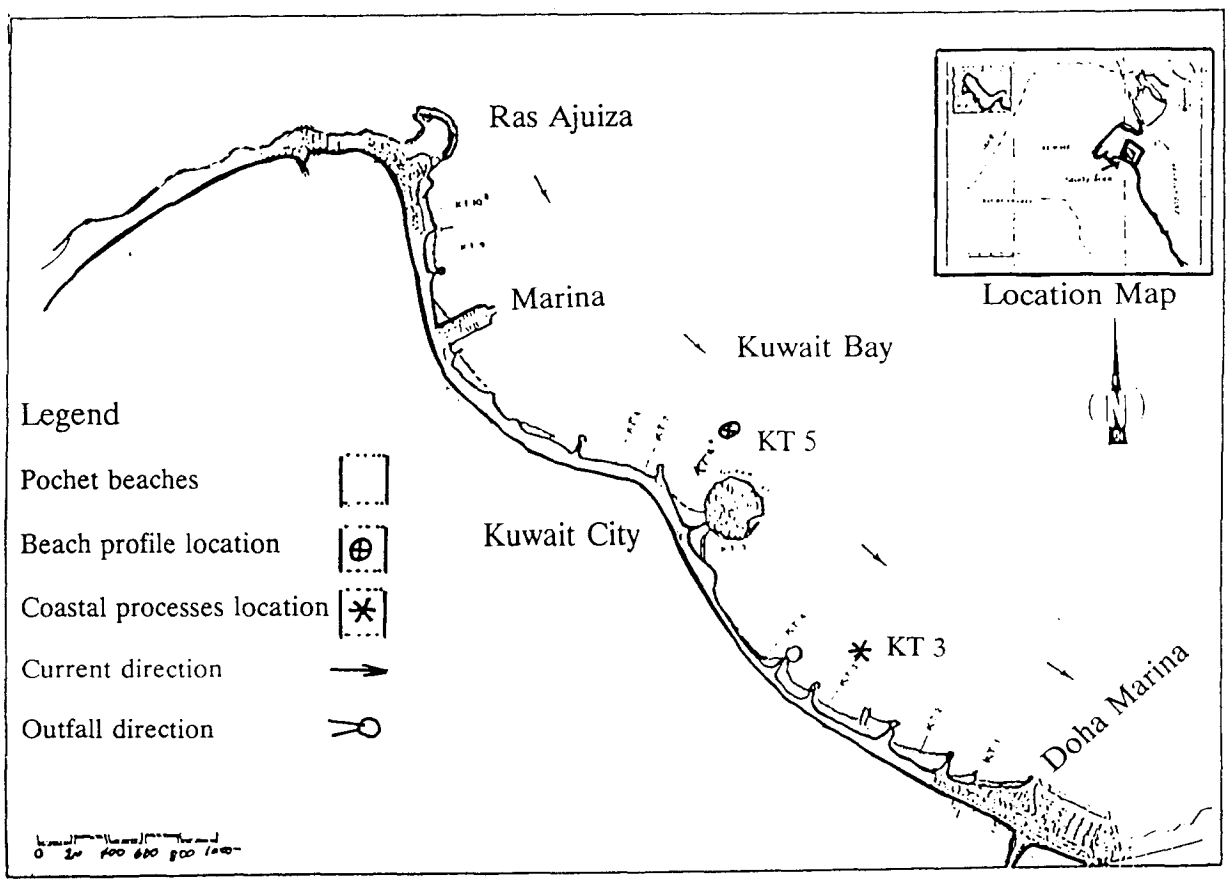
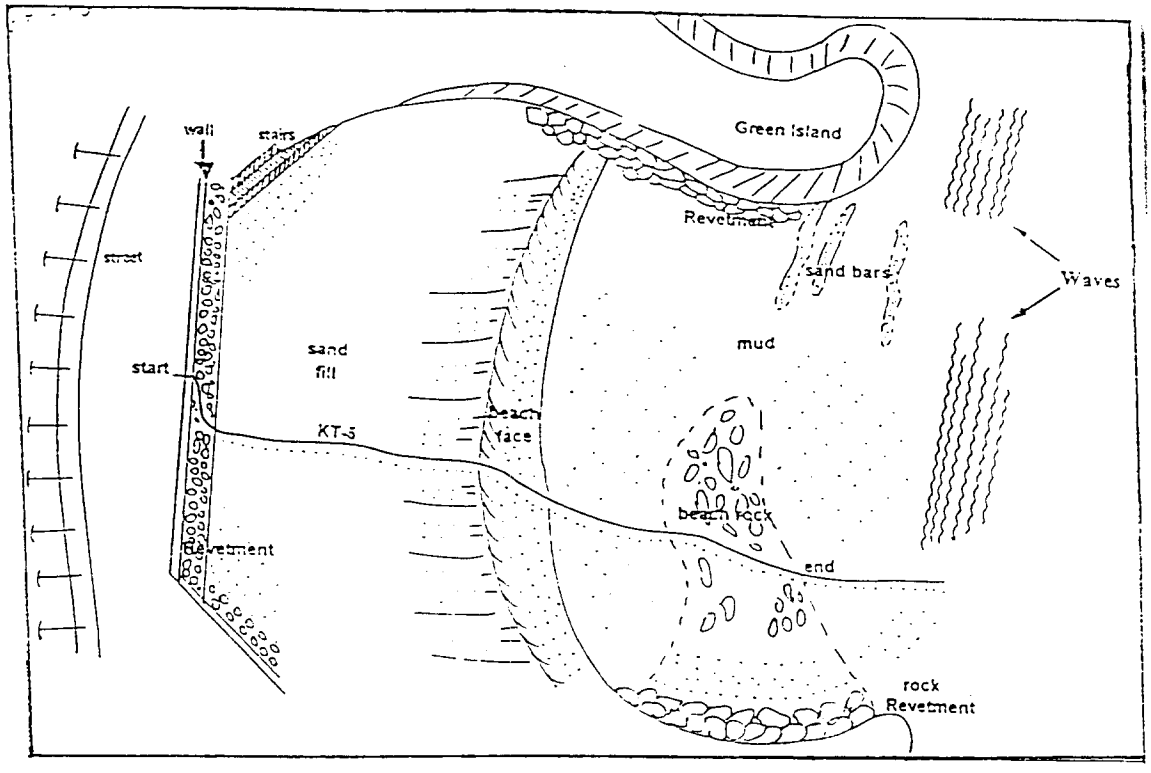


Fig. 1. Map, showing the study area with locations of beach profiles and coastal processes.

Fig. 2. Sketch diagram, showing location KT-5.



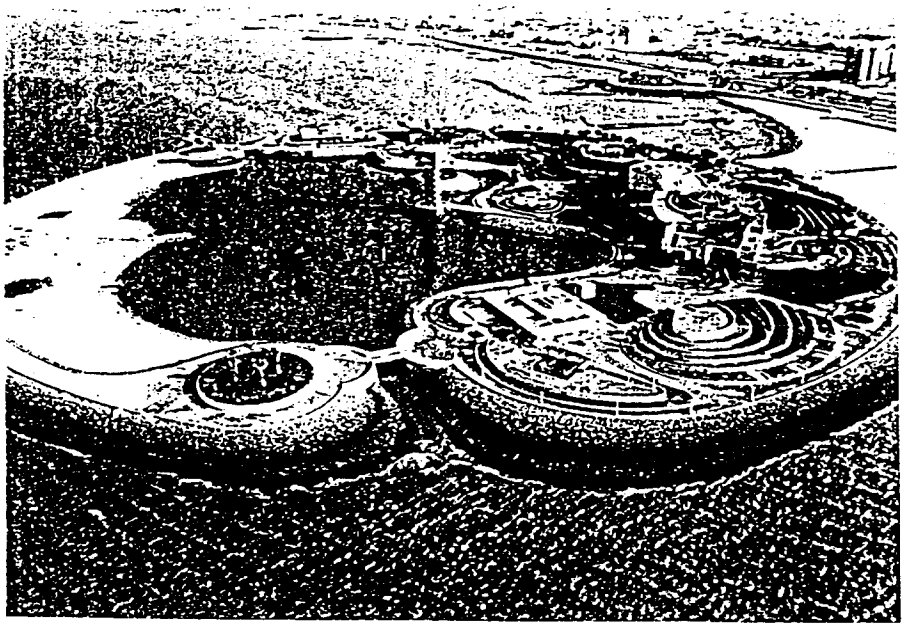
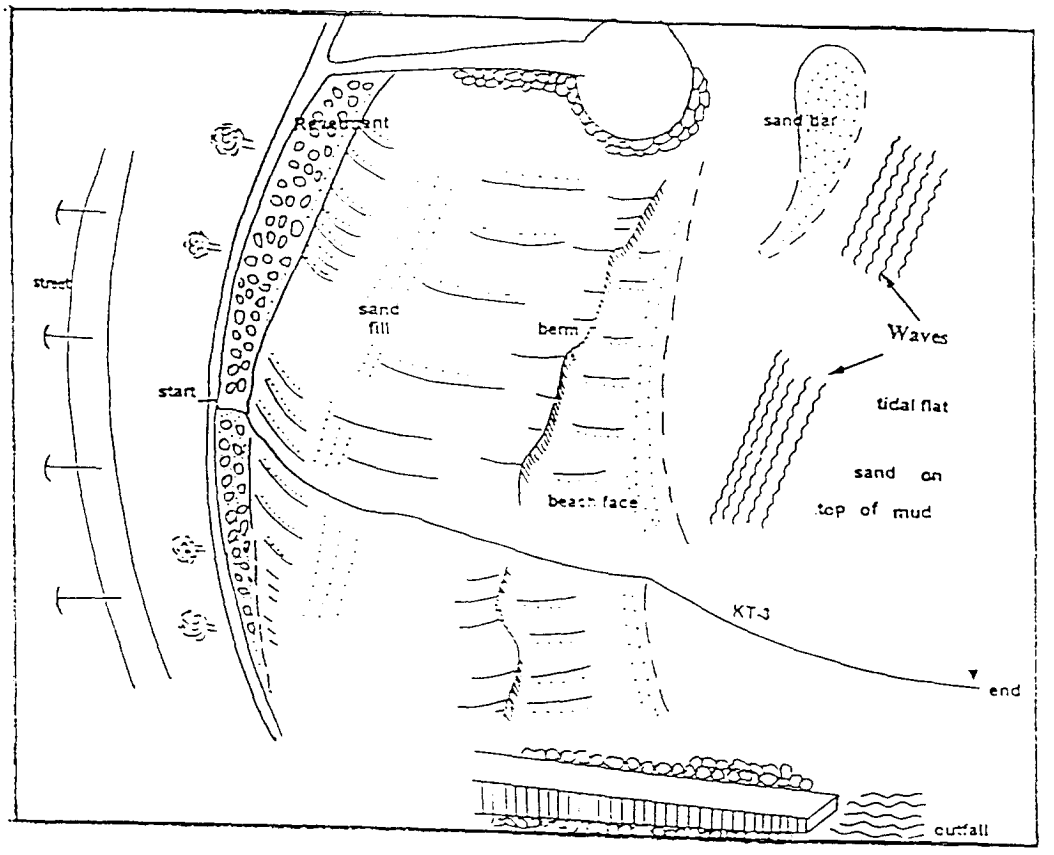


Fig. 3. Photograph of location KT-5.

Fig. 4. Sketch diagram, showing location KT-3.



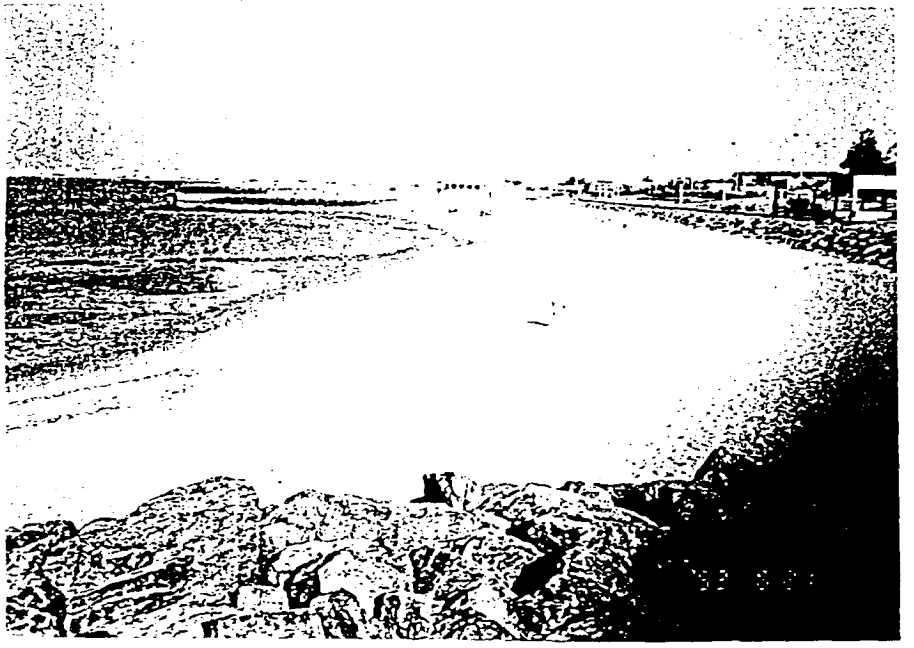


Fig. 5. Photograph of location KT-3.

Fig. 6. Shoreline between Ras Al-Ardh headland and Ras Ajuiza before the construction of the waterfront project.

Fig. 7. Shoreline from Ras Al-Ardh headland and Ras Ajuiza after the construction of the waterfront project.

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COASTAL ZONE DEVELOPMENT IN KUWAIT

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KEYWORDS: Coastal zone development, erosion, accretion, cliffs, siltation, engineering.

ABSTRACT

The State of Kuwait is mainly flat desert, and most of its land is restricted to the oil companies where no major development is allowed. The major urban, industrial, commercial and recreational activities are concentrated along the coast. Coastal development in Kuwait started to take place during the early 1950's when there was no proper planning for the best usage of the coast in general. Problems associated with coastal development such as beach erosion, sediment accumulation, cliff retreat and siltation are mainly due to unsupported management and lack of engineering planning and design.

INTRODUCTION

The State of Kuwait is situated at the north-western corner of the Arabian Gulf, lying between longitudes 46° 30' and 48° 30' East and latitudes 28° 30' and 30° 08' North. Its coastline extends to approximately 500 km, including the islands (Fig. 1). Before the discovery of oil, Kuwait was historically dependent on the water of the Gulf, both for fishing and pearl trading. After the discovery of oil in the 1930's, most of Kuwait's land area was restricted to the oil companies where no other development was allowed. The actual development in the State of Kuwait started in the early 1950's. Most urban, industrial, commercial and recreational activities are concentrated along the edge of the coast. With the intensive utilization and special demands made on the coastal zone, the problem of coastal change associated with such rapid development is noted along the coastline.

Although some studies have been conducted on the coastal zone management of Kuwait (Abou Seida & Al-Sarawi, 1990), environmental geology (Al-Sarawi et al., 1988), geomorphology and sedimentology (El-Sayed & Al-Bakri, 1994) and coastal mineralogy (Khalaf & Ala, 1980; Khalaf et al., 1984) of Kuwait, information on the effect of coastal structures on beach stability and sediment movement is lacking.

Coastal development in the State of Kuwait started to take place in the early 1950's when the wealth from oil production first began to be distributed among the local people. Most of the projects in the governmental and private sectors were concentrated along the coast to gain maximum benefit from the simplicity of the geomorphic setup of the coastline. The vast, unorganized development exposed major problems along the coast, most of which are still creating legal controversies and endangering coastal stability.

The purpose of this paper is to highlight the major problems associated with the rapid development along the coast and to specify the effect of such construction on beach stability.

GEOMORPHOLOGY

The coastline of Kuwait is formed mainly of large intertidal flats where evaporate and sabkha formations exist. The sediment composition consists of quartz sand, carbonate (ooilitic limestone) and feldspars. The beach morphology is highly affected by tides and wave actions. The northern coast of Kuwait is formed of a large tidal flat consisting of soft mud with a gentle beach profile and spit formation along Ras

Al-Subiyah (Fig. 1). The width of the tidal flat reaches 0.75 to 1.25 m at low tide. The northern section of the coast is influenced by the southern flow of Shatt al Arab deposits. Kuwait Bay, which is the middle section along the coast, is formed by a large, shallow embayment which has two distinctive tidal flats, i.e., Sulaibikhat Bay and Kadhmah Bay. The approximate thickness of the tidal flat deposits within this section reach 5 to 7 m and are formed mainly of silt and clay. The upper tidal flat is covered with a thin veneer of aeolian sand deposit. The beach profile is flat with no berm formation. Coastal dunes which are fixed with shrub vegetation are found only along the northern part of Kuwait Bay (Fig. 1). The southern section of the Kuwaiti coast is formed of a series of headlands which might reflect a tectonic activity during the Pleistocene. The beach consists of coastal dunes, cliffs, sandbars and tidal inlets. Sediment composition reveals more carbonate formation and fewer soft sediment deposits. The beach profile is steep with berm formation.

HYDRODYNAMICS

The main hydrodynamic factors affecting Kuwait's coast are tides, currents, and waves. In Kuwait Bay, the tides are semidiurnal and range from as high as 4.2 m during the spring tides to as low as 0.5 m at neap tides (Harms et al., 1982). The maximum current velocity never exceeds 0.5 m/s. The wave climate is very mild and waves may reach 1.5 m in height with 3-5 s periods (Lo et al., 1987). For the southern coast, the tides are mixed; the mean tidal range is from 1.6 m at neap to 2.4 m at spring. The maximum current velocity extends 1.0 m/s. Waves may reach more than 4 m in height for a period of 9.0 s. The highest waves are likely to approach from the east-southeast. Generally, currents are approximately parallel to the coastline (Gopalakrishnan et al., 1988), and littoral drift is in a clockwise direction. Hayes et al. (1977) found that wave energy and longshore transport are low in magnitude along the developed waterfront of Kuwait City. Longshore currents are higher along the southern coast than those along the northern and middle coasts. Kana et al. (1988) estimate net southerly rates of $5x10^4$ m^3/yr south of Ahmadi Port (Fig. 1). Southerly winds of 30 to 40 km/hr along the southern coast cause tremendous beach erosion and cliff retreat.

COASTAL DEVELOPMENT

The major activities along the coast (Abou-Seida and Al-Sarawi, 1990) are those of residential areas (cities and holiday beach houses), power stations (power and desalination plants), industrial complexes (oil refineries and petrochemical industries), port facilities (oil-loading and cargo terminals), harbours and marinas (naval base, coast guard, fishing, and private), and recreational developments (onshore coastal motorway, resort beach houses, and the waterfront and Al-Khiran projects).

Economic developments and population increases have caused more extensive utilization of and special demands on the coastal zone. There are proposals for new residential areas, townships, holiday villages, a multipurpose harbour, and a causeway linking Kuwait City with Failaka Island. Such economic developments should not be considered isolated activities. In addition, waste, thermal and chemical discharges released from power stations may have an adverse impact on the marine environment. Recreational developments usually destroy also fishery nursery habitats if their environmental impact is not considered.

COASTAL CHANGE

Construction along the Kuwaiti coast has created tremendous problems, especially along the middle and the southern coast:

(a) In general, the middle section (Fig. 1) has been mainly developed by governmental construction such as the Shuwaikh harbour (Fig. 1), loading jetties, and hospital areas. Most of these constructions occurred within the intertidal flat and has caused a decrease in longshore currents which have increased the amount of siltation within this area. The thickness of soft mud has increased by 30-35% reaching an average thickness of 5-7 m in some locations. The high amount of emergency storm drain outfall has had a major impact on water quality and has reduced the biological activities within this section. The

misuse of such outfall by small industrial areas will increase the deterioration of this environment and will later affect the fishery nursery grounds which exist to the north of Sulaibikhat Bay. The extension of Shuwaikh Port along the tidal flat within the middle section (which was begun in the early 1970's) has reduced sediment transport.

The impact of the development of Shuwaikh Port is clearly seen nowadays in that the huge amount of siltation causes navigation problems. The urban area around Sulaibikhat Bay suffers from hydrogen sulphide odours and those of other pollutants as a result of the direct flow of untreated sewage into Sulaibikhat Bay during emergency cases only. The weak currents and waves are not able to maintain water quality in this area.

(b) The major problems affecting the southern coast are mainly from the private sector (i.e., summer beach houses and residential areas) where people have extended their property into the upper tidal flat area (i.e., beyond the high tide waterline). Al-Sarawi et al. (1988) studied the major impacts of private beach houses on beach stability and listed more than 456 illegal activities that occur within 45 km of shoreline (Fig. 2). These private activities included boat ramps, groins, jetties, and shadow sites, all of which have been built within the tidal flat and have caused increased sediment accumulation on the southern sides of these structures leaving the northern sides exposed to more wave action resulting in beach erosion and great loss to the properties.

A well managed project along the northern part of the southern section is the waterfront project, where 12 km of nourished beaches were developed from 1984-1986 (Fig. 3). Monitoring along the artificial beaches reflects stability and very minor erosion problems (Al-Obyad, 1994).

DISCUSSION AND CONCLUSIONS

The whole coast of Kuwait has been greatly affected by rapid, undirected development which has caused environmental as well as geomorphic changes. The amount of sediment transport has decreased in certain areas where beach erosion and cliff retreat have started to take place. Human activities around the coast have caused major problems for the hydrodynamic processes. The lack of clear laws, direct punishment, and regular institutional monitoring has allowed the destruction of the natural setup of the coast. Coastal zone management is urgently needed to rehabilitate the shoreline. There is also a need to evaluate the administration, regulations and laws for the coastal zone.

ACKNOWLEDGMENTS

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Fig. 1 Location map, showing the major coastal sections in Kuwait.

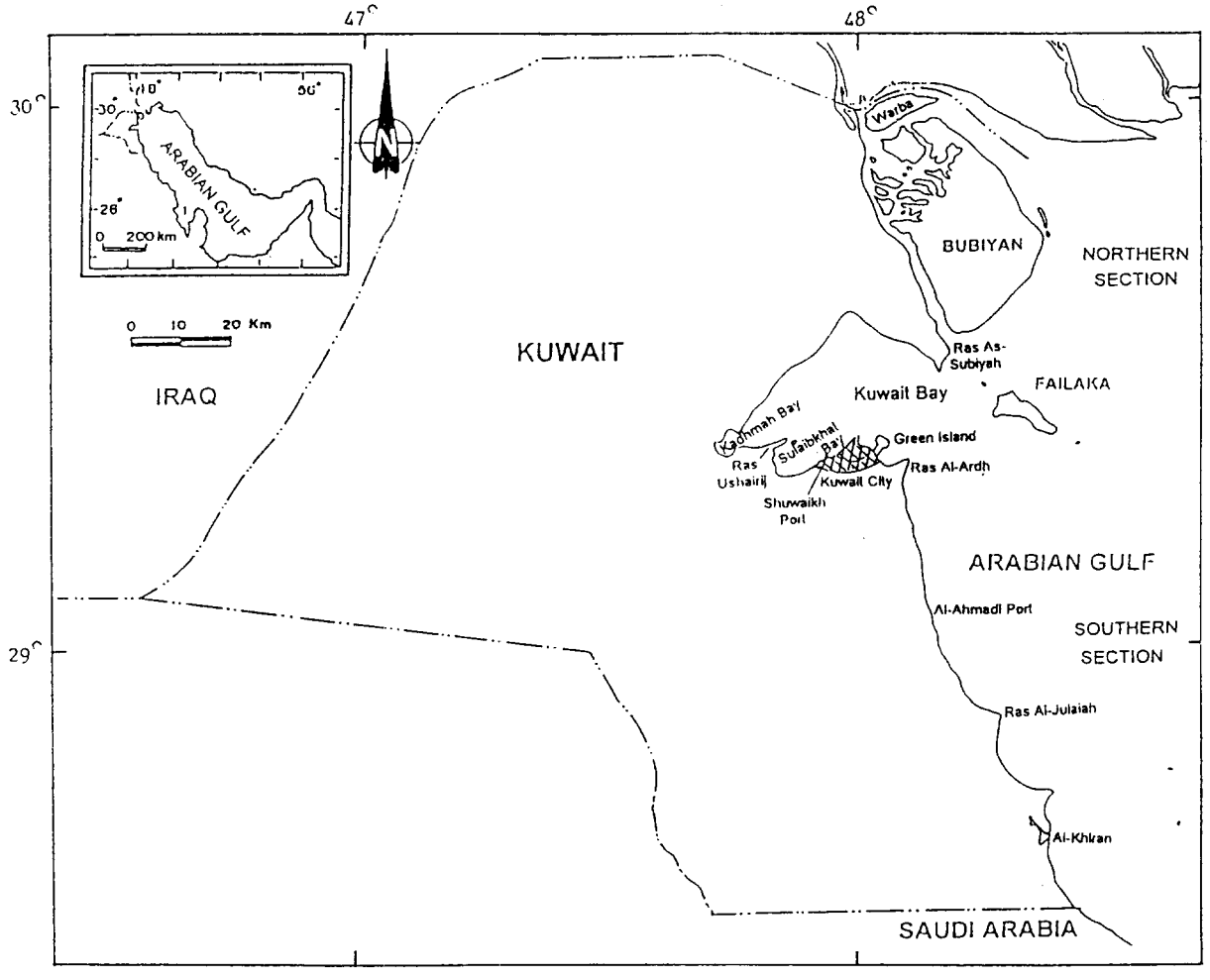
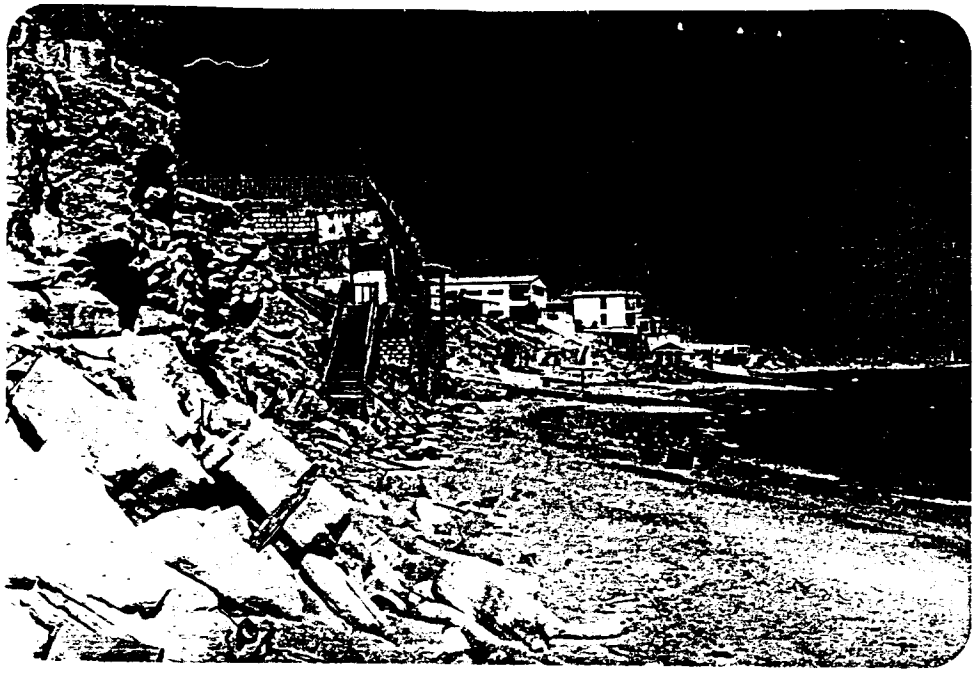


Fig. 2. Beach houses along the southern section, Kuwait.



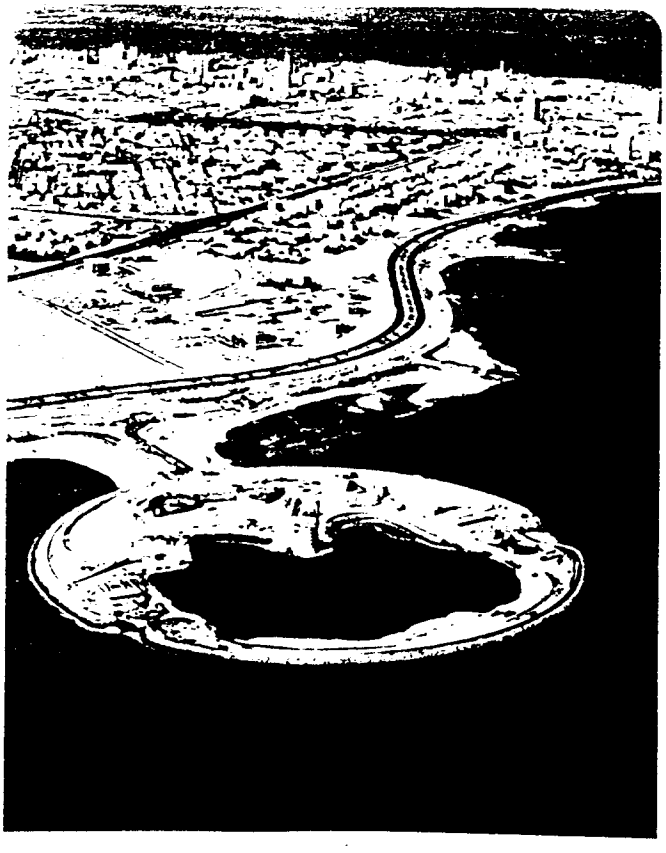


Fig. 3. Nourished beaches along the waterfront project, Kuwait.

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AN ANTHROPOGENIC IMPACT UPON THE BLACK SEA COAST OF RUSSIA

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KEYWORDS: anthropogenic impact, artificial beach, beach nourishment, beaches, coastline changing, degradation, ecology, gravel beach, bays, sediments, improvement of ecological situation, Black Sea, wave-reflecting wall.

ABSTRACT

An assessment of the anthropogenic impact on the evolution of the Russian Black Sea coastline is made. In the north of the region there are relic sandy beaches. They suffer from natural degradation due to lack of a nourishment source. This degradation is not connected with man's economic activity. On the coast between Anapa and Tuapse the shore suffers from anthropogenic impacts.

INTRODUCTION

The Russian coast of the Black Sea stretches from the Taman peninsula in the north up to the boundary Psou river in the south (Fig. 1). The modern look of the coast was formed in Pleistocene-Holocene under the uplifting of the Caucasian ridge and fluctuations of the Black Sea level. At the same time, the land and especially the coastline in some places have been considerably changed by man.

The main types of economic activity here are the following: recreation by the Russian people and port activities. The recreational institutions are located along the whole coastline. Most exploited are in the areas of the towns Sochi, Gelendzhik and Anapa. The large ports are located in the cities of Novorossiisk and Tuapse cities. Lately Russia has come across the problem of the construction of new ports on the Black Sea and the Sea of Azov shore, since it had lost a number of the Black Sea ports after the disintegration of the USSR. This fact prevents the development of recreational institutions.

GEOMORPHOLOGY OF THE SHORE AND OF THE COASTAL ZONE

In Pleistocene-Holocene (since about 600 thousand years ago), five large transgressions of the Black Sea level took place. They were provoked by glacial eustatic fluctuations of the World ocean. Since the Caucasian mountains were uplifted at this time, each transgression left its signs on the coast as an abrasive terrace, the steps of which exist between Sochi and Novorossiisk. The height of the individual terraces increases from north to south, which confirms the differential movements of the Earth's crust. Terraces and shelf were formed on the continental slope, the new parts in the zone of the wave influence at the periods of every regression of the sea level (Yesin, 1993).

In the north part of the region, between the Taman peninsula and Anapa town, there is a low-lying sandy shore (Fig. 2). Accumulative bodies, i.e. spits, bay bars, dunes, are composed of deposits which originated from one of the Kuban river branches that disappeared at the end of the last century. According to Zenkovich (1958) the Taman peninsula has existed only for several centuries. Earlier it was an archipelago of the islands. Later the space between the islands was filled with Kuban river deposits, and the archipelago turned into a peninsula.

Near Anapa town, the coast rises sharply towards the south-east and turns into the Caucasian mountains composed of the flysch series which suffer from wave erosion. The height of the cliff is 100 m and more. Between Anapa and Novorossiisk, there are mainly abrasive-denudated

and abrasive-landslid coasts. Only on some coastal sections of 100 m length, is there an accumulative coast composed of gravel and boulders.

An abrasive-denudated coast is characterized by the destruction of the cliff foot under the influence of abrasion, and the demolition of its surface by denudation. The rates of abrasion and denudation are interdependent; the greater the rate of abrasion, the greater the gradient of the cliff and the rate of denudation (Yesin et al., 1980; Yesin & Dmitriev, 1987).

The mechanism of the abrasion-landslide process has the following sequence. Abrasion cuts the base of the high, almost vertical, cliffs, creating the conditions for tearing off and moving of great mass of rock. The Utrish and Utrishonok capes are composed of landfall rocks. The frontal lobes of ancient landfalls can be traced well in the relief of the shelf. The beaches on the abrasive-denudated coast are usually narrow, composed of pebbles of different coarseness. When the depth becomes larger, the pebble size becomes larger. At the depth of more than 3-4 m, there are skid boulders on the bottom. In other areas the bottom is composed of flysch strata covered with algae.

On the abrasive-landslid coast there are vast gravel beaches. There are pebbles, gravel and boulders on the bottom.

In the region between the Cemesskaya Bay and the mouth of the Tuapse river, the shore is of a rather monotonous character. The coastline is smooth and presents nothing but alternations of small bays and capes. Hanging valleys cross the coast and the height of the cliff along the coast is constantly changing.

Gravel beaches hardly exist except in the mouths of large rivers. Southward from Gelendzhik near the Novomikhailovka settlement there is a relic sandy beach. Its length is several kilometers.

The bench consists of ridges and is partially covered with algae. Starting from a depth of 2 m, there are rounded boulders on the bottom. The beaches on the capes are composed of the sharp-edged fragments of the flysch rocks and of faceted pebbles. In small bays narrow beaches composed of well rounded gravel are concentrated.

The Cemesskaya and Gelendzhik bays relieve the monotony of the coastline. Their original coasts were abrasive-denudated ones. At present there is a port and a good number of hydro-engineering complexes.

The Gelendzhik Bay is a depression filled with water by the Holocene transgression. Many recreational institutions are located on its coast. The coast of the bay runs a danger of anthropogenic impact.

From Tuapse town and further to the south-east as far as the frontier with Georgia, the geomorphology of the natural coast is almost the same as in the region between Gelendzhik and Tuapse. But also here during the present century the coastline has been changed by man, and shows the features of technological influence. This problem will be examined in detail below.

THE DYNAMICS OF THE COAST

The evolution of the coastline between Anapa town and Zelezny Rog Cape was influenced by the following factors. Sandy coasts were formed by the Kuban river, but in the last century for more than 100 years no natural nourishment took place. As sand is slowly eroded, its fine fractions are washed out by waves to the deep sea. Coastal retreat is inevitable. Such a process of sand attrition and of the coastal retreat can be observed at several places. But this process is slowed down for the present time by the following factors. Great reserves of sand are concentrated on the coast here, both in fixed and shifting sandy dunes. When heavy northern and northern-eastern winds blow, the sand is transported to the coastal zone and the beaches are raised.

A problem is, however, that at present the coast is occupied by hotels, holiday inns, hard roads and so on. As a result the capacity of eolian flux decreases and the nourishment of the beach is reduced and erosion intensifies.

On the coastal section between Anapa and Tuapse, the coast is composed of rather solid rocks and the rate of its retreat is insignificant. Our field investigations for many years show that the rate of the cliff destruction here is 2-3 cm/yr, and of the bench 2-5 mm/yr (Yesin et al., 1980). Though the rate of the natural abrasion is not

large, the protection of the coast from abrasion becomes a very important task in order to maintain the economic activity, since hotels, holiday inns, resorts have been built near the coastline.

ANTHROPOGENIC INFLUENCE ON THE COASTAL PROCESSES

When analyzing the anthropogenic impact on the coastal processes it is necessary to bear in mind the following. A sandy beach on the coastal section between the Anapa town and Zelezny Rog Cape presents a common dynamic system. Therefore an anthropogenic impact on any section of the system affects the coastal processes of the whole system. To the south from Anapa and up to Tuapse the length of the coastal dynamic systems is not large. From several hundred meters to several kilometers, there is no common longitudinal sedimentary flux. As a rule, the dynamic systems are separated by capes. Modern coastal processes, proceeding in any small bay, do not influence the processes beyond their capes.

To the south-east, sediments including gravel material were transported from Tuapse town to the south-east towards Sochi. Several coastal dynamic systems exist here. Now this section is strengthened by groins with small reserves of gravel material. For this reason there is no longitudinal sedimentary flux.

Taking into account everything told before, we may say that the closing of the Kuban river branch, that had been submerged by the Black Sea earlier, was caused by a global process which has changed essentially the coastal processes on the Anapa beaches. After that the accumulation and broadening of the beach was replaced by slow coastal erosion. In this century the economic activity that favours beach degradation was added to this natural process.

On a given coastal section, the general sedimentary flux is directed from the cape of Zelezny Rog towards Anapa. Its discharge decreases approaching the limit of the sandy beach in Anapa. The port mole protects the extremity from wave influence (Fig. 3). This section of the coast was retreating very slowly. We noticed its degradation, i.e. fining of sand, 20 years ago. Waves brought no new material to this section.

Over the length of almost 50 km of the Anapa town beach no hydroengineering complexes, preventing sand movement, were built. A channel that connected the sea and the Vityaz firth was the only erection of this type. Now and then it was filled with sand and then dregded. The sand was thrown ashore out of the channel. This has slightly reduced the supply of material to the southern side of the channel with the result that essentially erosion of the coast only happened here.

The case is somewhat worse for the beach located within Anapa town. There is no aeolian nourishment of the beach at all and there is no longitudinal sedimentary flux. The beach is only retained due to the protective presence of the port mole. But a large percentage of the fine fractions of sand predetermined its unsteady state. In 1990 a wave-reflecting wall was built which ran through the unstable beach (Fig. 3). It changed considerably the hydrodynamics of the coastal zone. It increased the current velocity of near bottom water. Due to this flow, the process of sand resuspension and transport to sea has increased (Kos'yan & Pykhov, 1991). In the end, the beach in front of the wave-reflecting wall was completely washed out and catastrophic erosion of the neighbouring sections began. Today this process is still going on, and there are no grounds for the hope that the coast will stabilize itself. The wave-reflecting wall started to be ruined too.

Thus, the necessity arouse to protect the sandy beach from the wave influence. We offered two variants of the beach rescue. The first one is to dismantle the wave-reflecting wall and to build a sandy beach of the same volume which has been here earlier. Sands should be stored in a reserve on the shore to compensate for the natural annual losses.

The second variant is the construction of a short rock-filled groin from the end of the wave-reflecting wall and to build a gravel beach between the groin and the port jetty for protection of the wave-reflecting wall from the wave influence (Fig. 4). On the other side of the groin, the initial form of the beach should be

restored, by filling up with coarse sand and concentrate here a sand reserve for compensation of the natural losses.

It should be noted that the situation with the beach of Anapa is such, that the beach can only be retained by periodic addition of coarse sand. There are no favourable conditions for natural restoration. Without adding sand, the beach here is condemned to a complete disappearance.

A high coast between Anapa and Novorossiisk has little economic activity. Only a road is built close to the town. It runs to the beach, and the beach is built of the residual building material. The rest of the coast is kept in its original state.

The coast of Cemesskaya Bay today is practically completely covered with port moles, wave-reflecting walls and groins. There are no natural coastal processes left. The economic activity in the bay does not influence the coastal processes outside the bay. But the port and town exert an essential influence on the ecology of the adjacent sea.

On the coast between Novorossiisk and Tuapse economic activity takes place in the valleys of large rivers. Here recreational institutions have been built and a resort industry has developed. Free beaches and beaches protected with groins are being built. At the same time the cutting down of the forests along the river valleys and river mouths, removal of gravel material everywhere in the rivers, result in the reduction of river runoff and exhaustion of gravel beaches that had a great recreational value. Gravel material especially is rapidly eroding. During one year the losses due to attrition were between 4 and 10 % of the whole volume of beach gravel.

Gelendzhik Bay contains today numerous holiday-camps, holiday homes, hotels, which are located all over the bay's perimeter. The shore is shallow and groins are built not far from each other. They prevent longitudinal water circulation and pollutants washing out to sea. This has led to a sharp increase of pollutant concentrations (heavy metals, oil products, organic combinations, and so on) near the shore in summer windless months. All these aspects decrease the recreation potential of the bay.

In 1971 a sandy beach, 200-300 m in length, was filled in the southern part of the bay. Sand for its construction was taken from the bottom of the bay. Today sand is shifting under the wave influence to the central part of the bay.

The authors of this paper elaborated a program of the improvement of the ecological situation in the bay and an increase of its recreation potential (Yesin & Kos'yan, 1993). One of the basic elements of this program was the creation of gravel beaches, 30-40 m in width, all over the bay coast. The beaches play a coast-protective and recreative role. Besides this, a gravel beach will considerably improve the ecological state of the bay. Spaces between groins, where stagnant water is formed, are filled with gravel and water exchange and pollutant washout to sea becomes more intensive.

Today the above mentioned program has been realized. The beach, 1.5 km in length, has already been filled near the southern coast (Kos'yan et al, 1994). It has improved water quality. Water became clearer, the pollutant concentration in water has decreased.

The building of gravel beaches in the bay in combination with the other measures, aimed at decreasing the amount of entering pollutants, will improve the recreational parameters of the bay and will attract more people.

The port of Tuapse is located in the bay that represents a lithodynamic system. Hydroengineering complexes built in the bay for port protection do not influence the coastal processes outside the bay. The port and the town of Tuapse are the sources of pollutants entering the sea.

South-eastward from the Tuapse town the coast is considerably changed by man. Earlier, its geomorphology was roughly the same as for the coastal section between Novorossiisk and Tuapse. Only the gradients of the coastal slope were larger here. A flux of gravel material had been observed, which was directed south-east wards.

At present a cliff wall has been artificially moved toward the land for several tens of meters and a terrace has been formed at the height of 5 m along the coastline. A railway runs along this terrace to Sochi town and further to the south. Groins and a wave-reflecting wall were built for

the protection of the coast and the railway. The spaces between the groins were partially filled with gravel. Those structures have stopped the longitudinal sediment shift. Each year hydro-technical erections are repaired and gravel is added between groins.

THE STRATEGY OF COASTAL PROTECTION

The present-day general strategy of the Black Sea Russian coast protection consists of building reinforced concrete constructions, i.e. wave-reflecting walls, groins, breakwaters, etc. The practice of those construction has revealed their negative features. Rather quickly (during 15-20 years, and sometimes shorter) waves destroy coast-protective constructions, and they have to be repaired or replaced by new ones. On the other hand these constructions cause essential changes of the coastal processes and provoke such negative events as the bottom erosion, wash out of sandy beaches, intensification of the coastal erosion on the boundaries of the protected section, and degradation of the natural landscape. Since the beginning of 1990s KRASNODAR-BEREGOZASHCHITA firm began to use a method of Black Sea and Sea of Azov coastal protection by the construction of free gravel beaches (sometimes - sandy ones), which performed coastal-protective and recreational functions. The theory of this strategy is described in the works (Yesin et al., 1984; Yesin & Moskovkin, 1986; Yesin & Dmitriev, 1988).

The positive aspects of the coastal protection by means of free beaches are the following:

- the conditions for the people's leisure become better, the water quality in the recreational zones improves and the coast obtained a higher aesthetic value. Besides, the costs of free beach construction is half that of reinforced concrete erections.

ECOLOGY

The industrial development in the Black Sea region, the growth of urban settlements, the spreading of the resort complexes all increase industrial-domestic pollution. The intensification of the petroleum transport by sea and of sea traffic and the underwater extraction of oil influence unfavourably the cleanness of water and bottom in the Black Sea coastal zones. Discharge of industrial and agricultural wastes (pesticides, fertilizers) is very dangerous too. Almost all rivers that discharge into the Black Sea are more or less contaminated. Among toxic pollutants, entering the sea water, are combinations of some heavy metals (lead, mercury, zinc, nickel). Lately organic contaminants such as phenols, creosotes, detergents were found in sea water. A considerable part of synthetic detergents finds its way to the sea, and at present vast water areas can be observed covered with foam.

Ecological investigations in the coastal zone of the Black Sea and the Sea of Azov revealed the presence of pesticides (including organochlorines), herbicides, petroleum products, PAH (including 3,4-benzopyrene and 1,1,2-benzoperylene, which are carcinogenic) and organic matter. The highest concentrations of these substances occur near the water edge zone, i.e. in the recreational zone and in the zone of intensive water intake. At present the construction of new ports and a considerable development of existing ports are planned on the Black Sea and the Sea of Azov coasts. The volume of transport by sea of various cargoes including rather toxic ones will increase. In this case the probability of shipwreck and of extensive pollution will increase too. For the sea of Azov, where the degree of pollution is already higher than the maximum permissible concentration for a series of pollutants, this can result in the loss of biocenoses and the sea faces a transformation into a lifeless state.

The main reason for the high pollution of the near water edge zone and of the coastal zone is in general the discharge of inadequately treated storm water, the composition of which is similar to that of sewage waters, and the discharge of non-treated sewage water to the coastal zone. On the Black Sea coast the lengths of all deep water outlets of sewage waters (excluding one) do not meet the requirements of the sanitary standard (3.8 km). They are usually much shorter. Therefore they contaminate the zone of the water use.

The contents of organochlorine pesticides in the water column, according to surveys performed in 1990-1991, are shown in Fig. 5. The same are shown for oil products in Fig. 6 and for zinc in Fig. 7 (Yesin et al., 1993).

Thus, on the beach to the north of Tuapse town the oil product content in water was 0.05 mg/l, the same of 3,4-benzopyrene was 0.6 μg/l, the same of 1,1,2-benzoperylene was 1.2 μg/l (Yesin et al., 1994).

A repeated survey in April, 1993 has shown that the concentration of pesticides in water has reduced roughly by one order of magnitude. The same was valid for the concentration of oil products. According to these measurements, the region near Anapa town, where the children's recreational institutions are situated, had become the cleanest. The pollutant concentration was, however, increasing to the south-east from Anapa to Sochi. The highest contamination for oil products was observed near Novorossiisk and Tuapse.

The reduction in the pesticide concentrations since 1992 happened due to the reduction of pesticide application in agriculture because of the self-financing of the collective farms. Thus, a tendency of deduction of some pollutant concentrations in sea water has been outlined.

CONCLUSIONS

In conclusion we should say that the intensification of the economic exploitation of the Black Sea coast has influenced the coast dynamics, i.e. it increased the rate of the coastal erosion. Sandy beaches near Anapa are slowly retreating due to the absence of beach nourishment material. The construction of wave-reflecting walls in the town resulted in beach erosion and a coastal retreat of 20-30 m. On the coastal section between Anapa and Tuapse, the shore has retained its original state, but the rate of abrasion has increased due to the drop in runoff. On the coastal section between Tuapse and Sochi, the shore is strengthened by hydrotechnical constructions.

The coastal zone is seriously contaminated by pesticides and oil products. But during the last years a tendency of reduction of some pollutant concentrations has become obvious.

ACKNOWLEDGEMENTS

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Fig. 1. The Russian sector of the Black Sea and the Sea of Azov coastline.

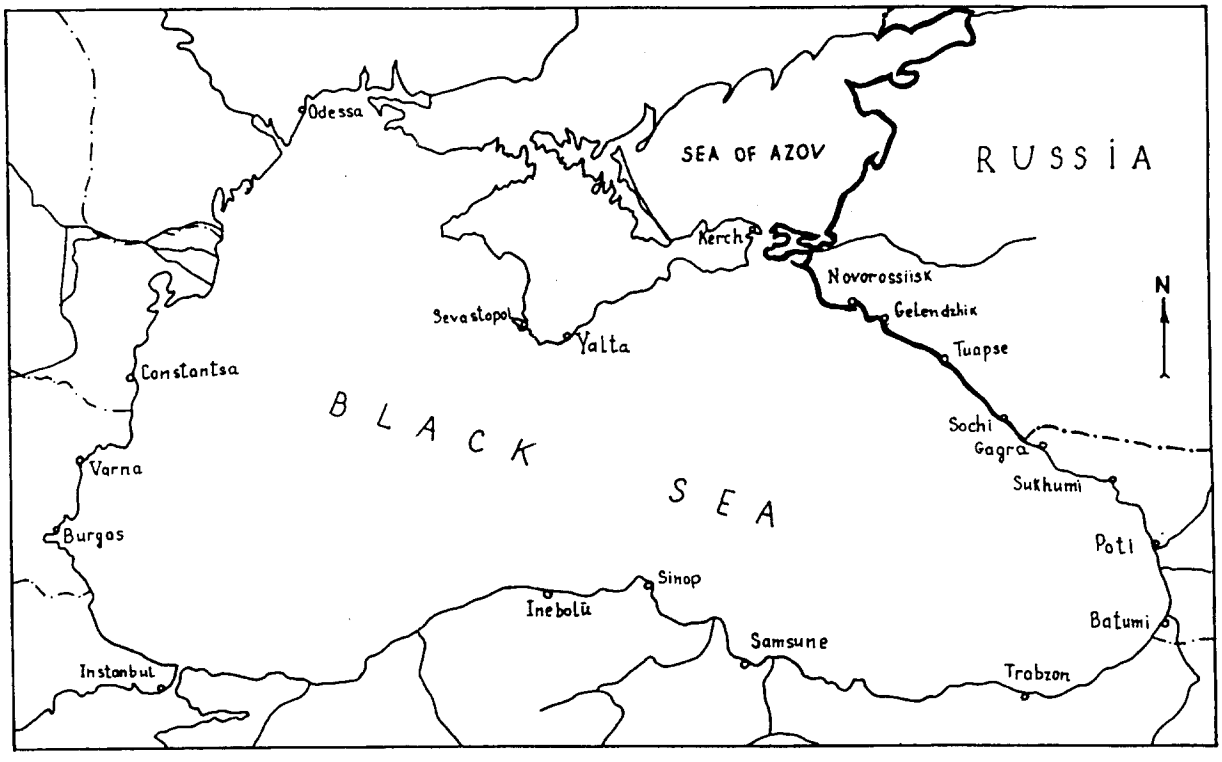
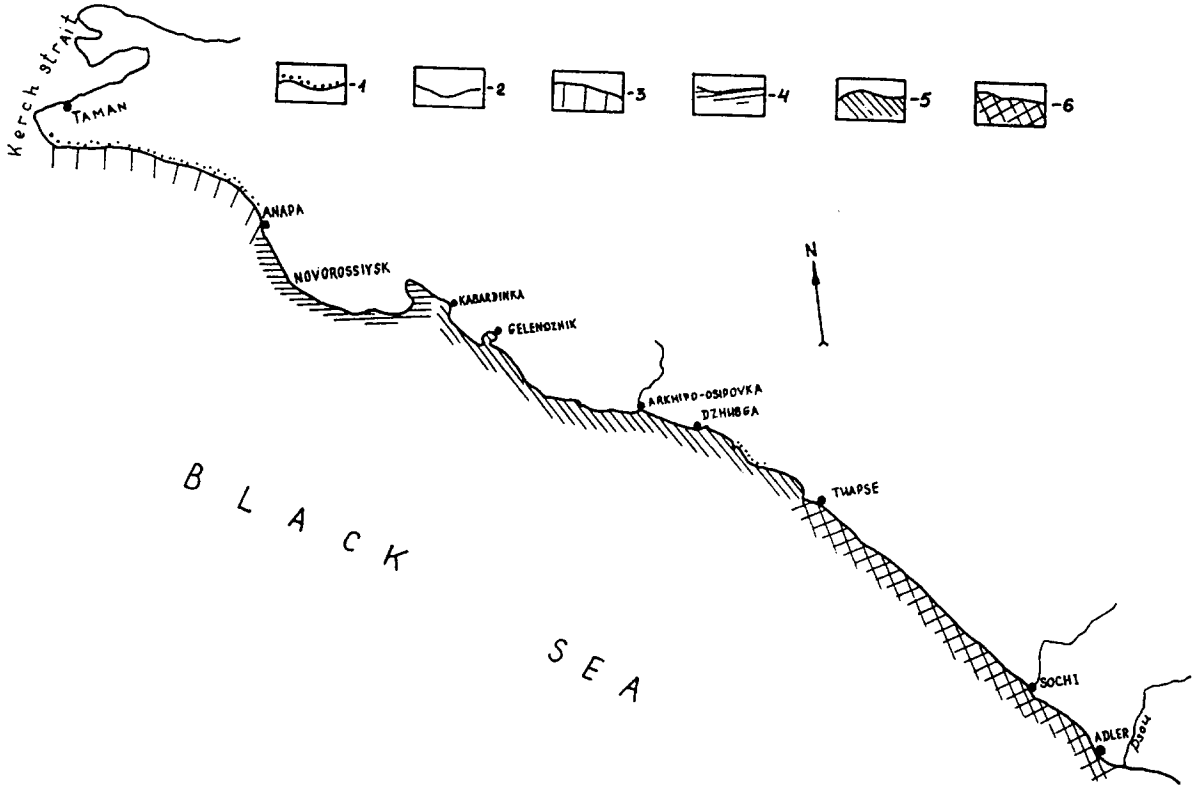


Fig. 2. The Russian sector of the Black Sea coastline. 1 -sandy beach; 2 -coast, composed of the flysch series; 3 -assess of anthropogenic impact; 4 -anthropogenic impact is weak; 5 -anthropogenic impact is moderate; 6 -strong anthropogenic impact, technogenous coast.



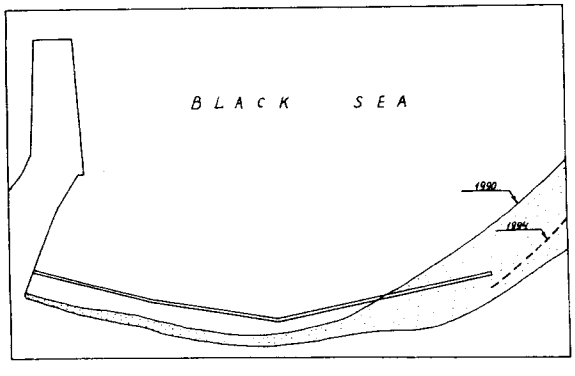


Fig. 3. The erosion of the extremity of the sandy beach in Anapa after the wave reflecting wall construction.

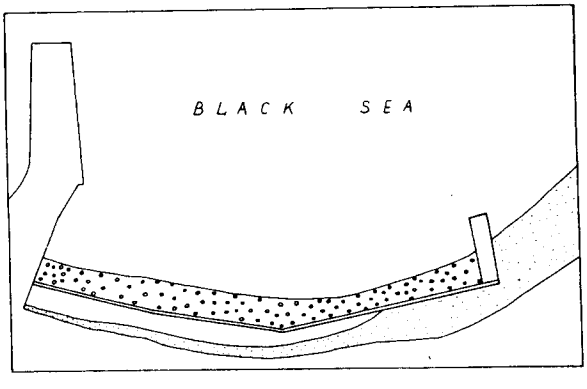
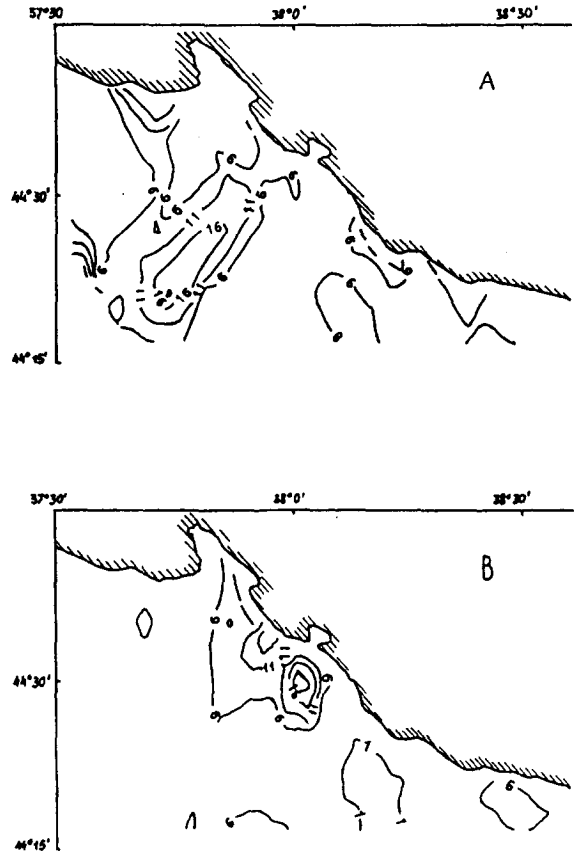


Fig. 4. The scheme of the shore protection and the sandy beach restoration.

Fig. 5. Pesticides distribution in the surface sea water layer (mg/l * 10^{-6}). A- α-HCH; B- ß-HCH.



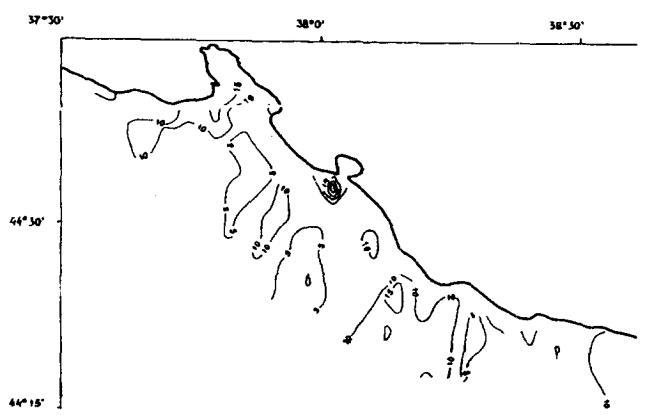


Fig. 6. Distribution of the Bituminous matter in the modern sediments (% * 10-4).

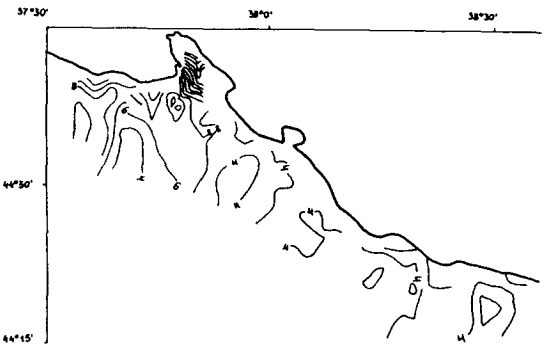


Fig. 7. Zinc (Zn) distribution in the surface sea water layer (μg/l).

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A MODEL OF STORM-GENERATED MORPHOLOGICAL RESPONSE IN THE NEAR SHORE ZONE

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ABSTRACT
A numerical model is proposed describing short-term changes in three-dimensional bottom topography caused by storm events. The model structure consists of wave, current, sediment transport and seabed update modules. Comparing with other known models a simpler treatment is adopted using analytical approaches wherever possible. Wave height field is determined from the equation of energy balance. Storm-driven currents are treated in terms of depth integrated linearized equations of motion and water conservation equation. The undertow velocity is determined using Stive & Wind's (1986) estimation of shear stress at wave-trough level. To evaluate the sediment transport rates the energetic concept of Bagnold (1963) is applied. The bed changes are calculated from the equation of sediment mass conservation, with Lax-Wendroff's numerical scheme used. The model predictions of morphological response in the nearshore environments are compared with field data collected at the Baltic Sea coast.

1. INTRODUCTION

Short-term morphodynamic development in the nearshore zone depends to a greater extent on impact of storm gravity waves, inducing sediment transport, that results in erosion and accretion on the bottom slope area. On sandy beaches storm-generated changes in bottom topography are characterised by magnitudes of order 1 m. The efficient approach to the prediction of these bed changes is apparently a numerical modelling of coastal dynamic processes.

Recently a number of two-dimensional models have been developed to simulate a beach profile evolution during storm events (Larson & Kraus, 1989, Roelvink & Stive, 1989, Hedegaard et al., 1992, Leont'yev, 1994). In spite of significant differences in basic assumptions, most of these models are able to reproduce the main features of bed changes observed in laboratory tests (performed with both regular and random waves) including bar formation. However the applicability of 2-D models is restricted by the requirement of the uniformity of dynamic conditions along the coast line. That is not an ordinary situation in the nearshore environments, where three-dimensional patterns of bottom topography are usually clearly seen.

In this paper a numerical model is proposed describing a time-depended three-dimensional morphological response in the nearshore zone. Storm-generated bed deformations are calculated on each time step from the spatial distribution of sediment transport rates, which are computed from the wave and current fields determined in coastal region. The model structure consists of separate, but linked, wave, current, sediment transport and seabed update modules. Comparing with 3-D model of Wang & Miao (1992) a simpler treatment of waves and currents is adopted using an analytical approach wherever possible. However, in the present model the vertical structure of current field is to some extent accounted for by incorporating the undertow effect on sediment transport.

The two-dimensional version of the model is tested using wave flume data on a beach profile development. The model predictions of morphological changes in three-dimensional bottom topography are compared with field data collected at the Baltic Sea coast.

2. FORMULATION

The object of investigation is the bottom slope area (Fig. 1) between the shore line and outer boundary at a distance X_0 and confined by two

shore-normal cross sections separated by a distance $Y\underline{0}$. The initial depth field $d(x,y,t_o)$ and mean grain size of bed sand $d_s(x,y)$ are assumed to be known input data. It should be noted that time-depended variations of d_s due to grain movements cannot be reproduced by present model version.

Bottom topography $d(x,y,t_o)$ is regarded as a smooth uninterrupted function with spatial gradients of order 10^{-2} that is typical of sandy beaches.

The model operates with a random wave field characterised by a Rayleigh type height probability distribution and narrow-banded in frequencies and directions. The following input parameters are specified at the outer boundary: *rms* wave height H_o, period of peak of spectral density T and angle of incidence θ_o (the angle between shore normal and wave direction, Fig. 1).

The depth scale at the outer boundary d_o may be of order $10H_o$, implying that latter value roughly marks the zone of sensible wave-generated bed changes.

See for the next sections
3. WAVE REFRACTION, SHOALING AND DISSIPATION, 4. STORM-DRIVEN CIRCULATION, 5. UNDERTOW & 6. SEDIMENT TRANSPORT AND BED CHANGES: see ANNEX 1

7. APPLICATION AND DISCUSSION OF RESULTS

The two-dimensional version of the model was verified with Roelvink & Stive's (1989) wave tank experiments in which initially linear and barred slopes consisting of fine sand (0.1 mm) were exposed to 12-hour effect of random wave field. In Fig. 2 the origin and final (measured and predicted) bottom profiles are depicted. Computations were performed with standard values of constants;

$$\varepsilon_b = 0.1,\ \varepsilon_s = 0.01,\ \tan\phi = 0.6,$$

$$\varepsilon = 0.4 \textit{ and } \rho_s/\rho = 2.65$$

It is seen from Fig. 2 that observed and predicted tendencies of morphological changes are similar in general and the magnitudes of bed deformation are of the same order. Besides the model can reproduce to some extent the bar formation.

The generation of the bar in the present model is mainly controlled by the temporal variation of the cross-shore distributions of the undertow velocity. The latter calculated at different stages of beach slope development are shown on Fig. 3 together with predicted bottom profiles corresponding to 12- and 18-hour wave impacts. It is seen that bar-trough morphology certainly responds to wave-like shapes of current profiles, the maximum off-shore flow occurs over the seaward bar slope and its minimum (or even on-shore flow) correlates with a trough location. The bar crest position correlates with maximum velocity gradients.

Hence the model is very sensitive to variations of parameters m and b, scaling the undertow velocity. The optimum values of $m = 0.7$ and $b = 0.008$ were accepted providing appropriate agreement with observed data and satisfying the requirement of numerical stability.

The sensitivity tests also indicated that changes in mode of parametrization of velocity moments have a rather weak effect, while the choice of bed friction parameter, scaling the sediment transport rates, evidently influences beach profile development. The use of f_w quantities exceeding twice the value, given by equation (26), results in a rapidly eroding non-barred profile. It was also ascertained that the presence of bottom gradient in transport formula pronouncedly contributes to stability of numerical procedure.

In order to verify the model in the case of three-dimensional bottom topography it was applied to calculate morphological response in coastal region of the Baltic Sea at Lubiatowo site (Poland), where the data on three successive storm events have been collected in autumn 1976 (Gizhevsky et al., 1978). The nearshore zone at Lubiatowo is characterised by barred bottom slope (Fig. 3). The bed is composed of fine sand with mean size 0.1-0.2 mm; coarser sand occurs at the shore line and in some small distinct areas.

Wave parameters and durations t_w of different stages of each storm are given in the Table 1.
Quantity Z_0 represents observed mean sea level. Wave incident angles Θ_0 were roughly estimated taking into account the measured wind directions during wave growth and decaying and implying that increase of wave period results in decrease of Θ_0 due to more effective refraction. It seems that wave measurements at Lubiatowo were accompanied by methodical errors resulting in too low waves, that are incompatible with observed bed deformations. The reasonable *rms* wave heights are obtained by multiplying of values cited in work of Gizhevsky et al. (1978) on factor 1.5.
Spatial distributions of bed changes observed after each storm cycle are shown on Fig. 5 and corresponding calculated patterns of bed deformations are depicted on Fig. 6. It is difficult to compare smoothed observed distributions with computed detailed drawings. Nevertheless looking on Fig. 5 and Fig. 6 one can discover some similar features. In particular, both observed and calculated pictures look like a combination of shore-parallel strips correlating with bar crests and troughs.
The analysis of deformation patterns in the nearshore section of the investigated area (x>400 m) indicates that both observed and predicted erosion and accretion zones alternate in cross-shore direction in the same manner, and the bed change amplitudes are of the same order too. The maximum predicted deformations are of the order 1 m.
However, in the offshore part of coastal region the computed values are evidently less than the measured ones. This discrepancy can be explained by the greater influence of the non-wave-driven transport mechanisms affecting the bed at time lapse between storm events.
The examples of calculated current patterns, corresponding to highest stages of storm events, are shown on Fig. 7. The stream line pictures indicate that flow conditions are essentially non-uniform along the coast. The meandering longshore currents predominate, though the eddy-type circulation cells are also occur. The maximum flow velocities are about 0.7-0.9 m/s, that is in agreement with observed values.

8. CONCLUSIONS

A numerical model has been proposed describing time-dependant changes in near shore bottom topography induced by storm waves. The time scale of the model is suitable for a single storm up to a series of storm events.
It has been demonstrated that the model is able to reproduce the evolution of two-dimensional beach slope observed in wave tank, including generation of the bar. In the present model the bar formation is mainly induced by temporal variations of cross-shore distribution of undertow velocity, which has been found to be very sensitive to changes in shapes of bottom profile. The influence of variations of higher order velocity moments appears to be of less importance.
The model also has been applied to predict three-dimensional morphological response due to actual storm events at the Baltic Sea coast. The series of three successive storms has been simulated including stages of growth and decay in each storm cycle. The results obtained are in reasonable agreement with the field data. The most pronounced discrepancies occur in outer part of the nearshore zone, where the morphodynamics is to a great extent is of the non-wave nature.
It should be noted in conclusion that only the "short wave" part of energy spectra in the nearshore environment is taken into account in the present version of the model. Also it is desirable to incorporate in transport mechanisms the contribution of infragravity motions, relating to surf beats and edge waves.

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ANNEX 1.

3. WAVE REFRACTION, SHOALING AND DISSIPAPTION

Wave refraction is calculated by satisfying the irrotationality of wave number vector. The incident angles $\Theta(x,y)$ are determined from the equation of the form

$$\frac{\partial\Theta}{\partial x}\cos\Theta - \frac{\partial\Theta}{\partial y}\sin\Theta = \frac{1}{C}\left(\frac{\partial C}{\partial y}\cos\Theta + \frac{\partial C}{\partial x}\sin\Theta\right), \qquad (1)$$

where the wave phase speed C is computed from Nielsen's (1982) approximating formula

$$C = \sqrt{gh}(1 - h/L_\infty), \qquad L_\infty = gT^2/2\pi. \qquad (2)$$

Herein $h = d + \zeta$ is the total water depth including wave set-up ζ, g is the gravity acceleration and L_∞ is the deep-water wave length. Equation (1) is numerically integrated with initial values $\Theta(0, y) = \Theta_0$.

Wave heights are determined from the equation of energy balance

$$\frac{\partial}{\partial x}(EC_g\cos\Theta) = -D, \qquad E = \frac{1}{8}\rho g H^2, \qquad (3)$$

where E and C_g are the wave energy and the rate of its transfer. In order to define the rate of dissipation D two approaches of both Battjes & Janssen (1978) and Thornton & Guza (1983) are combined yielding

$$D = 2\hat{P}\frac{E}{T}, \qquad \hat{P} = \left(\frac{H}{\hat{\gamma}h}\right)^4, \qquad \hat{\gamma} = \frac{1}{2} + \left(\frac{H_0}{L_\infty}\right)^{\frac{1}{2}} \tag{4}$$

where $\hat{P}$ is the probability of wave breaking and $\hat{\gamma}$ is empirical factor. Denoting $f_1 = H^2$ one can transform equation (3) into

$df_1 / dx + a_1 f_1 = -a_2 f_1^3$.

Dividing on f_1^3 and substituting $f_2 = f_1^{-2}$ we have

$df_2 / dx - 2a_1 f_2 = 2a_2$,

that is solved analytically. The final expression for wave height is of the form

$$H^2 = \left[C_g \cos\Theta \left(\beta \int_0^{\tilde{x}} \frac{d\tilde{x}}{\tilde{h}^4 (C_g \cos\Theta)^3} + \frac{1}{F_0^2} \right)^{\frac{1}{2}} \right]^{-1}, \tag{5}$$

$$F_0 = H_0^2 C_{g0} \cos\Theta_0, \qquad \beta = (4X_0 / T) / (\hat{\gamma} d_0)^4,$$

where $\tilde{h} = h / d_0$, $\tilde{x} = x / d_0$ and C_g is computed from Nielsen's (1982) explicit approximating formula

$$C_g = \sqrt{gh}\exp(-\pi h / L_\infty). \tag{6}$$

Evaluating total depth on each step of wave height calculations we are restricted to the first-order approximation of wave set-up $\zeta^{(1)}$ and use the cross-shore momentum balance equation in simplified form

$$\frac{\partial \zeta^{(1)}}{\partial x} = -\frac{1}{\rho g h}\frac{\partial S_{xx}}{\partial x}, \tag{7}$$

where S_{xx} is the shore-normal component of radiation stress and ρ is the water density.

The values $H(0, y) = H_0$ and $\zeta^{(1)}(0, y) = 0$ are input at the outer boundary. The validity of wave height estimations based on the outlined model has been confirmed by both laboratory and field tests (Leont'yev, 1993).

4. STORM-DRIVEN CIRCULATION

The wave-induced steady currents are treated in terms of the depth-integrated linearized equations of motion and water conservation equation

$$\frac{\partial \zeta}{\partial x} = -\frac{1}{\rho g h}\left(\frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{xy}}{\partial y} + \tau_{bx} \right), \tag{8}$$

$$\frac{\partial \zeta}{\partial y} = -\frac{1}{\rho g h}\left(\frac{\partial S_{yy}}{\partial y} + \frac{\partial S_{yx}}{\partial x} + \tau_{by} \right) + \frac{1}{\rho g}\frac{\partial \tau_l}{\partial y}, \tag{9}$$

$$\frac{\partial}{\partial x}(Uh) + \frac{\partial}{\partial y}(Vh) = 0, \tag{10}$$

where U and V are the depth-averaged mass transport velocities. The radiation stress components S_{ij} are defined as

$$S_{xx} = \frac{E}{2}\left[\frac{2C_g}{C}\left(1+\cos^2\Theta\right)-1\right], \qquad S_{yy} = \frac{E}{2}\left[\frac{2C_g}{C}\left(1+\sin^2\Theta\right)-1\right],$$

$$S_{xy} = S_{yx} = -\frac{E}{2}\frac{C_g}{C}\sin 2\Theta, \tag{11}$$

The bottom friction terms τ_{bx} and τ_{by} are taken in the form

$$\tau_{bx} = C_f\rho\overline{|\tilde{u}|U}, \qquad \tau_{by} = C_f\rho\overline{|\tilde{u}|V}, \tag{12}$$

where C_f is friction factor, which is adopted as constant value 0.01, $\tilde{u}$ is wave-induced horizontal orbital velocity near the bed defined from the linear wave theory and overbar denotes averaging in time.

The lateral friction term is given by

$$\tau_l = \rho\nu_l h\frac{\partial^2 U}{\partial x\partial y}, \qquad \nu_l = 2\cdot 10^{-4}X_0\sqrt{gd_0}, \tag{13}$$

where ν_l is lateral eddy viscosity coefficient. Estimation of ν_l in (13) has been obtained empirically satisfying the numerical stability of used finit-difference scheme and is in agreement with the field data of Bowen & Inman (1974).

At the outer boundary of investigated area the following conditions are adopted: $\zeta(0,y)=0$, $U(0,y)=0$ and $V(0,y)=0$ or $V(0,y)=V_e$, where V_e refers to external longshore current of non-wave nature (in particular, wind drift and tidal currents).

5. UNDERTOW

Superimposed on depth-averaged current field the undertow itself can provide cross-shore sediment transport even if the depth-averaged velocity U is of zero value. Undertow velocity U^* is controlled by the local momentum balance in water column

$$\frac{\partial}{\partial x}\left(\bar{p}+\rho\overline{u^2}\right) = -\frac{\partial}{\partial z}\left(\rho\overline{uw}\right), \qquad -\rho\overline{uw} = \rho\nu_z\frac{\partial U^*}{\partial z}, \tag{14}$$

where Z, W and ν_z are the vertical coordinate, vertical velocity component and vertical eddy viscosity coefficient. Implying that mean pressure $\bar{p}$ in presence of waves deviates from hydrostatic pressure on the value $-\rho\overline{w^2}$, the left hand side of (14) is rewritten as $(\partial/\partial x)\left(\rho\overline{u^2}-\rho\overline{w^2}\right)+\rho g(\partial\zeta/\partial x)$. Taking approximations $\overline{u^2}-\overline{w^2}\approx\overline{\tilde{u}^2}$, $\rho\overline{\tilde{u}^2}\approx E/h$ and estimating set-up gradient from equation (7), where shallow-water approximation of S_{xx} is used, we have instead of (14)

$$\frac{\partial}{\partial z}\left(\rho\nu_z\frac{\partial U^*}{\partial z}\right) = -\frac{A}{h}, \qquad A = \frac{1}{2}\frac{\partial E}{\partial x}+\frac{E}{h}\cos^2\Theta\frac{\partial h}{\partial x}. \tag{15}$$

Determining the undertow velocity from (15) we suggest that the vertical distribution of U^* mostly depends on the shear stress τ^* at wave trough level $z=-z^*$

$$-\nu_z(\partial U/\partial z)_{z=-z^*} = \tau^*, \qquad \tau^* = D/C, \tag{16}$$

where τ^* is defined according to Stive & Wind's (1986) model.

Satisfying the requirement of mass flux balance

$$\int_{-d}^{-z^*} \rho U^* dz = -Q, \qquad Q = m\frac{E}{C}\cos\Theta, \tag{17}$$

where Q is wave-induced on-shore mass flux concentrating above the wave troughs and m is empirical value (m=1 in sinusoidal waves and m<1 in non-linear asymmetric waves (Dalrymple,1976)), we obtain the velocity profile $U^*(z)$. The final expression of the undertow velocity at the bottom is written in the form

$$U_d^* = -\frac{h}{\rho\nu_z}\left(\frac{A}{3}+\frac{1}{2}\frac{D}{\sqrt{gh}}\right) - m\frac{E\cos\Theta}{\rho\sqrt{gh}}, \quad \nu_z = b\left(1+\hat{P}\right)h\sqrt{gh}, \tag{18}$$

The vertical eddy viscosity coefficient according to Stive & Wind (1986) is of order $10^{-2}h\sqrt{gh}$. Its local value however would increase due to excess turbulence penetrating into water column from breaking waves. To take this fenomena into account we incorporate in expression of ν_z the dependence on probability of wave breaking $\hat{P}$, which is defined in (4).

6. SEDIMENT TRANSPORT AND BED CHANGES

In order to estimate the cross-shore and longshore sediment transport rates q_x and q_y we apply the energetic concept of Bagnold (1963), keeping in mind that total flow velocity near the bed is the sum of wave oscillatory $(\tilde{u})$ and steady (U, U_d^*, V) components and suggesting $U^2, U_d^{*2}, V^2 << \tilde{u}_{max}^2$. The following transport formulae are deduced

$$q_x = \frac{\varepsilon_b}{2\tan\Phi} f_w \rho(\overline{\tilde{u}^3}\cos\Theta + 3\overline{\tilde{u}^2}(U+U_d^*)) + \varepsilon_s(F+B)\left[W_s/(U+U_d^*) - \frac{\partial d}{\partial x}\right]^{-1}, \tag{19}$$

$$q_y = \frac{\varepsilon_b}{2\tan\Phi} f_w \rho(\overline{\tilde{u}^3}\sin(-\Theta) + 3\overline{\tilde{u}^2}V) + \varepsilon_s(F+B)\frac{V}{W_s}, \tag{20}$$

where the first and the second terms on the right hand side represent the bed-load and suspended-load contributions respectively. The q_x and q_y values express the immersed weight of sediment carried in unit time through unit flow width. In the above relations ε_b and ε_s are the efficiency factors of sediment transport, $\tan\Phi$ is the grain-to-grain friction coefficient, f_w is the hydraulic bed friction coefficient and W_s is the grain fall velocity. The F and B values represent the rates of energy dissipation near the bed due to both bed friction and excess turbulence generated by wave breaking

$$F = \frac{1}{2} f_w \rho\left|\overline{\tilde{u}^3}\right|, \qquad B = D\exp(3/2(1-h/H)), \tag{21}$$

where the second expression is based on the model of Roelvink & Stive (1989).

Velocity moments are determined from the semi empirical formulae obtained by decomposing total oscillatory velocity on two harmonics with varying amplitudes and phase shift

$$\tilde{u}(t) = u_m\cos\chi(t) + u_{2m}\cos(2\chi(t)+\varphi). \tag{22}$$

If $u_{2m}^2 << u_m^2$ one can find from the above expression

$$\overline{\tilde{u}^2} = (1/2)u_m^2 \tag{23}$$

and

$$\overline{\tilde{u}^3} = (3/4)u_m^3(u_{1m}/u_m)\cos\varphi.$$

It seems reasonably to suppose that ratio of harmonic amplitudes is proportional to the Ursell number $Ur = HL^2/h^3$. Implying that harmonic phase shift φ tends to $\pi/2$ in bor-like breaking waves and taking into account that in breaker regions the probability of wave breaking $\hat{P}$ tends to 1, we come to following relations

$$u_{1m}/u_m = const \cdot HL^2/h^2, \qquad \cos\varphi = 1 - \sqrt{\hat{P}}.$$

Using shallow-water approximation in L value we have finally

$$\overline{\tilde{u}^3} = 1.8\cdot 10^{-3}\frac{gT^2}{h}\frac{H}{h}\left(1-\sqrt{\hat{P}}\right)u_m^3. \tag{24}$$

The validity of the equation (24) has been confirmed by calibration with Roelvink & Stive's (1989) wave tank data (Leont'yev,1994).

Within the framework of assumptions $u_{1m} << u_m$ and $\varphi \approx 0$ the even third velocity moment is expressed by $\left|\overline{\tilde{u}^3}\right| = (4/3\pi)u_m^3$. However one can easily find out by using (22) that if $u_{1m} \to u_m$ and $\varphi \to \pi/2$ the value of $\left|\overline{\tilde{u}^3}\right|$ decreases and approaches to about one half of above quantity. Relating variations of $\left|\overline{\tilde{u}^3}\right|$ with probability of wave breaking event $\hat{P}$ we suggest

$$\left|\overline{\tilde{u}^3}\right| = (4/3\pi)\left(1-0.5\sqrt{\hat{P}}\right)u_m^3. \tag{25}$$

The velocity amplitude u_m is defined from the linear wave theory.

As it was argued by Nielsen (1992), for practical purposes the bed friction cefficient for a combined wave-current flow can be calculated as if only the wave orbital velocities occured at the bed. Hence in order to estimate f_w values we can use the formulae recommended by Nielsen for the rough oscillatory flow

$$f_w = \exp\left(5.5\left(\frac{r}{a_m}\right)^{0.2} - 6.3\right), \qquad r = 5\theta d_s + 8\eta^2/\lambda, \tag{26}$$

where a_m is the amplitude of horizontal water particle excursions at the bottom, r is the bed roughness, θ is Shields' parameter, η and λ are the ripple height and length defined by Nielsen's (1992) equations.

The bed changes are determined from the equation of sediment mass conservation

$$\frac{\partial d}{\partial t} = \alpha^{-1}\left(\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y}\right), \qquad \alpha = (1-\varepsilon)(\rho_s/\rho - 1)\rho g, \tag{27}$$

where ε and ρ_s are the porosity and density of bed sediments. Equation (27) is integrated by using Lax-Wendroff numerical procedure with typical time step varying from two to five hundreds of wave periods, depending on wave strength and properties of bottom topography. The required time step Δt can be roughly estimated from empirically determined criterion

$$\frac{\Delta t}{T} \le 2.\cdot 10^3 \frac{X_0}{T\sqrt{gd}}\sqrt{\frac{\overline{\tilde{d}_s}}{H_0}}, \tag{28}$$

where $\bar{d}$, is the typical grain size.

A spatial grid used in calculations is of uniform step lengths $\Delta x = 0.01X_0$ and $\Delta y = 0.01Y_0$, where the scales of X_0 and Y_0 are of order 1 km, being $Y_0 \geq 2X_0$. In computations of wave refraction and storm-driven circulation the explicit finit-difference schemes are used, including smoothing procedures to provide sufficiently high numerical stability.

Table 1. Characteristics of storm events observed at Lubiatowo.

H_0, m	T, s	Θ_0, degrees	t_w, hours	Z_0, m
Storm 1: 28.09-01.10.76				
0.5	5.5	45	15	-0.25
1.0	6.5	40	6	-0.30
0.9	6.5	35	12	-0.37
0.9	6.5	30	6	-0.44
0.6	6.5	25	16	-0.47
Storm 2: 06.10-09.10.76				
0.5	5.5	-45	24	-0.44
0.6	6.0	-40	15	-0.48
1.1	6.5	-35	21	-0.31
0.9	6.5	-35	6	-0.36
0.6	7.0	-30	12	-0.36
0.5	7.0	-25	6	-0.38
Storm 3: 12.10-19.10.76				
0.5	5.5	45	24	-0.25
1.3	7.0	35	9	-0.20
1.4	7.5	30	18	-0.31
1.1	7.5	30	6	-0.31
1.0	7.0	30	18	-0.40
0.8	7.0	30	36	-0.51
0.7	6.5	25	24	-0.65
0.5	6.5	20	24	-0.65

Fig. 1. Scheme of nearshore zone.

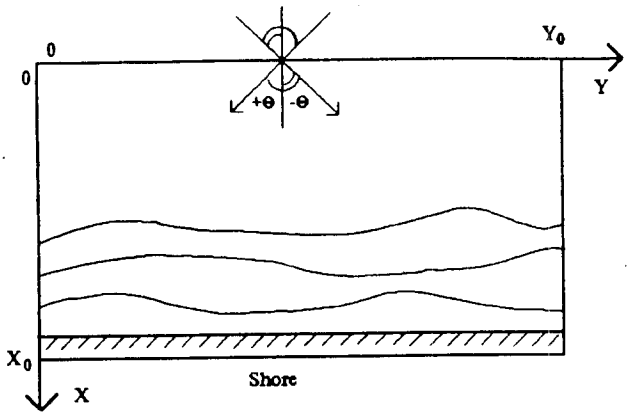
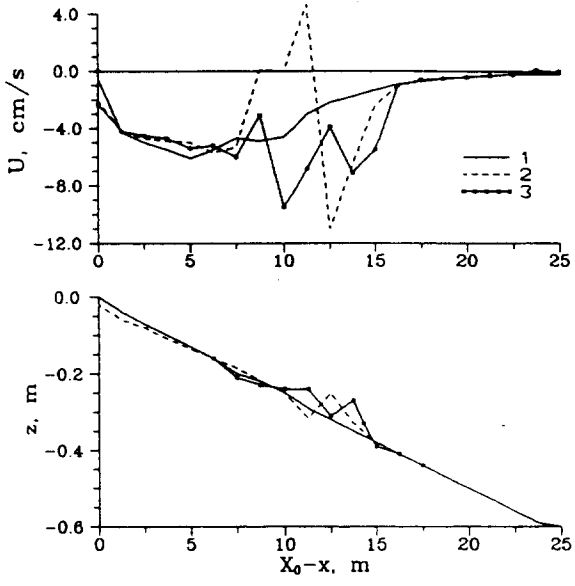


Fig. 2. Comparison of observed (Roelvink & Stive, 1989) and computed deformations of beach profiles, exposed to 12-hour impacts of random waves for initially liner and barred slopes, composed of fine sand (0.1 mm). Input *rms* wave heights are 0.123 m for linear and 0.133 m for barred slopes, wave periods in both cases are 2 s. 1: initial profile; 2: final measured; and 3: calculated profiles.



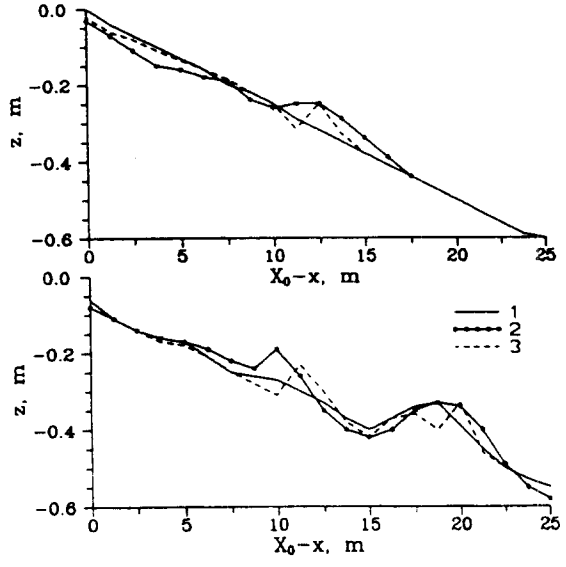


Fig. 3. Temporal variations of bottom profiles and cross-shore distributions of undertow velocity. Computed data refer to different time lapses after the beginning of wave action: 1: t=0; 2: 1=12 hours; 3: t=18 hours. Input wave height and period are 0.123 m and 2 s.

Fig. 4. Nearshore bottom topography at Lubiatowo (the Baltic Sea coast). Depths are given in m.

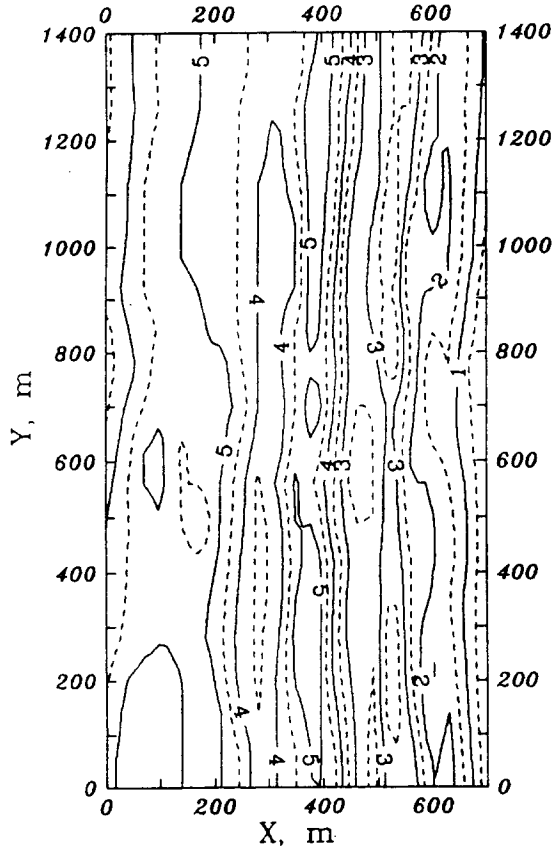


Fig. 5. Observed morphological changes at Lubiatowo caused by three successive storm events. 1: accretion area; 2: erosion area. Magnitudes of bed deformations are given in m.

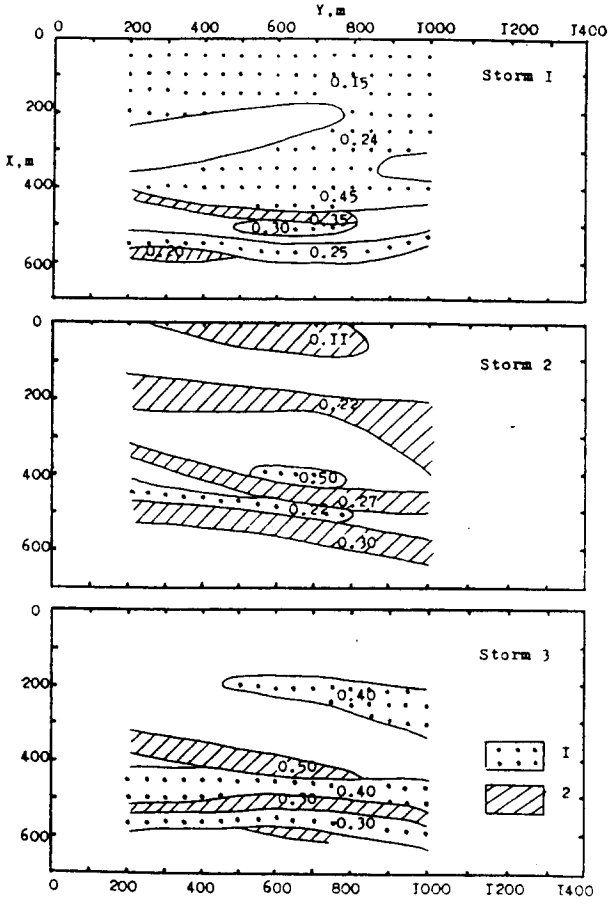


Fig. 6. Calculated morphological changes at Lubiatowo. Erosion areas are shaded. Magnitudes of bed deformations are given in m.

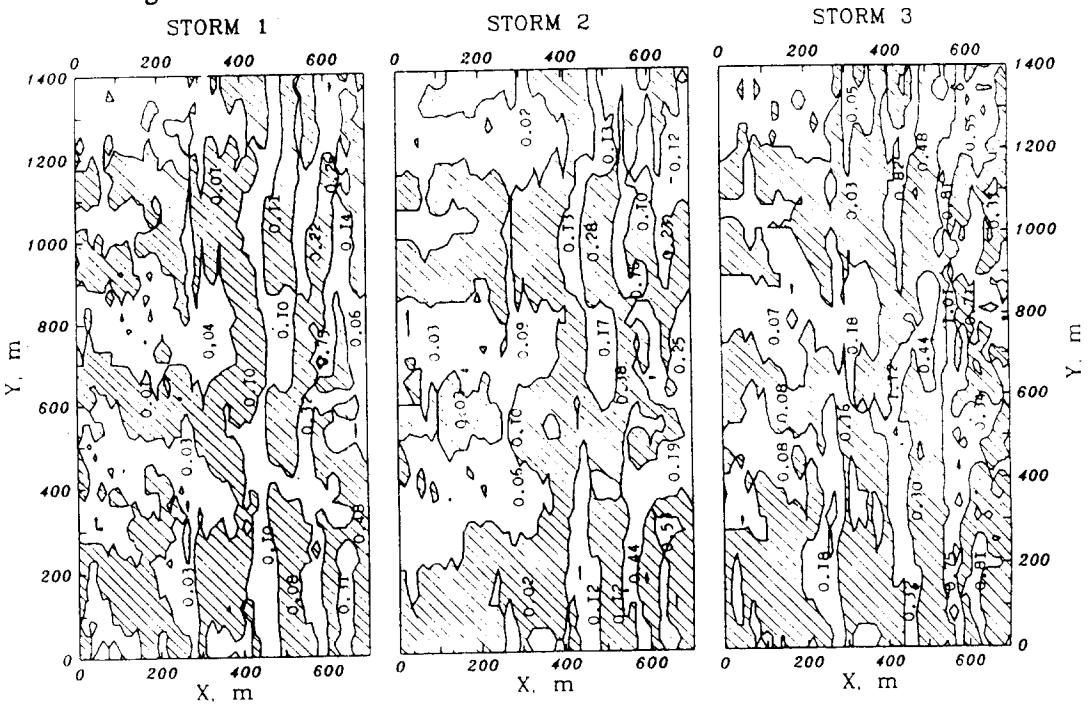
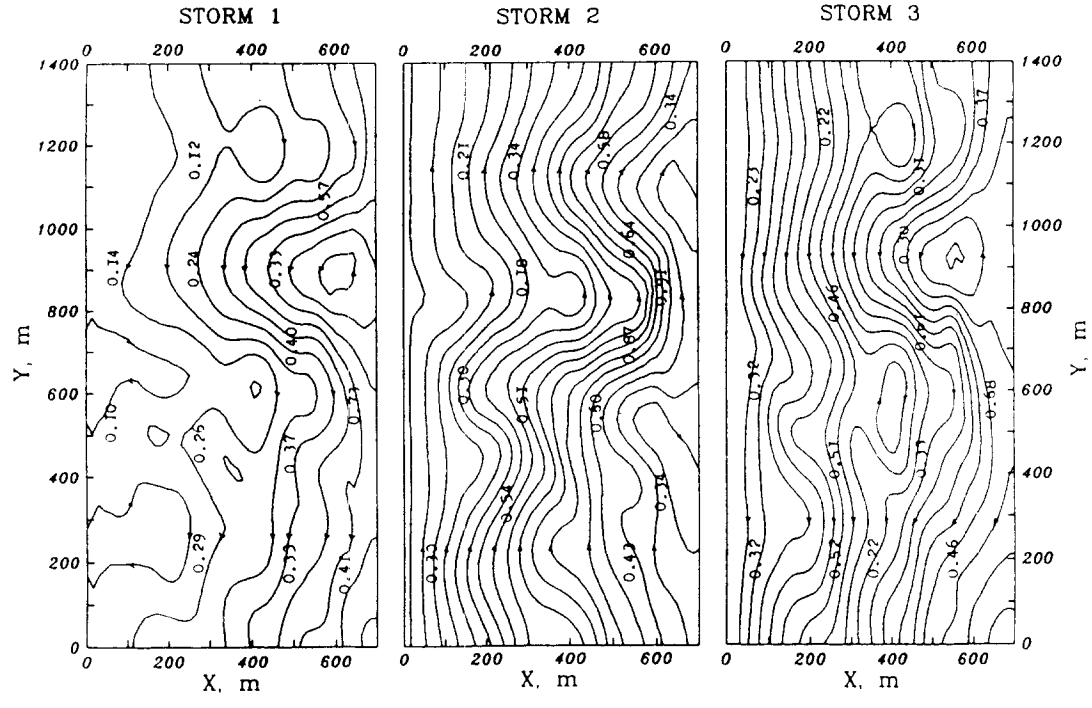


Fig. 7. Calculated storm-driven currents at highest stages of storm events. Stream line gap is 35 m^3/s for all pictures. Flow velocities are given in m/s.



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PRÉVISION DES EFFETS DE LA MARÉE SUR LA STABILITÉ DES PENTES INTERTIDALES ET PERSPECTIVES DE PRÉVENTIONS

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MOTS CLÉS: sol, stabilité, pente, berge, intertidal, effets de la marée, milieux poreux - écoulement cyclique, modèle numérique, essais en nature, CESAR-LCPC.
KEY WORDS: soil, stability, slope, bank, intertidal, tide effects, porous media - cyclic flow - numerical model, field test, CESAR-LCPC.

RÉSUMÉ

Inclus dans le vaste domaine de la mécanique des milieux poreux, l'étude de l'écoulement dans les berges, les massifs et les pentes de rives, soumis à la marée constitue un thème de recherche jusqu'alors très mal connu. Ce thème complexe, marqué par l'importance de ses applications à l'aménagement des rives intertidales, présente un grand intérêt scientifique par son aspect inter-disciplinaire à la frontière géotechnique-hydraulique. Nous proposons une suite de résultats originaux sur ce thème:

- Proposition de premières expérimentations en nature, malgré de nombreuses difficultés liées à des contraintes naturelles ou matérielles, permettant de valider les modèles existant.
- Tester l'adaptation d'un modèle numérique, basé sur la théorie des milieux poreux non saturés, conçu par le Laboratoire Central des Ponts et Chaussées.
- Application de certains résultats obtenus, dans la mise en évidence des effets de la marée sur la stabilité des pentes intertidales.

Cette démarche scientifique interdisciplinaire menant de front expérimentation en nature et modélisation numérique a ainsi permis d'obtenir un ensemble de résultats originaux pouvant présenter un grand intérêt pour la connaissance du comportement des zones intertidales tout en ouvrant de nombreuses perspectives de recherche de préventions pour ces pentes.

ABSTRACT

Included in the vast area of the porous media mechanics, the study of the flow in banks and slopes under tide effects, constitutes a theme of research up until now very poorly known. This complex theme, marked by the importance of its applications to the adjustment of intertidal banks presents a great scientific interest, by its inter-disciplinary aspect to the common frontier of geo-technics-hydraulics.

We have been able to propose many original results on this theme:

- First field testing proposal, despite many difficulties linked to natural constraints or material ones, allowing to validate existent models.
- To test the adaptation of a numerical model based on the theory of the non-saturated porous media, conceived by the "Laboratoire Centrale des Ponts et Chaussées".
- Application of some obtained results in order to emphasize the tide effects on the intertidal slopes stability.

This interdisciplinary scientific approach leading experimentation front in nature and modelling, has thus permits to obtain an original results, being able to present a great interest for the knowledge of the behavior of intertidal zones while opening many perspectives of research of preventions for these slopes.

1. INTRODUCTION

Dans les zones littorales soumises à de fortes marées, apparaissent de nombreuses perturbations sur des rives, instabilité des berges ou même ruines de pentes et d'ouvrages, induites par des contraintes océaniques. Ces contraintes sont

dues à la houle ou à la marée. C'est pourquoi l'étude de l'écoulement dans les massifs estuariens subissant l'action de la marée constitue un thème de recherche particulièrement intéressant d'un point de vue:
- scientifique : la marée agissant sur un massif crée un écoulement cyclique dans le sol le constituant, par une alternance de remplissages et de vidanges. Cet écoulement est conditionné par les caractéristiques de la marée comme facteur excitateur et du massif comme récepteur;
- économique : les massifs intertidaux sont situés dans des zones littorales ou estuariennes marquées par l'importance des aménagements portuaires ou touristiques. L'étude de leur comportement et de leur éventuelle instabilité revêt une grande importance pour la prévision de ces risques dans l'analyse de la localisation et du dimensionnement des ouvrages implantés dans ces régions d'un grand intérêt économique.

En nature, lors des oscillations de la marée, le talus se remplit et se vide (Fig. 1). Des phénomènes complexes se manifestent à l'intérieur du sol et sur l'interface eau-sol. Il s'agit d'étudier le comportement de l'écoulement et ses éventuels effets sur la stabilité des pentes semi-immergées. Les variations cycliques du champ de pression dans le massif sont probablement importantes. De même, du fait du débit sortant, les vitesses d'écoulement deviennent importantes en pied du talus. Ces phénomènes peuvent altérer la stabilité globale ou locale du massif (glissement, érosion, affouillement...).

Nous avons présenté par ailleurs l'étude numérique de l'écoulement dû à la marée (Rezzoug, 1994) au moyen de modèles mathématiques de l'écoulement à surface libre dans les massifs portuaires soumis à la marée. La synthèse des différents modèles montre que le module NSAT de CESAR-LCPC, basé sur l'équation de Richards des milieux non saturés, paraît adapté au problème étudié. Dans un but de validation des résultats théoriques, nous avons également effectué des expérimentations en laboratoire (Rezzoug et al., 1993) et en nature (Alexis et al., 1994).

Nous proposons dans cet article:
- des mesures de l'évolution du niveau piézométrique le long d'un cycle de marée. Ces mesures sont effectuées sur le site des Sablières situé à l'embouchure dans l'estuaire de la Loire;
- une simulation numérique au moyen de NSAT de CESAR-LCPC, de l'action de la marée sur ce site;
- une confrontation est établie entre des résultats numériques et expérimentaux;
- une analyse du rôle que jouent les écoulements internes dans les ruptures de pentes intertidales ainsi que des perspectives de prévention.

2. ECOULEMENT A SURFACE LIBRE DANS UNE RIVE INTERTIDALE

2.1. Realisation des mesures in-situ

En Nature, les phénomènes sont complexes en raison de la variabilité de l'onde marée et surtout de l'hétérogénéité des sols d'estran liée à leur histoire géologique mouvementée et à leur positionnement dans des zones marquées par une instabilité hydrosédimentaire engendrant des processus d'érosion-sédimentation.

Compte tenu des hypothèses restrictives de toute modélisation (mathématique ou physique) et compte tenu de la complexité du phénomène naturel, il nous a paru plus important d'effectuer des mesures sur site naturel pour les comparer aux résultats de la modélisation.

Les mesures doivent être effectuées d'une part sur un site protégé de toutes les perturbations engendrées par la houle et d'autre part pendant une saison sèche, pour éviter les problèmes liés aux infiltrations dues aux précipitations, ainsi que les écoulements des nappes souterraines .

L'estuaire de la Loire constitue une région scientifiquement intéressante. Elle fait l'objet d'études hydrologiques et hydrosédimentaires depuis plusieurs dizaines d'années.

2.1.1. *Description du site*

Le site des Sablières de l'Atlantique (Fig. 2), est un talus de remblai situé dans la zone portuaire sur la rive nord de l'estuaire de la Loire (FRANCE), à proximité du Pont de Saint Nazaire. Le schéma de la coupe géologique montre des dépôts successifs de couches de sable et de vase. Le sol peut être qualifié de sable

localement vasard de compacité moyenne. Pour stabiliser la pente qui est déjà assez douce (environ 1/5), le talus porte un enrochement en pierres naturelles (sécurité contre l'effondrement et l'entraînement par le courant).
La pleine mer (5 m cote marine, notée C.M.) couvre quasiment la pente d'enrochement. Alors qu'à basse mer (environ 1,5 m C.M.), le pied du talus est découvert, la hauteur d'eau est d'environ 1,5 m C.M.. La basse mer découvre un fond vaseux traversé par des trous d'affouillement d'environ 50 cm de diamètre, à travers lesquels le talus se vide pendant le jusant.
Nous avons réalisé 5 forages (F1 à F5), de 2,5 m de profondeur sur le site, forés le long d'une ligne normale à la rive et distants respectivement du point de la pleine mer de 13,00 m ; 20,95 ; 29,35 ; 38,89 ; 67,16 (Fig. 2). Ces forages ont permis la mesure du niveau piézométrique de la nappe, et donc d'effectuer le suivi de la surface libre pendant le cycle de marée.
Les mesures ont été relevées le long d'un cycle d'une marée, avec:
- coefficient de marée 44,
- basse mer: 1,75 m C.M. à 8 h 17
- pleine mer: 4,20 m C.M. à 14 h 36

2.1.2. *Résultats de mesures*
La Fig. 3 synthétise les mesures de niveau d'eau effectuées pendant le cycle de marée en joignant simplement tous les points de mesures. Le système d'axes est composé de la hauteur verticale mesurée en mètre C.M. et de la distance mesurant la pénétration horizontale dans le remblai. Les résultats sont représentés à chaque quart du cycle : mi-flot (t = 0), pleine mer (t = 3 h), mi-jusant (t = 6 h) et basse mer (t = 9 h), (Fig. 3).
Deux résultats importants apparaissent sur cette figure:
- la variation du niveau d'eau est importante au voisinage de l'interface eau-sol et diminue en s'éloignant de celui-ci. Au bout d'une distance horizontale d'environ une centaine de mètres comptée à partir du milieu de l'interface intertidale, le niveau se stabilise complètement à une valeur que nous appellerons niveau d'équilibre.
- le niveau d'équilibre dans le remblai est voisin de celui de la pleine mer. Il est à noter que le niveau d'équilibre (Ne = 4,57 m C.M.) est supérieur à celui de la pleine mer du jour (4,20 m C.M.). Ce résultat semble indiquer que le niveau d'équilibre s'établit autour d'une moyenne sur un cycle lunaire des niveaux de pleine mer.

2.2. Simulation numerique du site des sablieres
2.2.1. *Modélisation Mathématique*
Compte tenu des hypothèses restrictives de la modélisation mathématique (le sol est considéréré comme milieu poreux, perméable, homogène et indéformable; l'écoulement suit la loi de Darcy), et compte tenu de la complexité du phénomène naturel, il est important de confronter les mesures sur site aux résultats du modèle mathématique:
l'équation générale régissant les écoulements en milieux saturés et non saturés dans les sols, (Humbert 1984):

$$div\left(k_r(\varphi)\bar{K}\ g\ r\vec{a}d\ h\right)-C(\varphi)\frac{\delta h}{\delta t}+q \quad (1)$$

où h est la charge hydraulique; $\bar{K}$ est le tenseur de perméabilité du milieu saturé et q le débit volumique en cas d'existence de source d'alimentation. $k_r(\psi)$ et $C(\psi)$ régissent respectivement les lois de la perméabilité relative et la capacité capillaire dans la zone non saturée au-dessus du niveau de la nappe. Elles sont fonction de la succion ψ et les coefficients a, b, c, d.
Compte tenu des conditions aux limites de l'agitation marée sur la pente intertidale, nous supposons que la marée agit comme une onde sinusoïdale directe avec une période de 12 heures, une amplitude constante A et avec une pulsation ω:

$$h(x,t) = A \sin\omega t \quad (2)$$

Nous utilisons pour notre simulation le module NSAT qui fait partie des modules fonctionnels du programme général par éléments finis, CESAR-LCPC du Laboratoire Central des Ponts et Chaussées.

2.2.2. *Simulation par NSAT de CESAR-LCPC*

La complexité géotechnique de ce site (couches de sable et les lentilles de vase) est source de difficulté dans la simulation. Il s'agit toutefois d'un cas naturel fréquent en zone estuarienne, et donc en zone aménageable. Du fait de l'hétérogénéité du massif, la perméabilité et la porosité locales ne peuvent être représentatives. Nous avons estimé les valeurs globales à: k = 2,6 10^{-4} m/s et n = 0,2; avec des coefficients liés à la succion: a = 3.10^6 cm^b; b = 5; c = 4.10^4 cm^d; d = 1,8.

Nous avons simulé la coupe du site naturel (Fig. 2) en tenant compte de son hétérogénéité et de sa géométrie; mais la présence d'un nombre important de lentilles de vase rend le milieu trop hétérogène et son exécution par NSAT complexe.

Le maillage adopté est représenté sur la Fig. 4.

2.2.3. *Résultats de la simulation*

La Fig. 5 montre l'évolution de la charge hydraulique sur 3 points désignés sur la légende. Nous remarquons qu'au bout de 80 cycles un niveau d'équilibre est établi dans tout le remblai. Pour pouvoir comparer la remontée du niveau d'équilibre avec les niveau de la marée, la Fig. 6 donne l'évolution de la charge hydraulique en deux points: l'un en pied du talus (présentant le mouvement de la marée) et l'autre dans le massif (présentant le niveau d'équilibre).

Le niveau d'équilibre est stable et égal à 3,65 m, valeur proche de la moyenne entre le niveau moyen de la marée (2,98 m) et celui de la pleine mer (4,20 m), mais inférieure au niveau d'équilibre mesuré sur le site (4,57 m).

2.2.4. *Confrontations et Analyse des résultats*

La Fig. 7 montre la différence entre les mesures en nature et les valeurs obtenues par la simulation numérique du site par NSAT en trois points.

L'origine des écarts apparus entre le modèle numérique et l'expérimentations ne semble pas être liée à d'éventuelles insuffisances de la formulation, mais plutôt à:

- la représentativité de la marée: Dans l'ensemble de l'étude, la marée a été supposée idéale (sinusoïdale) alors que cette onde est pseudo-périodique. Or, les mesures montrent que l'écoulement en nature "intègre" les variations d'amplitude (déchet - revif). En raison de la complexité la complexité du phénomène, et la durée importante du temps de calcul de sa simulation numérique, nous avons ainsi choisi, dans cette première étude, de ne pas effectuer les calculs sur un cycle lunaire, qui auraient été 28 fois plus longs;
- la représentativité du sol : les valeurs des caractéristiques prises en compte ne sont pas toujours parfaitement représentatives de l'état réel du sol, en raison de son hétérogénéité.

Néanmoins, la remontée d'eau exprimée par les deux approches présente un élément affirmé, et original de grande importance. Elle montre une surpression interstitielle de l'ordre de la pleine mer (mesurée en colonne d'eau), dans certains cas de pentes douces et vaseuses (Rezzoug et *al.* 1993a et 1993b), qui sollicite d'une manière nuisible la stabilité globale du massif.

Les profiles de surface libre se confondent dans le remblais et se distinguent, dans la pente, en se rapprochant de l'interface eau-sol. Ils prennent un fort rabattement au moment de la marée basse. D'une part, ils traduisent l'importance des vitesses de filtration pendant la vidange du massif, et d'autre part, ils définissent et caractérisent la longueur de la zone perturbée par les changements instantanés et cycliques de pression interstitielle.

Nous avons ainsi montré que les résultats sont remarquablement intéressants, et la confrontation entre les mesures en nature et les résultats du modèle numérique NSAT semble généralement satisfaisantes. De même, nous nous sommes assuré de l'adaptation du module NSAT au

calculs des écoulements dans les pentes de rive et les berges intertidales.
Cette analyse comparative donne ainsi des résultats qui semblent suffisamment satisfaisants pour nous permettre d'envisager des applications qui peuvent mettre en évidence le rôle que jouent ces nouveaux éléments dans la rupture des pentes intertidales ainsi que des perspectives de prévention.

3. INFLUENCE DE LA MAREE SUR LA STABILITE DES PENTES

Après l'entrée d'eau dans le massif pendant la marée montante, il apparaît un écoulement sortant à marée descendante. Du fait du débit sortant, les vitesses d'écoulement peuvent être importantes en pied de talus. Les variations cycliques de pression de l'eau provoquées par la marée peuvent causer des changements importants dans l'état de contraintes, une diminution notable des forces inter-granulaires, et des déformations significatives. Ces phénomènes peuvent altérer la stabilité globale ou locale du massif (glissement, érosion, affouillement...).
L'écoulement peut engendrer des ruptures globales (grand glissement) ou superficielles (érosion, affouillement). Dans cet article, nous étudions l'influence de cet écoulement sur la stabilité d'un talus en considérant un mode de rupture: le grand glissement.

3.1. Approche preliminaire

Les forces dues à l'écoulement permanent de l'eau sont toujours importantes et celles dues aux écoulements transitoires le sont encore davantage, mais dans notre cas elles sont mal connues. L'exemple suivant, (Fig. 8), est donné par Pilot 1970 ; il montre que l'action de ces forces, dans le sens d'un glissement, peut-être de l'ordre de grandeur des forces de pesanteur qui constituent la cause naturelle des ruptures.
Soit: moment moteur dû à la force d'écoulement, et moment moteur dû au poids de l'élément; γ et γ' sont les poids volumiques, respectivement des terres sous l'eau et de l'eau. Le rapport des deux moments est:

$$r = \frac{\Delta M_e}{\Delta M_p} = \frac{\gamma_w}{\gamma'} \frac{\sin\alpha \, \sin(\theta+\alpha)}{\cos\theta} \quad (3)$$

Pour $\theta = 60°$; $\alpha = 30°$ et $\gamma' \approx \gamma_w$, on a $r = 1$, on constate que l'élément de volume ΔV est soumis à une force d'écoulement dont la participation au moment moteur est de l'ordre de celle de son poids ; à cette intervention de l'eau il faut aussi ajouter, tout le long de la ligne de rupture, la diminution de résistance au cisaillement provoquée par les pressions interstitielles.
On n'a envisagé, ci-dessus, qu'une forme d'intervention de l'eau dans la stabilité des talus, celle qui consiste à évaluer les pressions interstitielles le long des surfaces de glissement et à introduire la force résultante dans les équations d'équilibre. Dans notre cas, il est avantageux aussi d'envisager une autre forme d'intervention en introduisant la force de percolation ou poussée d'écoulement.
Dans le cas général d'un écoulement quelconque dans un talus en rupture circulaire, on a ainsi équivalence entre les deux systèmes de forces : résultante de pression interstitielle et résultante de forces d'écoulement. Dans certains cas géométriques simples, celui des pentes naturelles, par exemple, où le calcul de la force de volume, (poussée d'écoulement), est immédiat, cette seconde forme est plus commode, (Pilot 1970).

3.2. Application de la methode des perturbations

La méthode de perturbations est l'une des méthodes de calcul par tranches d'un glissement selon une ligne quelconque. Elle se base selon Faure et al. (1975), sur le principe suivant:
Les forces qui agissent sur une masse de sol en mouvement (méthode globale), sont:
- force de pesanteur (le poids);
- résultante des pressions interstitielles le long de la courbe de rupture;
- force de résistance au cisaillement. Sur un petit élément de la courbe de rupture agissent la contrainte normale effective σ' et la contrainte tangentielle

$$\tau' = \frac{1}{F}(c' + \tan\varphi') \quad (4)$$

où F est le coefficient de sécurité et c', φ' sont respectivement la cohésion et l'angle de frottement effectifs du sol. En utilisant les trois équations de la statique pour décrire l'équilibre, on obtient un système nécessitant une hypothèse sur la répartition des contraintes σ le long de la courbe de rupture. D'où la recherche d'une loi de répartition de la contrainte normale σ sur la courbe de rupture, plus satisfaisante que celle utilisée par Fellenius. Dans la méthode des Perturbations, cette hypothèse s'écrit:

$$\sigma = \sum \gamma_i \, h_i \cos^2\alpha(\lambda + \mu\tan\alpha) \quad (5)$$

Des recherches ont abouti à la conclusion que cette loi de répartition est la plus satisfaisante, (Filliat 1981). λ et μ sont avec F les trois inconnues du système des trois équations de la statique (F apparaissant au dénominateur, la solution est délicate mais possible). Cette méthode largement utilisée en France pour les ruptures circulaires et non circulaires fournit en plus une expression du lobe de contrainte qui est un moyen de contrôle du calcul et qui offre la possibilité d'envisager d'autres développements comme la prise en compte des déplacements, (Faure 1992).

En mécanique des sols, le rapport des forces résistantes aux forces motrices (désistabilisantes), définit pour un massif de sol le coefficient de sécurité F.

En rupture circulaire, le coefficient de sécurité F peut être calculé simultanément par les trois approches (Fellenius, Bishop, Perturbations); en rupture non circulaire, la méthode des perturbations a été la seule retenue en raison de sa fiabilité, (Faure 1992). Nous avons utilisé le programme de calcul de stabilité des pentes PETAL84 de LCPC, car il nous semble bien adapté.

3.3. Résultats

Nous traitons ici un exemple d'application, un talus de rive sollicité par la maré dont les caractéristiques sont données sur la Fig. 9. Avec la méthode des perturbations nous avons effectué des calculs sur PETAL84 pour plusieurs cas d'inclinaison α = 7,5°; 10°; 15°; 22° et 30°. A titre d'exemple, nous avons choisi comme matériau un limon sableux frottant dont les caractéristiques mécaniques sont: c' = 4 kPa et φ' = 40° avec γ = 22 kN/m^3.

La Fig. 10. montre la variation du coefficient de sécurité pendant le demi cycle du jusant. L'axe des abscisses représente la différence de niveau entre nappe intérieure (fixé au niveau de la pleine mer), et extérieure (variable, descendante). Nous remarquons que le coefficient de sécurité décroît dans les premiers temps du jusant, et prend à la fin une direction asymptotique horizontale. Malgré les caractéristiques mécaniques fortement favorables de ce matériau, la pente d'inclinaison 22° reste la limite admissible de stabilité.

La Fig. 11 présente le même exemple de la Fig. 9 dont l'évolution du coefficient de sécurité est exprimé sur la Fig. 10 par le cas de α = 30°. Cet exemple concrétise l'influence du niveau d'eau dû à la marée sur la stabilité d'une pente de rive à marée. Si nous considérons comme on le fait souvent dans le calcul de stabilité que le niveau d'eau dans le talus est égale au niveau de la mer, le coefficient de sécurité est, très confortable, de l'ordre de 2,5 (Fig. 11a, b).

A la lumière des études précédentes, nous considérons que le niveau d'eau, dans le talus, à toute instant, reste voisin de la pleine mer. Dans ce cas, pendant le jusant et au moment de la basse mer, le coefficient de sécurité chute de sa valeur importante (2,5) à une valeur critique de l'ordre de (1,5) exprimant l'instabilité de la pente (Fig. 11c).

Cet exemple montre l'importance de la prise en compte de la remontée du niveau d'équilibre dans le dimensionnement des pentes de rive et les berges intertidales.

4. CONCLUSIONS ET PERSPECTIVES DE PREVENTION

L'écoulement dans un talus portuaire soumis à la marée constitue un processus physique complexe à la frontière hydraulique-géotechnique. Nous avons proposé des expérimentations sur site naturel. La comparaison des résultats expérimentaux en nature à ceux obtenus lors d'une simulation du site par NSAT fait apparaître une concordance suffisante entre théorie et expérimentation. Cette concordance est complétée par des apports spécifiques des mesures validant les résultats de la modélisation.

Des éléments nouveaux, et originaux, sont apparus à l'issue de cette étude:

- Une onde progressive d'écoulement pénètre à l'intérieur du talus. Elle s'amortit sur une distance fonction de la perméabilité du milieu, caractérisant la longueur d'une zone perturbée par les changements instantanés et cycliques de la pression interstitielle.
- Les vitesses d'écoulement sortant du massif pendant le jusant sont importantes.
- Il apparaît une surcote du niveau d'équilibre (*Ne*) dans le talus par rapport au niveau moyen de la marée (H_m), (Fig. 1). Ce niveau est proche du niveau de la pleine mer (P.M.), dans le cas des pentes naturelles (douces), et vaseuses.

Nous avons présenté ensuite le rôle que jouent ces nouveaux éléments dans la rupture des pentes intertidales.

Nous avons pris en compte l'action de ce niveau piézométrique, à différents moments de la marée, sur la stabilité au grand glissement du talus. Au moyen de la méthode des perturbations, nous avons pu établir l'évolution du coefficient de sécurité en fonction de la différence des niveaux des nappes (entre l'intérieur du talus et le niveau de mer à l'extérieur) pour différentes pentes. A travers les exemples traités, nous avons pu montrer que pour le talus :

- la stabilité d'ensemble est nettement réduite par la surpression engendrée par la remontée du niveau d'eau dans le talus;
- les forts rabattements de la surface libre engendrés dans le sol près de la pente créent des gradients hydrauliques et des vitesses de sortie importants. Ils peuvent être une cause majeure de glissement de la pente et d'affouillement en pied de talus;
- l'instabilité apparaît ainsi directement liée à la position horaire dans le cycle de marée. Nous avons pu ainsi évaluer le coefficient de sécurité de la pente en fonction de la différence des niveaux de nappes pour le cas d'un sol type et pour différentes inclinaisons. Quant à ce sol, il paraît une inclinaison-limite de stabilité. Seuls les talus de pente inférieure ou égale à 22° restent stables pendant l'ensemble du cycle de marée.

La présente étude reste applicable à d'autres sites en France (Estuaires de la Gironde et de la Seine par exemple), et dans d'autres régions soumises à la marée (nombreuses dans les pays en développement), en vue d'établir des prévisions du comportement des sites estuariens à aménager. Elle sera complétée par une étude ultérieure sur les ruptures superficielles par érosion et/ou affouillement.

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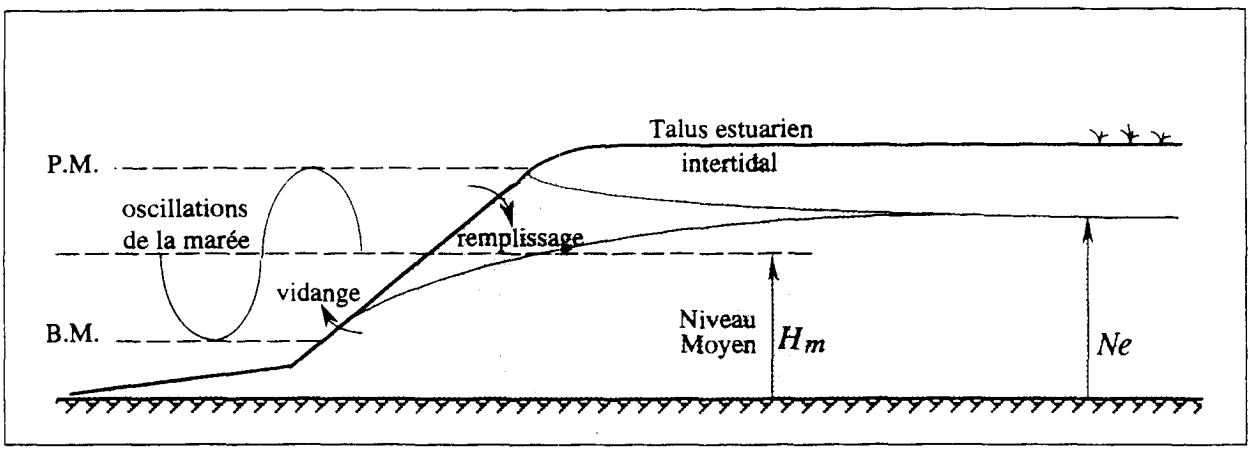
Fig. 1. Modélisation de l'action de la marée sur une pente côtière. (P.M. pleine mer; B.M. basse mer; H_m niveau moy. de la marée; *Ne* niveau d'équilibre)



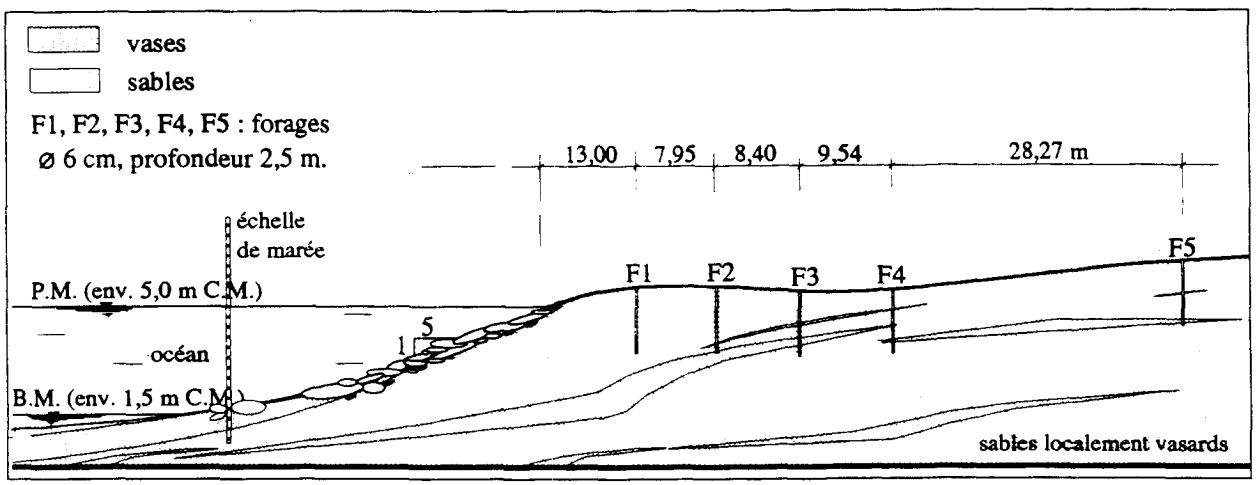


Fig. 2. Site des Sablières, coupe du remblai.

Fig. 3. Résultats des mesures de l'évolution du niveau piézométrique dans le remblai des Sablières.

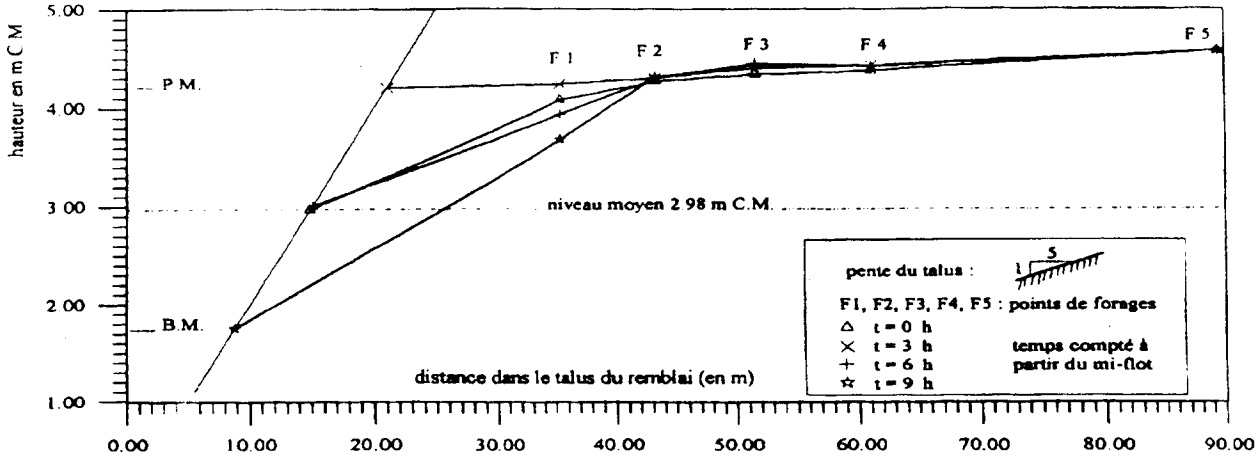
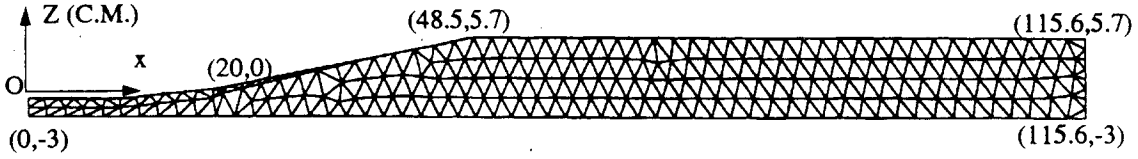


Fig. 4. Discrétisation par éléments finis triangulaires de la coupe verticale du remblai des Sablières au moyen de NSAT, (coordonnées en m C.M.).



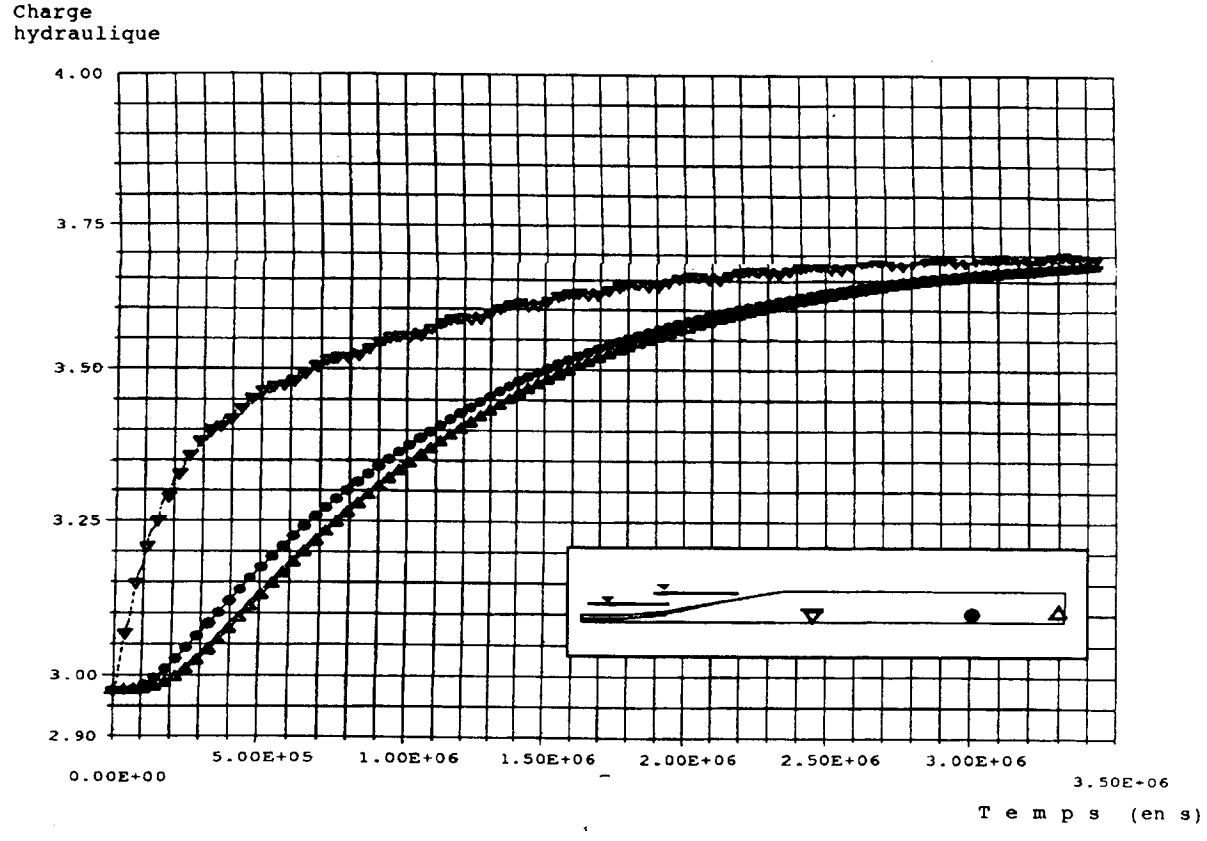
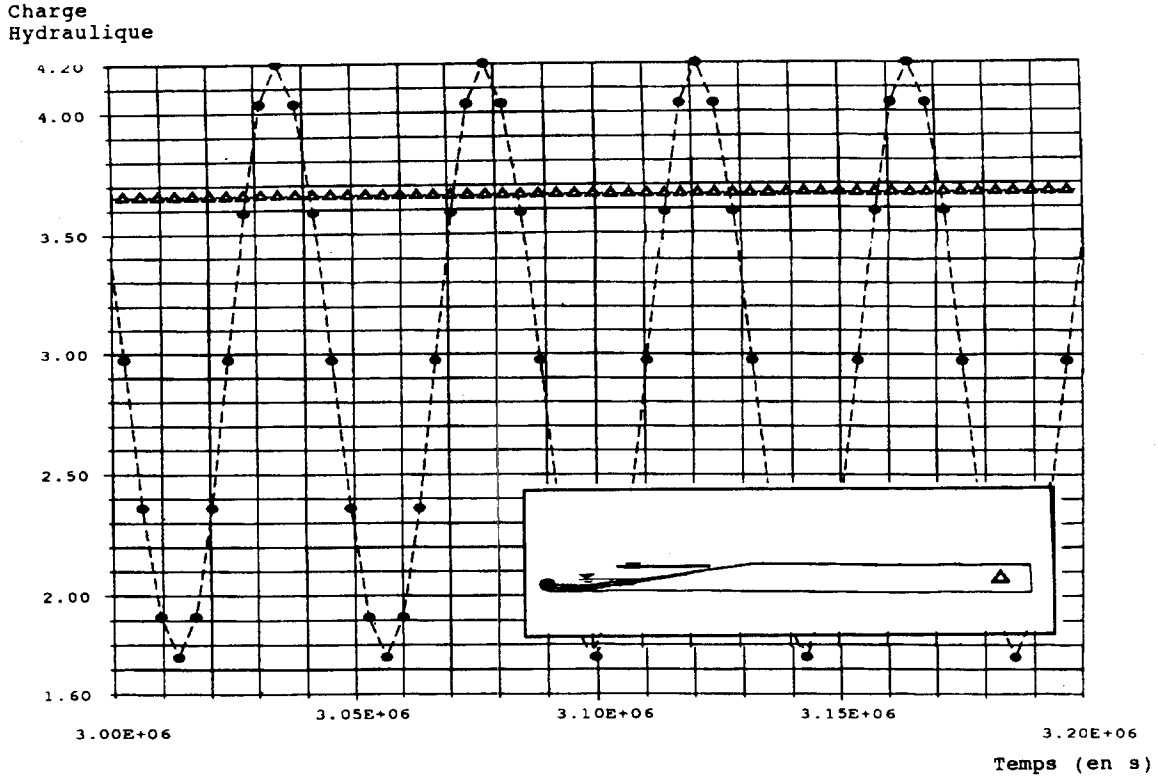


Fig. 5. Evolution duniveau piézométrique sur les 80 premiers cycles de marée, aux points indiqués.

Fig. 6. Charge hydraulique en deux. points fonction du temps, (visualisation des 70-74 èmes cycles).



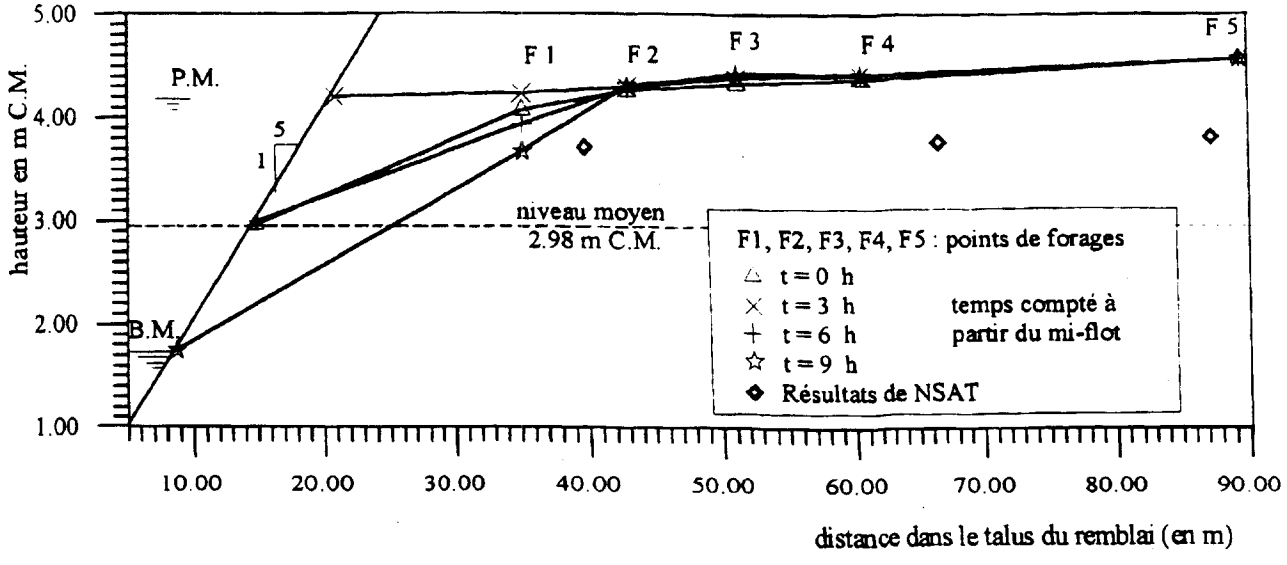
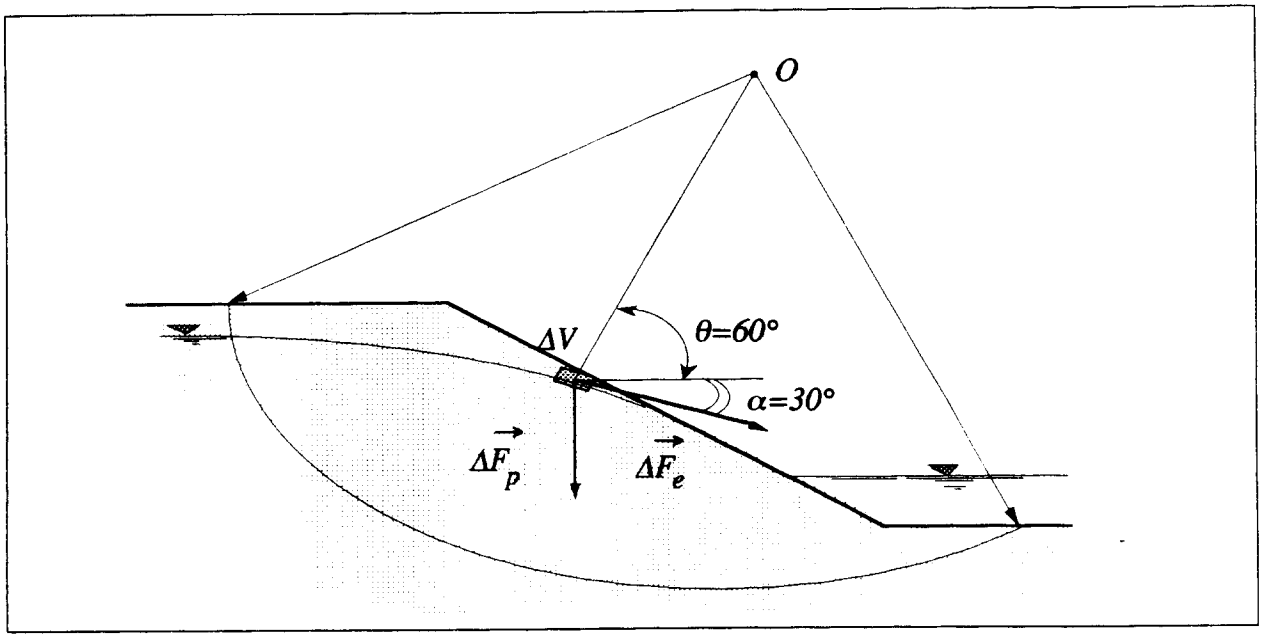


Fig. 7. Valeurs du niveau d'équilibre, calculé par NSAT, comparées aux résultats des mesures de l'évolution du niveau piézométrique dans le remblai des Sablières.

Fig. 8. Influence de l'écoulement d'eau sur la stabilité d'un talus.



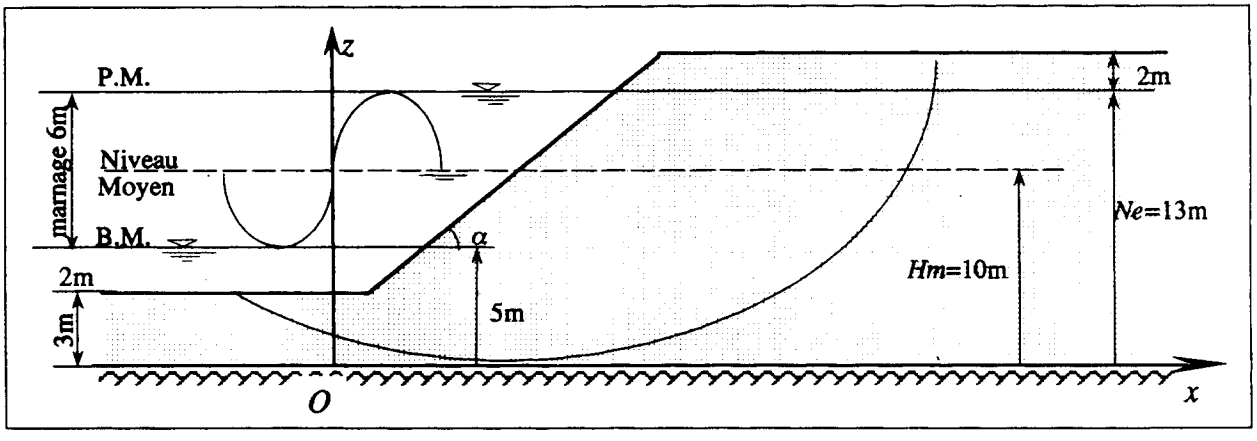


Fig. 9. Schématisation du cas étudié.

Fig. 10. Variation du coefficient de sécurité durant le jusant sur un talus de pente α.

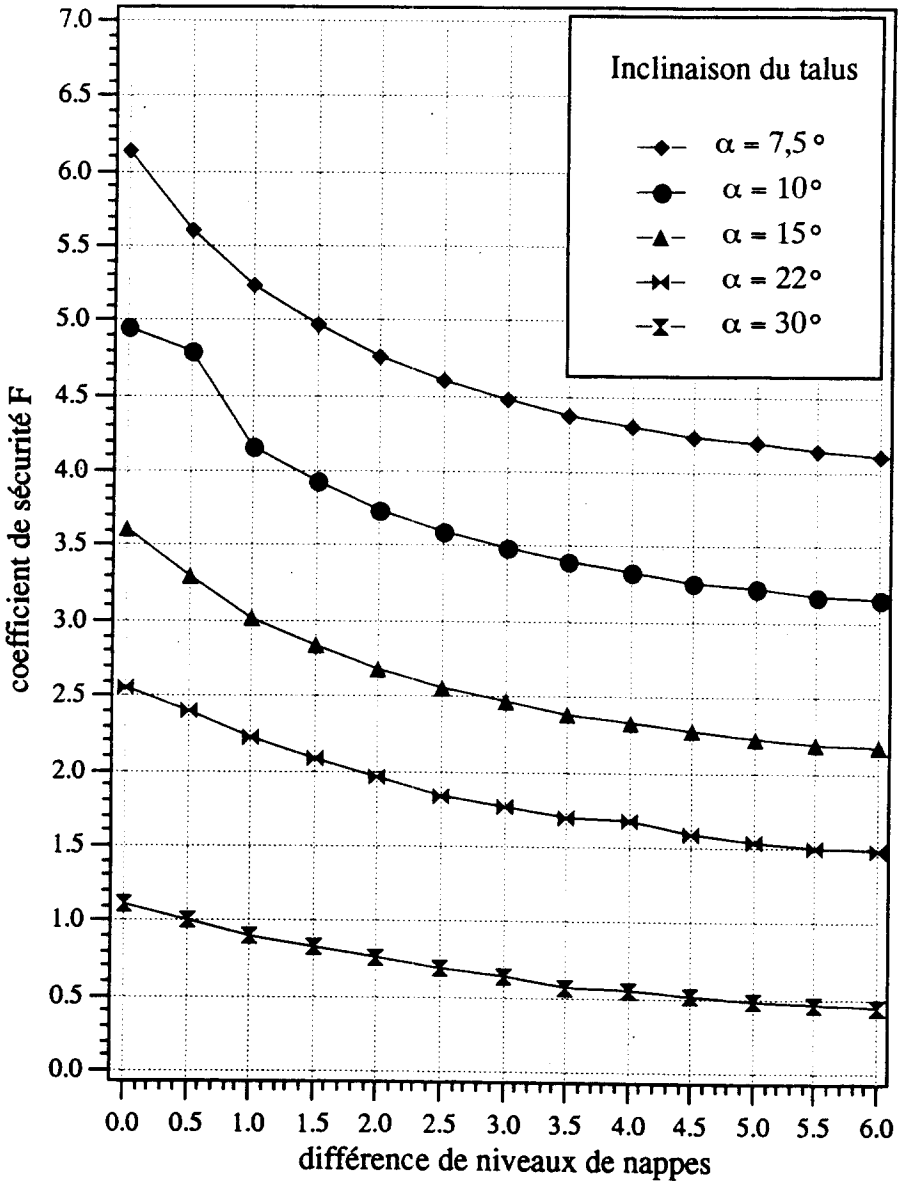
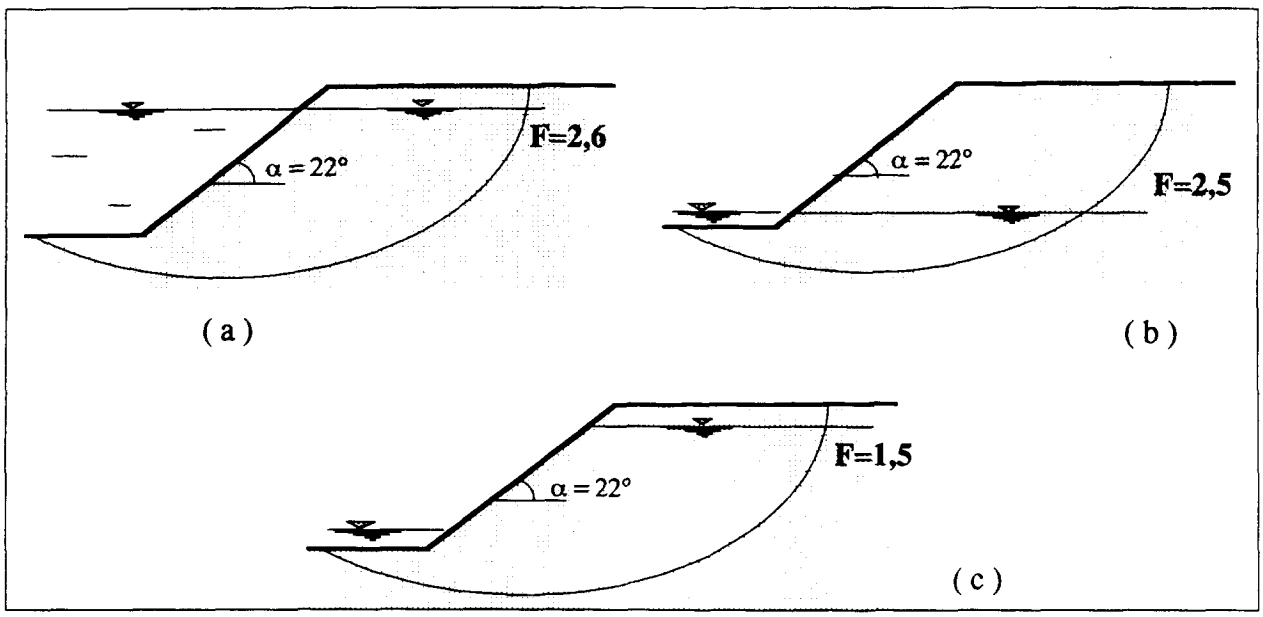


Fig. 11. Exemple d'influence du niveau d'eau dû à la marée sur la stabilité d'un talus de rive intertidale.



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EVOLUTION AND LONG-TERM MORPHO-DYNAMIC RESPONSE IN A SPECIAL TYPE OF ESTUARY

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ABSTRACT

Thousands of rocky hills and islands, scattered in the Pearl River delta plain and the adjacent coastal waters in South China, have been or will act as a deposition nucleus during the evolution of the delta. The Huangmaohai estuarine complex contains two of the eight major outlets of the Pearl River system. When the sea level reached its present level approximately 6,000 years ago, and especially in the last 250 years, the Huangmaohai estuarine complex has progressed to the sea by *filling up* the sea inlets between these rocky islands and between the mainland and these islands. This *filling up* process left deep imprints on the long-term morpho-dynamic equilibrium in the estuaries. The present paper reveals that the long-term morpho-dynamic relations, originated from this *filling up* process in the Huangmaohai estuarine complex, are in several aspects different from those in many other coastal plain estuaries and, in particular by the:

(1) longitudinal variation of the estuary width,
(2) longitudinal variation of the tidal range,
(3) unique combination of small scale dynamic structures,
(4) bi-directional jet systems, and
(5) velocity field and turbidity maximum.

INTRODUCTION

All present-day estuaries are geologically young, having been formed when the sea level reached the present level approximately 6,000 years ago. Estuaries represent a geologically ephemeral transition zone, and their diverse features of geomorphology, water circulation, biogeochemistry and ecology have lead to a variety of descriptions and classifications in different categories with unique combinations of their characteristics (Caspers, 1967; Pritchard, 1967). Although a considerable documentation exists regarding estuarine variability due to latitude, climate, fluvial influences and tidal dynamics, little has been reported on the variation in estuaries as a result of their geological evolution (Roy, 1984); even less on the effects of geological evolution on the present-day morpho-dynamic relations. Yet, throughout the Quaternary Period (past 2 million years), or even more in the last 15,000 years, eustatic sea level changes have repeatedly shifted the estuarine environment back and forth across the continental shelves and coastal plains. These movements altered the character of individual estuaries by varying their geometry, river gradient, discharge and wave climate, which in turn have influenced salinity, circulation and sedimentation. Long-term morphological and hydrographical behaviour of estuarine coasts, in response to human interference and changing environmental conditions, is an increasingly important issue. We are becoming aware of the needs for sustainable development and are facing threats such as accelerated sea level rise and climate changes in coastal and estuarine environments. It is not a surprise that long-term behaviour of coastal morphology and low-frequency coastal and estuarine dynamics have attracted more and more attention (Cheng, 1990; Vriend, 1993). Although some existing model concepts, such as coastal models, enable us to cover significant time spans, even historical and geological scales (cf. De Vroeg et al., 1988), long-term modelling of coastal behaviour is still in its infancy (Vriend et al, 1993). The gap in our knowledge on long-term estuarine morpho-dynamics is probably, among other factors, the result of a lack of mutual communication between coastal engineers and geologists or geomorphologists, and a lack of multi-disciplinary research. One way to have a better understanding of the present long-term

morpho-dynamic relations is to link them to the evolutionary history of the estuaries. The present study is a primary work focusing the intention to reveal some important long-term morpho-dynamic equilibrium of an estuary originating from its geological evolution.

SETTING

Is It a Delta or Not?

When a geographer or a geologist drives in the Pearl River delta, he will come across low terrain, hills and even mountains over 600 m height surrounded by the low-lying plain and might not recognize he is in a delta plain. This is exactly what Heim (1929) thought more than half century ago. Is this a delta or not? Some said yes (Hubbard, 1929); some said no (Chen, 1934). The argument finally ended when several sets of typical wave-cut caves with well preserved wave-cut platforms and foreheads were found and identified (Wu, 1937) in the Qixing Hill (Seven Star Hill) and in the suburb of Guangzhou (Canton) City, which indicated that the sea once reached at least to Guangzhou which is at present several tens of miles from the sea. The variety of landform makes the Pearl River delta unique. The hundreds if not thousands of hills scattered in the present delta plain had been isolated islands in the sea at one stage during the last 6,000 years. At present, there are still more than 400 rocky islands in the offshore region along the Pearl River delta coast (Zhao, 1992). They act as nuclei for deposition of sediment, supplied by rivers. Today no one argues the existence of the Pearl River delta; however, compared to other coastal plain estuaries this evolution process has left many imprints on the deltaic estuaries and made them unique in many aspects.

The Pearl River Delta and Its Estuarine Complexes

The Pearl River delta is located in Guangdong province, South China. When entering the delta area, the West River, North River and East River, are the three main tributaries of the Pearl River. They bifurcate continuously and form the network system which is one of the most complicated river network systems in the world. The Pearl River discharges finally into the South China Sea through eight major outlets (estuaries), which interact through the network system and form several estuarine complexes.

Of the eight outlets of the Pearl River, seven have the suffix 'men', such as Humen (meaning 'tiger gate'), Modaomen (gate of sharpening a sword), Hutiaomen (gate of a jumping tiger), Yamen (cliff gate). 'Men' means 'gate' in Chinese. A 'men' is located in the mouth of an estuary where rocky hills guard in both sides of the outlet as a gate. These gates control the width of the estuaries at that point. The morphological outline and many aspects of the morphology-dynamics equilibrium are greatly affected by the location and physical size of these islands.

Huanghaohai Estuary

Not only is the network system of the Pearl River one of the most complicated river network systems in the world, each estuary has very special morphology-dynamic relation too, originated from its unique evolution process, mainly due to the geological and geomorphological settings which are different from most coastal plain estuaries.

The Huangmaohai estuary is located in the west of Pearl River Delta. The Tanjiang River and a distributary of West River (Hutiaomen) flow in from the north of China, which regions are the principal sources of fresh water (Fig. 1). Geomorphologically, the estuary is a drowned river valley. It is 40 km long and 1.9 km wide in the upper north end and has maximum width of 34 km near the mouth. The estuary has a surface area of 548 km^2 and an average depth of 3 m. Two sets of rocky islands line up near the mouth, oriented ENE-WSW. The estuary is bathymetrically complicated. A scoured deep channel extends 20 km from the head towards the south, which is mainly the results of fresh water runoff and strong tidal currents in the upper estuary. The North Channel is about 300-900 m wide and 12 m deep. Two channels are found in the lower estuary. The West and East Channels are separated by Damang Island. In the centre, the North Channel and the channels in the south are separated by a broad shoal or river mouth bar, where the water depth is only 2 m, which is the major obstacle for navigation. The present estuary is connected to the sea through three openings: the East opening between Gaolan and Hebao Island, the West opening between Hebao

and Daqin islands, and the opening between Daqin and the mainland (Fig. 2).

The mean tidal range is 133 cm in the mouth of the estuary (Hebao Island), while it is 10 cm lower (124 cm) near the head. The annual mean fresh water discharge is 1436 m^3/s.

Several multi-disciplinary surveys have been carried out since the 1980s in the estuary. Since its topography is complicated, with channels, shoals and tidal flats situated alternately, the fresh water discharge is subject to significant seasonal variations against the unequal semi-diurnal tides. In many aspects, its dynamic characteristics are unique and are not well understood. A low energy (velocity) zone in the central estuary acts as a sediment trap. A unique combination of several small scale dynamic structures and their sedimentation effects are reported (Wu and Wu, 1994).

GEOLOGICAL AND MODERN EVOLUTION OF THE ESTUARY

The Huanghaohai estuary is a typical *filling up* estuary. This *filling up* process can be clearly demonstrated in two time scales:

(1) geological evolution of the estuary response to eustatic sea level variation in the last 15,000 years,

(2) modern evolution of the estuary response to long-term morpho-dynamic relations in the last 250 years.

Evolution of the Estuary Response to Sea Level Variation in the Last 15,000 Years

The geological or the geomorphological evolution of the Huangmaohai estuary since the latest glaciation can be summarized into five episodes:

(1) 15,000 years before present (BP). The sea level reached its lowest level, some 70-110 m below the present sea level, at the end of the regression of the glacial period. The old delta formed in the last transgression was exposed and underwent erosion, cutting, and weathering. The weathered surface was widely found at 20-30 m below the present delta plain, which was formed during this period. The Paleo-Pearl River developed a delta with its outer skirt 100-200 km to the south of the present coastline. The Huangmaohai estuary at that time was a river valley between partially dissected hills and mountains (Fig. 3a). The paleo-channel system was cutting through the old delta plain. Hebao, Gaolan, Damang and many other islands were hills on the paleo-delta.

(2) 7,000-8,000 BP. Since 12,000 BP, sea level started to rise at a rate of 10-18 mm/yr, which is an order of magnitude greater than that of the present sea level rise (2 mm/yr), which is believed to be the result of greenhouse effects. When the sea reached this area some 7,000-8,000 yrs ago (Fig. 3b), an upward fining sequence of deposition was formed in the drowned valley, which is widely distributed underneath the modern network channels.

(3) 5,000-6,000 BP. About 5,000-6,000 BP ago, the transgression reached its maximum and the sea level was approximately the same as the present level, but the coast line at this period was much to the north. The wave-cut caves and wave-cut platforms in Qixing Hill are believed to be nature's work in this period. The present Huangmaohai was in a shallow sea environment. Many hills such as Gaolan, Hebao, Daqin became isolated rocky islands scattered in the sea (Fig. 3c). It was more or less a ria form of coast.

(4) 200-300 BP. Since 5,000 BP, the sea level has been stable with possible minor fluctuations. A new Pearl River delta was developed and overlapped the paleo-delta. Sediments, carried by the West and North Rivers, were the major source to build the delta. The present annual total sediment discharging to the South China Sea by Pearl River system is 88.2 million m^3. The many rocky islands in the shallow sea not only enhanced the deposition, they also made the outline and morphology of the estuary more complicated. Until the second half of last century, the Huangmaohai estuary had its embryonic form. There were seven wide openings (sea inlets) formed between islands or between islands and the mainland, connecting the estuary to the sea (Fig. 3d).

(5) Modern. Mainly depending on the orientation of the openings and the dominant current direction of the estuary, the fates of the openings have been different. While the estuary and the delta progressed to the sea, the openings, with their orientation having a sharp angle to the main

current direction (north-south, in this case), were gradually closed by sedimentation, caused by the hydraulic environment (turbulence, large scale eddies) and the rich sediment supply from the rivers, from the adjacent estuaries, and longshore drift (Fig. 3e).

Filling Up Process in the Last 250 Years.

Maps from county annals and navigation charts since 1861 clearly show the evolution of the estuary response to long-term morpho-dynamic and sedimentation relations:

(1) 1723-1820. Fig. 4a is a 'general map for coastal defense outposts' cited from 'A Sketch of Macao' (Yin,1723-1734). Fig. 4b is the 'Map of Guangzhou Prefecture' in 'Jiajing Revised Unified Annal' (1820). Both maps were made before the modern cartography was adopted. But one can still recognize the embryonic form of the Huangmaohai delta and the several islands surrounding the estuary.

(2) 1861. Fig. 5a is a sketch map, based on a navigation chart published in 1861. Till the second half of last century, the Huangmaohai delta was a shallow sea rather than an estuary. 'Hai' means sea in Chinese. There were seven wide openings formed between islands or between islands and the mainland connecting the estuary and the sea.

(3) 1951. Among the seven openings the one on the west side of the estuary (between Tonggou and the mainland) was the first to be filled up and closed by sedimentation. This is because:

(1) its orientation was at a sharp angle to the main current direction,

(2) the sediment from the river system was transported to the sea mainly along the west bank of the estuary due to the Coriolis force.

The openings on the east bank of the estuary were closed one by one from north to south. In 1951 four inlets remained (Fig. 5b). The last one between Gaolan and mainland was closed in 1992 by human activities in order to construct the Zhuhai Harbour.

This *filling up* process of an estuary is unique and quite different from the evolution process of other coastal plain estuaries and has profound effects and influence on its long-term morpho-dynamic equilibrium.

HYDRODYNAMIC RESPONSE TO MORPHOLOGICAL FEATURES

Longitudinal variation of estuary width and its dynamic effects

During the evolution process of a coastal plain estuary (not a *filling up* estuary), the morphology and the controlling factors, e.g. river runoff, tides, waves etc., are under continuous adjustment. Consequently their relation is more or less in a state of dynamic equilibrium. For example, the relation between width of the estuary B_x and distance x from the head for many coastal plain estuaries can be described by an exponential function:

$$B_x = \alpha e^{\left(\frac{\delta x}{l}\right)} \quad (1)$$

where L is length of the estuary. Table 1 lists parameters α and ß for some estuaries.

Since the morphological boundary in a *filling up* estuary more or less depends on the 'nuclei' of rocky islands, this is reflected to the width-distance relation. A unified width-distance relation may or may not exist. The width variation along Huangmaohai and Lindingyang estuaries has a linear form:

$$B_x = B_0 + \beta x \quad (2)$$

where B_x is the width of the estuary at point x, x is the distance to the head of the estuary, B_0 and ß are a constant and a proportional coefficient, respectively (Fig. 6). These morphological boundary conditions have direct effects on the variation of the tidal range.

Longitudinal Variation of Tidal Range

In an estuary with an exponential variation of width without friction, the tidal range η_x can be expressed as (Ippen, 1967),

$$\eta_x = \frac{\eta_0}{2} e^{\delta\left(\frac{l-x}{2l}\right)} \cos[\sigma t - k(l-x)] \quad (3)$$

while in an estuary with width varying linearly the tidal range varies as

$$\eta_x = \frac{\eta_0}{2}\sqrt{\frac{l}{x}} \cos[\sigma t - k(l-x)] \quad (4)$$

where η_0 is tidal range at the river mouth, σ and k are tidal frequency and wave number respectively. This morphology-dynamics relation is responsible for a very special tidal range variation or distribution along estuary of Huangmaohai and Yamen.

Based on eqation (3), Fig. 7 shows how the tidal amplitude varies along the estuary with different coefficients α and δ. The change of the tidal range (amplitude) is much gentler in an estuary with linear variations of width than that in an estuary with exponential variations of width. The Huangmaohai estuary from Yamen to the sea is bell shaped, however, its mean tidal range is 133 cm in the mouth of the estuary (Hebao Island), while it is 10 cm lower (124 cm) near the head. From Yamen up to Kaiping County, which is 65 km from Yamen, the tidal range gradually increases as is shown in Table 2. The mechanism of this abnormal distribution of tidal range along the estuary (decrease in the bell shaped section and increase up stream in the river section) is not completely clear. Several factors may contribute to this:

(1) the linearity of the width variation,
(2) the character scale of the estuary to the length of the tidal wave and
(3) tidal wave reflection caused by the channel morphology.

Unique Combination of the Small Scale Dynamic Structures

Small scale dynamic structures (SSDS) with Rossby Numbers from 1 to 10, including density driven circulation, jet current, river mouth horizontal circulation caused by Kelvin wave or vorticity variation and large scale eddies, have profound effects on the overall dynamics, sedimentation, and more broadly, the ecosystem of the estuarine environment. These active dynamic structures often exist in different parts of an estuary and interact with each other. The unique combination of the small scale dynamic structures in the Huangmaohai estuarine complex, originating from the *filling up* evolutionary process, is not commonly found in other coastal plain estuaries. Based on field data and mathematical simulations, four small scale dynamic structures are found in the estuary along the North and East channels from north to south:

(a) a vast bi-directional jet system in Yamen,
(b) density driven circulation migrating from the head of estuary in dry season to mid estuary where it causes serious siltation in flood season,
(c) the afflux system developed near the gorge between Damang and Sanjiaoshan Island which is a dominant dynamic feature in the East Channel, and
(d) the horizontal circulation in the lower estuary which is considered the results of the combined effects of Kelvin wave, vorticity variation, topography and West Guangdong drift (for more details refer to Wu and Wu, 1994).

Bi-directional Jet Systems

During the *filling up* process, narrow scoured troughs were often formed between rocky islands. While the fluvial sediment was continuously eroded and deposited, the rocky islands became the controlling points and have played an important role in the dynamics of the sedimentation process. In head of Huangmaohai estuary a vast bi-directional jet system, formed in Yamen, became the 'gate' during flood and ebb tides. A calculation with 2D and 3D numerical models and several hydrographical surveys, indicate that this system is the dominant dynamic feature in the upper estuarine complex and has important effects on the morphology and sedimentation of the estuary in different evolution stages. This jet system can actually reverse the tidal current velocity field of the adjacent water. It increases the flood tide velocity and decreases

ebb tide velocity in Yinzhouhu, which is to the north (upstream) of Yamen and decreases the flood tide velocity and increases the ebb tide velocity in the North Channel, which is to the south (downstream) of Yamen. Table 3 lists the maximum tidal velocities from several surveys near the Yamen gorge.

Yingzhouhu is a special section of the estuary from Yamen up to Sanjiangkou. The total length is 25 km, the average width is 1.5 km, the average water depth along trough is 10 m with the maximum over 27 m. Compared to the small valley of Tanjiang River, Yingzhouhu contains a disproportionally vast volume of brackish water. The vast bi-direction jet system is one of the factors maintaining the outstanding water depth for navigation and potential harbour site in Yinzhouhu.

The other jet system is developed in the narrow scoured trough in the upper East Channel between Damang and Sanjiaoshan Islands (Fig. 1). It has also played an important role in the sedimentation process. The gorge is approximately 1500 m wide. The water depth exceeds 5 m in the trough and decreases to 2-3 m to both sides of the gorge which separates the mid shoal in the East Channel into two parts. The seaward and landward changes in the water depth are considered to be the response to an afflux system or simply, the deceleration flows. Tidal current velocity exceeds 1.0 m/s in the upper layer and 0.8 m/s in the lower layer in station III 3 (Fig. 1) near the gorge, and decreases rapidly in both directions. Shown in Fig. 8 are the gradual changes of tidal current velocities calculated from the 2-D model which decreases with the increase of the distance from the gorge.

The distance from the top of the shoal in the north to the gorge is approximately 8 km and this distance is 4 km in the south. Studies indicate that the distance from the top of a depositional shoal to the jet mouth is about 4-6 times the width of the jet. This shows a reasonably close agreement with our observations. The afflux system has restrained and has actually replaced the density driven circulation near the gorge as a dominant dynamic process. The gorge afflux system is sedimentologically significant. The deposition of the shoal to the north of the gorge is the result of density circulation acting as a sediment trap and the deceleration of the jet flows as well. The shoal to the south of the gorge is mainly the result of the afflux system. Since the jet system is physically stable, the shoals on both sides of the gorge have not shown significant changes since at least the 1930s, based on the navigation charts published from 1861 to present. As a comparison, the shoal in the West Channel has experienced a significant seaward migration in the same period. The inner slope of the shoal has been scoured and the isobath of 5 m migrated 40 m per year seaward in the last 40 years. In the mean time the outer slope advanced 36 m/yr to the sea.

Velocity Field and Turbidity Maximum

The morphological boundary of a *filling up* estuary may have an influence on important estuarine processes. Turbidity maxima are found in most estuaries in the world. They have an important role in sediment transport, formation of the river mouth bar and determine other physical, physicochemical and biochemical processes. Since Glangeaud (1938) first reported the existence of the turbidity maximum (Bouchon Vaseux) in Gironde River, the turbidity maximum has received continuous attention. Several mechanisms have been proposed to explain this phenomenon, of which two received most attention:

(1) flocculation, the earliest explanation proposed in the study of Gironde Estuary (Glangeaud, 1938; Eisma, 1986; Kirby, 1988),

(2) density driven circulation or vertical gravitational circulation (Festa and Hansen, 1978).

There is also another mechanism which may be responsible for the elevated suspended sediment concentrations in the Huangmaohai Estuary (Wu and Wu, 1994). The spatial distribution of current velocities, based on hydrographic surveys and the verified 2-D model with incorporated suspended sediment dispersion and 3-D numerical models, indicates the existence of a low energy (velocity) zone in the mid-estuary, which is spatially linked with the river mouth bar and the turbidity maximum at high runoff. Fig. 9a shows the current velocity in particular phases of a tidal cycle. Shown in Fig. 9b is the isogram of a Eulerian residual current. The maximum ebb current exceeds 110 cm/s in the North Channel and 90 cm/s in the lower estuary, while it is less than 60 cm/s in the mid-estuary. During most of the time in a tidal cycle, the current velocity over the mid-bar is substantially lower than that in

both the upper and lower estuary. Table 4 shows the possible maximum tidal velocities (PMTV) along the estuary from north to south, based on harmonic analysis (Li et al, 1984).

This low energy zone acts as a sediment trap for both suspended and bed loads from inland and marine sources. It is an example that the velocity distribution, due mainly to morphological boundaries, could induce a high concentration zone in an estuary.

SUMMARY

The Huanghaohai estuary is a typical *filling up* estuary. This *filling up* process can be clearly demonstrated in two time scales by:

(1) geological evolution of the estuary in response to eustatic sea level variation in the last 15,000 years, and

(2) modern evolution of the estuary response to long-term morpho-dynamic relations in the last 250 years.

This *filling up* process of an estuary is unique and different from the evolution process of a 'normal' coastal plain estuary and has in several aspects profound effects on its long-term morpho-dynamic equilibrium:

- The relation between width of the estuary B_x and distance x from the head for many coastal plain estuaries can be described by an exponential function. Since the morphological boundary in a *filling up* estuary more or less depends on the rocky islands, which act as 'nuclei', this is reflected in the width-distance relation. A unified width-distance relation may or may not exist. The width variation along the Huangmaohai and Lindingyang Estuaries has a linear form. These morphological boundary conditions have direct effects on the variation of the tidal range along the estuary.

Small scale dynamic structures (SSDS) with Rossby Number from 1 to 10 including density driven circulation, jet current, river mouth horizontal circulation caused by Kelvin wave or vorticity variation and large scale eddies, have profound effects on the overall dynamics, sedimentation and, more broadly, the ecosystem of the estuarine environment. The unique combination of the small scale dynamic structures in the Huangmaohai estuarine complex, due to the evolutionary *filling up* process, is not commonly found in other coastal plain estuaries. During the *filling up* process, narrow scoured troughs were often formed between the rocky islands. While fluvial sediment was continuously eroded and deposited, the rocky islands became the controlling points and have played an important role in the dynamic and sedimentation processes. These jet systems can actually reverse the tidal current velocity field and become dominant dynamic features of the adjacent waters, such as the vast Yamen bi-directional jet.

The morphological boundary of a *filling up* estuary may have influence on other estuarine processes. The unique velocity field and turbidity maximum in the Huangmaohai estuary can be attributed to its special morphological boundary.

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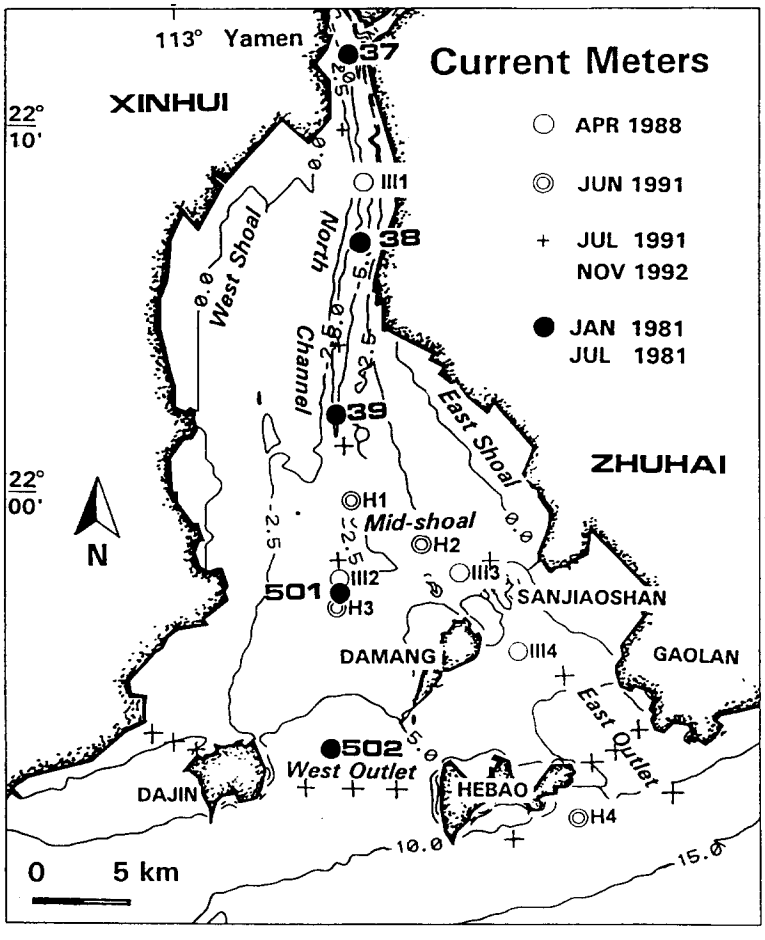


Fig. 1. Map of the Huangmaohai estuary with stations of current meter moorings.

Table 1. The values of α, δ for some estuaries.

River /Estuary	α	δ
Jiantang River	1,705	2.60
Yellow River	608	1.80
Ou River	260	3.12
Rhone River	57.5	2.29

Table 2. Longitudinal variation of tidal range (m, annual mean)

Station	HEBAO	SANHU	YANAN	HUANG CHONG	SANJIANG KOU	SHIZUI	GONG YI
x (km)	0.0	22.8	38.5	48.7	63.5	87.5	104
Tidal range	1.33*	133*	123	123	125	136	150

**averaged over the period of April 16 - May 15, 1988*

Table 3. Maximum tidal current velocity (m/s).

Location	Flood tide	Ebb tide	Time of Survey
Yinzhouhu	0.94	0.93	July, 1970*
North Channel	0.49	0.59	January 9, 1981
" "	0.36	0.50	April 16, 1988

** Cited from 'Tides in Yinzhouhu' (Institute of Surveying and Designing, Pearl River Water Resources Commission, Ministry of the Water Resources).*

Table 4. Possible maximum tidal velocity (m/s)

Stations	37	38	39	501	502
PMTV	2.17	1.97	1.78	1.40	1.66

Fig. 2. Topography of the Huangmaohai estuary.

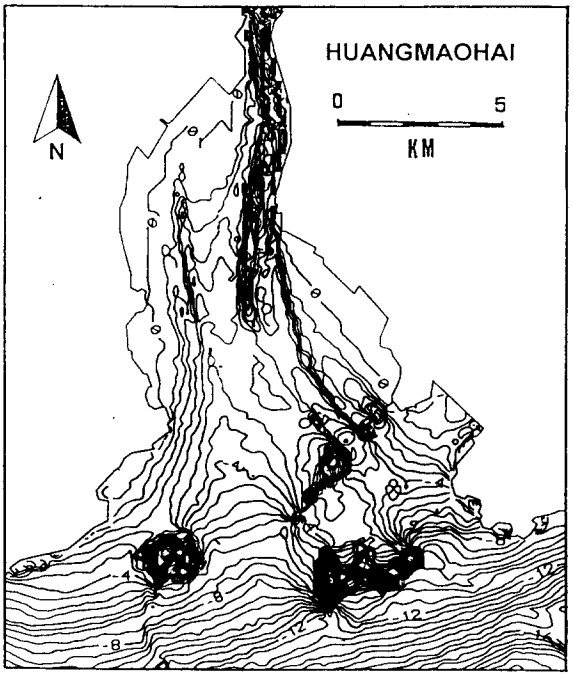
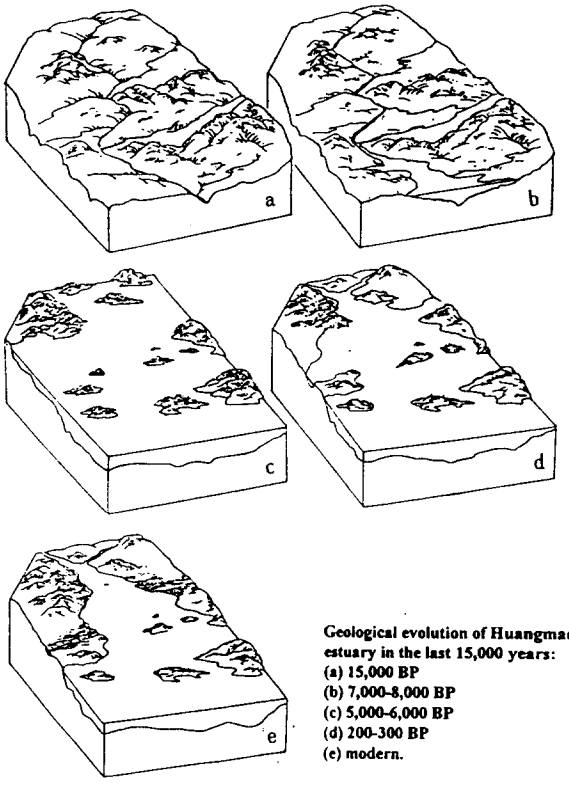
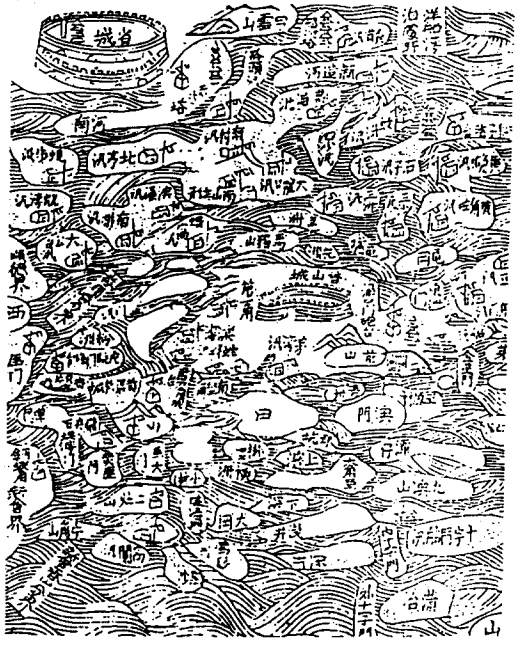


Fig. 3. Geological evolution of the Huangmaohai estuary during the last 15,000 yrs.



Geological evolution of Huangmaohai estuary in the last 15,000 years:
(a) 15,000 BP
(b) 7,000-8,000 BP
(c) 5,000-6,000 BP
(d) 200-300 BP
(e) modern.

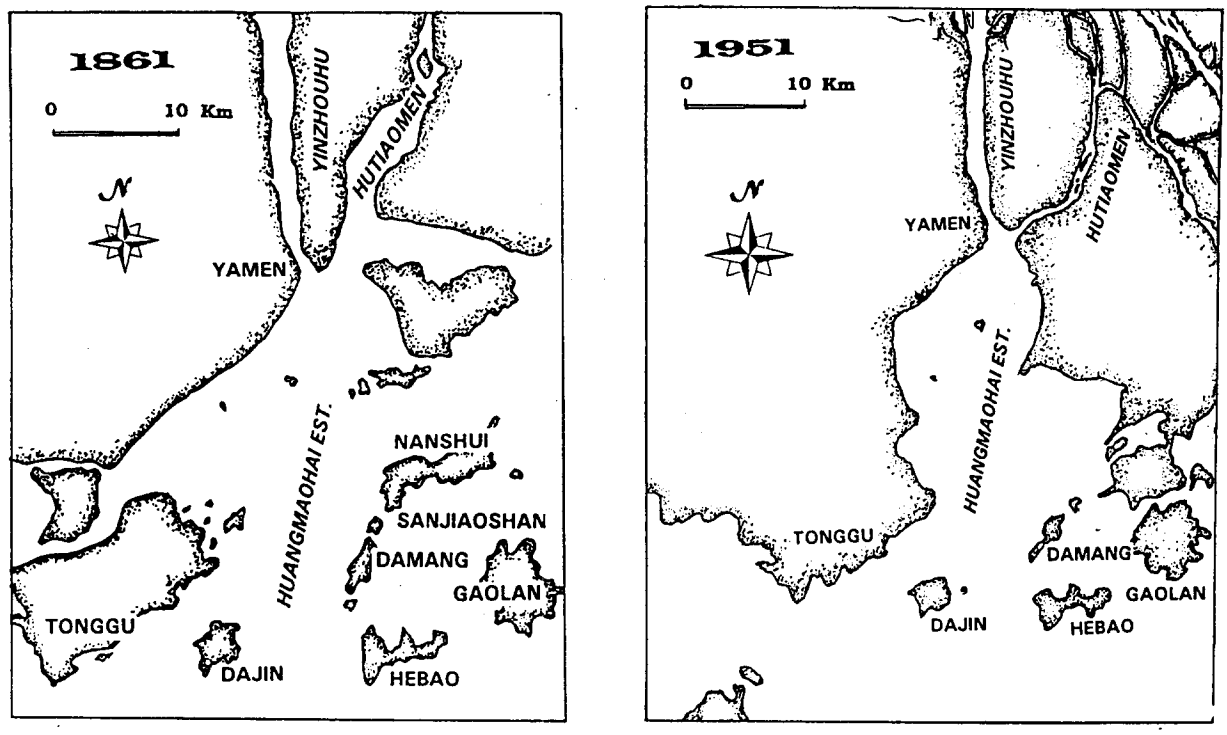


(a)

(b)

Fig. 4. Historical maps of the Huangmaohai estuary, (a) 1723-1734; (b) 1820.

Fig. 5. Sketched maps, based on navigation charts, published in (a) 1861 and (b) 1951.



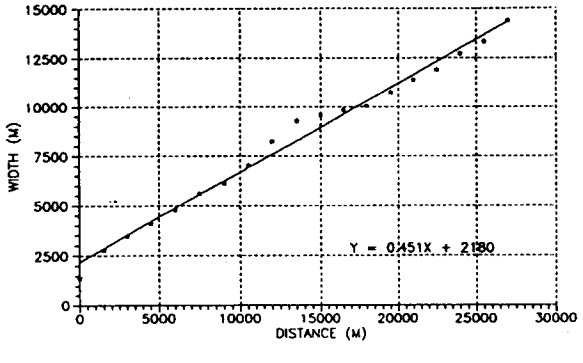


Fig. 6. Width variation along the Huangmaohai estuary.

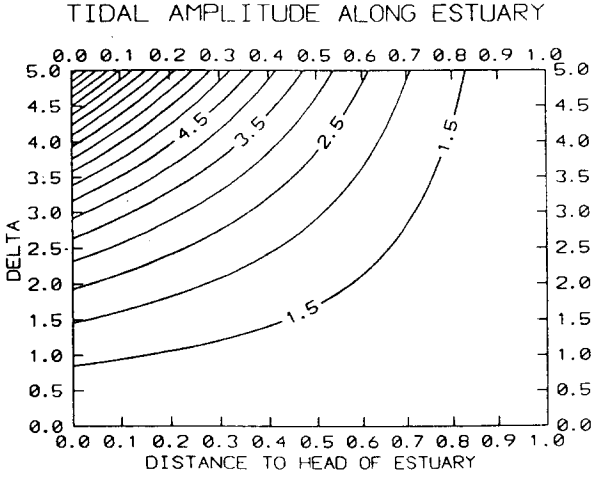
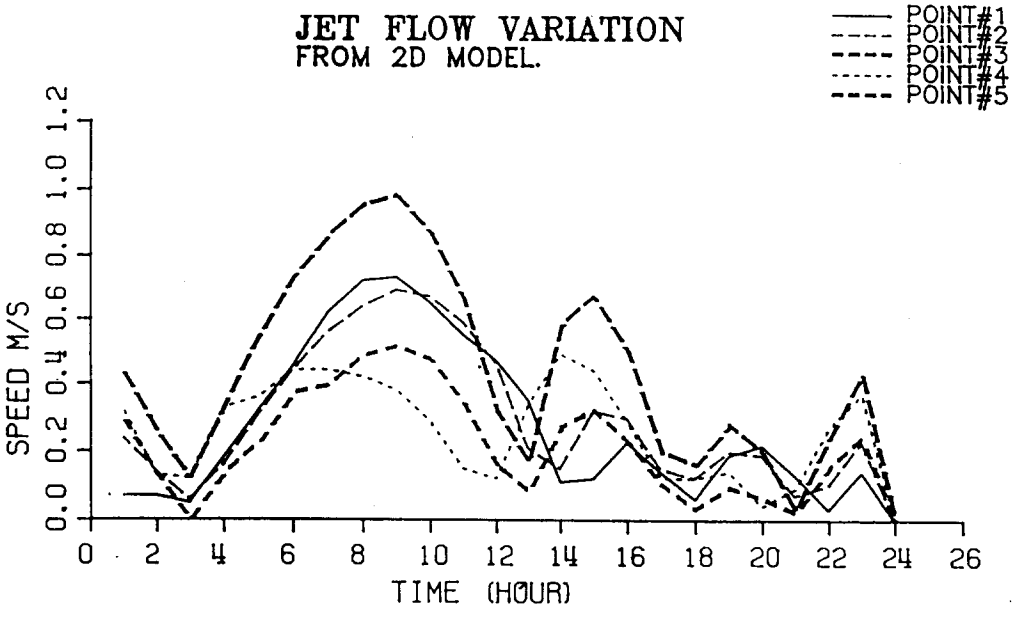


Fig. 7. Tidal amplitude along the estuary for different coefficients δ.

Fig. 8. The centerline current velocity in the Sanjiaoshan bi-directional jet system, based on a 2D model, with P#3 in the mi-gorge and a sampling interval of 800 m.



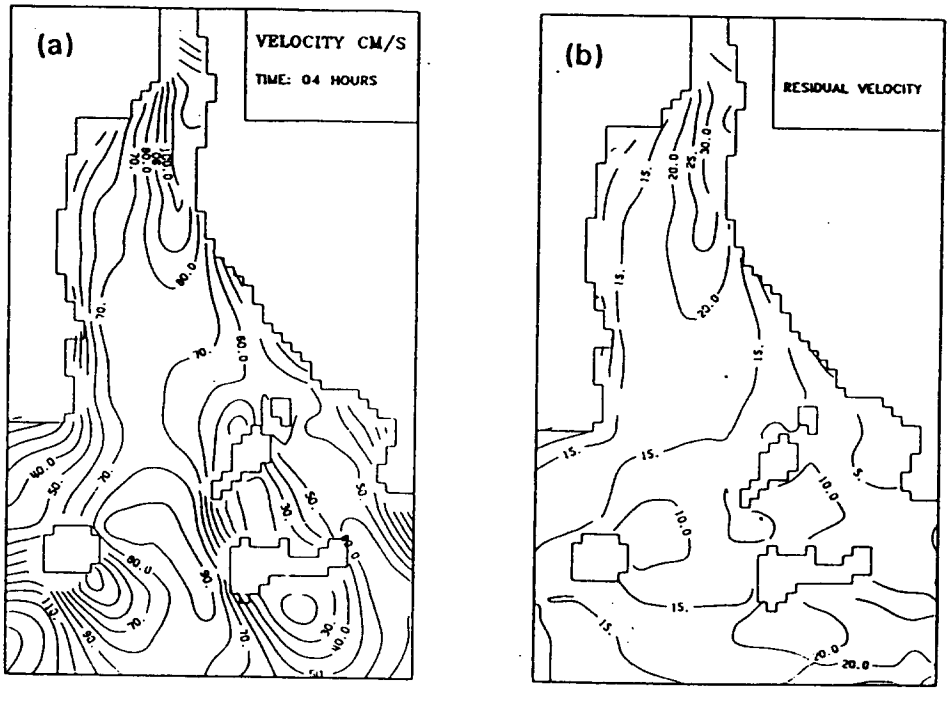


Fig. 9. Velocity field from a 2D numerical model, indicating a low energy zone in the central estuary.

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RECENT PLAIN COASTAL CHANGE IN EASTERN CHINA

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ABSTRACT
About 1/10 of the world sediment load, entering into the sea ($2x10^{11}$ tons yr^{-1}) from soil erosion, comes from mainland China. The annual sediment load of the Yellow and Changjiang rivers can reach $1.6x10^{10}$ tons. Over the last several millennia, those sediments have been transported, dispersed and deposited along the east China coasts, resulting in the formation of the extensive estuarine deltaic plains and intertidal mudflats. During the last several hundred years, especially since the establishment of the New China, the rapid growth of population, the establishment of harbours, cities and industries in the coastal areas, fisheries and the increasing rate of reclamation, have caused a dramatic change in the coastal ecological environment.

1. Characteristics of the plain coastal change

(1) Deltaic plain coast
Coastal erosion and accretion are controlled by the shifting of river mouths entering the sea, and by the distribution of water and sediment. The former is represented by the Yellow River delta, while the latter is represented by the Changjiang delta. Estuarine sedimentation has played an important role in this type of coast.

(2) Tidal deltaic coast
Its development is based on abandoned deltas and strong tidal effects. The predominant factors are the diversion of the large river channels and constructions, blocking water and sediment loads landward. The geomorphic features are characterised by the radiated tidal inlets and tidal ridges. The development of the radiated sandy shoals in the northern Jiangsu Province and the formation of the estuarine tidal inlets in the Yalu River represent the different stages of the land-ocean interactions along this type of coast.

(3) Embayment muddy coast
Its initial configuration was controlled by the Post-Glacial sea level rise, later by the dispersion of the sediment load from the large rivers entering the sea nearby and the infilling by sediments, originating from the small rivers, in the bay, resulting in the development of the intertidal mudflats. This type of infilled coast is mainly distributed along the Bay of Liaodong, Bay of Hangzhou and coastal areas in the eastern Zhejiang Province.

2. Influence of human activity on the coastal change

a. Large scale land-reclamation has resulted in the loss of the coastal wetland, deterioration of coastal vegetation community and benthic habitats.
b. The estuarine dam constructions have caused increased siltation and consequently influenced flood defence and navigation.
c. Subsidence and saltwater intrusion.
d. Coastal erosion and protection.
e. Waste water disposal has resulted in the worsening quality of coastal waters.

3. Effective approaches to monitoring the coastal change

Waters along the eastern China plain coast are very turbid, in which sediment transport is active. The sediment load in these coastal waters is controlled by tides, monsoon climatic changes and tropical storms. As a result, coastal erosion and accretion patterns are periodic. To determine the direction of the sediment transport, the range of sediment dispersion, the location of sediment deposition and the distribution of turbidity maxima and high suspension concentration areas,

it will be important to control and manage the effects of coastal change. Satellite and aerial remote sensing can play an effective role in the management of coastal change effects. Meteorological and ocean satellites will be very useful for the determination of the ranges of nearshore sediment transport and their variations. Land observation satellites will be helpful to analyze water fronts, sediment plumes, topography and the high suspension concentration area. Air photography and image spectrometry can identify the characteristics of objects on land and estimate coastal erosion rates.

SESSION VII

Coastal and Inshore Information Systems

Chairman: J. van der Weide
Rapporteur: J. van der Weide

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DESIGNING INFORMATION STRATEGIES FOR COASTAL ZONE MANAGEMENT

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Effective Coastal Zone Management requires large amounts of very diverse data, and is thus heavily influenced by prevailing strategies for information management. At the same time, the particular needs of coastal zone managers place new demands on information supply and data handling which may be difficult to meet through conventional techniques - necessitating the development of new approaches. Coastal Zone Management and information handling thus develop together, each drawing from and contributing to the other.

THE COASTAL ZONE IN CONTEXT

The coastal zone represents the interface between marine and terrestrial systems of both a bio-physical and a socio-economic nature. It is complex and highly dynamic, and thus requires both forward planning and day-to-day management if its quality and productivity are to be maintained and enhanced. The very strong concentration of socio-economic assets and functions in the European coastal zone further highlights the need for informed management, while the exceptional environmental value and sensitivity of many parts of the coast add yet another planning priority (Clark, 1993a).

The currently dominant approach to coastal zone management (CZM) developed in the USA in the late 1960s and early 1970s as a response to a perceived conflict between development pressure and environmental sensitivity. This close link between CZM and environmental management was maintained throughout the 1970s, and had the effect of ensuring a strong bio-physical basis for the CZM process, even though many of the most intractable conflicts were between opposed socio-economic interests (industry, transport, tourism, fisheries), rather than between society and environment (Patterson and Dawson, 1991). Coastal zone legislation and procedure in the USA enshrined certain fundamentals that have since transferred to the thinking of most European countries:

1. Since the coastal zone functions bio-physically within defined sub-units (so-called littoral cells), these units offer an ideal framework for CZM (Motyka and Brampton, 1993). (In practice, however, it is often the case that CZM is imposed within political or administrative boundaries).
2. The coastal zone operates in an integrated fashion, and its effective management must also be integrated. Not only is it necessary to seek a holistic view of the coastal environment itself, but also to link it to the adjoining terrestrial environment and relate it to the associated socio-economic assets and functions (Clark, 1995a). This functional inter-relationship is both spatial and temporal. (In practice, integration is usually sought either through inter-agency co-operation, or through the designation of a formal integrated coastal zone management authority.)
3. The search for an optimum management response in the coastal zone is best served (and most obviously demonstrated) if several alternative scenarios are evaluated before a preferred option is chosen, implemented and monitored (Clark, 1994).
4. Positive intervention in the management of the coastal zone is economically and socially costly, and must be justified by a demonstration that the benefits to be gained warrant this price (MAFF-WO, 1993). In practice, CZM strategies came to be assessed through benefit-cost analysis.
5. Since conflicts of interest in the coastal zone inevitably imply either prioritisation or prohibition of action, CZM (like the related approach of Environmental Impact Assessment) was founded on a structure of public and professional commu-

nication and consultation (Rendel Geotechnics, 1993).

These relatively simple but fundamental guidelines are now regarded as basic to CZM in most countries, but subsequent debate and conceptual advance have given rise to two further constructs:

6. Society plans its own affairs, and manages the fabric of its environment, in the light of a series of major social goals including efficiency, freedom of action, flexibility, equity and sustainability (Clark and Gardiner, 1994). These concepts must demonstrably be built into CZM if it is to serve Society.

7. CZM requires decision-making against a background of imperfect knowledge and understanding. Traditionally, such deficiencies of information have been regarded as flaws which have sometimes been used by agencies and governments to justify avoiding or delaying decisions. It is now increasingly apparent that uncertainty is inherent to both natural and socio-economic systems, and that coastal management under uncertainty is a primary aim of CZM (Clark and Gardiner, 1994).

It is clear that Coastal Zone Management is a complex process which carries significant responsibility and thus requires a firm foundation in information strategy. Information thus becomes a primary driver for the management process, with targets rooted both in the general move towards a more holistic planning approach and in the specific demands of the post-Rio years.

2. COASTAL ZONE MANAGEMENT AND INFORMATION MANAGEMENT

On examination, it becomes apparent that each of the seven bases of integrated CZM listed above represents the assembly, integration, transfer and communication of information. Thus in practice, CZM systems and procedures have generally been developed alongside information-handling systems and procedures. Both to achieve professional performance targets and to meet the requirements of public accountability, coastal zone managers have turned to information systems to provide the inputs for decision-making, to suggest the implications of proposed scenarios, to communicate intentions and to monitor outcomes (c.f. Clark, 1995b). Currently, coastal zone information systems have been used primarily for decision support, but it can be assumed that actual decision-guidance and decision-making systems will be operationalised - at least for a subset of real-time requirements.

A Geographic Information Systems (GIS) has a role of particular importance to play in CZM, since it offers all of the enquiry, analytical and modelling functions of other database and data handling packages, while adding the synthesis and integration that is provided by spatial (geographical) referencing). GIS brings together information from a wide range of disparate sources, integrating it within a common reference system and providing it for visualisation, analysis, modelling or import into a decision structure. Despite some clear problems (Clark, 1993b), spatial data and GIS are now strongly represented in the operations of major coastal zone authorities, where they serve a range of core functions including:

1. Data standardisation, acquisition and conversion. (Scale, projection and datum)
2. Data quality review and logging.
3. Data archiving and management.
4. Selective query (geographical, temporal or attribute selectivity)
5. Visualisation and mapping.
6. Data integration and synthesis.
7. Data modelling (Trend, extrapolation, interpolation)
8. Scenario building and simulation modelling (event and response).
9. Evaluation (asset, opportunity, constraint) and cost-benefit comparison.
10. Prioritisation (Resource, reactive response, proactive response).
11. Organisation (optimisation of operations).
12. Communication and information dissemination.
13. Monitoring, accountability, post-project appraisal.

It is notable that these core functions provide a technical approach to meeting the general requirements of CZM enshrined in the seven fundamental planning remits listed in Section 1 above. It is also increasingly apparent in both CZM and GIS that future developments will focus

on, or at least include, linkage with complex models and simulations to further the extent to which the broad social goals can be met and monitored. Indeed, this linkage offers an ideal framework within which to blend the predictive power of objective techniques with the social responsiveness and judgement of a consultation-based management procedure.

3. MEETING THE MULTIDIMENSIONAL CHALLENGE

Given the complexity of the information-handling role in the coastal zone, it is no surprise that the technological response has been multidimensional (Roper, 1993). Coastal zone scientists are well used to the essentially multivariate nature of their subject, with variability being in both space (depth as well as location) and time. Additionally, however, coastal zone managers are faced with the need to develop and implement multifunctional systems, seeking return on the substantial investment required by establishing a variety of uses for each data set. Increasingly, both the multidimensional volume of information, and its multifunctional use, have served to encourage the development of multimedia information handling systems.

GIS has demonstrated significant potential as the integrating technology for multivariate data in the coastal zone, and is increasingly used as a basis for both planning and management. Coastal pollution management is a case in point, with oil spill contingency planning being the subject of considerable GIS (Gundlach and Hayes, 1978; Jensen *et al.*, 1990; Perkins, 1989; Simms and Waters, 1990; Trudel *et al.*, 1989). GIS functions such as map overlay (combining information sets) and index weightings (a basis for controlling the emphasis given to individual entities and attributes in the combined outcome: Clark, 1994) are an ideal foundation for scenario development, and subsequently for the design and implementation of coastal plans. The same example serves to indicate the scope for multifunctional use, since both planning and management may draw upon the same data sets. In effect, this multifunctionality goes much further, for many of the data inputs to oil spill contingency planning are standard components of shoreline management and planning in general.

Clark *et al.* (1995) discuss the power of multimedia systems as frameworks within which to handle information for both oil spill contingency planning and spill emergency response. In a prototype system, scanned coastal zone management documents provide a background reference source within a hypertext shell (*Microcosm*) which permits on-screen recovery of official documents. Within the hypertext session, it is also possible to gain interactive access to other applications such as spreadsheets (for assessment of economic implications of management scenarios under consideration) and oil spill models. The use of such multimedia information integration systems, perhaps fed from the Internet and feeding into a management GIS decision-support system, might well be seen as an appropriate technological foundation for coastal zone management in the future.

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INFORMATION AND ACTION: AN INTEGRATED APPROACH TO COASTAL ZONE MANAGEMENT (PAGHAM HARBOUR, SOUTHERN ENGLAND)

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Coastal Zone Management in the UK is increasingly being based upon a broad background of integrated coastal environmental science, rather than on fragmented specialist studies. This approach can be particularly effective for high-value, high-vulnerability coasts such as that at Pagham Harbour, Southern England. A Scientific Committee has been established to co-ordinate the planning of the several agencies involved in management of the harbour, including the Local Authority (West Sussex County Council), the National Rivers Authority Southern Region, and English Nature (the Government Nature Conservation Agency). A recent comprehensive scientific review of the harbour undertaken for this Committee has established a series of process patterns which have explanatory power, and also offer a basis for designing management options in response to present coastal problems and the scenarios likely to be experienced over the next half century (GeoData Institute, 1994).

In practice, the definition of management response is itself a complex operation, which requires a substantial exercise to "translate" the scientific data into management-relevant information. Consultation is an important part of this process, and again requires creative information presentation. It is also clear that the handling of uncertainty in the scientific models (both present and future) lies close to the heart of the challenge of ensuring a strong link between scientific input and management output. At Pagham, as elsewhere, uncertainty can be approached by developing highly adaptive strategies, and by phasing the programme of responsive action - both of which permit strategy to be retuned in the light of future gains of information.

A CONTEXT FOR COASTAL ZONE MANAGEMENT ACTION

Three components combine to provide the context within which coastal zone management action takes place-engineering (and related technical services), environment (and related conservation services) and planning. The planning function has traditionally been seen as moderating between the often-conflicting approaches and interests of the engineering and environmental sectors. Increasingly, however, engineers and environmentalists are converging on common standpoints from which they look to planners for guidance rather than judgement.

In areas such as Pagham Harbour, it is now inappropriate to conceive of conservation management as being separate from the overall task of coastal zone management (GeoData Institute, 1994). Such piecemeal approaches have been commonplace until recently, but as integrated approaches to the environment, and to its interaction with society, have come to dominate public and professional thinking, there has been a strong move towards holism and away from reductionism. The roots of this change are very broad-based, but in the present context what is of most immediate significance is the fact that the holistic management paradigm has been embraced by both the scientific and political communities. The proper focus under the prevailing philosophy is thus to address the needs and challenge of ensuring that conservation imperatives receive their full share of attention and investment within the integrated coastal zone management plan. This is basic under all circumstances, and becomes absolutely pivotal in

an area with the environmental quality, sensitivity and complexity of Pagham Harbour. One of the outcomes of this approach is that coastal conservation is now seen as resting upon awareness of a set of interacting domains:

- the present-day integrated physical/biological process system, and its interaction with the present-day socio-economic system.
- changes in the external bio-physical forcing factors, including climatic change, sea level change, alteration of freshwater and sediment inputs from the river system, and any long-term drift in the status of individual species or ecological complexes.
- changes in external anthropomorphic forcing factors, incorporating inadvertent human impacts, unforeseen economic and social circumstances (changes in legislation/regulation, or in EC support funding), newly imposed or re-imposed deliberate management interventions, and any long-term drift in the status of existing management interventions (such as deterioration in sea defences).

Short-term reactive responses generally address perceived shortfalls in the performance of the first of these domains, but the real challenge of conservation management lies in instituting practices which are capable of sufficient resilience and flexibility to absorb the detrimental impacts of the latter two domains. This requirement emerged in the aims of coastal zone management more than two decades ago, and has more recently come to be viewed as central to the necessity to develop strategies for management under conditions of uncertainty, and to achieve sustainability in the ensuing environmental systems and practices (Clark and Gardiner, 1994).

THE PHYSICAL BACKGROUND TO ACTION

Pagham Harbour is a small tidal inlet system, with a drainage basin of 50 km^2 and a harbour area of 2.83 km^2 situated 20 km East of Portsmouth on the South Coast of England. On the beaches, the sediments consist of well-sorted sand and gravel, whilst the seabed around Selsey Bill is covered mainly with gravely sediments. The sediment supply to the coastline is mainly from the adjacent seabed and coastal erosion. Bedforms including megaripples, sandwaves, sand ribbons, gravel waves and gravel furrows are present on the seabed. Intertidal sediments of the flats behind the shingle spits consist of silts and fine to medium sands, with small scale topographic and spatial variation.

The sedimentary material which forms the coastal zone and the size of the harbour imply that this area is sensitive to the prevailing hydrodynamic conditions (i.e. waves, tides, and storm surges). Given this sensitivity, and the fear that present coastal defence and protection efforts might be inadequate or inappropriate to meet the expected changes in coastal environment over the next century, a Scientific Committee was set up to gather information pertinent to management decision-making. This approach was innovative from the outset, since it represented a joint action by three major interested parties - West Sussex County Council, English Nature and the National Rivers Authority. This Committee commissioned a scientific study to examine environmental processes operating within Pagham Harbour Local Nature Reserve and the adjacent coastline (GeoData Institute, 1994). The objectives of this project were:

- to indicate the nature of current physical and biological processes,
- to illustrate how these have changed over Holocene and Recent periods,
- to identify potential changes consequent upon varying process rates, such as rising sealevel and enhanced wind and wave climates,
- to establish the interactions, with the biological systems and the Harbour's special conservation value,
- to identify research potential and propose monitoring activities to validate predictions,
- to act as feedback into management.

The nature of the commission indicated that in this case, scientific studies would provide a direct input to the coastal zone management decision-making process, on which basis the information assembled was indeed a prelude to action. The basic process system revealed by this compilation study suggested that three components would determine future coastal behaviour, and would therefore influence management - the status of

the harbour mouth, the tide/wave/current system in relation to sediment transport, and the predicted rise of sea level.

Historical changes in the morphology of the harbour are significant, in terms of the position of the entrance channel and the shape of the ebb tidal delta i.e. the inlet system is very unstable. The reason for this is that the flushing ability of the entrance channel, provided by the tidal prism, is much smaller than the magnitude of the longshore drift. The degree of stability is reduced further because of land reclamation which has continued since at least 1585, with significant losses after 1637, the first recording of Pagham Sea Wall.

The relatively strong tidal currents and wave-induced currents, sometimes in combination with storm surges, cause active sediment movement. On the beaches, the overall longshore transport is mainly directed towards the northeast between Selsey Bill and Pagham Harbour. Longshore drift is of the order of 2.4×10^4 to 4.2×10^4 m^3 yr^{-1} (Lewis and Duvivier, 1976). Sediment discharges through the entrance to Pagham Harbour are approximately 3.4×10^4 m^3 yr^{-1} to seaward and 1.8 10^4 m^3 yr^{-1} to landward, with a net discharge of 1.6×10^4 m^3 Yr^{-1} (Barcock and Collins, 1991; Gao and Collins, 1994). In the offshore areas, long-term sediment transport is directed towards the northeast in deep waters (>15 m deep), but it is towards the west in shallow waters. Generally, the sediment transport patterns which have been identified cause coastal and seabed erosion. Accretion takes place only over the salt marshes and intertidal flats within the harbour. Hence, the coastline has been retreating at a rate of 1 to 8 m yr^{-1}, before the beach was artificially protected. The Pagham Harbour area receives large amounts of tidal and wave energy and is influenced frequently by storm surges. Such a hydrodynamic regime, in combination with the regional geological and sedimentological conditions, causes intensive sediment transport in directions parallel to the shoreline. As a result, the harbour system is unstable as an inlet and coastal/seabed erosion is taking place, necessitating coastal protection over the last 30 years.

Relative sea-level rise in the future, with a likely overall magnitude of 58 cm towards 2100 AD, will enhance the erosive processes along the Pagham coast (Shennan, 1989). If no coastal protection works are undertaken, then the shoreline will retreat, reducing slightly the harbour area. However, there will be an increase in tidal prism due to sea-level rise, and this would be beneficial to the engineering work involved in stabilising the position of the entrance channel. Sea level is rising at a rate of between 0.7 and 5 mm yr^{-1} over the Pagham Harbour area. It is likely that an overall sea-level rise of 42 cm will take place towards 2070 AD (under the revised "best estimate"). In response to this, the shoreline will retreat by 150 to 275 m, assuming that no coastal protection schemes are undertaken. This latter process would reduce the harbour area by approximately 5%. Furthermore, there will be an increase in the tidal prism by 6.8 % without coast protection; it would be 12.8 % if the coastline were to be protected (GeoData Institute, 1994). Any increase in the tidal prism would be beneficial to the engineering works involved in stabilising the entrance channel.

CHANGE AND MANAGEMENT

The present status of coastal zone process in the Pagham area provides a considerable challenge to management, but this is exacerbated by three possible future changes. First, the sequence of coastal protection and land reclamation activities which stretches back some 1800 years into the past must also be continued into the future. There is much debate concerning the optimum form for this strategy to take, since even the decision to permit some coastal retreat would represent a positive intervention into the present situation (Brooke, 1991). Second, there is evidence of a well established die-back of the *Spartina* marsh in the area, and together with sensitivity in other habitats in the harbour, this represents a serious challenge to the vegetative (and thus sediment retention) status of the area. Third, the prospect of sea level rise has been seen to indicate not only an increased threat of coastal induration and recession, but also a bathymetrically and

geomorphologically very significant increase in the tidal prism of the harbour and its mouth.

It is accepted that management options will need to emerge from a blend of scientific study, public consultation and flexible strategy design. Monitoring is acknowledged to be a vital source of information for management decision support, and an appropriate programme is to be implemented.

Nevertheless, coastal zone management is similar to integrated river basin management in the extent to which they both take place within a context of uncertainty which derives from the fact that suppositions repeatedly have to be made (and justified) about many of the attributes of the bio-physical and socio-economic systems concerned (Clark and Gardiner, 1994). At the present, discussion of the problem of uncertainty in the coastal zone tends to focus on the physical response to global climatic change and associated sea level rise, but in practice the same sorts of observations could be made about biological or even economic and social aspects of coastal management. Indeed, in the MAFF-sponsored study of the economic implications of sea level rise on the South Coast (Ball *et al.*, 1991: Clark *et al.*, 1992), economic uncertainties were found to be a greater constraint on modelling and decision making than physical uncertainties. It follows that effective coastal planning must take account of any major shifts in the assumptions being made about any of the systems involved, and any uncertainty concerning the nature or rate of assumed processes will be reflected in related uncertainties of management or planning (GeoData Institute, 1994). In the past, the tradition has arisen for elements of uncertainty in science and engineering to be regarded primarily as products of model simplicity, limited data availability and inadequate measurement resolution. Since in this approach any inherent uncertainty is in effect explained as being the result of technical constraints, the response to uncertainty is handled through such correspondingly technical devices as the use of error margins, confidence limits and factors of safety. In essence, this approach regards uncertainty as a temporary deficiency in the planning process, and the primary aim of that process is to remove or find ways of safely ignoring the uncertainty.

THE IMPORTANCE OF PROCESS INFORMATION FOR COASTAL MANAGEMENT

Coastal zone management action in the form of nature conservation is a positive and planned intervention in the operation of "natural" systems aimed at maintaining and enhancing their quality and viability. As such, it implies availability of sufficient information on process systems to permit that intervention to be both efficient and effective, and to ensure that adverse implications or side effects are minimised (GeoData Institute, 1994). The expenditure of effort directed towards conservation implies that the system concerned is viewed as sub-optimal, or at risk of becoming sub-optimal in the absence of conservation. This implied mismatch between the idealised state of the environment and the present or predicted environmental state provides a target for the conservationist to tackle, and traditionally the resulting activity has adopted one of two fundamentally different perspectives. It is commonplace for some aspect of the environmental system to be regarded as underperforming or actually damaging-threatening, and in such cases intervention takes the forrn of action to counter the effect of the processes concerned (an example might be the assumption that erosional wave energy is detrimental to coastal stability, so that it should be countered by the emplacement of devices to absorb or divert that energy). Alternatively, the sub-optimal state of the system can be attributed to under-performance of an identified process or factor, and the conservation effort is devoted to strengthening the attributes concerned (an example could be the assumption that wave energy has become erosive because of an inadequate availability of beach material, so that an artificial enhancement of sediment supply is called for). Against this background, it can be seen that process understanding can contribute to coastal management efforts in a number of inter-connected ways:

- to provide a broad understanding of system operation (particularly the links of energy or mass

between components of the system) appropriate to the development and evaluation of management strategies.

- to identify "control valves" within the system which represent components which are amenable to feasible (i.e. effective, predictable and economic) external intervention with system operation.
- to identify thresholds of dynamic systems behaviour which represent the margins of system resilience without exceeding the capability for elastic change. If a process threshold is crossed, the system will not be capable of self-restoration.
- to indicate particular sensitivities or vulnerabilities within the system which could be used to allocate priorities for conservation effort.
- to form the basis of a model of system behaviour which could be used to offer predictions of future state, or of response to imposed change (whether an external forcing factor such as sea level rise, or a management intervention such as sediment injection or a revegetation programme).
- to provide a baseline description of system operation against which to monitor and assess the nature, direction and pace of future change.

Effective long-term coastal zone environmental management is heavily reliant on process understanding in all of these contexts, and much of the improvement of nature conservation practice through time has been triggered by advances in such understanding. For this reason, it can be seen that the provision of structured information on processes within Pagham Harbour has been a necessary precursor to the discussion of past, present and future change, as well as being the basis for the design of management options and the implementation of management action.

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USE OF HYDROGRAPHIC OFFICES' CHART DATA BASES FOR COASTAL ZONE MANAGEMENT

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ABSTRACT

An increasing number of Hydrographic Offices (HO) among Member States of the International Hydrographic Organization (IHO) are in the process of establishing marine databases. Such databases are intended for the production of paper charts and/or Electronic Navigational Charts (ENC), the latter being used to operate Electronic Chart Display and Information Systems (ECDIS) onboard ships. Paper charts and ENCs are products for mariners and the content of HOs' data bases is therefore navigation oriented, i.e. they include and describe all features likely to assure the safety of navigation at sea: water depths and contours, buoyage and lights, traffic separation schemes etc... However the great variety of features concerned, makes this data of interest to non-traditional users of chart information. Data such as water depths, currents, tides, seabed nature, submarine cables, caution areas, coastline etc... will very likely be helpful to all those involved in coastal zone management.

INTRODUCTION

National Hydrographic Offices are responsible for provision of information required for safe navigation at sea. Such information is commonly produced in the form of publications and nowadays as digital data files. Among these products is the nautical chart, which contains essential information, primarily marine but also of the adjacent land, to allow mariners to navigate safely. Although nautical charts are still delivered in paper form, governmental digital charts are now being prepared, under the auspices, and encouragement, of the International Hydrographic Organization (IHO). These digital charts, called Electronic Navigational Charts (ENC), will be used aboard ships as part of specific equipment known as ECDIS (Electronic Chart Display and Information System) in which the chart data and the navigational inputs can be merged. In recent years, Hydrographic Offices have started to establish data bases intended for the production of both paper and/or digital charts. These data bases are being populated from digitized paper charts and digital data resulting from new hydrographic surveys. It is expected that information contained in Hydrographic Offices' chart data bases will be of considerable use to coastal zone managers.

CHART DATA DESCRIPTION

This information can be classified as follows:

- Data describing physical aspects of the sea or the land, e.g. coastline, soundings, depth contours, fishing grounds, vegetation area, beaches, and cliffs;
- Data describing physical and cultural aspects of the sea or the land, e.g. bridges, submarine cables, wrecks, fish farms, and towers;
- Data describing aids to navigation, e.g. lighthouses, buoys, fog signals, lights, and radar stations;
- Data describing areas subject to administrative control, e.g. anchorage areas, national territorial areas, traffic separation zones, harbour areas, and custom zones;

It should be noted that, whilst information on sea is generally provided in detail in chart data bases, land data is normally limited to features that are visible from the sea and useful to marine navigation. A total of about 200 such "objects" have been identified by the IHO in the framework of the development of its international Standard for the Exchange of Digital Hydrographic data. This official IHO Standard, known as S-57,

includes an Object Catalogue listing all the above objects. Associated to the objects are attributes which serve to qualify each of them, e.g. a coastline can be steep, flat, sandy, stony etc... The latter are in fact possible values of the attribute "Category of coastlines". A set of about 160 identified attributes form a section of the Object Catalogue. The latter also includes "Meta objects" which may be used to qualify a group of objects contained within a defined polygon, e.g. accuracy of data or unit of measurement, and "composite objects" formed in assembling several single objects, e.g. a lighthouse comprising a tower, a light and a fog signal.

REFERENCING SYSTEMS

Internationally agreed IHO Specifications state that ENC data for ECDIS should be referenced to the world geodetic horizontal datum WGS-84. Consequently, chart data contained in Hydrographic Offices' data bases are required by the Standard to be based on that datum. However, other datums may be used in special cases, e.g. when digital data derived from the many existing paper charts not based on WGS-84, is not intended for ECDIS purpose, or when national laws impose a particular datum. IHO Standard S-57 includes a list of 108 horizontal datums likely to be found in nautical charting and another IHO publication, numbered S-60, provides transformation parameters from any of these local datums to WGS-84.

Regarding vertical referencing, it should be noted that depth data is referenced, for safety reasons, to a low tide level, so that the sea surface goes rarely below that level, whereas elevations on land are usually referenced to mean sea level. The intransigence of hydrographers and land topographic mappers to move from their separate positions on this matter causes difficulties when merging marine and terrestrial data into common products, such as producing coastal zone maps. Not only is this a problem but within hydrography itself, difficulty exists in choosing a single quantitative vertical datum. In spite of considerable efforts over many years, the low water datum has rarely been standardized in qualitative terms and several vertical datums are in use within the Hydrographic community depending of the area concerned and/or the tide regime, e.g. Mean Low Water Springs, Lowest Low Water, Lowest Astronomical Tide. The IHO Standard S-57 includes a list of 21 vertical datums reportedly used in nautical charting. However, it is recognized that multiplicity of sounding datums is not desirable in the digital chart data base domain and the possibility of adopting an unique datum, perhaps Lowest Astronomical Tide, is currently being discussed, once again, within the IHO. It is further envisaged to investigate the possibility of referencing all vertical measurements to a common level such as the geoid, although the difficulty of precisely determining the geoid may make this approach impractical.

PRODUCTION AND AVAILABILITY

Digital data creation is actively being undertaken in many Hydrographic Offices in view of ENC and/or paper chart production, e.g. in France, Germany, Japan, Australia, Canada, USA, Norway. However, due to the complexity of the Standard and a need to still maintain the paper charts, the process is slow and it is not expected to have a worldwide coverage of coastal waters before the end of this century. The IHO Standard S-57 states that ENC data should be available to mariners according to a number of defined scale ranges, e.g. 1:40 001 to 1:80 000, 1:80 001 to 1:200 000, etc... It is most probable that national digital chart data bases will be organized in a similar way. Among the possible scale ranges, the two following seem likely to be of particular interest to coastal zone managers: > 1:10 000 and 1:10 000 to 1:40 000. Although this data is mainly intended for navigation purposes it is thought that it will also be of considerable interest to all those involved in marine activities, particularly those involved in oceanographic modelling and those developing Geographic Information Systems of the coastal zones. Chart data will be distributed according to the official IHO format known as DX-90 and which is part of the IHO Standard S-57. For the two above scale ranges, data will be grouped in cells of 7.5' or 15' size. Addresses of IHO Member States' Hydrographic Offices can be

found in the IHO Yearbook, publication P-5 or on application to the author.

CONCLUSION

Digital chart data, produced according to tight international standards will soon be available from several national Hydrographic Offices. Although the data is primarily intended for navigation purposes to be used with ECDIS Systems, it will undoubtedly be of considerable interest to all those involved in marine research and management. In particular, it should be of considerable use to those involved in oceanographic modelling and the production of multi-parameter GIS used to describe and manage the coastal zones.

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SEDIMENTARY CYCLES AS A REFLECTION OF COASTAL CHANGES: AVOIDANCE OF MISTAKES IN DATA INTERPRETATION

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The sedimentary cycles (SC) reflected laws of changes in properties of sediments in the column and, as a rule, in the size of the material. These changes are caused by sea level and coastline oscillations. As the sea level is raised, a transgressional spectrum of the SC appears. Sediments with a large grain-size at the top of the sediment column are substituted by those with small ones. When the sea level is lowered, a regressional spectrum of the SC in the column of sediments is observed with an opposite succession of sediment grain size.

The SC changes in the modern coastal zone are connected with glacio-eustatic oscillations of the sea level in the Quaternary period. The events causing the coastal zone changes are confirmed by the changes in the populations of fossil organisms and recorded in the stratigraphic chronicle. Because of this, authors have proposed the use of the SC as stratigraphic units. The following names were proposed for these: "depositional sequence" (Vail et al., 1977); "cyclic-time-stratigraphic units" (Vella, 1965); "sechrons" (from "sequence" plus "chron", Mitchum et al., 1977). One should be careful in the interpretation of events in the coastal zone using the SC because there are false transgressional-regressional SCs.

About 70% of sediments covering the continental shelves were classified as relict (Emery, 1969). These sediments have been formed in the time of different positions of the coastline in the past and were submerged on the shelves in more recent times. The role of relict sediments is a great one for wide, gently sloping and planar shelves. Modern sediments are accumulated generally near the coast-line and on the inner shelf only. The first type of sediments is located right at the shoreline and is represented by different sizes of sediments from psephitic (pebble, gravel) to aleuro-pelitic (silt-clay). The next sediment type is layered more deeply, up to 30-40 m, and is mainly aleuro-pelitic.

If the sea level was dropping now, the coastline would move seawards. Coarse sediment would accumulate at the new coastline and cover the finer size modern sediment. A regular regression type of SC would be found in the column of sediments. Almost immediately, fine size sediments would cover the coarse-sized relict ones. This process forms the false transgressional type of SC in the column of sediments.

An example of the false SC is shown in drilling core 2V taken from offshore in the Sea of Japan, near Vladivostok. This core was described in connection with the coastal zone changes in the Quaternary period (Markov, 1983). The column contains deposits of the Late Pleistocene and Holocene containing a complex of cold and warm type foraminifers (Troitskaya, 1974). These complexes allowed the separation of deposits according to chronology using the Blitt-Sernander scheme.

The section of Late Pleistocene sediments begins with Middle Drias (Q_{2III} lying on Pliocene sediments. This horizon corresponds to the Zyrijankan stage of the Early Würm glacial epoch. The higher sea level corresponds to the accumulation of this horizon in the Riss-Würm (Kasantzevan) interglacial stage (Q_{IIII}). This sea level is recorded by steps on the modern coast as sediments on a 12 m terrace. The sediments of that time are absent into the column, because the position of the 2V well was located in the a-sedimentogenic part of the bottom for the paleoshelf (Fig. 1). So, the transgressive type of layers for the Q_{2III} horizon observed in the column corresponded in reality with the regressive

movement of the coastline, which is, however, a false one. The well is located in the accumulative paleozone, where fine sediments from Middle Drias are laid down on coarser relict sediments of that time (Fig. 1).

A small increase of sea level in the Allerod (Q_{3III}) marks the Karginskian interstage in the column with the normal transgressive type of section.

The sharp decrease of sea level in the last thermal minimum of the Pleistocene (Sartanian) is represented in the column by continental sediments of Upper Drias (Q_{4III}). These sediments are eroding and laid down on the fine offshore sediments. So, here it is possible to interpret a normal regressive type of section.

The gradual (oscillatory) increasing sea level took place in the Holocene. This increase is represented by normal transgressive series of sediment layers, which are Preboreal and Boreal (Q_{1IV}), and also Atlantic (Q_{2IV}). Some coarsening of material in the Atlantic is caused by the fact that the well position was near to the accumulation and transit zones of the paleoshelf. The decreasing sea level in the Subboreal (Q_{2IV}) and Subatlantic (Q_{3IV}) is marked by "reverse" (i.e. false) transgressive layer-successions in the column. It is connected with the fact that the well position is located in the offshore mud-accumulation area for the regressive movement of coastline.

This example of an analysis of the paleoenvironment through the sediments of the 2V well shows that the correct determination of the SC type for every paleoepoch can be made with the understanding of the location of the relict and the recent sediment fields on the paleoshelves (Likht, 1993). This analysis of true and false SC is especially important for coastal zones with large dynamic processes of natural and human activity.

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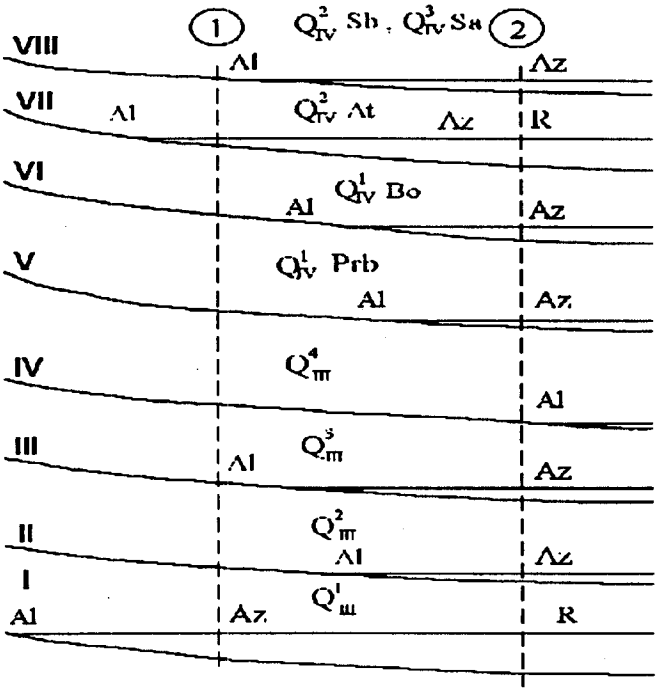

Fig. 1. Paleoenvironmental changes in position of the 2V well in Late Pleistocene and Holocene.
I-Riss-Würm (Kazantzevan) interglacial stage (Q^1_{III}).
II-Early Würmian (Zyriankan) glacial stage (Q^2_{III}).
III-Wurm (Karginskian) interglacial stage (Q^3_{III}).
IV-Late Würmian (Sartanian) glacial stage.
V-Subboreal (Q^2_{IV} Prb).
VI-Boreal (Q^2_{IV} Bo).
VII-Atlantic (Q^2_{IV} At).
VIII-Subboreal (Q^2_{IV} Sb)., Subatlantic (Q^3_{IV} Sa.
Numbers into circles: 1-modern coastline, 2-location of the 2V well.
Paleofacies: Al = alluvium, Az = accumulative zone of offshore bottom, R = asedimentogenic area of Paleoshelf covered by relict sediments.

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ASSESSMENT OF COASTAL VULNERABILITY TO CLIMATE CHANGE: THE IPCC COMMON METHODOLOGY, RESULTS AND SYNTHESIS

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INTRODUCTION

The threat of global climate change in the coming century, including accelerated sea-level rise, has stimulated efforts to improve our understanding of the physical, ecological and societal implications of such changes, as well as their implications for coastal zone management. In coastal areas, the IPCC Common Methodology (or CM) was developed for this purpose (Fig. 1) (IPCC, 1991; 1992; WCC'93, 1994). The concept of *vulnerability* embraces

(1) the physical and socioeconomic susceptibility to global climate change, and

(2) the ability to cope with these consequences (i.e., susceptible countries or areas may not be vulnerable).

In assessing vulnerability to sea level rise, the CM considers three scenario variables:

(1) global climate change factors;

(2) local development factors; and

(3) response options. It considers present sea level and (global) rises which approximate the low and high estimates of the IPCC 1990 Scientific Assessment -- 0.3 and 1.0 meters by the year 2100. These global scenarios should be converted into relative (or local) scenarios of sea level, including vertical land movements. The CM recommends considering development and expanding coastal populations by extrapolating 30 years from the present situation (although in practise this has not often been accomplished). A range of response options should be considered - and at a minimum, the extreme options of retreat and total protection.

This paper reviews the 22 national scale case study results available in January 1994, including a global aggregation and comparison of these results (see Nicholls, 1995 for more complete details). Not all the studies were conducted using the CM, but it provides a useful reference frame for this analysis. Aggregation is useful as it helps to identify common findings and trends, while some results can be used to validate (or otherwise) the results of the Global Vulnerability Analysis (GVA) (Hoozemans et al., 1993).

METHODOLOGY

The scenarios of a 1 m rise in sea level over the next 100 years and no development (present population and economic status) were the most suitable common denominators for aggregation purposes (Nicholls, 1995). The results therefore tend to overstate the implications of sea level rise, and to understate the implications of other changes in climate, and pressures and development due to socioeconomic trends. The factors selected for the aggregation are summarized below:

(1) Number of people affected -- the number of people living in the risk zone -- the area that will be subject to erosion, inundation (submerged beneath high tide) or flooding given sea level rise. Therefore, it aggregates people displaced from their homes with people subject to an increased risk of flooding. Both absolute and relative values were extracted, the latter expresses the former as a percentage of the national population.

(2) Number of people at risk -- a statistical estimate of the number of people who will experience flooding for a given return period event assuming sea-level rise. This factor was only provided in 6 studies, reflecting a number of difficulties in its estimation.

(3) Capital value at loss -- the capital value of the dry land and infrastructure that will be perma-

nently lost by inundation or erosion. This factor is aggregated as an absolute figure, and as a percentage of GNP.
(4) Area of land at loss -- the area of land (both dry land and wetland) that will be permanently inundated or eroded. This factor is aggregated as an absolute and as a relative figure -- expressed as a percentage of the total national area.
(5) Wetlands at loss -- the natural areas of coastal wetlands that will be lost or dramatically changed.
(6) Protection and adaptation costs -- the protection and other adaptation costs required to maintain existing protection levels after a rise in sea level. The total price at present price levels is determined. It is assumed that the lifetime of the protection infrastructure will be 100 years. Then the annual cost is 1% of the total cost, providing the annual percentage of GNP required for protection.
To better assess the vulnerability of the 18 countries with the most complete results, vulnerability profiles were developed using the classes defined in Table 1 (IPCC, 1992). These profiles are presented in Fig. 2 (using only integer values). For missing elements, an assessment has been made on the basis of expert judgement (Nicholls, 1995).

RESULTS

The aggregated results are presented in Table 2. In summary, they suggest the following minimum impacts assuming a no protection response:
- nearly 179 million people could be affected (at least 30 million being displaced from their homes;
- assets with a current value of more than US$ 1,100 billion could be lost;
- an area of dry land over 90,000 km^2 could be lost due to erosion and inundation;
- nearly 59,000 km^2 of coastal wetlands could be lost, or dramatically changed.

Nearly 80% of the people affected come from just two countries: 72 million (or 6.5% of national population) in China and 71 million people (or 60% of the national population) in Bangladesh. In both cases these results consider both inundation and increased flooding. For Bangladesh, the interaction between sea level rise and river floods as well as the possibility of increased precipitation are considered. Sea level rise increases river floods considerable distances inland in low-lying coastal areas. Other studies of Bangladesh estimated that about 13 million people would be displaced from their homes by a one-meter rise in sea level, demonstrating the more than fivefold increase in the number of people affected by considering increased flooding from rivers and storm surges. In relative terms, the number of people affected varies from 0.3% of the total population in Venezuela to 100% of the population in Kiribati and the Marshall Islands (both comprise low-lying coral atolls).
The estimated (dry and wet) land losses range from 0.05% of the national land area in Uruguay to over 80% of the national land area of the Marshall Islands. On average, the estimated loss is about 1% of the total land area of the 22 countries considered.
It appears that coastal wetland loss could be substantial. Further, it appears that wetland migration could not fully replace the wetlands which are lost due to sea level rise, but this is not well quantified due to limited topographic and other data. The study of the U.S.A. did consider wetland migration and estimated that on average about 5,400 km^2 of dry land would be converted to wetland by a 1 m rise in sea level. Therefore, protection of all dryland areas increases net wetland losses from 49% to 66%. It should be noted that coastal wetlands are often more immediately threatened by existing degradation and human reclamation and substantial losses can be expected without any acceleration in global sea-level rise (Hoozemans et al., 1993; Nicholls and Leatherman, 1995).
Therefore, vulnerability to sea-level rise varies considerably from country-to-country and from factor-to-factor. While one can debate the merits of the class boundaries selected for Table 1 and Fig. 2, this variability is significant. Deltaic settings and small islands, particularly coral atolls, appear most vulnerable. For instance, of the 10 countries which have a *critical* or *high* vulnerability with respect to people affected by a one-meter rise in sea level rise, five are small islands and three are associated with deltas. Considering land at loss, the Marshall Islands has a *critical* indication and

Kiribati and Bangladesh have a *high* vulnerability. Coastal wetlands seem threatened in most settings with 16 countries having a *high* or *critical* vulnerability.

To counter the impacts described, protection and adaptation measures are likely. Eighteen case studies give protection and adaptation costs, totalling at least US$ 378 billion. This cost is dominated by Japan and the U.S.A. whose protection costs constitute 53% and 38% of the total, respectively. Two small island countries have a *critical* vulnerability: the Marshall Islands and Nevis, while Antigua, Benin, Egypt, Guyana, Senegal and Uruguay have a *high* vulnerability, reflecting the importance of the coastal zone in these countries and/or the present (small) size of the economy. In Uruguay and Senegal, these high costs are largely related to beach nourishment at tourist resorts -- a pattern that could be repeated elsewhere in the world.

DISCUSSION/CONCLUSIONS

Vulnerability assessment is one possible trigger towards improved integrated coastal zone management. Even if there are pressing immediate problems and needs, these studies show the need for a long-term (50+ years) perspective as part of coastal management. Climate change is an important metaphor for all the long-term issues of coastal management.

The existing case studies provide important guidance for improvements to future analyses which will provide better information for coastal management:

- better consideration of future socioeconomic changes and better evaluation of non-market values, including subsistence lifestyles (McLean and Mimura, 1993).
- evaluation of sensible intermediate response options, including exploration of opportunities for low-cost anticipatory adaptation such as planned retreat (setbacks) and accommodation responses.
- improved understanding of the vulnerability of coastal wetlands, including the non-linear wetland response to sea level rise and the evaluation of the potential for wetland migration, under various response options.
- consideration of other coastal implications of climate change, particularly changing storm frequency and intensity (e.g., McLean and Mimura, 1993).

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Table 1. Vulnerability classes

Impact categories	Vulnerability classes			
	Low	Medium	High	Critical
People affected (#people / total) * 100%	<1%	1-10%	10-50%	>50%
People at Risk (people * probability)/1000	<10%	10-100%	100-500%	>500%
Capital value at loss (total loss / GNP) * 100%	<1%	1-3%	3-10%	>10%
Dry land at Loss (area / total area) * 100%	<3%	3-10%	10-30%	>30%
Protection / adaption costs (total cost / GNP) * 100%	<0.05%	0.05-0.25%	0.25-1%	>1%
Wetland at loss (area / total area) * 100%	<3%	3-10%	10-30%	>30%

Table. 2. Results of national case studies assuming a no-protection response scenario.

	People Affected		People At Risk	Capital Value At Loss		Land at Loss		Wetland at Loss
	#People * 1000	%Total	#People	Mil US$	%GNP	Km^2	%Total	Km^2
COUNTRY STUDIES								
Antigua	38	50	1,900	-	-	5	1 0	3
Argentina	-	-	-	5,600[1]	6	3,400	0 1	1,100
Bangladesh	71,000	60	-	-	-	25,000	17 5	5,800
Belize	70	35	-	-	-	1,900	8 4	-
Benin	1,350	25	-	126	12	230	0 2	85
China	72,000	7	-	-	-	35,000	0 4	-
Egypt	4,700	9	30,000	59,272	204	5,800	1 0	-
Guyana	600	80	60,000	4,000	1115	2,400	1 1	500
Japan	15,400	15	-	807,000	72	2,300	0.62	-
Kiribati	9	100	-	2	8	4	12 5	-
Malaysia	-	-	-	-	-	7,000	2 1	6,000
Marshall I	40[5]	100	20,000	175	324	9	80	-
Mauritius	6	1	-	-	-	10	0 5	-
Netherlands	10,000	67	24,000	186,000	69	2,165	5 9	642
Nigeria	3,200[2]	4	-	18,000[3]	52	18,600	2 0	16,000
Poland	235	1	196,400	24,000	24	1,700	0 5	36
Senegal	>110[2]	>1	-	700	14	6,100	3 1	6,000
St Kitts-Nevis	-	-	-	-	-	1	1 4	1
Tonga	30	47	-	-	-	7	2 9	-
Uruguay	13[2]	<1	-	1,800[3]	26	96	0 1	23
U S A	-	-	-	-	-	31,600[4]	0 3	17,000
Venezuela	56[2]	<1	-	350[3]	1	5,700	0 6	5,600
TOTAL	178,857		332,300	1,107,025		149,027		58,790
NUMBER OF STUDIES	18		6	13		22		14

Notes:

2 Minimum estimates - number reflects estimated people displaced

3 Minimum estimates - capital value at loss does not include ports

4 20,000 km^2 of dry land is lost, but about 5,400 km^2 are converted to coastal wetlands

5 National estimate.

Fig. 1. Seven steps of the common methodology.

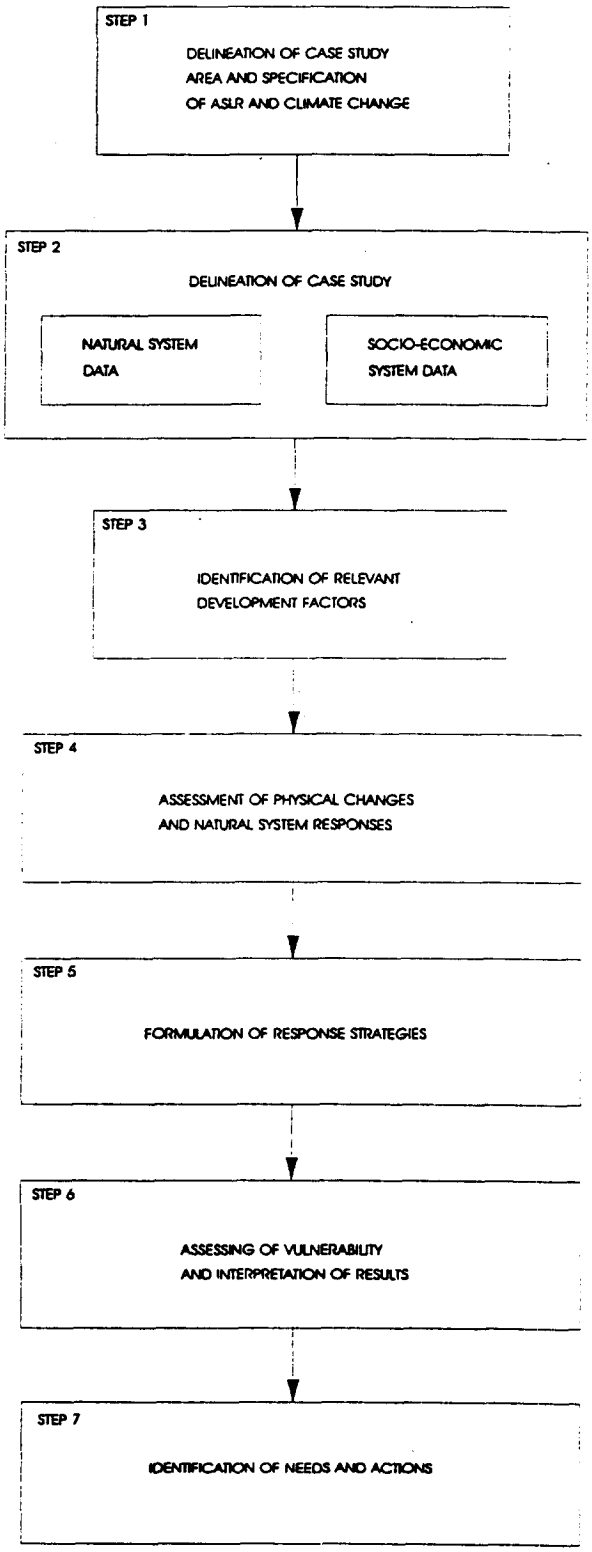
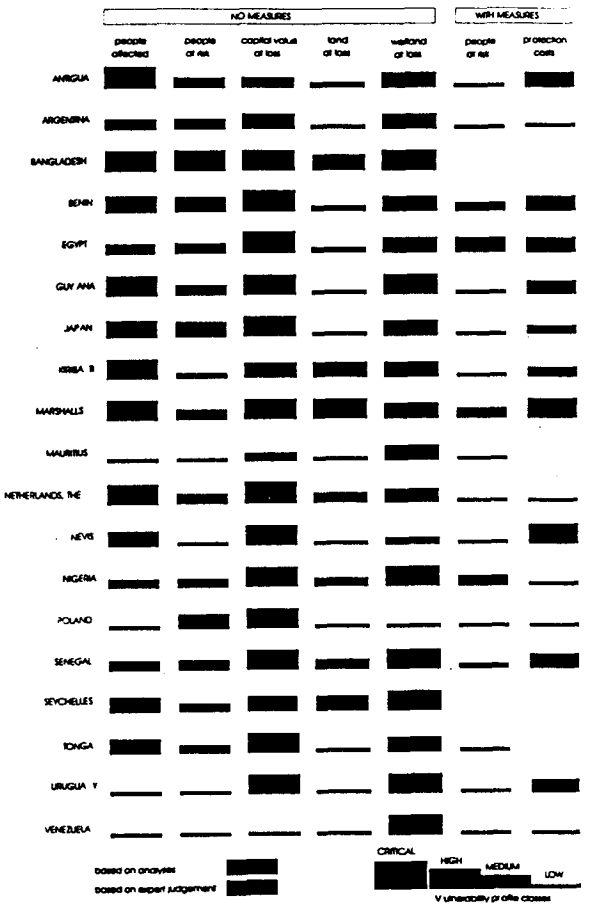


Fig. 2. Country vulnerability profiles.



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LOW-FREQUENCY CHANGE OF THE BLACK SEA RIVER DISCHARGES ASSOCIATED WITH THE COUPLED OCEAN-ATMOSPHERE VARIABILITY IN THE NORTH ATLANTIC OCEAN

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KEYWORDS: River discharge, interannual and interdecadal variability, coupled ocean-atmosphere system, sea surface temperature.

ABSTRACT
The interannual and interdecadal variability of discharges of four Black Sea rivers are examined from 1921 to 1992. It is shown that a typical magnitude of low-frequency fluctuations of these discharges is the same as a typical amplitude of a seasonal cycle. These are mainly due to natural changes in the coupled ocean-atmosphere system. The predictability of the interannual and interdecadal fluctuations of the river discharges, associated with sea surface temperature and atmosphere circulation anomalies in the North/Tropical Atlantic, is discussed.

1.INTRODUCTION

It is well-known that a coupled global ocean-atmosphere variability manifests itself in regional low-frequency variations of different hydrometeorological fields (e.g., Polonsky & Sizov, 1991). In particular, year-to-year and trend-like variations of the Black Sea river discharges are due to global low-frequency processes. Low-frequency changes of river discharges lead to interannual and interdecadal variabilities in the coastal zone, especially in the North West Black Sea (Simonov and Al'tman, 1991).

The question is: How strong are the natural year-to-year and decade-to-decade (trend-like) fluctuations of the Black Sea river discharges, in comparison with the magnitude of a typical seasonal cycle and with the human impacts. What is the main cause?

The goal of this paper is to study the interannual and trend-like variability of the Black Sea river discharges in the 20th century, associated with the global and North Atlantic variability of the coupled ocean-atmosphere system.

The paper is organized as follows. Data, processes and procedure are presented in Section 2. Results and discussion follow in Section 3. Finally, some concluding remarks are formulated in Section 4.

2. DATA AND PROCESSING PROCEDURE

We used monthly river discharge data of the Hydrometeorological Service between January 1921 to December 1992 (Kadeev and Kolinko, 1993), monthly sea surface temperature (SST) in a regular 5 degree grid in the North Atlantic from January 1957 to December 1990, and monthly magnitudes of the sea level pressure (SLP) and Rossby index (RI) from 1984 to 1988 (Polonsky and Sizov, 1991). The river discharges of the Dunay, Dnepr, Dnestr and Uzhny Bug give more than 75 % of total Black Sea river discharge. The accuracy of the calculation of the monthly river discharges is quite high with reliable estimates on the interannual and interdecadal fluctuations, especially after the Second World War. Typical errors are less than 5% of the average monthly values. Their anomalies will be correlated with the SST, SLP and RI anomalies. The RI is calculated as a difference of the SLP in the Azores High and Iceland Low areas. The monthly SLP in the Azores High and Iceland Low was determined as a sum of four (5 by 5 degrees) squares centred on 35° N, 25° W and 65° N, 20° W, respectively, using volunteer ship observations. These observations were used also for the monthly SST calculation. Observation accuracy, the level of relatively high-frequency noise, and aliasing problems were discussed by Polonsky and Sizov (1991). They concluded that typical random error of calculation

of monthly average SST and SLP anomalies (SSTA and SLPA) in a (5 by 5 degrees) square varies in the North Atlantic Ocean from 0.2 to 1 °C and from 1 to 5 mb, respectively. Thus high-amplitude large scale SSTA and SLPA may be determined with typical relative errors from 15 to 50 %.

The data set was processed universally. First the average annual cycle of each of the analyzed parameters and monthly anomalies were calculated. Then the trends and Fourier spectra of all monthly series were estimated. Finally, the correlation of SST anomalies, RI, and river discharge anomalies for various lags were calculated.

3. RESULTS and DISCUSSION

3.1. Average seasonal cycle of the river discharges.

It is clear that seasonal cycles of the river discharges depend on their sources. For instance, about 60% of the total annual discharge of Dunay occurs in March to July. Seasonal variability is close to an annual harmonic cycle with a maximum in May and a minimum in October. This is the result of mixed Dunay feeding (alpine snow melting and flood discharge in Central Europe). The Dnepr originates in the mid-Russian Heights, whereas the Dnestr and the Uzhuny Bug are of the Carpathian origin. As a result, sharp late and early spring maxima of the discharges of Dnepr and Dnestr/Uzhuny Bug (respectively) occur (Fig. 1).

The average annual contribution of the Dunay discharge to the total Black Sea river discharge exceeds 60%. However, this contribution changes from less than 60% from February to May, to about 70% between July and September (Fig. 2). The Dnepr and Dnestr are characterized by strong artificial regulation since 1955, when the reservoir hydrosystems and hydroelectrical power stations were built. As a result, the amplitude of the seasonal variations of the Dnepr discharge has decreased significantly since 1955 (Simonov and Al'tman, 1991; Fig. 3a). However this is not a case for the seasonal cycle of Dnestr discharge and for the average annual discharges of both rivers (see below). The typical variance in contribution, associated with the annual harmonic in total 5 years running variance of Dunay discharge in 1945 to 1984, was about 40%. However, it changed from about 25% around 1972, to about 55% around 1977. The significance of the annual harmonic/seasonal fluctuations (without annual harmonic) decreases/increases in the variability of discharges of the Dnepr and Dnestr, and especially for the Uzhny Bug. For instance, the portions of annual harmonic and seasonal fluctuations (without annual harmonic) in total variance of the Uzhny Bug discharge were about 20% and 70 %, respectively with quite strong interannual changes (Fig. 3a, b). So, the interannual variability of the river discharges manifests itself in year-to-year fluctuations of average annual values and changes of seasonal cycles and their magnitude.

3.2. Year-to-year and decade-to-decade variability of river discharges

Figs. 4 and 5 demonstrate the high-amplitude interannual and interdecadal fluctuations of all analyzed river discharges. An artificial variability, due to human activity in the Dnepr and Dnestr basins, does not manifest itself in the average annual discharges. Moreover, in spite of building of Dubossar hydroelectrical power station in 1955, the discharge of Dnestr increased after 1955 for at least two decades. The average annual discharge of the Dnepr did not change practically after 1955, in spite of a strong artificial regulation of the seasonal cycle. Averaged over all periods of observation, linear trends are positive for practically all rivers and months except for the spring/summer discharge of the Dnepr (as a result of regulation of the seasonal fluctuations of the Dnepr discharge) (Fig. 6). Certainly, the linear trend is not a best approximation of low-frequency variability of the average annual discharges (for instance, the linear trend of Dunay discharge is insignificant for the period from 1947 to 1992), whereas the second order trend is significant on 95% confidence level for mostly all months (Table 1). However, this result shows that such a variability is mainly due to natural processes.

Time series and periodogrammes of average annual river discharges show that there are three

typical scales of natural variability, namely quasi-biannual, between 3.5 to 6.5 years and from one to a few of decades. The first and second scales are typically responsible for 5 to 10 % and from 10 to 20 % (respectively) of the total variance of annual discharges in the intervals of period from 2 to 33 years, whereas the contribution of the interannual fluctuations of river discharges in total variance, in intervals or periods from 2 months to 5 years, is the same as the part due to the annual harmonic variation (cf., Figs. 3a and 8). However, these portions are changed significantly during period of observation. The Uzhny Bug is characterized by a minimum interannual fluctuation of its discharge. The discharges of the Dnepr and especially of the Dunay vary strongly from year-to-year. Apparently this is a consequence of the larger basin squares (S) of the last two rivers, S = 63,700 ; 72,100; 504,000; and 817,000 km^2 for the Uzhny Bug, the Dnestr, the Dnepr and the Dunay, respectively.

The following question arose: what is the cause of the interannual and interdecadal fluctuations of the river discharges? Results of Polonsky & Sizov (1991), Sizov et al. (1991), Dzhiganshin & Polonsky (1994), and Voskresenskaya & Polonsky (1993; 1994) show that this may be due to ocean-atmosphere interaction over the globe and especially over the Atlantic Ocean.

3.3 Low-frequency variability of sea-air interaction in the North Atlantic Ocean

There are three distinct temporal scales of interdecadal and interannual variability of hydrometeorological fields in the North Atlantic. The first scale is due to global warming occurring during the last century. The second and third ones are due to natural fluctuations of the atmosphere-ocean system. Their typical time scales are of a several decades and 2 to 7 years, respectively.

The first and second types of variability look like a trend, if the analyzed data set cover a few of decades. Just this kind of data sets is available for the reliable detection of low-frequency variability of the coupled system.

The second type of variability is mainly due to a change of meridional heat flux in the upper ocean layer. The third one looks like a quasi-periodical (random?) signal due to year-to-year fluctuations of the coupled system on the globe.

El Niño-Southern Oscillation (ENSO) and North Atlantic Oscillation (NAO) are the main manifestations of this signal. The natural low-frequency variability of the coupled system prevails in the North Atlantic (Voskresenskaya and Polonsky, 1993; 1994). The global ENSO-events manifest in the North Atlantic fields. Change of amplitudes and phases of annual and semi-annual harmonics in various hydrometeorological parameters and high-amplitude anomalies of average annual values in the coupled atmosphere-ocean system in the North Atlantic during ENSO events were revealed and documented by Hastenrath (1991), and Polonsky & Sizov (1991) (see also, Table 2). Anomalous conditions develop in the North-Tropical Atlantic and in the equatorial Pacific simultaneously, with an accuracy of one season. However, the Atlantic anomalies usually reach their mature phase faster than the Pacific ones, owing to their difference in size and the geographical particularities of these Oceans. Before the typical ENSO-event, the atmosphere centres of action shift to the North, and the atmosphere circulation intensifies in the North Atlantic. Concurrently, the negative and positive SSTA are generated in the eastern tropical and subtropical/mid-latitude North Atlantic, respectively. After the ENSO-event starts, the atmosphere circulation weakens in the North Atlantic and Pacific Ocean simultaneously with a displacement of the centres of action to the South. In that time, the positive SLTA/SSTA appear in the Tropical Atlantic and cyclone trajectory changes in mid latitudes (Dzhiganshin & Polonsky, 1994; Polonsky & Sizov, 1991; Voskresenskaya et al., 1991).

Of course, individual features of the ENSO events occur. They may explain partly some contradictions concerning lag-lead relationship between Atlantic and Pacific variability. At the same time, about 20 to 50% of the total variance of the hydrometeorological fields, due to year-to-year variability in the North Atlantic coupled system, do not correlate significantly with the ENSO-like variability. It means that the Atlantic fluctuations,

such as NAO, may be also the effective cause of year-to-year variability in the coupled ocean-atmosphere system. The strong negative correlation of the SLPA in the Azores High and SSTA in the Tropical Atlantic in 1957 to 1974 confirms such suggestion (Sizov et al., 1991). The active role of the North Atlantic Ocean in multidecadal variability of the coupled ocean-atmosphere system on the globe is confirmed by a significant linear trend of the RI in 1957 to 1988 and by the absence of significant Pacific SOI trends in that period. The second-order RI trend was insignificant in that period. However, it becomes significant when the analyzed period is augmented by about 10 years (Table 3). Voskresenskaya & Polonsky (1994) revised the results of Bunker (1980), Flohn & Kapala (1989) and Voskresenskaya & Polonsky (1993). They showed that a typical period of low-frequency variability of the coupled ocean-atmosphere system in the North Atlantic Ocean is about 50 to 60 years.

We should emphasize the active role of ocean SST variability in low-frequency fluctuations of the coupled ocean-atmosphere system. In particular, the influence of SST trend on total sea level heat flux (SHF) is very important. Accordingly to Voskresenskaya and Polonsky (1993), the linear trend of difference of sea surface and sea level temperatures (SST-SLT) was a negative one in most of the North Atlantic Ocean in 1957 to 1991. Its typical magnitude was about -0.1 deg. per decade and occurring only in the Newfoundland vicinity. At least 50% of these trends are due to the SST change, especially in the mid and high latitudes. The SLT increase is manifest is in the low and mid latitudes of the North Atlantic.

Simultaneously the cooling of the low troposphere occurred in the high latitudes of the North Atlantic. Apparently it was a result of cooling of the sea surface, associated with the conveyor belt variability. This means that the natural processes are hampered by the human impact of the warming of the low troposphere during analyzed period. At the same time, the sign of trends of most hydrometeorological parameters of the North Atlantic changed in 80s (Voskresenskaya & Polonsky, 1994). So high-amplitude natural fluctuations of the coupled system in the North Atlantic Ocean may completely mask (dampen or intensify) the greenhouse warming of the low troposphere (Voskresenskaya and Polonsky, 1994).

Unfortunately we have not complete long-term series of the Black Sea river discharges for a reliable analysis of this type of variability from the statistical point of view. At the same time the Tropical Atlantic SST is characterized by significant "dipole-type" variability with typical time scale of about one to two decades. This manifests itself in the interdecadal change of the meridional SST gradient.

Brazilian and African climate changes correlate strongly with this type of Tropical SST variability (Hastenrath, 1991). This type of variability was revealed also in the Black Sea river discharges (see paragraph 3.2).

Following above consideration, we will test first of all the correlation of river discharge anomalies with the North/Tropical Atlantic Ocean SSTA.

3.4 Correlation of river discharge anomalies and North/Tropical Atlantic Ocean anomalies and Its reasons.

Fig. 9 demonstrates the strong correlation of monthly anomalies of the Dunay discharge and SSTA in the North Atlantic Ocean. The coefficient of correlation is at a maximum in the N.W. Tropical Atlantic and in the Gulf Stream and North Atlantic Current vicinity. It reaches about -0.6 and -0.5 in that regions, respectively. The module of correlation coefficient tends to increase when the lag of Dunay discharge anomalies rises from zero to one year in the Gulf Stream and North Atlantic Current vicinity and from zero to two years in the N.W. Tropical Atlantic (Fig. 10). In the other words, after anomalous cooling of the North and especially N.W. Tropical Atlantic, the Black Sea river discharges tend to be larger during one or two years (the correlation coefficients between low-frequency variations of the discharges of Dunay, Dnepr, Dnestr and Uzhny Bug vary from 0.55 to 0.95). The lag increase leads to an increase of the correlation coefficient to about 0.5 on decadal scale. This result is statistically significant on a 99% confidence level. Linear de-trending of the

time series does not change significantly the magnitudes of correlation coefficients. This confirms a crucial role of the natural variability of the coupled ocean-atmosphere system in inter-decadal changes of the river discharges.

Periodical features of correlation between SSTA and the Dunay discharge anomalies (with a period of about one decade), which is clear from Fig. 10, give a principal base for the long-term predictability of the river discharges. The geophysical mechanism of the predictability of the year-to-year river discharge changes corresponds with a long-term memory of the Ocean. After anomalous warming of the North Tropical Atlantic the low-troposphere zonal circulation is intensified in the subtropical latitudes. This leads to increase of the RI magnitude, of the snow cover and rainfall intensification in the Central and Eastern Europe. Maximum magnitude of the RI anomalies (and hence snow cover anomalies) occurs in winter before ENSO event beginning (see paragraph 3.3). The positive anomalies of river discharge have to increase with some lag period. For instance, the Dunay discharge lags behind SSTA by about one/two years. However, some abnormal and intense ENSO events do not confirm this simple scheme. It seems that interdecadal variability of the river discharges, associated with the changes in the coupled ocean-atmosphere system, may be more predictable than interannual (see a regular decadal cycle in Fig. 10). Fig. 10 shows also that the circulation mechanism of this predictability differs from the year-to-year one, because the sign of correlation SSTA and the Dunay discharge anomalies changes, when lag periods become larger from a few years to decades. Opposite signs of the second-order trends of the Dunay discharges and RI after the Second World War (cf., Tables 1 and 3) confirm this statement because the correlation coefficient of year-to-year SLP variability in the Azores High (and hence RI change) with year-to-year Dunay discharge changes is a positive (it reaches 0.46). Results of Kazakov (1993) give the clear decadal circulation patterns resulting in trends like variability of the sea level pressure on the globe. On the other hand the time series are relatively short and this result is achieved purely from the statistical point of view. For instance, Fig. 7 shows the strong change of amplitude of decadal harmonic cycles of the river discharges has to be studied more carefully.

4. CONCLUSIONS

We reveal a strong interannual and interdecadal variability of the Black Sea river discharges especially of the large rivers, such as the Dunay and the Dnepr. The typical magnitude of low-frequency fluctuations of these discharges resembles a typical amplitude of the seasonal cycle. These fluctuations are mainly due to natural changes in the coupled global and North Atlantic ocean-atmosphere systems. Geophysical mechanisms of year-to-year and decade-to-decade variations differ from one to another. The first of them is mainly due to ENSO-like variability and hence to change of the coupled system in the tropical Pacific Ocean. The second one is many due to conveyor belt variability and hence to North Atlantic changes. Unfortunately, the statistical structure of the time series is not steady; hence, a good forecast of river discharge anomalies is not a simple (and formal) procedure, in spite of the lead of North Atlantic anomalies. Perhaps the interdecadal variability of the river discharges associated with SSTA in the North/Tropical Atlantic is more predictable than interannual one.

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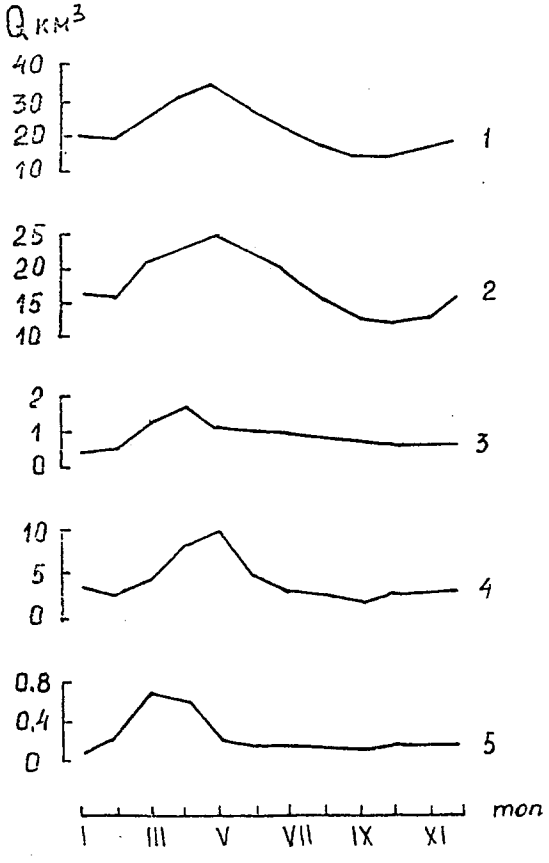


Fig. 1. Average seasonal variability of river discharges from 1923 to 1985 (Simony & Al'tman, 1991). 1-Total discharge of NW Black Sea rivers; 2-Dunay; 3-Dnestr; 4-Dnepr; 5-Uzhny Bug.

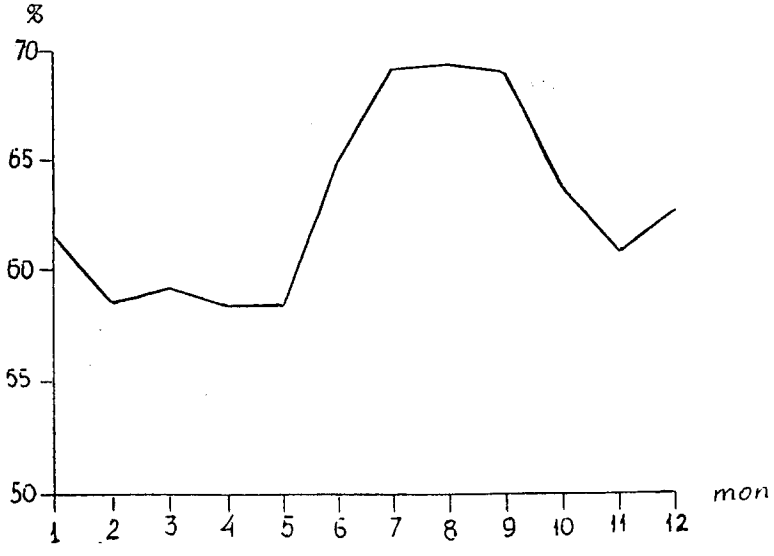


Fig. 2. Seasonal variability of the Dunay portion (%) of the total Black Sea river discharge, averaged over 1921 to 1982.

Table 1. Magnitudes of the second order trends (km^3/yr^2) of monthly Dunay discharge in 1947-92. Significant (95% confidence level) magnitudes are underlined. All magnitudes are a nagative (sign "-" is omitted)

months	J	M	M	J	S	N
coeff. of trends x10	0.1	0.1	0.15	0.1	0.9	0.05

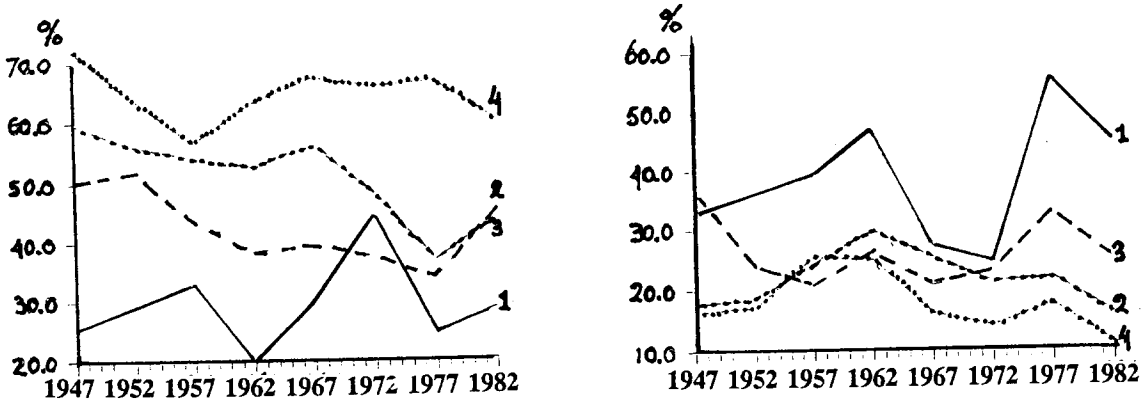
Table 2 Average seasonal variability of the Rossby index (RI=SLPazor. - SLPisl.) in 1946-1988 (upper row) and in 1951, 1957, 1972, 1965, 1986 (the years of the rather typical ENSO-events after the Second World War - low row)

Mean annual magnitude (mb)	Amplitude of the harmonics (mb)		Phases of the harmonics (rad)		r.m.s. resid. (mb)
	annual	semi-annual	annual	semi-annual	
15.75	3.26	1.93	2.61	2.09	1.38
15.88	6.87	4.50	2.09	2.09	4.75

Table 3. Magnitudes of the RI linear trends (upper row, mb per decade in 1957 to 1988) and of the RI second-order trends (low-row, mb per square decade in 1946 to 1988). Significant (95% confidence level) magnitudes are underlined (after Voskresenskaya and Polonsky, 1993)

months	J	M	M	J	S	N	an.
coeffic. of lin. trend x10 1957/88	5.9	4.9	0.4	0.6	-0.0	1.3	0.9
coeffic. of sec.-or. trend 1946/88	3.6	1.6	>0	1.1	>0	0.8	1.0

Fig. 3. Part (%) of annual harmonic (left) and seasonal fluctuations (without annual harmonic) (right) in total variance of the river discharges over 5 years' running intervals from 1945 to 1984. 1-Dunay; 2-Dnestr; 3-Dnepr; 4-Uzhny Bug.



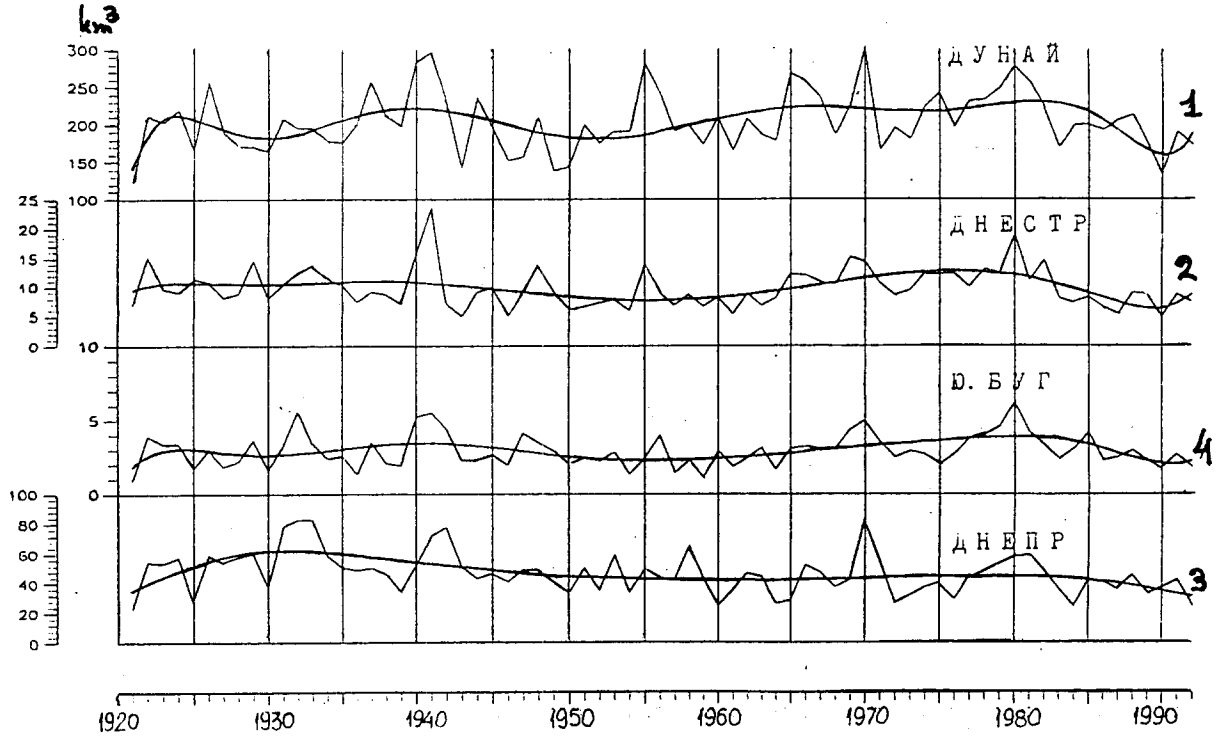
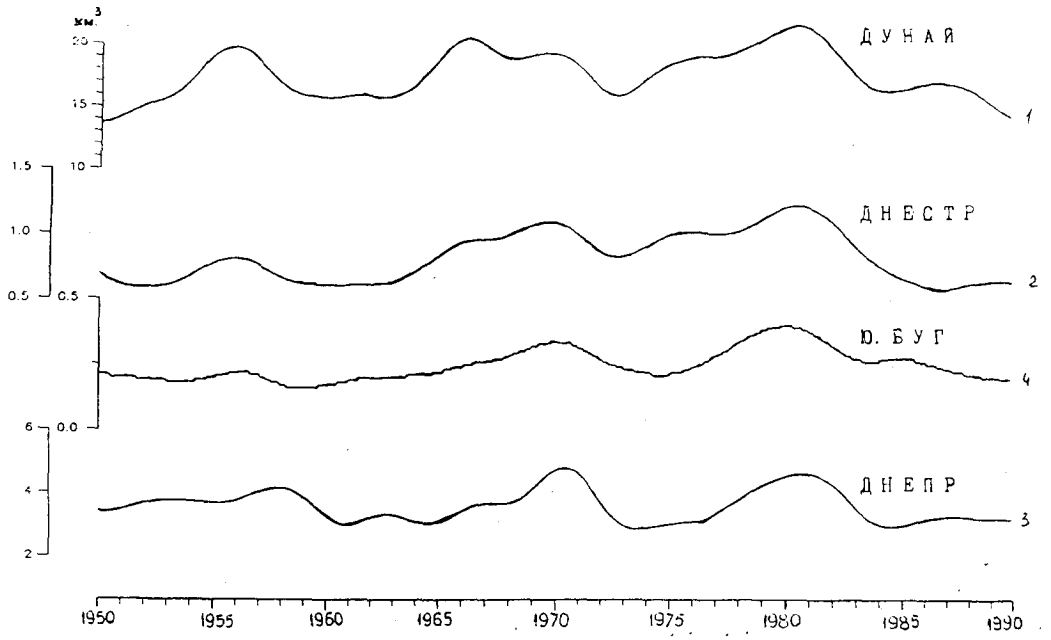


Fig. 4. Variability of the average annual river discharges from 1921 to 1992. 1-Dunay; 2-Dnestr; 3-Dnepr; 4-Uzhny Bug.

Fig. 5. Low-pass filtered variability of river discharges from 1948 to 1992 (Cosin filter with T = 36 months was used.



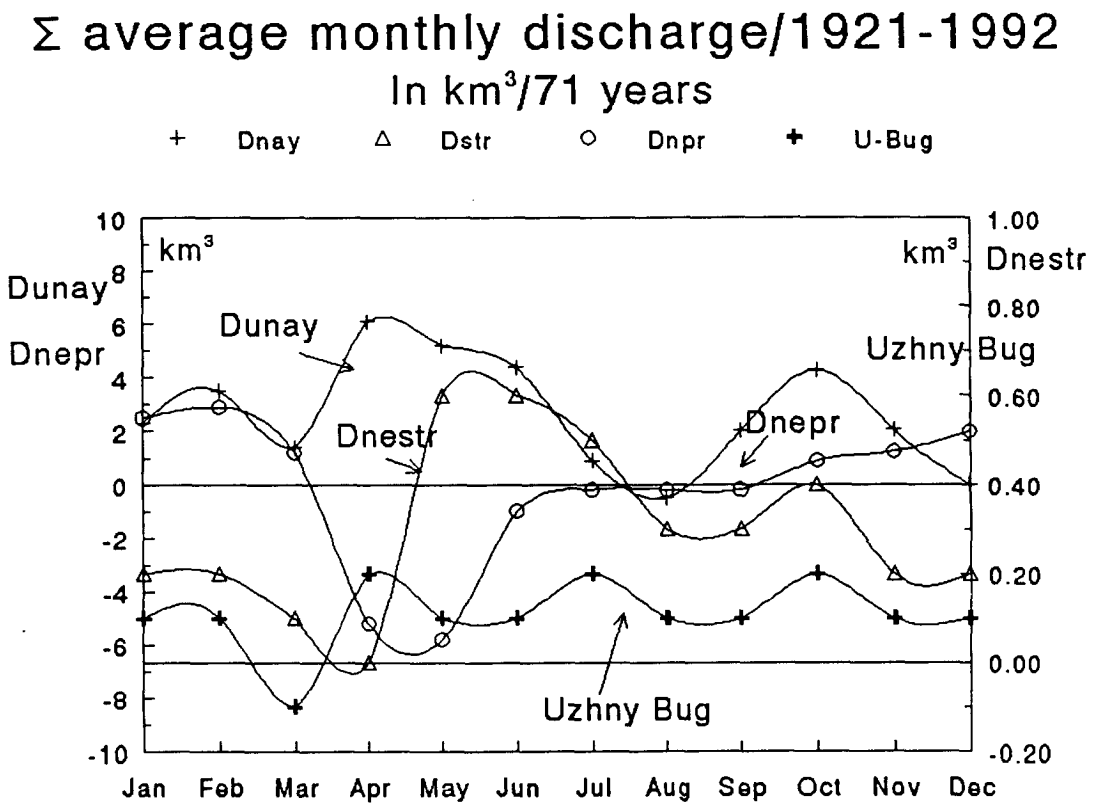


Fig. 6. Average monthly discharges over the complete period of observation from 1921 to 1992 (km³/total period). Right Y-axis: Dunay & Dnepr; Left Y-axis: Dnestr & Uzhny Bug.

Fig. 7: Running 33 years' periodogrammes of annual river discharges (in % of total variance over intervals of periods from 1 to 33 years). A-Dunay; B-Dnestr; C-Dnepr.

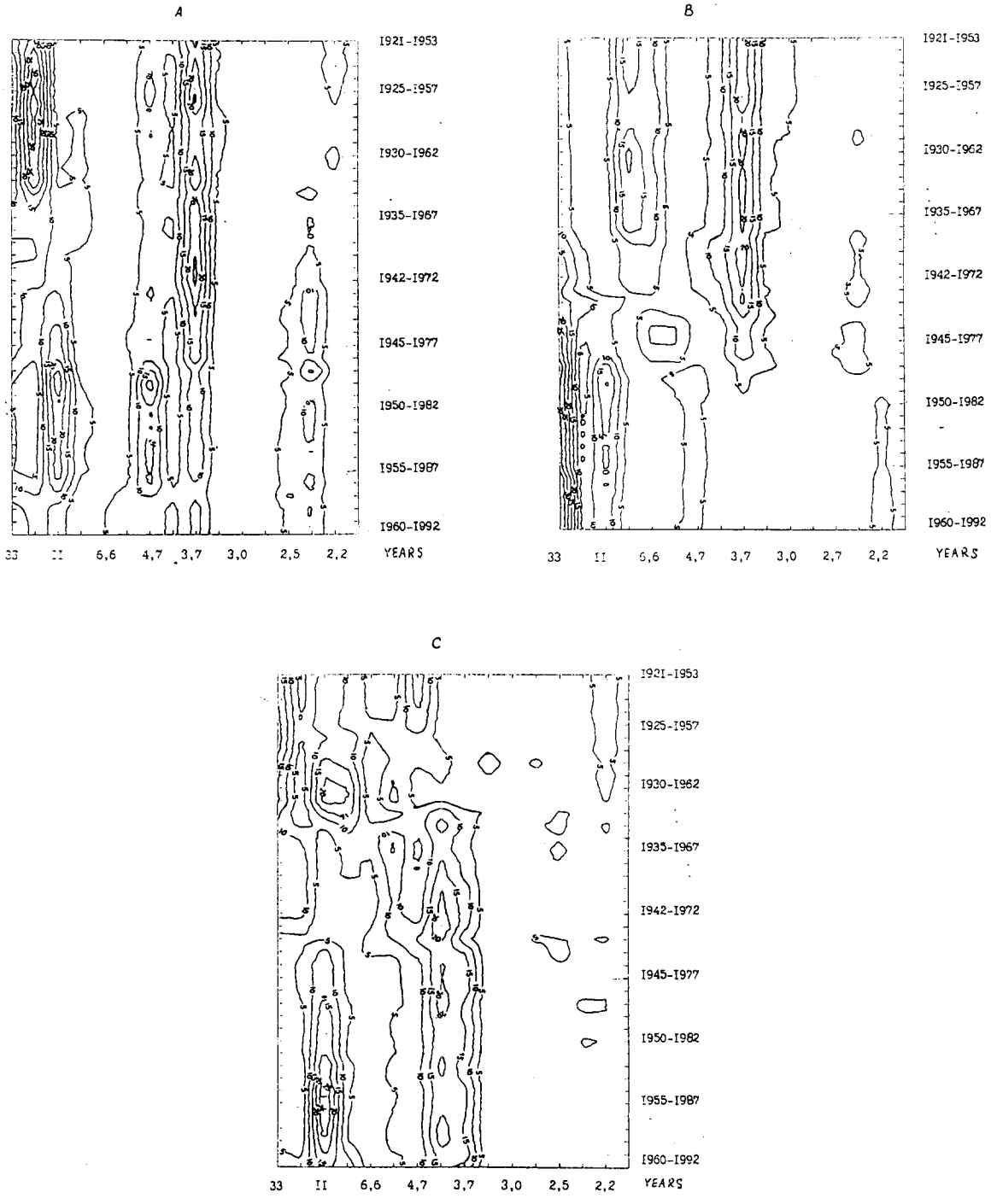


Fig. 8. Part (%) of biannual fluctuation (a), and fluctuations with T>27 months (b) in total variance of the river discharges over 5 years' running intervals from 1945 to 1984. 1-Dunay; 2-Dnestr; 3-Dnepr; 4- Uzhny Bug.

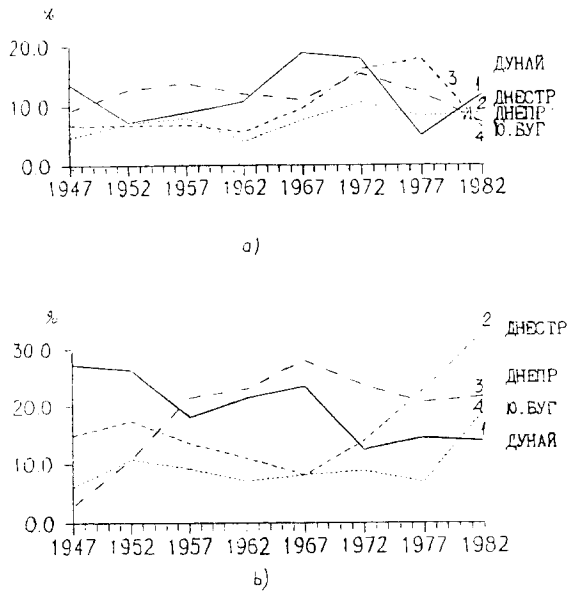
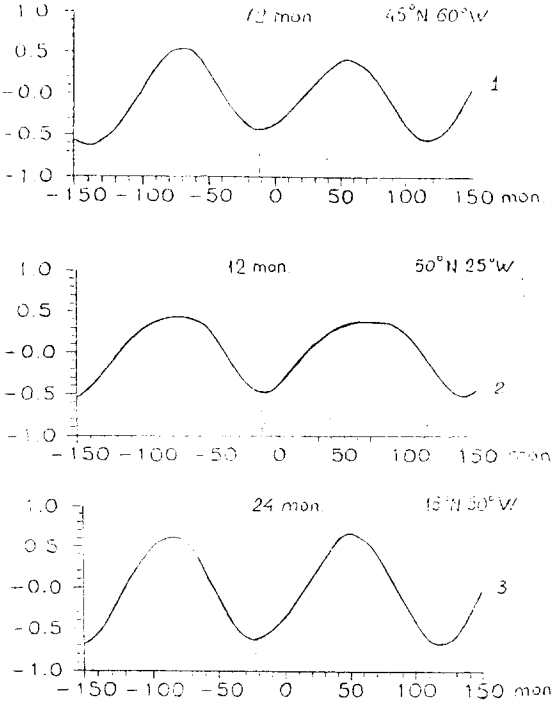


Fig. 10. Lag-lead correlation of monthly anomalies of the Dunay discharge and monthly SSTA in the vicinity of the Gulf Stream (1). North Atlantic Current (2), and North-West Tropical Atlantic (3). Running annual harmonic was removed.



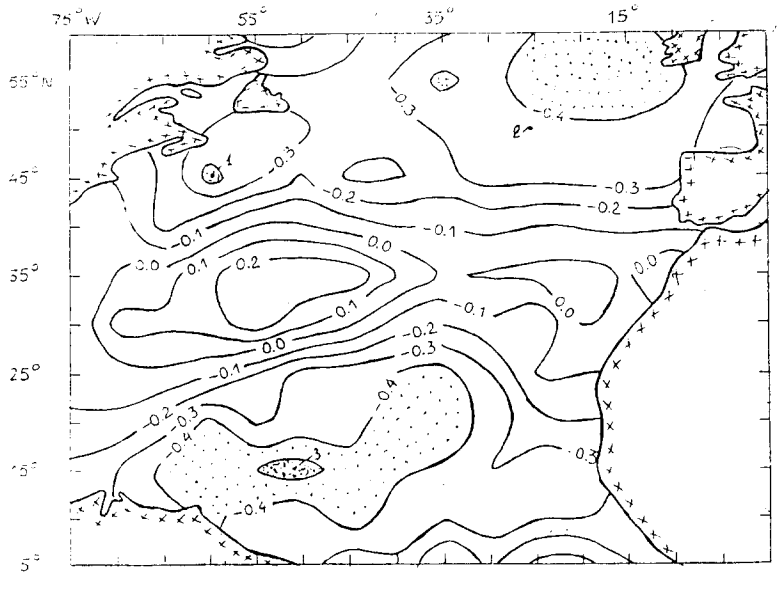


Fig. 9. Spatial distribution of correlation coefficients between monthly anomalies of the Dunay discharge and SSTA averaged over 5 by 5 degree mesh. Series from 1957 to 1990 were used. Lag of Dunay discharge is 12 months. The numbers 1, 2 and 3 show the areas for which the lag-lead correlation is done in Fig. 10.

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MISE EN PLACE D'UN SYSTÈME D'INFORMATIONS GÉOGRAPHIQUES POUR LA GESTION ADMINISTRATIVE ET LE SUIVI ENVIRONNEMENTAL DU BASSIN D'ARCACHON DANS LE CADRE DE L'ÉTUDE INTÉGRÉE D'IFREMER.

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Le Bassin d'Arcachon est une zone particulièrement complexe d'un point de vue d'aménagement où cohabitent dans la zone littorale conchyliculture, pêche, plaisance et tourisme d'une manière générale. C'est pour cette raison que la station de l'Institut Français de Recherche pour l'Exploitation de la MER (IFREMER) à Arcachon a reçu la mission d'une "étude intégrée" devant réaliser la compilation de l'ensemble des données disponibles, faisant appel à un système d'Informations Géographiques. Ce système permet un croisement d'informations de natures différentes qui facilite l'analyse des phénomènes et les prises de décisions dans le domaine de l'aménagement du littoral. La nécessité d'une telle gestion est renforcée par la rapide évolution morphologique du bassin qui implique une mise à jour régulière des documents à la source des études techniques et scientifiques portant sur le site d'Arcachon.

Mise en place d'un système d'Informations Géographiques pour la gestion administrative et le suivi environnemental du Bassin d'Arcachon dans le cadre de l'étude intégrée d'IFREMER.

Le Bassin d'Arcachon est une zone particulièrement complexe d'un point de vue d'aménagement où cohabitent dans la zone littorale conchyliculture, pêche, plaisance et tourisme d'une manière générale. C'est pour cette raison que la Station de l'IFREMER à Arcachon a reçu la mission d'une "étude intégrée" devant réaliser la compilation de l'ensemble des données disponibles, faisant appel à un Système d'Informations Géographiques. Ce système permet un Croisement d'informations de natures différentes qui facilite l'analyse des Phénomènes et les prises de décisions dans le domaine de l'aménagement du Littoral. La nécessité d'une telle gestion est renforcée par la rapide évolution Morphologique du bassin qui implique une mise à jour régulière des documents à la source des études techniques et scientifiques portant sur le site d'Arcachon.

Mise en place du Système d 'Informations Géographiques

Ayant débuté au cours de l'année 1993 par une expérimentation sur une zone restreinte, la mise en place d'un outil de gestion complet est prévue pour fin 1995. Son objectif sera de valoriser les données dans le cadre d'un observatoire du littoral. L'échelle d'exploitation de ce système a été fixée au 1/20000e.

Les données suivantes ont été intégrées au SIG:

- les données thématiques disponibles à la station IFREMER d'Arcachon,
- les données bathymétriques de la campagne 1993 de l'IFREMER sous la forme de courbes de niveaux,
- les données cadastrales mises à disposition par le service des Affaires Maritimes,
- les données relatives aux bassins versants et à l'occupation de l'espace fournies par le CEMAGREF,

- la bathymétrie du Bassin d'Arcachon de 1972 fournie par le Laboratoire Central "d'Hydraulique de la France (LCHF),
- les données de la Base de Données Cartographiques (BD Carto) de l'I.G.N.

La mise en place complète d'un SIG nécessite notamment des outils pour l'acquisition des données, leur structuration topologique, les opérations mathématiques sur les objets graphiques, le couplage avec des Systèmes de Gestion de Bases de Données (SGBD) externes et la production de documents cartographique représentant des phénomènes géographiques. L'ensemble de ces critères a entraîné le choix de l'outil ArcInfo et ses produits annexes.

Gestion administrative

L'ensemble du parcellaire ostréicole, soit près de 9000 parcs répartis sur 70 feuilles cadastrales au 1/2000e, a été numérisé en collaboration étroite avec le Service des affaires Maritimes du quartier d'Arcachon. Numérisées dans un système cadastral local, ces données ont été ramenées au système géodésique Lambert III national en vue d'une superposition avec d'autres niveaux d'informations. Ces Données cadastrales ont double vocation: d'une part, le positionnement de Prélèvements sur le bassin dans le cadre de recherches scientifiques sur la Production aquacole par l'IFREMER et d'autre part la gestion administrative des concessions ostréicoles par le service des Affaires Maritimes.

Aux données graphiques sont reliées des données alphanumériques gérées par le service des Affaires Maritimes: le fichier des concessions (surface concédée, type d'exploitation, nature de culture, dates liées à la concession...) ainsi que le fichier des concessionnaires (nom, prénoms, date de naissance et adresse du chef d'exploitation...). Ces fichiers sont gérés de manière externe au SIG par des Moyens de SGBD propres à l'administration des Affaires Maritimes. Les données Peuvent Être liées à celles du SIG en vue de consultations graphiques.

Deux types d'interrogations sont possibles: par édition interactive en Positionnant le curseur dans la parcelle ostréicole ou par l'utilisation de requêtes (à la fois graphiques et alpha-numériques.

L'un des intérêts d'un Système d'Informations en partenariat entre différents Organismes réside dans le seul rapprochement et l'enrichissement des données.

Une bathymétrie récente, par exemple, se révèle Être un niveau d'information très important pour la gestion administrative des concessions basée sur les données cadastrales qui, datant des années 1930, sont relativement anciennes. Mis à jour de manière plus ou moins régulière au cours du temps en fonction Des moyens disponibles et des déclarations des exploitants, le cadastre ne correspond plus aujourd'hui au parcellaire ostréicole qui a évolué au rythme des mutations morphologiques du Bassin d'Arcachon: l'érosion ou la sédimentation des bancs a entraîné progressivement une évolution des Dimensions des parcs sans la moindre mise à jour des données cadastrales. Malgré une différence de précision liée à l'échelle d'acquisition des données, la bathymétrie apporte des indications significatives sur la précision de ce cadastre et permet un réajustement dans les zones de rapide évolution. D'autre part, le croisement des données cadastrales et bathymétriques indique un abandon quasi général des concessions dans les zones de hauts fonds du bassin, notamment au delà de la courbe des 2 mètres de côte marine. Les parcs cadastrés dans ces zones comme étant encore exploités le sont-ils encore ou est-ce un défaut de mise à jour ? Une visualisation graphique permettra d'orienter un contrôle sur le terrain en vue de mettre à jour les données.

De plus, ces informations bathymétriques pourront Être prises en compte lors de la sélection de nouveaux sites d'exploitations. Pour cela, d'autres niveaux d'informations devraient pouvoir Être utilisés tels l'évolution sédimentaire, la courantologie ou la prolifération algale...; c'est à ce stade qu'intervient la recherche scientifique réalisée par l'IFREMER dans les études de production ostréicole et le suivi environnemental du Bassin d'Arcachon.

Suivi environnemental

Des données de sédimentologie (1965 et 1989) et de végétation (1962 et 1989) fournies par J.M. BOUCHET du C.N.R.S. (Station de l'IFREMER d'Arcachon) ainsi que de proliférations algales (1991 et 1992) disponibles à l'état de plan papier à la station de l'IFREMER ont été numérisées au cours de la mise en place du SIG.

A l'issue d'une structuration topologique, un premier niveau d'informations est disponible sur l'ensemble du bassin aux différentes années de recensement. L'une des qualités d'un SIG étant à la base la production de plans thématiques, différentes cartes de données recensées permettent une visualisation générale sur l'ensemble du site, à une époque donnée, pour chacun des thèmes précédemment cités.

Un point fort du SIG est la possibilité d'effectuer des opérations booléennes sur les objets graphiques afin d'extraire à partir des données brutes un niveau d'information complémentaire tel l'évolution de phénomènes naturels par simple opération de soustraction ou d'intersection. Il est par exemple possible de calculer l'évolution des fonds entre 1965 et 1989 à partir des données sédimentologiques connues à ces époques.

Il sera ainsi possible de croiser différents types de données afin d'évaluer des hypothèses scientifiques. Le SIG en tant que tel est en mesure d'effectuer tous calculs entre des données diverses; il s'agira néanmoins d'en pondérer le résultat scientifique obtenu et d'y apporter une conclusion adaptée. Le SIG doit Être considéré comme un outil d'aide à l'analyse particulièrement performant, qui ne dispense pas d'une grande rigueur dans le choix et le contrôle des données utilisées, ni d'une réflexion approfondie sur les résultats de recherche obtenus.

Conclusion

Le Système d'Informations Géographiques en tant qu'outil de gestion et d'aide à la décision semble particulièrement bien adapté dans le cas d'une zone d'évolution morphologique rapide, caractérisée par des activités complexes et diversifiées telle le Bassin d'Arcachon. Il permet d'unifier certaines tâches des domaines administratifs et scientifiques, économisant des moyens et favorisant les échanges.

Fig. 1. Bassin d'Arcachon.

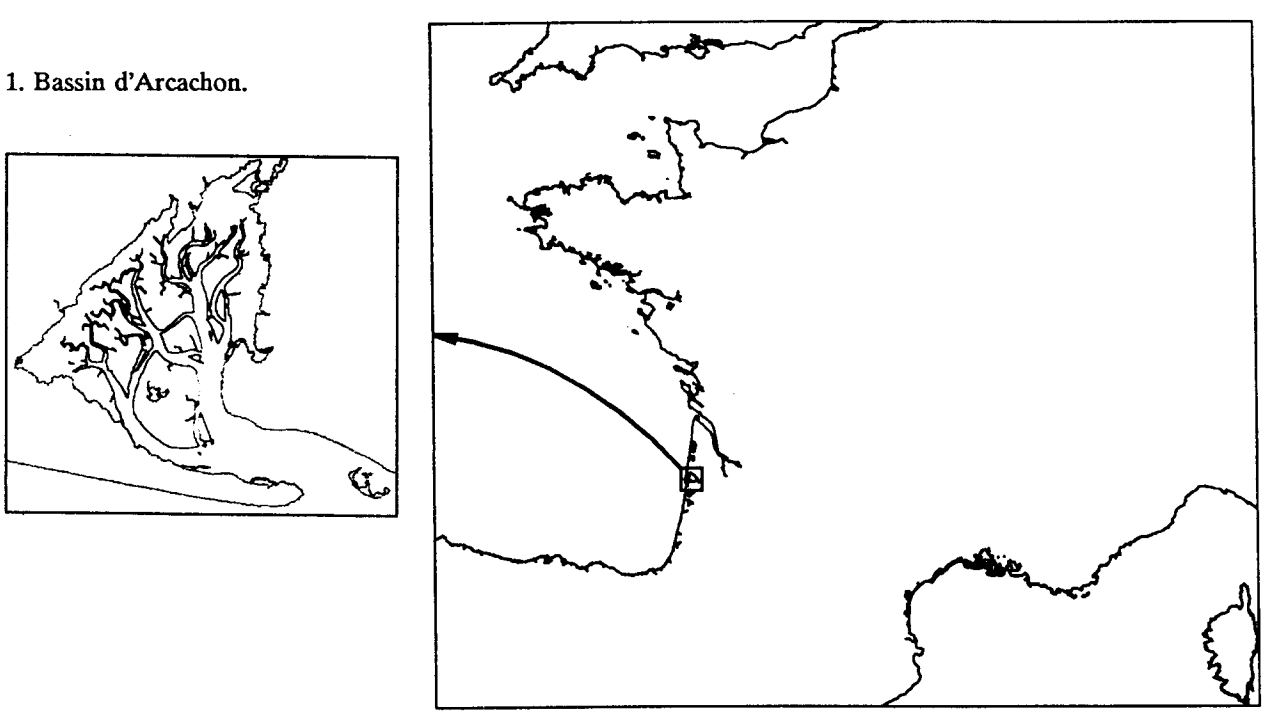

Fig. 2. Parcellaire ostréicole du bassin d'Arcachon.

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ON THE DYNAMIC MARGIN OF THE COASTAL ZONE

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KEY WORDS: Coastal zone, dynamical margin, silt line, wave shoaling, non-linear effects, high harmonics, Ursell number, undertow, bedload transport, skewness.

ABSTRACT

This study is an attempt to formulate the definition of the coastal zone as a dynamic system and to estimate the position of its outer margin on the basis of typical processes: The main process considered is the cyclic motion of sediments when sediment particles move alternately as bedload and suspended load. The point where the Ursell number is equal to 16 proved to be an outer margin of stable cyclic motion. This point is accepted as the seaward margin of the coastal zone. Some features of undertow are considered to demonstrate that the coastal zone as defined is a semi-closed system.

INTRODUCTION

It is paradoxical that, in spite of a huge number of publications on coastal dynamics, this zone itself is not well defined. Several definitions of the coastal zone exist and several estimates of its outer margin are given. The first of them considers the coastal zone as an object of fixed width, the outer margin of which coincides the so called "silt line". According to this approach the "standard coastal zone" is covered with sorted sediments with grain-sizes ranging from pebbles (or coarse sand) on a beach to silt near the outer margin. In essence the silt line is the margin of the geomorphologic area where sedimentation is a result of activity of many storms. The position of this line represents an average pattern of sediment-transport and settling. There is no clear sedimentological or morpho-dynamic basis for this approach.

According to the second approach the outer margin of the coastal zone is in the vicinity of the bottom contour $D = L/3$, where L is the length of the maximal waves observed once per year (Longinov, 1973). The area bounded by this contour is identified as the zone where relatively severe storm waves will shoal. The outer margin of the coastal zone in this case has a fixed position (as the silt line does), independent of the intensity of the particular storm. By this reason the actual shoaling zone may be placed both inside the coastal zone defined in this way or outside it. Thus the second approach operates with a static margin also, and is not connected to a particular sediment transport model.

Sometimes the isobath $D \approx L/3$ is used as the wave shoaling zone margin under particular storm conditions with wave-lengths equal to L, and the bounded area is identified with coastal zone (Longinov, 1963). According to Longinov the condition $H/D \approx 0.1$ is a similar characteristic of the shoaling zone margin as the condition $D \approx L/3$, and therefore both conditions may be used as dynamical margins of coastal zone. The process of wave deformation is used as a basis for this dynamic approach. However, only one characteristic of waves (length or height), was taken into account and, therefore, this approach has the same disadvantage as the static one.

At the same time the coastal zone may be considered as a field of action of specific sediment-transport processes, the spatial margin of which may be defined as the margin of the coastal zone. Obviously, this approach should be based on data concerning the main phenomena controlling coastal dynamics, rather than on some exterior features. In such a case one may consider the coastal zone as a dynamic area with momentary margins changing during a storm. The

problem is how to select the processes responsible for coastal zone behaviour and how to determine their offshore margins, which, in their turn define the outer margin of the coastal zone. The goal of this study is to formulate in this way a "dynamic" definition of the coastal zone and to find the position of its outer margin.

MODEL OF THE COASTAL ZONE

Let us consider a "standard" gently sloping coastal zone, where bottom sediments change regularly in the direction of the silt line as its outer margin. A two-dimensional field of wave induced mean flow in a cross-shore vertical plane may be introduced by a simple two-layer scheme (Fig. 1). Mass transport in onshore direction is in the upper layer positioned above the level of wave troughs, and the undertow occupies the area below this level. The scheme was drawn by the way of generalization of several mean velocity fields measured along the Black Sea coast at three research piers (Fig. 2).

The simple condition can be used to describe suspended particle motion: a particle may be suspended if its settling velocity (w) is smaller than the intensity of vertical turbulent pulsations (W'). The value of W' may be evaluated, for example, by the Fillips expression (Fillips, 1977):

$$W' = 2^{-1/2}\delta a Re_w^{-1/2} csch(kD) * \{e^{-bz} * [\cos(\chi + bz) + \sin(\chi + bz)] - \sin\chi - \cos\chi\} \quad (1),$$

$$\text{where } \delta = 2\pi/T,\ Re = \delta/\nu k^2,\ b = (\delta/2\nu)^{1/2},\ \chi = kx - \delta t$$

and z is the distance from the bottom. Isolines of pulsation intensity are shown by dashed lines in Fig. 3.

A further consideration will be made under the assumption of a stable dynamically (equilibrium) bottom profile. Let point B.L.M. in Fig. 3,I be the characteristic point where transport of sediments as bedload changes offshore by oscillations of particles. In other words, this is the most seaward point of the bedload motion. Obviously all sediment particles have to move in the onshore direction only and in the form of bedload transport. Otherwise the assumption of a dynamic equilibrium of bottom profile would be violated. Thus bedload transport goes in the direction of the point where the intensity of vertical turbulent pulsations is equal to the settling velocity of particles considered. At this point sediment particles lifted on the upper levels will be picked up by the undertow and will move back in offshore direction (Fig. 3,I). Resultant trajectories of particles moving inside of the area positioned onshore of point B.L.M. may be introduced as a set of ellipses (Fig. 3,II) with anti-clockwise rotation.

This cyclic type of motion is typical for particles which are able to move as suspended load as well as bedload in different situations under fixed wave conditions. At the same time finer material is removed by undertow seaward of point B.L.M. This material can not be transported as bedload and will be removed irreversibly. Thus point B.L.M. divides the whole area of sediment transport into the following two parts: 1) zone of cyclic motion, 2) zone of removal.

In my opinion this cyclic motion of sediments is the main, characteristic geomorphological phenomenon and this phenomenon may be used as the basis for the definition of the coastal zone as a dynamic system: It is proposed, therefore, to define the area of cyclic motion of sediments as the coastal zone. This zone is located between maximum run-up on the beach and the point of beginning of bedload transport in offshore direction. Now the problem is to find a simple criterion for the coastal zone outer margin.

WAVE ASYMMETRY AND BEDLOAD TRANSPORT OF SEDIMENTS

According to models of Bailard (1981), Roelvink and Stive, 1990) cross-shore bedload transport of sediment varies with the third power of horizontal near bottom velocity. This points out a major role of the asymmetry in wave motion. This asymmetry is caused by the following reasons:

1) increase of higher harmonics of wave motion when waves shoal (Elgar and Guza, 1986), and

2) increase of phase lag between high harmonics and the primary harmonic which tends to value $\pi(j-1)/2$ (j is a number of harmonic). As a result, shoaling waves tend to so-called "sawtooth" waves as a limit form of wave deformation (Flick et al., 1981).

Transformation of amplitude and phase spectra result from non-linear interactions between components of waves propagating in intermediate and shallow water. These interactions are weak and unstable in deep water, but they are getting stronger in the onshore direction when the depth decreases. Nevertheless, they demonstrate some oscillations and instability. However, beginning at a certain depth, wave motion shows the property to accumulate non-linearity. According to Lighthill (1978) this cumulative effect takes place when the Ursell number (Ur) becomes larger than 16, i.e.

$$Ur = 0.5*HL^2/D^3 \geq 16 \quad (2)$$

where H and L are wave height and length, D is the local depth. The condition (2) is deduced from the Korteweg and de Vries equation under the assumption that the non-linear and dispersive terms of the equation are about equal.

Lighthill's estimate (2) may be confirmed experimentally if appearance and growth of higher harmonics are observed when waves approach the point where Ur = 16. Energy spectra (Fig. 4) measured in a wave flume by the Qingdao Ocean University (China) in regular waves over sloping (1:33) bottom, demonstrate the stable growth of higher harmonics in the vicinity with the point with depth $D_o = 0.5*(HL^2/4)^{1/3}$, which is followed from (2).

A similar conclusion results from measurements at the research pier "Schcorpilovczi" of the Bulgarian Academy of Science (Fig.5). The pier is located on the Black Sea coast, where the bottom is covered by moderate sand with an average slope of 0.02, between contours of 0 and 5 m. The Ursell number for field data was rewritten in the form of: $Ur = 0.5*H_s L^2/D^3$, where H_s is the significant wave height. The wave length was calculated according to the linear dispersion relation for the primary harmonic period. The validity of such calculations is confirmed by good agreement between the primary harmonic phase velocity measured in the field and values calculated by linear theory (Kuznetsov and Speranski, 1993). It should be pointed out that results similar to those shown in Fig. 5, were found during measurements of the near-bottom horizontal velocity (Speranski, 1985).

Figures 4 and 5 suggest that the Ursell number may be used as an indicator of wave asymmetry since the last characteristic is a consequence of an increase in high harmonics. This is corroborated by the empirical relationship between the third statistical moment as a measure of horizontal asymmetry, (Elgar et al., 1990) and the Ursell number. Fig. 6 demonstrates this relationship, using data of Doering and Donelan (1993), who measured irregular wave surface elevation in flume conditions, and the author's data of field measurements. The growth of skewness (S_N) is observed when the Ursell number increases, and $S_N \approx 0.6$ near the point Ur = 16. This means that the amplitude of the onshore velocity is 1.6 times larger than that of the offshore velocity, and such values of skewness may be characterized as significant quantities corresponding to stable onshore bedload transport inside the area where Ur > 16. In other words Fig. 6 shows that the stable non-linearity generates the stable bedload transport. Inside the area where Ur < 16, the non-linearity is not stable and, therefore, bedload transport should be unstable as well. Consequently, the outer margin of stable cyclic motion and simultaneously the margin of coastal zone may be identified with the contour $D = 0.5 (HL^2/4)^{1/3}$.

COASTAL ZONE DEFINITION AND UNDERTOW

Undertow is the other phenomenon which is typical for coastal zones, and the validity of the coastal zone definition depends on the relation between the margin condition (2) and the undertow velocity at this margin. The semi-empirical formula was found by analysis of measured mean flow velocity fields (Fig. 2 demonstrates some of them) to estimate undertow characteristics near the coastal zone margin:

$$<U> = \left[8 * 10^{-4} g \pi H_s^2 T\right] x \quad (3)$$
$$[(\coth kD)/(D-H/2)^2]$$

where <U> is a local undertow, its flow velocity averaged over depth. Simultaneous solution of equations (2) and (3) gives the desirable quantity of velocity at the outer margin. They are shown in Table 1, where D_o is the "marginal" depth, T is wave period, $<U_1>$ is average undertow velocity at contour D = L/3). The calculations show that the undertow has a velocity of the order of 0.1 m/s in the close vicinity of the margin under typical storm conditions.

It is important that although <U>-values are much less than those near breaking line, this flow is able to transport suspended sediments through the margin of the coastal zone. Thus, the coastal zone as defined above, is not a closed system because the definition "permits" suspended sediments to be carried out of the coastal zone. On the contrary, the old definition of outer dynamic margin ($D_o \approx L/3$) does not satisfy this condition, since corresponding values of the mean velocity are practically equal to zero (the last row of Table 1).

DISCUSSION

The coastal zone is defined here as an area of specific processes, the intensity of which depends on storm conditions. The main specific process is the cyclic motion of sediments including bedload and suspended load. The offshore boundary of the cyclic motion is found to satisfy the condition Ur = 16, when the coastal zone is in the stage of dynamical equilibrium. Probably, this estimate is satisfactory for systems which are close to equilibrium, but it is not good for systems which are far from their stable stage. Our estimation may be considered as only the first step in a number of margin positions, when the coastal zone evolves.

It is difficult to point out the margin position in common cases of unstable profiles since the point where the bedload begins may be placed anywhere and the criterion used above is not valid. Probably there is no sediment transport criterion to mark the margin, and one can point out only the limiting position of the margin, assuming that the developing coastal zone tends to equilibrate. The only way may be, to use the condition Ur = 16 as a hydrodynamic criterion of the margin position.

It is of interest to determine under which storm waves the dynamic margin coincides with the static one (silt line). For example, along the Black Sea coast the silt line is located at a depth of 15 m approximately. Table 1 shows two possible combinations of the wave height and length: H = 5 m and L = 140 m or H = 6 m and L = 130 m. It means that both margins coincide along the Black Sea coast under conditions of severe storms. A similar analysis may be carried out easily for other coasts.

If we return to the first version of the dynamic margin, mentioned in the Introduction, we can write both these equivalent conditions ($D_o \approx L/3$, $D_o \approx H/10$) in the joint form (4).

$$HL^2/D_o^3 \sim 0.9$$
$$\vee \quad (4)$$
$$Ur - 0.5 * HL^2/D_o^3 \sim 0.45$$

The result of $Ur(D_o) << 16$ is that the non-linear term in the Korteweg and de Vries equation is much smaller than the dispersive one. The graph $S_N(Ur)$ gives zero value of skewness (Fig. 6), i.e. no bedload transport. Thus, according to the first version the coastal zone margin is located offshore of the area of stable bedload transport.

The expression (2) may be introduced in a more "criterional" form by using the wave number $k = 2\pi/L$ instead of the wave length. Then we find:

$$Ur = \frac{H/D}{(kD)^2} \quad (5)$$

Applying the margin condition Ur = 16, (5) becomes:

$$Ur - 0.8 \qquad (6)$$

This expression is proposed as a compact quantitative measure of the coastal zone margin. To estimate the significance of the bottom slope in the above estimates and definitions one should compare the width of the coastal zone $D_o/\tan ß$ (ß is a slope) with the distance of the nonlinear interaction $C^*\sigma$ (where C is the phase speed and σ is the time of interaction). The time of nonlinear interaction may be estimated according to Brehovskih and Goncharov (1982) as $1/2kU_o$ (here U_o is the amplitude of the orbital velocity). It may be shown that the coastal zone margin position is independent of the bottom slope when $\tan ß << (H/L)^{1/3}$. Thus for a typical range of wave steepness from 0.01 to 0.05 this gives $\tan ß << 0.2$. Otherwise the corresponding correction should be made.

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Table 1. Undertow velocity in the vicinity of the outer margin of the coastal zone

H, m	1	1	2	2	3	3	4	4	4	5	5	5	6	6	6
L, m	20	30	40	50	50	60	80	100	120	100	120	140	120	150	170
D_o, m	2	3	5	5	6	7	9	11	12	12	13	15	14	16	18
T,S	4.5	5.6	6.4	7.4	7.0	7.9	9.0	10.4	11.7	11.2	11.4	12.5	11.1	12.8	13.9
$<U>$, m/s	.04	.03	.06	.05	.08	.07	.09	.07	.07	.10	.09	.08	.11	.09	.09
$<U_1>$, m/s	–	–	- <	.01	–	–	–	–	–	–	- <	.01	–	–	–

Fig. 1. Two-dimensional scheme of mean flow in a cross-shore vertical plane.

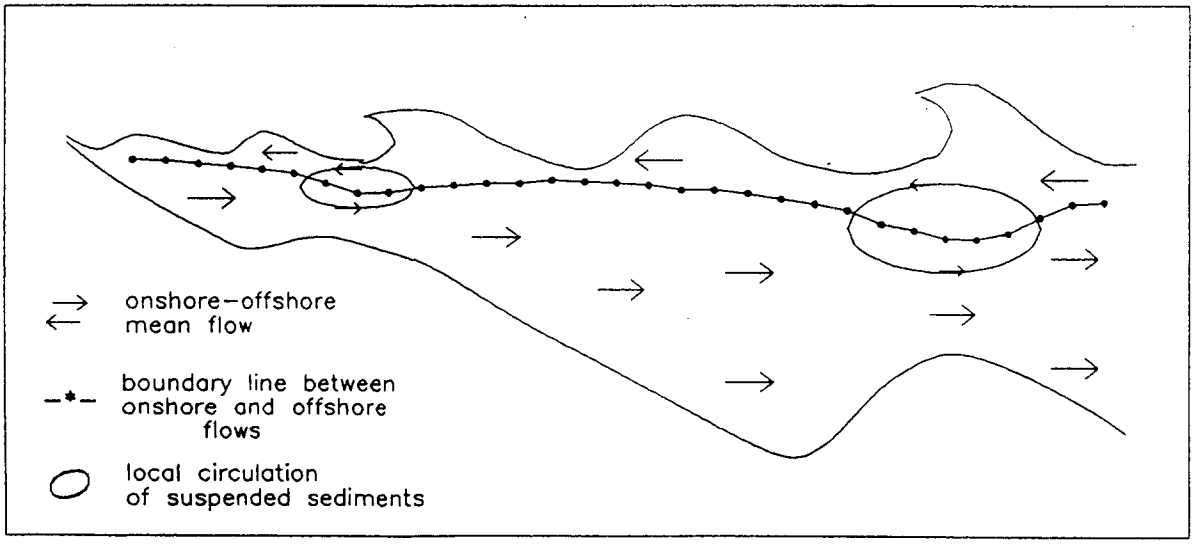


Fig. 2. Mean flow velocities, measured along the Black Sea coast: research pier "Donuzlav", 1975 (a, б) and pier "Schcorpilovczi", 1997 (b).

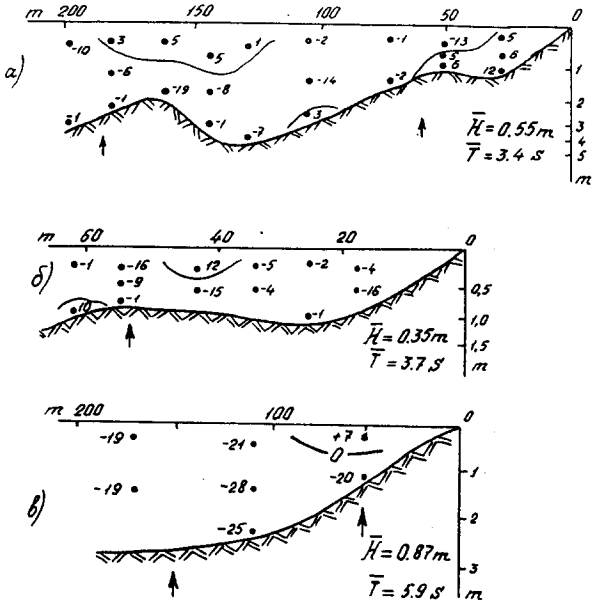
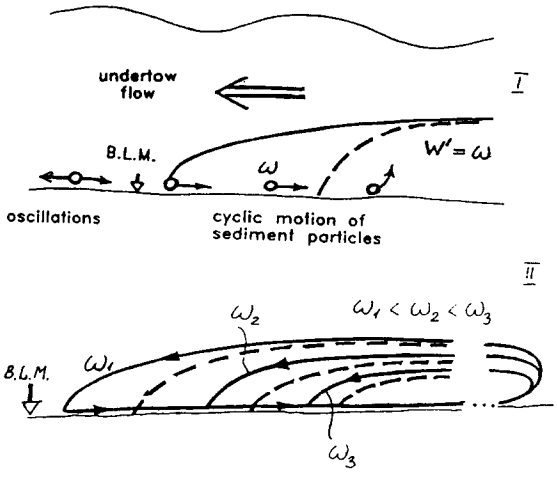


Fig. 3. Scheme of sediment particles motion, where w is settling velocity, W' is the intensity of the vertical turbulent pulsations.



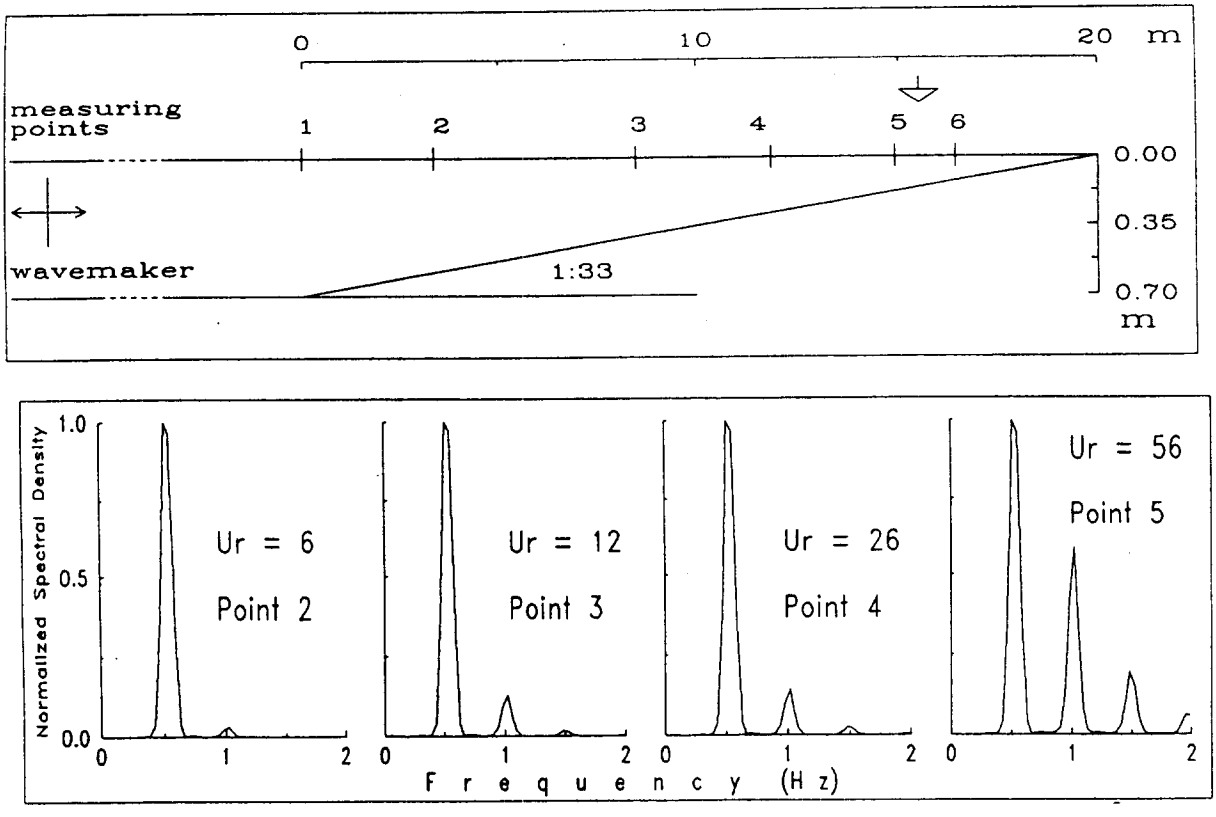
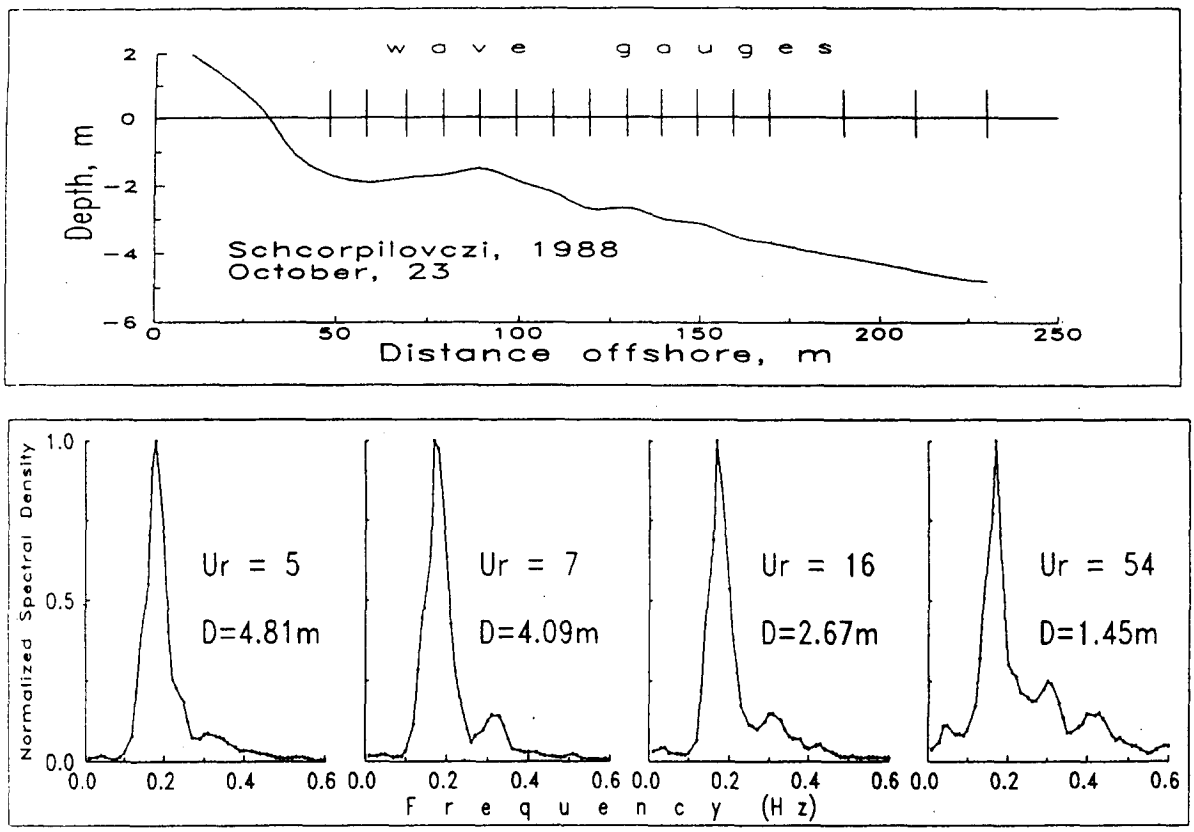


Fig. 4. Flume measurements of shoaling waves. Scheme of experiment (upper panel) and surface elevation spectra (bottom panel).

Fig. 5. The same as in Fig. 4, but measured at the research pier "Schcorpilovczi".



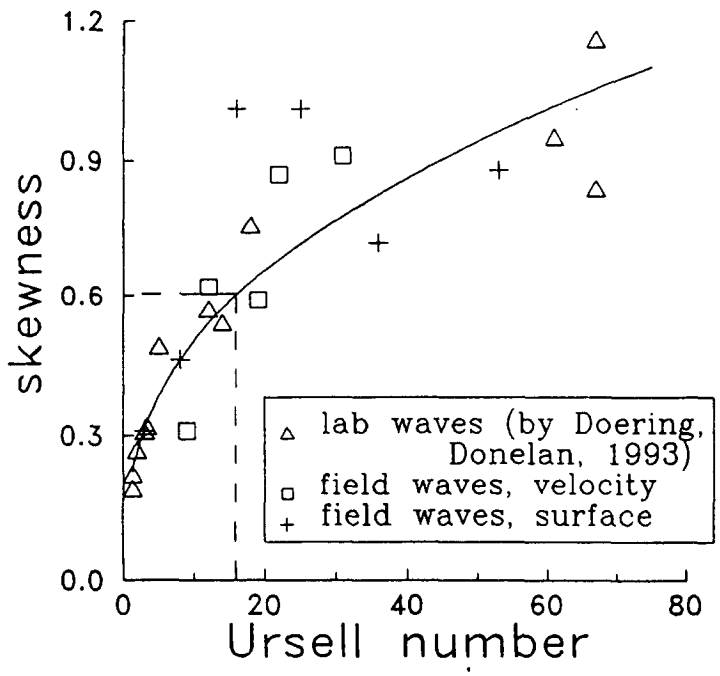


Fig. 6. Correlation between wave skewness and the degree of non-linearity (Ursell number).

SESSION VIII

Training, Capacity Building & Management

Session VIII-a
Training & Capacity Building

Chairman: R.A. Kenchington & P.C. Nwilo
Rapporteur: A.N. Balchand

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ADVANCED TRAINING THROUGH INTERNATIONAL COOPERATION WITHIN THE FRAMEWORK OF TEMA IN THE FIELD OF COASTAL AND NEARSHORE EVOLUTION

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TEMA

TEMA is IOC's programme of Training, Education, and Mutual Assistance in the Marine Sciences, outlined in the comprehensive Plan for a Major Assistance Programme to Enhance the Marine Science Capabilities of Developing Countries.

The present programme is implemented under the TEMA Strategy and Action Plan for 1991-1995. TEMA serves as a catalyst to initiate bilateral and multilateral aid projects around the world.

The term "mutual assistance" used in TEMA had been redefined at a high-level expert meeting in Bremerhaven, in September 1998, to "partnership". TEMA components are the IOC Research Fellowship scheme, shipboard training and training courses, donations, the installation of equipment through the IOC Voluntary Cooperative Programme (VCP), education and training of high-level specialists in basic marine sciences.

Since the inception of IOC, Germany has given high priority to TEMA. German Trust Fund contributions have considerably contributed to the implementation of the above-mentioned TEMA components.

Germany always felt that the best way to assist is the conduct of *Advanced Training Courses* to be held *in the region* where the programmes take place, with trainees from those countries which most need help, and with high-level instructors who have the know-how and who are able to use a local research vessel as training tool. Trainees from diverse countries are offered the unique opportunity to meet each other, and to establish links of cooperation or even friendships. It is always hoped that communication among all the participants is maintained and information exchanged even when the course is over. These courses are in German view the most promising steps to make joints ventures happen.

Since 1989, Germany gave more and more preference to courses related to coastal and nearshore geological phenomena including sediment dynamics and mineral resources as well as shelf features and structure. This trend was confirmed when the UN Conference on Environment and Development in Rio, in June 1992, highlighted the importance of the coastal zone.

At present, Germany has conducted three regional courses on this subject in 1989 (Quezon City), 1992 (Kuala Lumpur) and 1994 (Karachi) while planning a fourth course in Bandung, Indonesia, in 1996.

A description of these 4 courses provides you with a picture on how the lectures, exercises, laboratory works, geological field trips and research cruises can offer an interesting framework to pass know-how and team spirit to so many trainees from so different types of countries of the Indian Ocean and SE-Asia regions:

IOC Advanced Training Course on Continental Shelf Structures, Sediments and Mineral Resources, Quezon City, Philippines, 2-13 October 1989 (including shipboard training).

The objective of the Course was to enable trainees from the eastern Indian Ocean (IOCINDIO) and western Pacific (WESTPAC, SEATAR) regions to more effectively participate in research projects carried out in the Exclusive Economic Zones (EEZs) of their respective countries, often under the IOC/UN (OALOS) Programme on Ocean Science in Relation to Non-Living Resources (OSNLR). Therefore, the

main target was to give advanced training on current scientific and technical knowledge in marine geology/geophysics highlighting geomorphological charting, seismic profiling, sediment sampling for placer deposits, current measurements.
The Course was held in Petrolab, Mines and Geosciences Bureau, Quezon City (near Manila), and consisted of lectures, exercises, laboratory work, a geological field trip, and a two day cruise with the Philippine research vessel RPS "Explorer" in the Linguyan Gulf departing from San Fernando.
Lectures included subjects such as review of mineral resources, placer minerals, analysis of shelf sediments, sediment classification, carbonate facies, beach sedimentation (during field trip), sampling techniques of shelf sediments (on board); mapping of shelf areas; marine seismic facies models, seismic operations (on board), microplate tectonics; environmental impacts, sea level changes; offshore equipment, operation and management of research vessels, navigation and positioning (on board). Several case studies were presented. Besides, trainees were informed about the status and functions of regional organisations dealing with marine geology, geophysics, non-living resources research, and related environmental matters.
Exercises included the establishment of a bathymetric chart and of a map of sediment thicknesses, interpretation of a sparker profile, mapping of grain size distribution on a shelf, and the construction of a Holocene sea level curve.
For the field trip, trainees received a Pocket Magnetite Separator (Conrad Apparatebau, Clausthal-Zellerfeld) as a gift, which proved to be extremely useful.
Work on board included the use of a grab sampler, a piston corer and an airgun (reflection seismics). The collected sediment samples were consequently analyzed in a laboratory. Laboratory work included determination of grain size distribution and content of heavy minerals, use of magnetite separator, and calculation of economically important heavy minerals.Trainees were given an opportunity to briefly talk about their personal interests and the activities of their respective institutes.
The Course was attended by 4 instructors provided by Germany (with Chief Instructor Dr. Kudrass, BGR), and one from Japan, as well as 14 trainees from 7 countries including Pakistan, Sri Lanka, Myanmar, Malaysia, China, Indonesia, Philippines.

IOC/Germany Advanced Training Course on Nearshore Sedimentation, and the "Evolution of Coastal Environments, Kuala Lumpur, Malaysia 17 - 29 February 1992 (incl. shipboard training).
The Course was designed to respond to the urgent needs of the IOC Member States of the IOCINDIO and WESTPAC regions to learn more about the evolution of coastal environments, the influence of sea level changes, and the (non-living resources of nearshore areas.
Therefore, the immediate objective of the Course was to provide advanced training to scientists of the region in order to acquaint them with current scientific and technical knowledge on coastal and offshore mapping, shallow seismic profiling, sediment sampling and analysis, and interpretation of related data sets, and to enhance capacities of countries in the region by initiating future cooperative projects.
The 2 week Course was held in cooperation with the Hydrography Directorate of the Royal Malaysian Navy at University Technology Malaysia in Kuala Lumpur, and consisted of lectures, exercises and laboratory work to analyze samples and data collected during a one day research cruise with the Malaysian research vessel "PENYU", and two field trips to the west and east coasts of the peninsula.
Lecturing started with a general information on Intergovernmental Oceanographic Organisations in the Indian Ocean and in the South and SW-Pacific, with particular interest in marine geology, geophysics and non-living resources research as well as related environmental aspects and hazards.

Lectures and exercises included subjects such as:
- Sea level changes: causes, rates, and amplitudes
- Sea level variation and coastal evolution

- Sea level changes and related shifts of coastal depositional environments
- Carbonate sediment budgets in the coastal zone
- Composition of sand in marine sediments
- Four case studies on environmental impacts: damage through dredging in lagoon (Tongatapu); coastal erosion and accumulation on a reef fringed island (Rarotonga); an active submarine caldera (PNG); placer deposits on an island shelf (Sri Lanka)
- Instrumental methods used in geochemistry
- Sea water chemistry and estuarine processes
- Hydrothermal mineralisation along an active back-arc spreading centre (video)
- Field techniques, field data capture, evaluation of field data, and their presentation in sequence maps of the coastal Holocene
- Sea floor mapping: principles and instruments
- Remote sensing and coastal mapping
- Air photography interpretation
- Evaluation of aerial photographs from the coastal zone of the Kuantan area.

Laboratory work included

Introduction to analytical geochemistry, with analyses of field trip samples (chem. lab)
- Analyses of material collected during the cruise (chem. lab)
- Grain size analysis (shape, composition) and comparisons between beach sand samples from marine-intertidal to supra-tidal environments, and a drilled sample of fluviatile terrestrial sand (sediment lab).

The cruise included:

- Water analyses by semi-quantitative methods
- Sediment sampling
- Side scan sonar and echo-sounder profiling
- Trisponder and GPS navigation.

The excursions included

- Field training on drilling techniques, coastal sedimentary sequences, coastal environments and morphodynamics in the Sepang area, west coast south of Kuala Lumpur
- Field training on coastal morphology (erosion processes) and sediment sequences in beach, intertidal, and supra-tidal environments south of Kuantan, high energy east coast of the peninsula
- Field training north of Kuantan on beach sediments, rocky platforms and Holocene beach ridges.

A special seminar was arranged during which trainees were given the opportunity to talk about their own research work at home. Discussions on possible cooperation were held.

The Course was attended by 4 instructors provided by Germany (with Chief Instructor Dr. Kudrass, BGR), and one from Australia, as well as 16 trainees from 11 countries including Maldives, India, Sri Lanka, Bangladesh, Myanmar, Thailand, Malaysia, Indonesia, Vietnam, China, Rep. of Korea.

IOC/IOMAC/Germany Advanced Training Course on Marine Geology and Geophysics off Pakistan, in Karachi, Pakistan, and on board S.V. "Behr Paima", 12 - 26 November 1994

The aim of this Course was to provide IOC and IOMAC Member States of the region with information on the marine geology and geophysics of the continental shelf and its coastal areas so that they can learn more about the structure, sediment dynamics and mineral resources of their coastal zones and EEZs.

The Course was held in the premises of the National Institute of Oceanography (NIO) in Karachi (Dir. Gen. S.H. Niaz-Rizvi), and on board the Pakistani Survey Vessel "Behr Paima". A beach environment was studied during a geological field trip.

Following a joint IOC/IOMAC invitation 19 trainees from Indonesia, Iran, Kenya, Malaysia, Mauritius, Mozambique, Oman, Pakistan, Sri Lanka, and Thailand were selected. Four instructors came from Germany (with Chief Instructor Dr. Kudrass, BGR), one from the Netherlands, and two from Pakistan itself.

OC/CCOP/Germany Advanced Training Course on Sea Level Changes and the Evolution of Coastal Environments, in Indonesia, in early 1996 (incl. shipboard training)

The aim of this Course is to respond to the urgent needs of the IOC Member States of the region to learn more about coastal dynamics, the protection of coastal environments, and the wealth of nearshore resources. Training will include coastal and nearshore mapping, shallow seismic profiling, sediment and water sampling and analysis, and the interpretation of related data sets.

The Course will consist of lectures, exercises, laboratory work, field trips, and a one day research cruise in the Indonesian archipelago waters.

Approximately 20 trainees will be invited from countries of the eastern Indian Ocean, and the Southwest and South Pacific. 4 instructors will come from Germany, one from another country funded by CCOP.

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TRAINING, EDUCATION AND INFORMATION SERVICES IN DEVELOPING COUNTRIES ON COASTAL ZONE MANAGEMENT

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ABSTRACT

The coastal zone is a distinct region of earth, dynamically tuned by natural processes. It is affected by man's activities to a large extent. The coastal zone supports much of its world's population. A management of coastal areas acquires prime importance in the strategic planning towards a healthier and sustainable tomorrow. The roles of the developing countries are crucial and this paper describes the following aspects, comprehensively dealt within the realm of training, education and information services on coastal zone management (CZM).

The ultimate challenge of CZM is to find the right approach to maintain the needs and options of present and future generations at a sustainable level. This requires well established practices on varying time scales on a regional basis. Local issues, traditional practices, socio-economic status and community attitudes generally dominate short term perspectives but future sustainable coastal development will require a well codified management scheme based on medium and long term planning.

INTRODUCTION

Coastal zone is known for its cultural heritage imbued with the natural beauty of streams, rivers, estuaries and lagoons, often manifested by presence of coral reefs, mangroves, waterfalls, forest, wildlife and sandy beaches and of course, human beings. Coastal zone (CZ) is a distinct region of the earth, with a delicately balanced ecosystem dynamically tuned to natural processes. More than one third of the world's population, two thirds of the urbanized lands and more than 75% of the tourism related activities are within CZ. Two thirds of the world industrial output are located within this strategic land area. A rich socio-cultural heritage is characteristic of these regions. With current population trends and issues related to biodiversity, there are bound to be unprecedented demands and problems in supply and management of food, water, land, natural resources and energy (Balchand, 1994). Management of these areas has acquired prime importance within a well codified planning scheme towards a more healthier and sustainable tomorrow (Balchand & Nambisan, 1988), which refers also to Agenda 21 of the Rio Conference. CZM is recognized as a priority subject by scientists. The coastal zones of the world involve the most complex and productive environments which have naturally evolved, and contain many species. They also, and increasingly sustain man, his habitat, harvesting food and preserving material resources. The overall strategy in CZM will be an attempt to define the prime issues, the viable policies and regulatory actions. Altogether these provide the foundation for long term development of the coastal regions of all maritime countries.

Obviously such a strategy must be based upon scientific principles, traditional practices and pragmatic recognition of social realities. Management schemes for sustainable development involve the control and restrain of human actions so as to assure greater benefits to all communities for now and future. Though such communities may differ in utility based judgments regarding a reasonable approach, the

irrecoverable loss of the natural coastal environment inevitably brings cultural, social, economical deterioration for present and future generations. Hence a thoughtful well conceived coastal strategy is required for the prevailing, unique coastal regions of the world to guarantee sustainable form of development and a healthy society to exists and grow into the 21st century and beyond. At this juncture, we are to formulate a plan for two to three decades a head. On conservational management scheme, addressing issues of economical, environmental and cultural importance will dominate and this could be evaluated from time to time.

The normal chain of events in the history of human impact on a coastal zone is discovery, exploitation, overharvest, decline and finally the recognition for sustainable management (Kenchington & Hudson, 1988). In dealing with such a situation it is imperative that a thorough knowledge of the CZ in all its perspectives are gained. There are critical questions such as how will information on trends in the prevailing conditions and use of ecosystem be gathered, interpreted and processed in making decisions on the manner in which resources will be managed is of our interest (Olsen et al., 1992). Other issues relate to the response of the public and effected coastal communities to the proclaimed strategies and environmental objectives that are to be achieved (Balchand & Nambisan, 1988). More precisely, can the healthy conditions be maintained and nurtured with increasing activities of human beings and sustainable use practices effectively implemented to cater to human needs and uses without compromising the quality-quantity of the delicate ecosystems. What type of training and education should be imparted to generate public awareness and participation so as to answer the above questions? Such subjects which should form part of the information services towards common discussion and government policy debates are important aspects discussed in this paper. In this context, a review of the steps taken for training and imparting education on CZM to a large number of managers, technocrats and scientists from developing countries is useful since most of the vulnerable coastal zones of the world are located in these countries. It may be particularly noted that developing countries are not in a position to maintain a large technical-advisory-regulatory bodies to manage human activities on the CZ nor assert proper administrative directives in the absence of resources.

It is suggested that better results would evolve from planning and management in developing countries through locally qualified personnel receiving training and education on a regional basis with international support. This would help then to overcome fundamental issues and questions on CZM in the realm of political, administrative and technical decision making. The economic, environmental and cultural considerations should be viewed from a conservational management perpespective. On the economic front, does the CZ form an area of importance for subsistence and material extraction? Does the area serve as a nodal point in trade and commerce at local, national and international market? Again does the CZ generate income from recreational tourism?

On environmental aspects, does the physical setting ensure stability of the region to pursue economical and cultural goals? In most cases, a natural community of biodiversity exists providing the stock of aquatic life and genetic resources too. Every CZ has an aesthetical appeal and cultural identity (Salm & Kenchington, 1988). However, on the long run instances of significant damage have been well documented in respect to overfishing, eutrophication, contamination by oil, chemicals, nuclear wastes, alteration in water circulation and sedimentation due to deforestation, changing agricultural practices and mining. Also tourism and recreational activities have contributed to the environmental degradation of CZ in both developed and developing countries (Gomez, 1980; Hall, 1984). The consideration on cultural aspects relate to social practices, traditional use and religious purposes. A management proposal in this context for a region or whole country will have to take into confidence people close to area, rely on alternative resources, adequately compensate for

the losses and effectively interact with existing and upcoming governmental initiatives in the long run.

DEFINITIONS OF THE COASTAL ZONE

The definition by Ketchum (1972) is as follows:
"The coastal zone is a broad band of dry land (shore lands) and adjacent ocean space (water and submerged land in which land ecology and use directly affect oceans space ecology and vice versa). Functionally it is a broad interface between land and water where production, consumption and exchange processes occur at high rate of intensity. Ecologically it is an area of dynamic biochemical activity but with a somewhat limited capacity for supporting various types of human use. Marine influence (salt bottom) penetrate into estuarine areas to various extends and the effects of ocean tides may extend even further upstream than salt penetration. Pollutants added to inflowing rivers combines with direct pollutant inputs to impinge into the estuarine zone and inshore coastal waters".

Definition in Sri Lanka Coastal Conservation Act No.57 of 1981:
"That area lying within a limit of 300 m landwards of the mean high waterline and a limit of 2 km seawards of the mean low water line and in the case of rivers, streams, lagoons or any other body of water connected to the sea either permanently or periodically the landward boundary shall extend to a limit of 2 km measured perpendicular to the straight base line drawn between the natural entrance points thereof and shall include the waters of such rivers, streams and lagoons or any other body of water so connected to the sea".

Definition in Manual of Coastal Development Planning and Management for Thailand (1986) states:
"Coastal zone refers to a broad geographic area in which terrestrial and marine factors are mixed to produce unique land forms and ecological systems. The term zone is used to denote a landward and seaward area within which marine influences can be found in landward areas and terrestrial influences can be traced in the marine environment. Together these influences create unique association of plants and animals which are normally not found in upland of purely marine environment".
It is imperative to formulate a definition based on the theme or subject while codifying a management plan analogous in defining geological structures. CZ too has its own strong finger prints on the face of the earth. A definition, I perceive, shall be in the following lines: "Coastal zone is an embodiment of the marginal lands within the lithosphere adjacent to the shallow waters of the hydrosphere, both in association with atmosphere. This region exemplifies itself in the propagation of a complex, fragile but adaptive ecosystem with abundant scope in forestry, agriculture and mariculture, compounded by human habitation. Biologically, it is a continuum of inland through estuarine to nearshore to open ocean chain of aquatic life patterns. Chemically, this region has defined pathways of terrestrial inputs into ocean systems and physically the ground for land-sea interaction with variable geographical dimensions. The coastal zone manifests in its climatic setting, recreational aspects and aesthetical values as a zone of produces and supports agriculture, fisheries, wildlife, forestry and human habitat".

Training and education within czm
A training and education programme should form part of a well defined management scheme. At the outset, the goals of such a scheme be well defined. These goals will have to take into account the current practices in the sphere of social and cultural activities, economic gains and physico-chemico-biological setting. They may be explained as more less on a priority basis to ensure the protection of the CZ:
- preservation of species diversity
- protection of the habitat
- a regulatory operation to maintain sustainable biological productivity
- protection of commercially important species
- protection of natural heritage of aesthetical and historical importance
- regional self support
- harmonious national and international trade
- conservative mining

- balanced recreational activities and continued traditional use and
- socio economic support of coastal people.

The policy oriented management scheme should comprise a protective CZ approach ultimately in the interest of regional prosperity and extent its appropriateness within the context of universal applicability. All government decisions which are likely to interfere with policy directives should have a lowest limit on damage and open upper limit on the protection of the CZ. One option is to do nothing or simply, maintain the status quo. Alternatively, better results can be expected by preparing a realistic scheme for management, increased levels of present and future uses, contingent plan for introduction of new forms of uses with admissible exceptions. The actual planning process will invite inputs on information relevant to the area, site classification, use and access, commercial considerations and economical importance. Herein local community involvement is needed to define traditional interest so that the plan incorporates the interests of the local people, thereby limiting the constraints on future use and ensures profitable outcome. In this context, the established goals shall provide for sustainable development of CZ and protect the heritage as well as maintain the wholesomeness of biological resources.

CONSERVATIONAL MANAGEMENT SCHEME REVIEWED

Five basic approaches have been listed (Kenchington & Hudson, 1988):

1. Zoning.

a) Preservation zone - this is a genetic pool permitted only for minimum observational research.

b) Scientific research zone open for research work only.

c) Wilderness zone - this area open for limited human access (no hunting, fishing or collection).

d) National park zone - high human access but no hunting, fishing or collection.

e) Recreational zone - high human access with controls on level on hunting, fishing and collection.

f) General use zone - where commercial, recreational and subsistence activities are allowed with long term regulations to protect sensitive areas.

2. Periodic closure

This practice is followed for short term only for breeding purposes or to enable the habitat to recover.

3. Yield constraints

This approach permits only limited harvest with routine monitoring.

4. Equipment constraints

Restrictions imposed on net mesh size, anchor design, use of explosives or poison, entry of pollutants etc. which is strictly monitored and constraints properly implemented.

5. Impact limitation

This strategy permits entry of low levels of pollutants only, restricts the number of boats and divers etc. in a given area.

Concurrently, the investigation under a conservational management scheme requires knowledge and proper understanding of the physical, chemical and biological characteristics of the area and social and economical factors in relation to present and potential future human uses. Thence the realistic aim of any management related investigation must be to reduce progressively the area and degree of uncertainty on which decision are based; whilst being prepared to provide advise within the schedule of a programme which may be detrimental by political urgency (Knox & Miyabara, 1984).

Implementation of a management plan

Protection of the coastal zone envisages effective implementation of a plan which do not have any adverse effects and defines the right and responsibilities of the users. The plan works upon the assumption and assessment that the human activities are conducted within the limit prescribed so that the objectives of the plans will be achieved (Gomez, 1980; Gawel, 1982).

Classification of Coastal Zones

A rational approach on training and education as well as towards information exchange can be

easily based upon coastal zones being universally classified under a definite list. This may include:
1. Core and buffer areas - core representing a strictly protected area and the buffer zone a transition space.
2. Biological zones - where ecosystems are protected and genetic diversity allowed to continue.
3. Species zone - where a particular species remain protected.
4. Sustained yield harvest zones - where exploitation is allowed at sustainable levels using ecological sound method.
5. Fisheries management zones - where fish stocks are monitored and catch levels controlled.
6. Water quality control zones - pollution is monitored and checked.
7. Tourism management zones - recreation is permitted consistent to the carrying capacity of that area.
8. Scientific research zones - ecological sound research is allowed in relatively undisturbed areas.
9. Education zones - where instructional activities are permitted for students, general public in combination with other zones.
10. Cultural zones - where cultural activities encourage and monuments are preserved.

Elements of a Management Plan

It has been well appreciated that six critical elements go into the making and implementation of a management plan which are education, training, surveillance, enforcement, monitoring and review at periodic intervals.

EDUCATION

The general public should be aware of the existence of a plan that would affect their activities as well as benefit from them. Education permits the opportunity for cooperation and helps to clear any inherent difficulties while working within CZM. At no stage should the local people feel an external agency imposing restrictions on ideas, rather the plan should accommodates indigenous ideas which are consistent with sustainable use. If at the very outset the task involves common local people in plan development so that their ideas, issues and interest are incorporated within the plan, the task of increasing user support becomes easier. Often conflicts are generated by interests groups and mediation techniques could easily handle such cases. Every management plan should have a component for education designed for different target group with well identified and targeted messages. For example, the general public may be taught of the need to protect the CZ or its importance in our day to day life; the fisheries sector will benefits from the understanding of proven fishing practices in which full economic benefits, go hand in hand without damage to the prevailing ecosystem. Every other governmental agency should clearly know how the plan interacts with and complements their responsibilities. The higher level staff and concerned administrative officers/managers should have an overall view of the education imparted so that they themselves are involved to a large extent in the working of the plan.

TRAINING

This ensures that those trained carry out their duties well in accordance with the plan objectives. Education on the other hand is addressing a group of audience to deliver specific messages so as to effectively implement the plan. Upon training, the top management and decision makers, divisional heads form the core of personnel to run the programme. Field and office staff and volunteers constitute the secondary group. Kenchington & Hudson (1988) have illustrated the topics to be covered in training at appropriate levels:
1. Goals and objectives of the plan.
2. The ecosystem of the area.
3. Socio-economic character of the area and users.
4. Environmental issues in the area.
5. Cultural background and traditional practices by the inhabitants of the area.
6. Specific duties and implementation of the same.
7. Organizational management.
8. Procedures in emergency situation.

Training is essential, purpose oriented and has to be specifically provided by expertise to the people who need it. Several options exist in terms of efforts *vs.* benefits ranging from local training

courses, seminars, familiarization tours and visit to overseas countries.

SURVEILLANCE
This permits to accounts for the extent to which users have complied with the provision of the plan.

ENFORCEMENT
This part of the implementation of the management plan looks into infringements which are followed up by advice and counselling so as to ensure the ready compliance of the plan and also that corrective measures are administered from time to time.

MONITORING
This section of the plan helps to access at regular intervals the conditions of the physical, chemical and biological setting as well as the socio-economic conditions.

REVIEW
This facilitates the evaluation of the success and appropriateness of the objectives and the plan amended if required so.
In addition to above, a new component of management plan is on information services.

INFORMATION SERVICES
Information on CZ and its proper management is a topic of interest to all those who love nature. For a decade, with the growing interest and importance attributed to CZ, more and more published works are appearing in literature (Graaff et al., 1991). Our understanding is growing on all aspects of CZ on the inherent complexities which suggest opportunities for a healthier and prosperous tomorrow. This invariably calls for a management plan involving training, education and implementation of the guidelines in the upkeep of CZ. However this is effectively possible only by means of a strong network to support and disseminate information. However, to enhance the cause of a practical, feasible CZM plan it is essential that information is made available freely to all those concerned in just not understanding their own localities but appreciating and translating the gains achieved elsewhere. An exclusive network among coastal administrators and managers from all countries is a proposal worth considering for information exchange.

A BRIEF ON CZM IN DEVELOPING COUNTRIES
Coastal zone land areas of developing maritime countries inhabited by at least 30% to 40% of their population. These regions are highly urbanized, industrial outputs generally accounts for 2/3rd of GNP. Every nation's principle transportation infrastructure is generated from coastal zones which are nodal points. It is also true that tourism, a fast growing industry in many developing countries concentrate on CZ. These regions are also significantly known for environmental contamination. Obviously, 70% of the total annual fish production originates from CZ and as such for tropical regions, these areas exemplify the richest biodiversity, with substantial reserves of valuable minerals, significant extends of agricultural lands and sizable areas of usable lands not yet developed.
Of countries in south east Asia, Vietnam, Cambodia, Thailand, Malaysia, Singapore, Indonesia, Philippines, Burma, Sri Lanka and India with present population growth rate of about 2.5% will lead to a doubling in about 30 years of time. In this context there is bound to be very high pressure on the CZ both in terms of unexploited land and towards increasingly harvested food production. In general, development of the CZ becomes a complex task, its extend and influence not well understood in the context of growing population demands.
The objectives of training and education in most developing countries on CZM are:
1. define the coastal problems that need to be addressed,
2. set a priority list of these problems with reasoning.
3. the management team to set up appropriate bodies to address these problems,
4. clearly define the role of public and delineate the governmental and non governmental organization roles,

5. initiate and solve immediate problems,
6. to formulate a long term plan.

This approach would protect the natural coastal habitat, percent loss and degradation of archaeological, historical and cultural monuments and improve tourism recreational activities.

SRI LANKA COASTAL CONSERVATION ACT NO. 57 OF 1981

An implementation of plan for CZM would invariably attract administrative setup with financial expenditure. In regulating such a body, provisions are advisable as in 1 to 6, in an example from Sri Lanka.

1. Periodic revision of the plan
2. Permit and appeal procedure
3. Acquisition and development of coastal lands
4. Rehabilitation of CZ and ensured improvement in environmental quality
5. Continued R & D effort to understand problems and propose appropriate solutions
6. Regular contact programs on education, information and publicity to promote public awareness.

In developing countries research, education and training are generally insufficient to mitigate the ill effects of specific problems. As of today direct and immediate intervention is needed to sort out specific issues and generate information on parameters of interest in CZM. One approach is to gather information on human activities and support additional programs with specific targets relevant to management issues. Also international exchange of information freely available to such countries in need will be an added boon. Such steps will focus on the immediate future and also the most pressing problems. The training and education will elevate the public awareness for any natural resources management programme as public support is a prerequisite. As stated earlier, education at a local and regional levels in amongst administrators, managers and local inhabitants is a must. Each country should sponsor public awareness and education programmes which will focus on the general issues of CZM.

This may be illustrated further by CZM information from Thailand. In that country CZM recognizes the socio-economic values through a list of inventory on resources, namely, forestry , fishing & aquaculture, agriculture, minerals, tourism, human settlements and industry. The managers have listed the main problems in coastal developments as the deterioration of coastal resources by destruction, over exploitation and uneconomical use; mangrove forests, beaches, coral reefs have been degraded. To circumvent some of the above aspects the Office of National Environment Board (ONEB) of Thailand has set up general policies and measures to cover CZ. The system of EIA in Thailand is still evolving and adaptations are taking place as experience indicate (Baker & Kaeoniam, 1986). A 13 point basic principles on CZ resource management and planning has been evolved but implementation is in progress only. Zoning is an important aspect covered in the strategy and suitable matrices are drawn up to counter adverse effects (Kinsey & Soudheimer, 1984). One approach to mitigate problems in CZ is to divide the region into smaller units and draw prospective plans for development. This includes identifying existing activities and conditions on the ecosystem and possible uses. Guidelines are formulated on the basis of above evaluation and suggestions include the setting up of a central organization to coordinate activities and provincial subcommittees for regional\local developments and periodic review. One component emphasizes the requirement for training and education of personnel in CZM (Adulavidaya, 1982).

Proposal on czm training in developing countries

In CZM, specialized training is required for various members of staff and public; generally these are inadequate in developing countries. Some viable proposals are suggested herein.

The goal of CZM include zoning, preservation, control, development apart from specific objectives and techniques/constraints which differ regionally. Mostly, very few have in-hand experience and skills in this field. Higher-up administrative staff or managers/policy makers lack the interest or are less sensitive to problems and many more problems result from mismanagement. It is true that in developing countries, the lack of management skills (due to

lack of proper training) reflects a general lack of accepting the strategies of CZM elsewhere practised. It is necessary to train a group of people whose responsibilities is to then train others and as an acceptable option, secondary and tertiary recipients would necessarily be people from the local community. The overall training system summarized in Table 1.

The following points are a summary of the proposals:

* CZM strategies are to be made simple and popularly available.
* Training is required at all levels of personnel on CZM.
* The existing system is ready to incorporate training skills but takes considerable efforts, expense and time to organize and is relatively inefficient as only few stand to benefit.
* Generally English is practised and no specific language training is imparted to staff who organize local meetings.
* Little specific training for field staff is available anywhere.
* A three tier system of training for upper level policy makers/administrators, middle level managers-planners and lower level field staff had to be evolved.
* For those at upper level, they should be encouraged on independent study and be constantly supplied with recent information through a network; a short term policy orientation course and a booklet describing time to time development on a routine basis is suggested.
* At middle level, academic training is proposed at special centres of study; short-medium term training programs and reorientation courses are conducted time to time.
* The field staff and trainees at the lower cadre, constituting the large number has to be imparted basic knowledge, evolve a commitment to CZM and initiate physical skills and practices. Engage support staff to overcome language barriers, hold joint ventures with local clubs and hold routine field surveys and seminars. Besides they are to be trained in tourism related activities, physical skills of operations with individual responsibilities.

Proposal on education in CZM

Education generates awareness and interests and is an integral part of a long perceptive plan. The concepts on CZM should be translated by good staff members who impart interests and initiative to the public. The design of education programme may be specific for general public, fishermen, resource managers, tourists operators and government monitoring agencies. The technique include classroom study propaganda through TV, video, radio, news papers & magazines, publicity through films , books, pamphlets, posters, badges, demonstration via drama & story telling and holding field demonstrations, open meetings, seminars and conferences.

PROSPECTS

Management of CZ is a fast developing subject since last decade. This has accelerated with our increasing knowledge on the limited resources of the region and the need towards sustainable development. On a priority basis their exists the requirement for continued education and training and free exchange of ideas on implementation of plans on CZM between nations. Careful managed coastal seas may be able to provide an inexhaustible supply of food and wealth. At present in most countries destructive methods of harvest and short term profit making by over exploitation are serious damaging that possibility.. Theoretical concepts on the functions of coastal systems and the role of human activities are now well being documented (Clark, 1983). The stress is developing countries with growing population joining these enterprises by a developing positive attitude to preserve and protect coastal resources. The plan for the year 2000 and beyond, say 2020, will be to reorient our activities with available experience so that respectable success could be achieved. Towards this a method of accelerated (conservational based) development of CZ may be started through regional centres of excellence having CZM studies as a theme subject. It is proposed that Cochin serves this purpose for south east Asia. It has an establishment with staff from multidisciplinary subjects. External consultants may visit within a regular system of educational and training programme, conduct

appropriate field surveys and help in the consolidation of the ongoing CZ management studies complimented by staff from different countries of this region. Such a centre would serve as a platform in the fruitful interaction between representatives of states and large number of devoted workers who are actively engaged in CZM. Further housing sophisticated equipment and techniques which are currently available only in developed countries will more effectively work as a system towards technology transfer more than that is currently practised.

The proposed centre shall serve to overcome certain apparent problems in the approach to CZM in the perceptive of a plan beyond 2000. They include the abolition of a single administrative agency and sectoral approaches in solving coastal problems to a more acceptable comprehensive body inducting expertise on the six critical elements that go into the making and implementation of a management plan.

Regulations, if any, legally or otherwise are to be modified and revised in tune with objectives from time to time. In cases where more than one agency and more than one institution deals with management concerns, such as water quality, resource utilization and deploy a variety of management techniques, the need of the hour is to codify a well established practical approach in a proper perspective. The definition of CZ often used is too narrow geographically and seldom reflects the intrinsic interconnection within the components of a coastal ecosystem, resource utilization and habitat diversity. Also strengthening of bonds between local, regional and coastal communities is essentially felt in coordinating the activities of the CZM plans.

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Table 1. Overall training system of people whose responsibilities is to train other people, and as an acceptable option, secondary and tertiary recipients would necessarily be people from the local community.

Staff type	Training methods	Proposal
Administrative staff & Policy makers	Independent reading, Scientists, self-study	Short term orientation, study, conference attendance, courses, update data bank
Middle level managers & Planners	Independent study, Assignment experience, reading	Re-orientation courses, Field study, regional meetings, data exchange and career support
Field staff	Not specialized and no previous training experience	A model CZM plan is taught and on-job training
Trainers	Independent development from Govt. or other organizations like University staff etc.	Regional re-current training program and partial support as stated for above staff

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TRAINING TODAY'S COASTAL AND MARINE MANAGERS: A PERSPECTIVE FOR ASIA AND THE PACIFIC

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KEYWORDS: coastal, marine, management, training, decision-makers.

ABSTRACT

Coastal managers and decision makers come from a wide range of disciplines. Natural science has developed an understanding the issues and constraints relating to human activities and impacts in coastal and marine environments. This is rarely shared by the commercial, economic, engineering, social policy and public administration practitioners who drive the major social and economic decisions of society. An immediate priority is for multi-disciplinary in-service training and education in Asia and the Pacific. Current and future demand is large and urgent. To meet it will require the development of specific materials and approaches addressing the range of social and economic priorities in the regions.

INTRODUCTION

Management at the coast encompasses virtually all fields of human endeavour. Many management decisions of crucial significance to the coast are made by people who do not recognise that they are coastal managers. Recognition of the need for the holistic approach of integrated coastal zone management is relatively recent and training presents challenging problems.

Section 17.5 of the Rio Declaration (UNCED, 1992) concerned the issues of sustainable management of coastal and marine environments and resources:

'Coastal states commit themselves to integrated management and sustainable development of coastal areas and the marine environment under their jurisdiction. To this end, it is necessary to, inter alia: provide for an integrated policy and decision making process, including all involved sectors, to promote compatibility and a balance of uses;....'

The framework for addressing this commitment was addressed in Chapter 17 of Agenda 21 (UNCED, 1992) which identified the need for training in order to develop the necessary management capacity.

THE NATURE OF THE TRAINING TASK

There may be widespread acceptance of the need for integrated coastal zone management and for training to support it but there is a broad range of interpretations as what it involves (Kenchington and Crawford, 1993).

The changing and expanding table of contents of technical journals make it clear that modern coastal management is evolving from three sources and the term coastal manager covers an expanding range of disciplines.

The longest established is coastline management with an engineering focus on shoreline protection, reclamation and erosion control, the design of structures.

The second is the coastal component of statutory planning, land management and public adminstration with a focus on allocation and management of resource use.

The third and most recent is coastal environment protection and ecosystem management. This has a natural science focus on the physical and biological constraints which must be addressed to maintain biological diversity, natural processes and achieve sustainable use and development of coastal land and sea environments and resources.

A comprehensive coastal management system involves a multi-disciplinary approach within which each profession or discipline should have a sound understanding of the basic principles, opportunities and constraints arising from the others. This requires a broad approach to training and an ongoing process to provide for information exchange and interpretation between a range of disciplines and interest groups.
The tasks may be discussed in terms of preparatory training, through tertiary and post-graduate courses and programs, and ongoing or in-service training and information exchange.

TERTIARY AND POSTGRADUATE

In 1990 an ASEAN-US workshop on Coastal Area Management Education in the Asia Pacific Region agreed that the supply of trained personnel for integrated coastal zone management from educational institutions in the Asean region was inadequate. The emergence of demand is leading many universities and tertiary training colleges in South East Asia to develop coastal management units and courses. The importance of coastal management is reflected in its selection as one of the three initial priorities of the UNEP Network for Environmental Training at Tertiary Level in Asia and the Pacific (NETTLAP) which was established in 1992 . Hay et al. (1994) discussed the NETTLAP approach and noted that it should be seen as part of an evolving process to address four major needs identified at an intergovernmental meeting in 1977 (UNESCO 1977):
- Insufficient environmental education and training programmes;
- Lack of effective interdisciplinary approaches;
- General absence of problem-solving approaches
- A narrow focus in training on natural environmental components to the exclusion of social, economic and cultural perspectives.

A NETTLAP workshop held in late 1993 considered the availability of and the need for development of curriculum materials which addressed the priorities of Asia and the Pacific (Hay and Chou, 1993). Noting that many courses draw upon a literature which is relatively rich in examples from temperate developed economies it emphasised the need to assess and document existing and relevant case studies for the region. The workshop considered the incorporation of CZM topics into existing tertiary courses to be a key need and concluded: "Tertiary institutions in the region should give priority to main-streaming CZM topics in existing courses, taking into account the following:
- many students are intimidated by the scientific and process orientation of instruction in CZM;
- many students do not appreciate the relevance to their future prospects of CZM of an understanding of the fundamental processes operating in coastal environments;
- many students only have interest in some components of CZM, preferring, for example, to concentrate solely on economic policy issues;
- incorporating CZM topics in existing courses is often a necessary first stage in the development of fully comprehensive and distinct programmes; and
- the CZM issue and response options which are distinctive to the Asia-Pacific region."

The workshop foresaw NETTLAP facilitating the process of incorporation "in conjunction with relevant organisations and institutions including UNEP OCT/PACA, UNEP IE/PACA, UNESCO COMA and IOC by:
- preparing curriculum guidelines and instructional materials to support such developments;
- giving special attention to the development of materials for the lower levels of tertiary education and training, including colleges of education and vocational training institutes; and
-especially for the smaller or least developed countries, facilitating the use of innovative technology to develop materials which can then be provided to students using more conventional methods. For example staff may have access to information through electronic mail and bulletin boards but distribute it to students as printed copy."

The workshop also noted the importance of short courses in ICBM and the need for tertiary institutions to work with management agencies and industry in the development and delivery of such courses. It noted the need for NETTLAP activities to be coordinated with programmes with substantially common objectives including UNEP

EA-19 and the TOMES projects which are discussed below.

TRAINING MATERIALS FOR STAFF OF COASTAL ZONE MANAGEMENT AGENCIES. UNEP-COBSEA EAS 19

The Coordinating Body for the Seas of East Asia (COBSEA) oversights the activities of the UNEP Regional Seas Programme for East Asia. This includes a number of East Asian Seas (EAS) projects which address marine and coastal management issues of concern to the member governments. EAS-19 concerned the development of materials for training professional and technical staff involved in the establishment and management of Marine Parks. (Kenchington and Ch'ng, 1994).

The project was managed by the Malaysian Department of Fisheries. The first phase consisted of an initial design project to identify the scope and objectives. This was followed by a second phase in which draft materials were developed under contracts coordinated by the Great Barrier Reef Marine Park Authority. This phase concluded with a workshop in Malaysia at which delegations comprising managers responsible for marine park management and staff training in Malaysia, the Philippines and Thailand trialled and evaluated the materials and discussed proposals for their revision and for the implementation of training programmes. The third phase consisted of a review of revised materials in coordination with NETTLAP and concluded with publication in late 1994.

A similar process is currently under way to develop materials for integrated coastal zone management.

TARGET GROUPS FOR ONGOING TRAINING

One key to the design and implementation of effective training for integrated coastal zone management lies in identification of target groups which have particular roles in the achievement of sustainable management of the coastal zone.

The EAS 19 programme involved people responsible for training in home countries. It considered the training needs of the three other categories which were more precisely defined as follows:

- Directorate staff - degree or post graduate qualified officers responsible to a Government Minister for policy and programs at the central government or capital city level;
- Marine Park Officers - diploma or degree qualified officers responsible to the directorate for management operations and supervision of Marine Parks in national centres or districts; and
- Rangers - high school or diploma qualified staff responsible to Marine Park Officers for management patrols and day-to-day operations in specific Marine Parks.

In the broad context, training for integrated coastal zone management should address the management of agencies and activities which affect the coast even though they do not recognize their involvement in coastal issues. This broader approach should also address the capacity for staff to conduct or supervise more general public or community based education and information provision to develop and maintain awareness of, and support for, long term integrated coastal zone management in the face of short term sectoral pressures.

This leads to an expanded list of target groups for training which includes:

Staff of the management agency:

- Upper level administrators and policy-makers;
- Middle level planners and managers;
- Field level staff;
- People responsible for training in home countries.

Decision-makers and staff of other agencies:

- Ministers and departmental heads;
- Middle level staff whose activities affect the coastal environment;
- Field level staff operating in the coastal zone.

The community and coastal stakeholders:

- users, owners or custodians of coastal resources;
- local government;
- business, religious and other community leaders;
- school and college teachers.

CONTENT OF TRAINING MATERIALS

The EAS 19 materials consist of 12 modules:

1. The nature of the marine environment: The sea as an open and interconnected system
2. The nature of the marine environment: The sea as a place to live
3. The nature of the marine environment: The sea as a large dynamic system
4. Use of and threats to the marine environment and its resources
5. Marine Protected Areas of the World
6. Overview of day-to-day management of marine protected areas
7. Planning for Marine Protected Areas
8. Research and Monitoring for Marine Protected Areas
9. Public Contact Programs for Marine Protected Areas
10. Surveillance for Marine Protected Areas
11. Maintenance Programs for Marine Protected Areas
12. Enforcement

THE APPROACH OF THE MATERIALS

The materials for EAS 19 were designed as a resource for trainers who may be faced with a wide range of training audiences. The concept is to provide a menu of materials on a topic relevant to management in the expectation that the trainer will select relevant elements, augment them with local examples and as necessary translate them to the working language of the specific audience.

As an example, each group has a particular need to know the social, economic and ecological reasons for and the provisions of the Marine Park for which they are responsible. The focus for the directorate will be more on the general philosophy and policy background while that for the rangers would emphasise specific knowledge of the answers to the types of questions likely to be asked by the community and coastal zone users.

Other materials address particular job skills, for example the maintenance of plant and equipment but again there are different requirements. Training for rangers will involve providing them with the necessary specific skills to undertake particular tasks. For managers it will involve sufficient understanding of those skills to undertake direct supervision. For the directorate it mainly involves an understanding that these are functions which have to be carried out and of the resources, time and funding required for them to be carried out competently.

DELIVERY SYSTEMS

Training materials such as the EAS 19 modules can provide syllabus objectives and the information to address them. Individual courses or presentations for staff or client group education may use some conventional lectures but these should be placed in a context of adult education approaches. A conventional approach has been implemented in the TROMES (Tropical Marine Environment Studies) program which builds upon the ASEAN-AIDAB Living Coastal Resources Project (LCR). The objective is to enable ASEAN scientists trained in the LCR project to work with resource managers to establish networks and to use data already gathered to establish or improve the management of tropical and semi-tropical coastal marine environments.

The initial workshop, held in Malaysia, involved participants from Indonesia, Malaysia, Mauritius, Papua New Guinea, Philippines, Singapore, Thailand and Vietnam. Participants considered hypothetical management case studies in order to consider the issues and to develop program design for subsequent in-country workshops. It also included a real case study of the Pulau Redang management plan which provided a "hands on" example and served as a workshop for Malaysian participants.

The initial TROMES workshop was well received. It was followed by an additional element which consisted of a two day workshop for senior Malaysian policy makers which provided an opportunity for them to be briefed on the issues, implications and commitments involved in achieving ecologically sustainable management of coastal marine resources. This, too, was well received and has been incorporated as an additional component of the other in-country workshops.

A feature of the TROMES workshop approach is the facilitation and support of multi agency and

multidisciplinary working groups, which resemble the working situation, in order to identify and discuss complex problems and the options for resolving them.

At the time of writing, individual country workshops have been conducted successfully in Vietnam and the Philippines. In both countries the case study reports produced at the workshops have contributed to local policy and programme development and follow-on workshops for other regions are being proposed. Plans are in place for country workshops in Thailand and Mauritius in April and May 1995.

PLACEMENT AND SHORT COURSE TRAINING

The Great Barrier Reef Marine Park Authority has been able to provide a small amount of placement training whereby Marine Park staff from Belize, Egypt and Malaysia have been able to spend time at the Authority's offices and with the field management staff of the Queensland National Parks and Wildlife Service. While this form of instruction is effective and produces 'hands on' experience it is logistically demanding and expensive because the students need a tutor or mentor to manage the program and provide background instruction. The demands on the operational staff are stimulating because of the need to explain operational principles but they increase the workload or slow the work rate. The alternative is the conduct short courses with demonstration sessions and tutorial discussions with operational staff.

This approach is being pursued through the International Tropical Marine Resource Centre (INTROMARC) a consortium comprising the Australian Institute of Marine Science, the Great Barrier Reef Marine Park Authority and James Cook University of North Queensland. INTROMARC is approaching the issue in association with NETTLAP partners through development of an initial list of management topics which can be addressed by short courses subject to demand and funding. The list is still being developed through discussion and workshops and has yet to be prioritised.

INTROMARC LIST OF POSSIBLE SHORT COURSE TOPICS.

- Introduction to the marine and coastal management.
- Coastal Biology for non biologists
- Coastal physical processes for non physicists
- Community involvement in marine and coastal management
- Data bases, GIS and Information Management for ICZM
- Economics of coastal and marine resource use - for non economists
- Legislative aspects of ICZM
- Policy and administration for scientists and economists
- Marine Park Planning
- Marine Park Management
- Strategic planning for Integrated Coastal Zone Management
- Monitoring for marine environmental management
- Coral Reef Survey Techniques
- Mangrove survey techniques
- Seagrass and Benthos survey techniques
- Tropical fisheries and environment management
- Managing research for management
- Managing tourism in marine and coastal environments
- Field operations for ICZM
- Public education and involvement techniques for ICZM
- Public participation, appeals, reviews and dispute resolution
- Conduct and supervision of EIS for ICZM
- Discretionary decision-making and EI assessment
- Regional and International aspects of ICZM
- Operation and supervision of consultants in ICZM
- Management of local subsistence and recreational activity in ICZM
- Traditional knowledge and indigenous rights in ICZM
- Management of shipping and pollution
- Management of land based pollution
- Remote sensing
- Surveillance of area usage

Consistent with the approach of the UNEP-COBSEA training modules, each of the topics could be addressed at a number of levels. The initial assumption is a two week intensive short course for graduates but, depending on the educational background and the role of the target group, it might be approached by creating special remote learning materials for a longer course supported by tutorial arrangements. Alternatively, a number of the topics might be grouped in a combined longer programme leading to a certificate, diploma or masters course.

The critical question in designing a specific course within one of the topics is: "What message/s should the particular target group to understand and appreciate as a result of undertaking the course?"

DELIVERY OPTIONS

In considering delivery options, the issues include the form and formality of the package in terms of contact time, location, need for certification or qualification and the technical possibilities of information delivery.

A list of information delivery options includes:

Formal Instruction

- short course
- secondment or placement training
- certificate course
- diploma
- degree
- postgraduate course work degree
- postgraduate research degree

Community or public education

- talks by community leaders
- theatre/art/music
- newsletters/newspapers
- local radio/television
- sponsored advertising or promotional campaign

Conventional technologies

- Study tours
- Lectures
- Practical classes and demonstrations
- Slides and film clips
- workshops
- Manuals and textbooks

New technologies

- video recordings
- computer instruction disc
- computer games
- CD-ROM interactive package
- landline or satellite modem access to remote tutorial instruction
- teleconference/workshop

The ways in which training information may be presented have increased with new technologies and the blurring of distinctions between education, information provision and entertainment. This is reflected in one of the recommendations of the NETTLAP coastal zone management workshop addressed this:

"Recognizing the importance of computer modelling and role play in developing understanding and solutions for complex problems, it is recommended that NETTLAP, with support of relevant organizations and institutions such as UNEP OCA/PAC, UNEP IE/PAC, UNESCO COMAR and IOC, convene a small specialist working group to develop the flow chart for a computer-based, interactive simulation game providing entertainment, but also insight into the processes of coastal land stability and erosion and benefits, costs and risks associated with coastal property investment and development.

NETTLAP should subsequently arrange for staff and students at a relevant tertiary institution in the region to develop an appealing and educational interactive game based on the flow chart."

For flexibility and ease of presentation the materials for EAS 19 were developed on the basis of formal classroom instruction with simple visual materials which could be presented as slides, overhead projection transparencies or in a village situation as posters. In the evaluation, delegations suggested strongly that video presentations should be added since that would add versatility to the programme, enable students to repeat areas which are unclear on the initial run-through, and are particular helpful if the instruction is not in the primary language of the student.

Currently, new developments and applications of relatively inexpensive high capacity computer technology are resulting in rapid development of concepts of multi-modal learning. Personal

computers and computer-assisted interactive learning through materials on floppy discs, CD ROM and video-disc, provide the potential to augment traditional methods of learning and to enable students to proceed through courses at their own pace. This field is developing rapidly and presents educators and managers with opportunities to provide substantial parts of initial and refresher training with interactive technology, freeing contact time for more informed, problem solving tutorial approaches. It also raises the potential of training with less time spent away from home base with substantial advantages in terms of disruption of work programs and personal circumstances.

New technologies are not always the most appropriate solution. Hudson (1983) provided an overview of user and public education. Particularly in community education programs, familiar approaches including theatre, music, dance, puppets, story-telling and talks by community and religious leaders can be effective means of conveying messages to subsistence and customary users of coastal environments.

The critical question is: "What delivery system/s will most effectively reach the particular target group?"

THE ISSUES FOR ASIA AND THE PACIFIC

The areas of the South China Sea and the Gulf of Thailand may be regarded as the frontline in the development of integrated coastal zone management to achieve ecologically sustainable use and development of marine and coastal areas. The countries of this region are developing rapidly in economic terms and most are also experiencing rapid population growth. The need for such management is accepted by governments, international programmes and funding agencies.

If the goal of ICZM is to be achieved in Asia there is a massive need for training of policy makers and staff of a wide range of government and community agencies as well as those who already perceive that they are "coastal managers". There is also a massive need for public education and promotion of the concept and community benefits of ICZM. This in turn creates a massive need for trained staff in government and non-government agencies who can deliver such public information programs.

The region has relied on overseas training of a relatively small number of relatively senior staff, and on special in-country courses and projects by overseas experts. The NETTLAP program was established in recognition that the massive training task requires the development of massive training capacity within the countries of the region and of networks of professional support to assist the trainers and institutions of the region to develop and deliver a wide range of courses and programs.

The Pacific generally presents the issues of less developed countries with relatively small but rapidly growing populations which depend very heavily on the renewable resources of the coastal zone. As in Asia, there is a massive need for public education and promotion of the concept and community benefits of ICZM and a corresponding need for trained people to deliver such programs.

The staff training issues are somewhat different. In many of the countries the government and decision making structures are small and there is a communication and sometimes sharing of function between agencies and individuals. Consequently there may be little distinction between technical and policy aspects of management and between business, community and government decision making processes. The practical difficulty in such small systems is that if a key person is absent on training for a long periods there may be none to provide back-up so that the work and problems accumulate. In such situations there is an important role for training approaches which provide relevant information and understanding in situ through distance and network training techniques.

CONCLUSIONS

The establishment of ICZM in Asia and the Pacific will require a massive investment of time and resources into training on a very wide scale. The priorities lie in interdisciplinary or trans-disciplinary training which will bridge the gulf of understanding between communities,

governments, business , economists and scientists to produce a true integration in management.

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COASTAL CHANGE MANAGEMENT EDUCATION IN DEVELOPING COUNTRIES

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ABSTRACT

Coastal change management requires a complex array of highly skilled, multidisciplinary, professionals in order to address the issues. Any (altered) coastline is in dynamic equilibrium with natural processes. Increased levels of human activities in coastal areas have resulted in alteration of this equilibrium and consequently have led to changes such as increased wave height and frequency of storm surges, erosion, salinity intrusion, flooding, inundation, and wetland destruction. These changes including sea level rise have generated universal interest.

Developing countries need to establish adequate infrastructural, legislative, and institutional framework for effective management of coastal change. Education and public enlightenment are vital tools which will lead to better understanding and management of coastal change effects.

Finally, the United Nations and her agencies should offer the developing world financial and training assistance for capacity building.

INTRODUCTION

The coastal area of any nation is a very important part of the nation's territorial boundary. The coast is important for agriculture, fisheries, navigation, communication, military, commerce, tourism and mining. Crude oil exploration and exploitation, which contribute very significantly to the economies of developing countries in particular, are undertaken along the coast. These activities have attracted in most cases large populations. It is estimated that the coastal areas house about two thirds of the world's population (Hanson and Lindh, 1993) and by the year 2020, this number will increase to 75%.

The activities on the coast have led to the growth of many cities. Many important cities of the world such as London, Rotterdam, Tokyo, Venice, Shanghai, Cairo, Lisbon, and Lagos are located within the coast. Borrego (1994) stated that two thirds of the world's cities with over 2.5 million people are located within 60 km from the coast. As a result of the numerous activities and the location of big cities, most governments have invested a lot on infrastructure such as roads, airports, seaports and rail networks. These activities, investments and population concentrations have placed enormous pressure on the coast. The role of the coastal environment to humanity has made it imperative that special attention should be paid to it.

To effectively manage the coastal zone, accurate definitions of the concepts, boundary limitations, management goals and objectives, as well as factors that cause imbalances in the dynamic equilibrium of the coast must be understood and applied.

The boundaries of the coastal zone, as defined by the United States Coastal Zone Management Act of 1972 are the coastal waters, the adjacent shorelines, and the lands "therein and thereunder". The components of the coast, such as islands, saltmarshes, beaches, transitional and intertidal areas, were noted in the Act to be in proximity to the shorelines and to exert influences on each other.

COASTAL ECOSYSTEM COMPONENTS AND INTERACTIONS

The interactions fall into three broad categories: natural systems, user functions and infrastructure (van der Weide, 1993). The natural system

interactions occur through abiotic, biotic and chemical processes.

User functions specifically address the issues relating to anthropogenic activities and the resultant impacts. The coastal zone supports human populations and a complex array of developmental activities. Ballinger et al., 1994, noted the coastal region to be "one of the most heavily used, with many different activities taking place". Coastal zone resources exploitation have caused environmental degradation. The degree of environmental degradation is dependent on the assimilatory capacity of the affected zone.

van der Weide (1993) observed that a naturally big and robust system would have the capability to self-heal and would subsequently not display severe overall harm. Coastal nations with a small and sparsely distributed population, abundant natural resources and a rural economy would not show discernible adverse impacts (Thia-Eng, 1993).

Over time a coast attains a state of dynamic equilibrium unless destabilised by such natural events as earthquakes, storm surges, hurricanes or presence of canyons close to the coast, although these natural extreme events are part of the dynamics. The events cause coastal erosion, flooding, inundation and destruction of infrastructure. Recently, however, Man's action in the environment has become a great concern to humanity. Global warming, caused by the emission of greenhouse gases, and other human impacts have led to increase in sea level of the order 1 mm-2 mm per annum. The impacts of sea level rise on the coasts include: erosion, flooding, inundation, deforestation, more frequent storm surges and changes in coastal dynamics. Coastal subsidence exacerbates the rise in sea level and the associated impacts.

The most significant human activities that create changes on the coast include dam construction, land reclamation seawalls, mining, oil spillage, gas flaring, over fishing, farming activities in the hinterland and dumping of refuse (Nwilo & Onuoha, 1993). These human activities affect the environment in different ways. Some create changes in the physical environment while others affect the flora, the fauna or the chemical processes. It is well known, for example, that the construction of large dams along a river starves the coast of sediments which in turn could lead to erosion. The construction of seawalls destroys the aesthetic beauty of a beach, reduces the beach width and causes erosion on the downdrift part of the coast (Pilkey et al., 1988; Krauss, 1987 and 1988).

COASTAL CHANGE MANAGEMENT

Need for Coastal Change Management Education

Rapid increases in industrialisation, related economic and developmental activities in developing countries have been without adequate regard for introduced environmentally sustainable use of the coastal zone. These activities have created environmental degradation problems, resource use conflicts and are particularly "more serious in coastal development nations beset with hunger, unemployment, poverty and rapid population growth" (Thia-Eng, 1993).

The impacts of human activities on the coastal zone include, as stated earlier, erosion, deforestation, destruction of coastal infrastructure, flooding, inundation, salinity intrusion and destruction of breeding ground for fishes. The cumulative effects of such activities might cause the collapse of parts of the natural resources ecosystem (van der Weide, 1993).

The exact nature of the activities and the resultant impacts have led to the concept of integrated coastal zone management. Coastal zone management was defined by Knecht and Archer (1993) as "a dynamic process by which decisions are taken for the use, development, and protection of coastal areas and resources to achieve goals established in cooperation with user groups and national, regional and local authorities".

The application of an environmentally sustainable management scheme to identify, evaluate, monitor and control coastal change effects require the adequate education of relevant professionals.

Policy requirements

A management scheme must be representative of the environment where it is to be applied and

should reflect the level of industrialisation, socio-economic structure and cultural orientations.
Thia-Eng (1993) categorised management issues relating to the coastal zone as resource utilisation, environmental quality, institutional concerns and natural hazards. Irrespective of attempts at classifying such policy/management requirements, the management methodology must be technically and scientifically sound. Ballinger et al, (1994) and Cicin-Sain (1993b) identified some of the tools required as zoning, siting, standards, impact assessment, information management, coastal practice, mapping, modelling and long term monitoring. Unfortunately, the complexities of the coastal environment and the interactions with external factors do not present a platform for the adoption of a straightforward management strategy.

Management Education Problems

Inadequacy of appropriate guidelines, training facilities and the difficulty in calculating and assigning economic values to the benefits of the coastal environment (Ballinger et al., 1994) and the trans-boundary nature of environmental problems combine to make coastal zone management education very difficult.
Past management of coastal zone in developing countries have been short term, uncoordinated and within separate national frameworks. For example, the Nigeria Coast is one of the most grossly polluted coastal areas due to petroleum resources exploitation and the accompanying oil spillage. Despite the state of environmental degradation and the resultant social and economic impacts along this stretch, efforts at managing the Nigerian Coast have been haphazard, short term and incomplete due to the absence of a coordinated strategy. Measures aimed at the assessment of coastal interactions in this region have, often, been undertaken by academics and oil companies which have no mandatory reporting obligations to any Federal Government Agency. It has, therefore, been difficult to collate and share relevant coastal management information that would have produced more effective results.

Trans-boundary Management

Shared national interests in stretches of coastline in the transfer of pollutants between nations via the coastal environment have created the need to regionally coordinate coastal management efforts (Ballinger et al, 1994). Thia-Eng (1993) noted that conventional sectoral management is not effective in addressing the complex issues of the coastal zone. Management of coastal change could be evaluated and set up in stages. Vallego (1993) was of the view that the maturity stage of a coastal management should comprise of three characteristics namely;
(i) Consistency with the sustainable development principle
(ii) A non-mechanistic concept of the ecosystem
(iii) Multidisciplinary approach based on isomorphisms.
The management scheme should be compatible with the developmental objectives. It should also involve the analysis of developmental patterns and pressures and environmental hazards (Ballinger et al., 1993) and a probable requirement for the modification of entrenched patterns on accepted societal norms (Cicin-Sain, 1993a).
Since many developing countries are at different stages of the developmental and industrialisation process, identification of the patterns require more effort than would otherwise be applied to developed nations. The integration of the socio-cultural interpretations of the use of coastal zone resources into the overall management plan pose a difficult task. Some coastal inhabitants, in some cultures, see the coast as a cheaper waste dump than usual sanitary provisions.
The overall management scheme must, therefore, contain an accurate evaluation of all facets of the ecosystem.

Education and Training Needs

As a result of the complexity and the resource requirements of coastal management schemes, the availability of a multidisciplinary team is mandatory for a successful implementation of such schemes. Capacity building has been identified by Cicin-Sain (1993a) as being vital to the achievement of a sustainable development of coastal zones and oceans by nations. Thia-Eng (1993)

recommended undertaking institutional building through training and workshops to establish a core group of nationals in a region with the necessary capacity to execute integrated management programmes. The training must be multidisciplinary in nature (Barcena, 1991) providing skills in social and economic sciences and the utilisation of geographical information systems as well as engineering, institutional, political, legal and social/cultural interpretations. The implication is that such professionals as engineers, surveyors, geographers, economists, geologists, biologists, environmentalists and oceanographers are very vital in addressing the problems of coastal change.

Although in some developing countries facilities exist for the training of these professionals, the general trend is that most of the developing countries lack the necessary manpower and facilities for the training. Added to this is the issue of migration of skilled professionals to the developed countries due to poor conditions of service, lack of motivation, poor research facilities and general political instability. The structural adjustment programme adopted by most developing countries in the 1980's was aimed at introducing some level of sanity in the management of the third world's economy. The true situation is that it has led to unprecedented inflation, frustration and migration of professionals.

There is, therefore, a need for the development of a conducive atmosphere for professionals to work in their countries of origin, establishment of institutions and an emphasis during training on the importance of the coastal environment. It is observed that even in situations where the institutions are available for the training of professionals, there is a general lack of awareness about the significance of the coast which is reflected in the structure of the educational programmes. Awareness can be created through training workshops, conferences and seminars and also through public awareness campaigns. While the institutions, workshops, seminars and conferences will help in the training of the trainers, the public awareness campaigns will help to create a general awareness among the citizenry.

For the developing countries to meet their manpower needs, they need support from the United Nations (UN), her agencies and the developed nations in form of training, sponsorships at conferences and provision of training and research facilities. Furthermore, there is a need for the UN and her agencies to sponsor multidisciplinary regional training programmes, workshops, and conferences in the developing countries. Such training and workshops encourage professional, teachers, and managers to attend. In this way a larger group of people are being trained. We are aware that the United Nations, her agencies and the developed countries have been helping in manpower training in the third world. What is, however, being advocated is increased training aid and in particular regional training programmes. These training programmes should be conducted in collaboration with the limited available staff in the developing countries. Sponsorship of joint research between developing countries will also be of immense help. The good thing about using information from the developing country is that researcher can continue in that research area even after the particular research is completed. In addition, some facilities previously used in one particular area could be useful in other areas thereby saving costs.

CONCLUSIONS

The attainment of coastal change management goals require the training of multi-skilled professionals with capability to understand, evaluate, monitor and interpret coastal processes, environmental intervention processes and their impacts on the coast.

Education forms the crux of this management programme. Research, institutional capacity building with the incorporation of planning and legislative tools, collation, dissemination and sharing of information between nations should lead to an accelerated understanding of the impacts of coastal change.

Since developing countries often lack the requisite resources to successfully train and educate their manpower, a situation whereby the United Nations Agencies and the developed nations provide training facilities and experts will be very

beneficial. Collaborative researches between the developed and developing countries and holding of regional workshops are advocated. The few researchers and professionals available in the developing countries should be active participants. Such a situation will help in developing requisite data base, generate interest and encourage professionals to remain in their countries of origin in order to participate in the much needed capacity building.

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SESSION VIII

Training, Capacity Building & Management

Session VIII-b
Management

Chairman: J.F. Herrera
Rapporteur: J.F. Herrera

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IMPACTS OF CLIMATE CHANGE AND SEA LEVEL RISES ON COASTAL RESOURCES: IMPLICATIONS FOR EFFECTIVE COASTAL ZONE MANAGEMENT POLICY IN WEST AND CENTRAL AFRICA

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The paper examines aspects of the impacts of climatic variability and change, as well as sea level rise on past and present environmental dynamics and coastal change in West and Central Africa with particular reference to such issues as the impacts of coastal erosion and inundation, deforestation, drought and desertification, saline intrusion, pollution and subsidence. The paper then examines the impacts of climate change and sea level rise on the future of environmental dynamics and coastal change in the region with particular emphasis on:
(a) land at risk and at loss,
(b) socio-economic values at risk and at loss,
(c) estimated population at risk,
(d) estimated population that would be displaced as a result of sea level rise and
(e) possible cost of response measures and
(f) the implications of the response measures on environmental dynamics and coastal change.
The paper illustrates the characteristics of environmental dynamics and coastal change and their impacts with some detailed discussions of typical vulnerable areas, for example, the Niger and Senegal deltas, as well as the Cross River, Gambia, Guinea Bissau and Saloum estuaries.
The paper finally discusses the implications of these possible impacts of climate change and sea level rise for effective coastal management policy which should be structured and implemented to:
(a) carry out national policy objectives for coastal management through cooperation and voluntary partnership between Federal, State and Local governments,
(b) balance competing interests on the coastal zones and land use,
(c) preserve, protect, develop and where necessary restore and enhance the resources of coastal zone,
(d) encourage and assist the states and local governments as well as the local communities to develop and implement coastal management programmes to meet specified local and national governments and international agencies in achieving the objectives of the coastal management policy,
(f) create and/or increase public awareness for coastal dynamics and coastal resources conservation,
(g) promote education and training for effective management policy,
(h) improve the availability of data and information on the factors and characteristics of coastal dynamics and change,
(i) promote research activities for better understanding of the factors and characteristics of coastal dynamics and change,
(j) encourage and assist in the development and implementation of coastal management plans which will minimize losses of lives and property in hazardous areas and
(k) bring order to the development process, avoid unnecessary conflicts and losses in environmental quality and encourage sustainable development of coastal and marine areas.

[1] Abstract only. For further information please contact the author.

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DES CONFLITS SOCIAUX DANS L'AMENAGEMENT D'UNE ZONE CÔTIÈRE: LE CAS DE "LA BUFADORA" DANS LA BASSE CALIFORNIE AU MEXIQUE

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INTRODUCTION

"La Bufadora", prés de la ville d'Ensenada, Basse Californie au Mexique est une zone touristique très attractive. Le nom "La Bufadora" (souffler) vient d'un geyser marin ainsi nommé, qui se trouve sur l'Océan Pacifique au sud de la ville. Pendant les dix dernières années cette région a connu une croissance extraordinaire dans les flux des visiteurs, principalement, Nord-Américains. Mais les conflits sociaux n'ont pas permis un développement touristique et économique adéquat.

Le différend le plus important concerne les conflits pour la propriété de la terre. Il y a plusieurs acteurs sociaux qui réclament le droit sur le même terrain. La loi, -qui a changé radicalement dans les années quatre-vingt, n'a pas pu résoudre cette dispute et les possibilités d'investissement se sont arrêtés face à ce conflit. Ainsi, l'aménagement de cette région de la côte Nord-Ouest du Mexique est un défit pour le gouvernement local et régional. À ce propos nous avons réalisé une étude pour définir et identifier les divers acteurs sociaux qui possèdent des intérêts économiques ou politiques dans la zone côtière. Ils sont plusieurs et leurs projets ne sont pas toujours en coïncidence. Nous avons fait une description de tous les acteurs et de leurs projets pour l'avenir.

La bufadora et son environnement

La Bufadora se situe dans une micro région au Sud de la ville dEnsenada sur une petite péninsule nommée Punta Banda, où se trouvent divers villages distribués aux alentours de l'autoroute Ensenada-La Bufadora (23 km dextension). Ce sont les suivants:

1) le centre urbain de l'Ejido Coronel Esteban Cantú.
2) Punta Banda.
3) La Lengüeta Arenosa (barre de sable). Et
4) La Bufadora.

La municipalité dEnsenada se trouve dans l'état de Basse Californie sur la péninsule du même nom. Cette région se localise dans le Nord-Ouest du Mexique à 110 km de la frontière avec les Etats-Unis. La municipalité est la plus étendue superficie du pays: 51 273 km² (2.68 % de celle du Mexique). Au Nord, elle est limitrophe avec trois autres municipalités de l'état: Tijuana, Tecate et Mexicali. Au Sud, elle possède des frontières avec un autre état mexicain: la Basse Californie du Sud. A l'Est et à l'Ouest elle est limitée par les littoraux du Golfe de Californie et de locéan Pacifique, respectivement.

Le littoral dEnsenada est long de 893 km. Il a 74 800 hectares de lagunes côtières où l'on peut développer laquaculture. Le territoire comprend 10 îles, dont deux sont habitées, à savoir l'île des Cedros avec une surface de 36 750 hectares et 5 000 habitants, considérée comme l'île la plus peuplée du Mexique et l'île de Guadalupe avec 25 000 hectares et 250 habitants (XIII Ayuntamiento). Ensenada est la municipalité la plus vieille de l'état. La baie a été découverte en 1542 par le navigateur Juan Rodríguez Cabrillo, qui l'a nommé San Matéo. Puis, en 1602, Sebastian Vizcaino l'a appelé: "Ensenada de Todos los Santos". La fondation officielle dEnsenada fut le 15 mai 1882. Vers 1900, la population était de 1725 habitants. En 1904, un article dans le journal Los Angeles Times disait: *Ensenada a la plus importante population de tout le district et est le seul port de haute mer sur la côte occidentale de la péninsule* (VALDEZ).

Il faut souligner que lenvironnement régional dEnsenada s'entend au de là des frontières nationales, puisqu'il fait partie dun ensemble urbain qui, depuis Los Angeles Californie, s'étend

à San Diego, à Tijuana et arrive jusqu'au port dEnsenada (RANFLA & ALVAREZ). En plus, les relations les plus importantes de la ville et même de l'état se font avec la Californie, l'état voisin nord-américain, qui est le principal fournisseur de touristes.

L'économie régionale

Les caractéristiques économiques et sociales de cette région, de par le voisinage géographique avec la Californie (un des états les plus riches des Etats-Unis), sont différentes de celles des autres zones du Mexique. La dynamique commerciale est plus intense. Il y a une activité touristique très active. Le flux de main d'oeuvre transfrontalier constitue une importante source de devises. Lindustrie maquiladora représente un nombre demplois très important. Cette industrie consiste à importer de l'extérieur toutes les parties d'un bien intermédiaire, qui seront montées dans l'entreprise pour être réexportés comme biens intermédiaires. Elle profite de la main d'oeuvre bon marché et se trouve plutôt dans toute la zone frontalière du Mexique (Gonzalez & Barajas, 1989). Ainsi, dans cette région, il y a une interaction sociale et culturelle très particulière qui se produit dans les deux cotés de la frontière. Entre autres, tous ces éléments déterminent le développement économique de la région, qui depuis 1937 vit sous un régime de libre commerce. Ainsi, face à l'ALENA (Accord de libre échange nord-américain) et la politique économique de libération commerciale, qui a supprimé les tarifs douaniers. La région nest pas en train d'expérimenter quelque chose de nouveau, presque depuis plus de 50 ans elle a vécu sous ce régime (TAMAYO). Un panorama général de l'économie dEnsenada est le suivant. Elle apporte 99 % de la pêche de l'état et 20 % du total national. Elle fait 20 % de la production agricole de l'état et 80 % de lhorticulture. Elle constitue 3% de lindustrie et 6 % du commerce de létat. Ensenada représente 11 % du produit brut de létat (COPLADEM).

Ensenada présente donc une très vaste diversité d'activités productives par ses services, son commerce, sa pêche, son agriculture, son tourisme et son industrie. Elles constituent les facteurs fondamentaux qui ont eu un impact important dans l'emploi et le développement local et régional. Dans la ville le secteur économique prédominant est le tertiaire. Il apporte 54,2 % de l'emploi total, contre 22.3 % pour le secteur secondaire et 20.2 % pour le primaire.

CARACTERISTIQUES SOCIALES ET ECONOMIQUES DE PUNTA BANDA-LA BUFADORA

Caractéristiques démographiques

Dabord, il faut remarquer qu'à Punta Banda, il y a plusieurs habitants qui ne résident pas toute l'année dans la région. Ils partagent leur temps de résidence entre les Etats-Unis et Punta Banda, où ils possèdent des maisons pour passer une période de l'année. Le critère que nous avons pris pour définir un habitant de la région a été celui de considérer comme tel ceux qui résident plus de six mois au Mexique. Sous ce point de vue, il y a un total de 561 personnes, qui se distribuent de la façon suivante:

A.- 450 habitants dans le milieu ou centre urbain de l'Ejido "Coronel Esteban Cantú", qui comprend les villages de "Punta Banda" et "Las Palapas".

B.- 68 habitants dans le village connu comme la barre de l'estuaire de "Punta Banda".

C.- 43 habitants dans la "Bufadora" (INEGI).

Toute cette région a un taux de croissance démographique de 4.3 % (CONEPO).

Services Publics

Le centre urbain de l'Ejido Coronel Esteban Cantú possède le service d'électricité. Mais la Bufadora nen possède pas. Le centre touristique "Baja Beach & Tennis Club", situé sur la barre de lestuaire de "Punta Banda" a le service delectricité, mais, par sa propre initiative. La zone urbaine de l'Ejido n'a pas encore un réseau d'eau potable par tuyauteries. La source d'eau, la plus proche, se trouve dans la Vallée de Maneadero sur le bassin du ruisseau San Carlos. L'eau est transportée par camion. Les maisons possèdent des citernes. Il y a le projet de faire un forage pour avoir une autre source d'approvisionnement.

Le complexe touristique "Baja Beach" et "La Bufadora", acquièrent l'eau à travers de camions (citernes) qui emmènent l'eau d'un forage située dans la propriété de la famille "Villarino". Le coût de chaque livraison d'eau (5 671 litres) est de 30 US$.

Il n'y a pas dans la péninsule de service des eaux usées. La majeure partie des maisons possède des latrines, mais quelques-unes ont des fosses d'aisances.

L'infrastructure routière est très limitée. La seule route pavée est la nationale (de l'état) N° 15 qui lie "Maneadero" avec "La Bufadora". Cependant, le centre touristique "Baja Beach" possède le meilleur réseau de communication, car il a plusieurs rues pavées. Il n'y a pas un service de propreté publique effectif. Mais, les particuliers ont organisé gestion pour le ramassage des poubelles. Malgré cela, il y a quelques centres clandestins d'ordures qui sont une source de pollution.

Les autres services publics à considérer sont: la sécurité, le transport et le service téléphonique. Nous avons trouvé que ce dernier n'existe pas. Uniquement le "Baja Beach" en possède, mais d'une façon très coûteuse. La police de "Maneadero" et d'Ensenada assure la sécurité, quand il y a un grand flux de tourisme (week-end long aux Etats-Unis). Il y a le service de transport public, depuis Maneadero à la Bufadora et d'Ensenada à la Bufadora.

Le tourisme: Un pilier de l'économie de la région

Les plages, les paysages océaniques, les fruits de mer, le *geyser* marin ("La Bufadora") et bien d'autres attractions font d'Ensenada la seconde ville touristique de Basse Californie. Même si la localité de Rosarito - située au Sud de Tijuana-- a eu un vigoureux développement touristique, l'activité touristique de la ville d'Ensenada n'a pas diminué. Au cours des dernières années ont été mis en oeuvre quelques projets de grande ampleur, qui ont été à l'origine de beaucoup d'emplois et d'investissements importants.

En 1990 les emplois dans les activités des services hôteliers et de restaurants, ont été de 4 713. Dans le commerce, autre occupation très proche du tourisme, le nombre de personnes travaillant était de 13 127 employés. Pour le tourisme la plupart des emplois ont une forte relation avec les affaires commerciales (SECDESECON).

Malgré le ralentissement de l'économie de l'état voisin, la Californie, pendant les dernières années, l'activité touristique à Ensenada n'a pas connu de diminution ou réduction majeure. Mais elle n'a pas connu, non plus, un élargissement et une croissance. D'après les chiffres de 1988, sur le total de touristes étrangers qui ont traversé la frontière à Tijuana pour visiter le Mexique, 17.33 % avaient comme destination finale la ville d'Ensenada et moins de 2 % avaient l'intention de visiter les localités au Sud comme San Quintin ou la "baie de Los Angeles" (SECTUR).

En ce qui concerne les visiteurs qui arrivent par autoroute, selon les chiffres de 1988 et 1989, il y a eu une croissance extraordinaire. En 1988 un total de 4 066 véhicules a utilisé l'autoroute à péage Tijuana-Ensenada. L'année suivante le nombre a été doublé en passant à 8 118 (CYPFISC). En 1990 et 1991 le nombre de véhicules n'a pas changé de façon remarquable en dépassant les 7 000. Depuis 1987, le nombre des touristes qui sont venus par bateau a connu une augmentation considérable. En 1987 le nombre était de 88 264 passagers. En 1988 il est monté à 130 000. En 1991 le nombre a crû de façon extraordinaire, il est monté jusqu'à 360 000 passagers. En 1992, il est tombé à 220 000 (SECTUR).

Les activités économiques à la péninsule

D'abord, je présenterai la distribution de l'emploi selon les branches d'activité économique. En commençant pour l'Ejido "Coronel Esteban Cantú", nous avons trouvé la distribution suivante: 14.5 % (21 personnes) travaillent dans le commerce. Dans les champs pour accueillir les touristes, 17.2 % (25 personnes). En autres services, 26.2 % (38 habitants). Dans la pêche, 22.1 % (32 habitants). À l'agriculture travaillent 10.4 % (15 personnes). À l'élevage 9.6 % (14 personnes). Comme nous pouvons l'observer, les emplois se sont concentrés de façon plus évidente dans le secteur tertiaire. Les activités des services liés au tourisme sont plus attractives

que celles liées à l'agriculture et la pêche, c'est à dire au secteur primaire. Dans une interview avec le président de l'Ejido M. Eugenio Uribe, nous avons été informé qu'il y a actuellement 8 groupes dans l'Ejido qui travaillent dans différents terrains spécialement adaptés pour le tourisme. Au total, il y a 50 *ejidatarios* qui travaillent dans ce secteur. C'est ainsi que l'emploi dans le tourisme est en train d'augmenter dûne façon extraordinaire (INTERVUE).

Néanmoins, la pêche est encore une activité avec une certaine importance dans toute la région de Punta Banda, particulièrement avec le centre de population urbaine de l'Ejido "Esteban Cantú" où se trouvent 30 pêcheurs. De plus, l'Ejido possède une usine pour la transformation du hérisson marin, où il y a 17 salariés.

Une autre activité qui est en train de se développer et qui possède un potentiel important est la pêche sportive. Elle se pratique actuellement dans les terrains de M. Perinski.

Il faut souligner que pratiquement il n'y a pas d'activités industrielles. Par contre, le commerce est très visible, car il y a 20 établissements commerciaux comme: boulangeries, magasins d'alimentation, pharmacies et autres. Ainsi dans tout le parcours de l'autoroute, se trouvent une vingtaine de petits commerces improvisés où sont offerts de produits régionaux (olives, maïs, miel). Dans la Bufadora, ce type de commerces se trouvent dûne façon multipliée et concentrée, puisqu'il y en a 91. Presque tous les commerçants viennent de Maneadero ou de l'Ejido "Esteban Cantú. Les propriétaires travaillent dans leurs commerces et n'emploient pas de salariés. Ils gagnent plus, par rapport au salaire minimum (SMIC), leurs revenus moyens sont de 400 dollars par mois. Il faut remarquer que leur scolarité est peu élevée, mais ils savent lire et écrire (INTERVUES). Dans la barre de l'estuaire de la péninsule de "Punta Banda", l'activité économique principale se trouve dans le tourisme. L'attraction la plus importante est le paysage, la vue panoramique depuis divers points d'observation. Telles aires de falaise et des pentes. De plus, le geyser marin constitue la source la plus grande d'attraction. De même, la mise en marche dûn grand hôtel qui, depuis plusieurs années, était une construction non achevée. Il se trouve sur la "Lengüeta Arenosa". Aujourd'hui, il est le complexe touristique "Baja Beach & Tennis Club", qui a multiplié la valeur immobilière d'une façon extraordinaire. En augmentant les conflits autour de la propriété de la terre. Le groupe d'investisseurs de ce projet est le Groupe "Koster".

La cause fondamentale de l'orientation des *ejidatarios* vers les activités touristiques se trouve dans leurs revenus, qui sont les plus élevés par rapport à la pêche, l'agriculture ou autres. La location des terrains sur la côte, représente une activité moins laborieuse et plus rentable. Maintenant, il y a plus de vingt familles dont les emplois se trouvent dans cette activité.

Aujourd'hui, avec les changements à la loi sur la propriété de la terre (Art. 27), les *ejidos* peuvent vendre ou louer leur propriété. Les accords d'association entre l'Ejido et des investisseurs privés constituent une nouvelle manière de fonctionner. Avant, les terrains des *ejidos*, étaient par définition intransmissibles. Maintenant, les *ejidos* signent des accords de partenariat pour développer des centres touristiques dans une grande partie de leurs propriétés. Dans le cas de l'accord avec le groupe Koster, où l'Ejido n'a pas pu - jusqu'à aujourd'hui-- obtenir des avantages, parce que son partenaire toujours a dit "qu'il n'y a pas de profits". Malgré cette expérience, il est en train de signer un autre accord avec un autre groupe d'investisseurs.

Les conflits pour la terre: un héritage inévitable

À la fin du siècle dernier une compagnie foncière a donné à un étranger (Nordhoff) tous les terrains situés dans la péninsule de Punta Banda. En 1917, le gouvernement mexicain a décrété que les terrains qui avaient été donnés à des compagnies foncières devenaient propriété de la nation. Mais M. Nordhoff reste le propriétaire. En 1930 le gouvernement demanda le lotissement de tous les grands terrains. La taille en devait être de moins de 200 hectares. En 1937 le propriétaire est mort. Il n'avait jamais fractionné son terrain. Sa femme devint la propriétaire. A sa mort et tous les terrains sont passés propriété de la nation et

restent à la disponibilité de "ceux qui les demandent" (INTERVUE M. VILLARINO).
Ainsi, en 1938 M. Leon Zamora, qui développait l'élevage depuis 19 ans, a demandé au gouvernement la dotation dun terrain de 500 hectares. Et même de la "Lengueta Arenosa", qui ne se l'était pas attribuée, car le sol (dunes et sable) n'était pas approprié pour l'élevage. En 1941 il a reçu un titre de propriété provisoire. Mais quand il est mort en 1957, tous les terrains sont passés à la nation. Il faut souligner que les dunes de la "Lengueta" étaient propriété de la nation depuis 1952.
En 1959 M. Cardoso, étonné de la beauté de la région, décide de devenir propriétaire de celle-ci. Il était un homme politique très proche du président de la République à ce moment-là (M. López Mateos). À la ville de Mexico, il présente une fausse héritière de M. Nordhoff. Et en 1962 lui devient propriétaire de 11 000 hectares sous la promesse d'en vendre 6 000. Il a partagé plusieurs terrains entre ses amis du milieu politique. Dans le cas de la Lengueta, M. Cardoso a obligé les propriétaires (2 étrangers et d'autres particuliers) de vendre leurs terrains à lui. Mais il a trouvé certaines résistances de quelques-uns. Au de part du président Lopez, M. Cardoso a perdu son pouvoir et, une autre fois, la propriété passe au pouvoir de la nation. En 1968 un groupe de paysans demandent au gouvernement une dotation de terre. En 1971, le gouverneur de l'état a donné son appui à l'Ejido. Et en 1973, le président de la république (M. L. Echeverria) a fait un décret où, officiellement étaient donnés 15 005 hectares à l'Ejido. Au même temps, plusieurs particuliers qui sont affectés par cette décision ont fait un appel au tribunal supérieur de justice contre cette démarche. Ce tribunal trancha en faveur des particuliers. Mais l'Ejido fut reconnu officiellement par un décret définitif du président de la république. Depuis 1973 des difficultés surgissent, car l'Ejido est né en affectant trois propriétés privées. Il faut souligner que toutes les disputes ont commencé entre les "ejidatarios" et les propriétaires privés. Aujourdhui, ils sont toujours les acteurs principaux du conflit. Mais ils ne sont pas les seuls, il y en a maintenant plusieurs.

Les acteurs sociaux

Il y a au moins une dizaine d'organisations où se trouvent les différents personnages qui représentent une diversité d'intérêts économiques, écologiques ou politiques. Mais la majeure partie d'organisations s'est constituée à cause d'un facteur commun: la propriété de la terre. Ensuite, je ferai une description des caractéristiques que possède chaque organisation.

Les propriétaires privés

Ce groupe possède un niveau de vie relativement haut, par rapport à tout lensemble d'organisations. Ils sont des propriétaires qui depuis quelques décennies développent des activités économiques commerciales qui sont étroitement liées au tourisme. En prenant compte de leur expérience, ils obtiennent des profits supérieurs au reste.
Depuis le 19 février 1991, ils ont créé une organisation nommée "Groupe de Promoteurs et Propriétaires de Punta Banda: Association Civil" (GRUPPUNBAC). Le principal objectif de cette organisation a été celui davoir une réponse de la part de tous les petits et grands propriétaires privés face au grave conflit de la propriété de la terre. Mais aujourdhui les circonstances sont autres, il y a de nouveaux acteurs et de nouvelles situations qui sont plus complexes quauparavant. Ainsi, depuis dix ans, plusieurs intérêts sont apparus.
Le GRUPPUNBAC a développé un rôle très dynamique et actif dans la zone. Il est intégré par des personnalités importantes dans le milieu politique ou d'affaires, qui connaissent bien les différents niveaux de gouvernement et possèdent assez de pouvoir pour avoir une influence considérable dans toute prise de décision. Ils ont des rapports étroits même avec les autorités de la municipalité, le département ou la fédération. Cette organisation n'appartient pas à une grande corporation ou confédération, soit politique, soit professionnelle, soit d'autre type. Son activité politique et son défi principal est de solutionner le conflit de la propriété. La seule façon de résoudre ce problème est d'atteindre un accord avec les ejidatarios.

Les Ejidatarios

Les caractéristiques de ce groupe sont différentes par rapport à la situation antérieure. Le bien-être social de ceux-ci est plus bas. Leur scolarité, leurs revenus et leur hébergement sont inférieurs par rapport aux autres. Les Ejidatarios présentent des conflits avec GRUPPUNBAC et avec les commerçants de la Bufadora qui se sont organisés dans une coopérative nommée BUFA-EN. De plus, ils ont une relation très conflictuelle avec leur partenaire, le groupe "Koster" dans le centre touristique "Baja Beach and Tennis Club". De même, ils sont en train de développer plusieurs activités liées au tourisme et des nouveaux accords avec des autres investisseurs.

Politiquement, l'Ejido est une organisation qui appartient au parti officiel (Parti Révolutionnaire Institutionnel PRI), au pouvoir depuis 67 ans. Ils sont affiliés dans une confédération paysanne nationale du même parti. Leur activité politique est soumise à une structure corporative et autoritaire. Mais ce rapport institutionnel, leurs permettent d'avoir des concessions du gouvernement fédéral. Cependant, le système politique mexicain est en train de changer. Le corporatisme de l'Etat ne marche plus tout à fait comme auparavant. Le gouvernement de la municipalité d'Ensenada et de l'état de Basse Californie n'appartient pas au PRI. Ils sont de l'opposition. En conséquence, la situation pour les Ejidatarios est plus complexe, car l'appui fédéral ne suffit pas. Par exemple, dans le conflit avec les commerçants de la Bufadora, ils demandent du gouvernement fédéral un traitement spécial. Mais ce dernier n'a rien fait, parce que les gouvernements locaux possèdent un certain pouvoir de décision dans le conflit. Pour cela, la situation de protection dont étaient habitués les Ejidatarios, n'est plus la. Le rapport paternaliste entre le gouvernement fédéral et les organisations de bases a changé.

La situation des Ejidatarios est très conflictuelle. En premier lieu, l'accord signé avec le groupe "Koster" a été un échec pour eux. Depuis la signature, ils n'ont pas obtenu aucun bénéfice. Leur partenaire toujours affirme "qu'il n'a pas de gains". Et l'Ejido n'a pas les moyens de prouver le contraire. De plus, les terrains où s'est développé ce projet, sont disputés encore entre l'Ejido et des particuliers (INTERVUE M. URIBE).

En second lieu, dans la Bufadora les Ejidatarios sont seulement un autre groupe de pression. Il y en a au moins quatre. Aujourd'hui la Bufadora se trouve dans une situation chaotique. La route principale a été envahie par des commerçants. S'aggisant du geyser marin, un scénario n'arrive pas à s'organiser. Tous les projets et les schémas n'ont eu aucun succès. Toujours le même problème, il n'y a pas un accord sur les propriétaires des terrains. De plus, pour des raisons politiques, les différentes autorités du gouvernement (de la municipalité, de l'état et de la fédération) ne se coordonnent pas pour atteindre une politique commune.

En dernier lieu, le conflit des Ejidatarios avec les propriétaires privés est le plus grave. Depuis la création de l'Ejido, le conflit est apparu. Plusieurs propriétaires ont été affectés et ils ont réfuté les décrets du gouvernement. Jusqu'aujourd'hui, il n'y a pas une carte du terrain que tout le monde accepte. Et la justice n'arrive pas à mettre d'accord les différents acteurs.

Les investisseurs de projets touristiques

Dans ce groupe nous considérons tous ceux qui possèdent des investissements dans la région, comme le groupe "Koster", ou ceux qui sont intéressés à faire des investissements. Ils peuvent être des investisseurs locaux, régionaux, nationaux ou étrangers. Sans aucun doute, ces deux derniers possèdent plus d'expérience, des capitaux et des ressources par rapport aux investisseurs locaux. De plus, les groupes nationaux ou étrangers possèdent des relations politiques de haut niveau dans le gouvernement. Dans ce cadre, ils peuvent développer de grands projets avec l'appui du gouvernement. C'est le cas du groupe "Koster".

Ces groupes peuvent changer le visage traditionnel de développement de la région, qui n'a pas connu de gros investissements. Mais avec le "Baja Beach & Tennis Club", des nouveaux projets de grande taille ont surgi. Mais les conflits de la propriété restent les grands obstacles pour les investisseurs.

Les commerçants établis sur la Bufadora

L'activité commerciale a suivi une croissance extraordinaire, mais dans un désordre complet. La "zone commerciale" est composée de commerces tout à fait improvisés, qui se sont situés à côté de (ou sur) la route. Ainsi, il y a une dispute entre quatre organisations différentes pour gérer l'activité commerciale. Ces deux situations sont la conséquence de l'absence de planification et d'intervention de la part du gouvernement. Par exemple, la loi interdit la construction (quelque qu'elle soit) dans un périmètre de 20 mètres autour des routes. Dans ce but, la loi des transports et des communications n'a eu aucun effet.

D'autre part, les disputes entre les organisations ont créé un climat très tendu et des affrontements violents. Mais la croissance commerciale est en marche. En quelque temps, le nombre de commerces s'est multiplié. Par exemple, dans un recensement fait en 1989, il y avait seulement 35 commerces. En juin 1991, le nombre est monté à 71 établissements; 34 appartiennent à la société coopérative BUFA-EN. 6 à une autre société coopérative: "Servicios Turisticos Bufadora- Punta Banda". 11 appartiennent à l "Ejido Esteban Cantu". Et 16 n'appartiennent pas à aucune organisation, ils sont indépendants (CORTEZ & ALANIZ). En novembre 1991, le nombre de commerces a atteint un total de 97, dont 55 appartient aux coopératives; 22 à l'Ejido. Et 20 sont indépendants (SAHOPE). L'appartenance politique de ces gens est diverse et ils sont membres ou sympathisants des différents partis politiques. Par exemple les coopérativists possèdent des appartenances politiques différentes. A l'opposé de l'Ejido, ils soutiennent un rapport plus proche avec l'opposition. C'est à dire, avec le gouvernement local et régional. Ce le même cas, pour les commerçants indépendants.

La majeure partie de commerçants réside à Maneadero ou dans le centre urbain de l'Ejido. Jusqu'à aujourd'hui, les perspectives de gérer le développement de cette région sont pauvres, car la conciliation d'intérêts semble-t-il difficile.

Les écologistes et le gouvernement

Le groupe des écologistes le plus important est "Pro-Esteros". Ce groupe appartient à une organisation internationale qui s'occupe de la préservation des estuaires dans le monde. Les écologistes s'opposent à la construction d'une marina en face de "Baja Beach & Tennis Club". Ils possèdent certaine audience dans les médias.

Le gouvernement fédéral est l'acteur le plus important dans le conflit. Il a la responsabilité de gérer la propriété de la terre, soit dans la côte, soit dans la vallée. Le gouvernement de l'état et celui de la municipalité possèdent moins d'influence. Ils ne peuvent pas prendre de décisions à propos de l'attribution des propriétés et ils ne peuvent pas donner certains services publics, comme l'électricité.

La responsabilité majeure est celle du gouvernement fédéral. Plusieurs ministères au niveau fédéral doivent intervenir dans la région. Les ministères directement concernés sont les suivants: Ecologie et Développement Urbain, Marine, Réforme Agraire, Tourisme, Pêche et Agriculture. Il a deux priorités fondamentales. En premier lieu, l'élaboration d'une carte foncière où soient définis les limites de toutes les propriétés. En deuxième lieu, le gouvernement a la responsabilité de définir la concession de la zone maritime autour de la Bufadora. Il faut gérer et administrer ce centre touristique, en donnant des garanties à tous les commerçants sur la continuité de leur activité. Mais il faut qu'y ait un organisme privé ou public avec la responsabilité de l'organisation du commerce et du tourisme.

CONCLUSIONS

Cette région a connu une croissance extraordinaire de l'activité touristique pendant les dernières années. Mais le conflit de la propriété de la terre est un obstacle très fort pour le développement économique. Depuis la création de l'Ejido, le gouvernement n'a pas su gérer le problème foncier. Si ce n'est qu'il a donné de la terre aux gens qui en avaient besoin. Il a agit d'une manière non planifiée, en affectant plusieurs propriétaires qui possèdent un droit sur les mêmes terrains. De plus, la division des

propriétés, cèst à dire les décisions à ce propos, ont été pris à la ville de Mexico par des personnes qui ne connaissent pas la région. En conséquence, les définitions des limites qui se trouvent dans les cartes ne sont pas tout à fait correctes. Jusqu'aujourd'hui, il n'y a pas une carte du terrain que tout le monde accepte. Et la justice n'arrive pas à mettre d'accord les différents acteurs.

La coordination des ministères au niveau fédéral n'existe pas. Il y a eu des initiatives isolées. Mais la région n'a pas connu une politique intégrale qui coordonne les différents domaines de chaque ministère. De même, il n'existe pas non plus de la coordination entre les gouvernements de l'état et la municipalité.

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STATE AND MANAGEMENT OF COASTAL GEOSYSTEMS IN CUBA.

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ABSTRACT.

Oceanic and coastal zones such as swamps, estuaries and coral reefs are the habitats of an abundant diversity of animal and vegetable life and act as food supply sources for half of the global human population. This paper is aimed to show the present management state of coastal geosystems in Cuba with respect to their differentiation and delimitation, and factors such as coastal profiles, eroded zones, particularly sensitive to pollution, and physical and biological processes.

INTRODUCTION

The Cuban submarine platform - the widest in the whole Caribbean region - extends over 67,831 km^2, equivalent to 61% of isles and keys shaping the archipelago. The southern part, involving Batabano, Ana María and Guacanayabo bays, takes 60% of the whole platform. Within its limits the most valuable marine resources are found. Such territory is shallow in the first 30 meters from the shoreline. Further offshore, there are taluds of 60°-90° surrounding the key and coral reef barrier. Hence, biologic resources living in the shallow zone will be exposed not only to direct fishing activities but also to what is known as terra firma (or land) influence: fluvial runoff, shoreline changes, pollutant discharges, etc.

According to the present studies, there are about 5000 species of plants and animals living in the zone under study (pelagic planktonic species not included). Thus, we can find some 107 coral species, 180 sponge species and 47 gorgonian species. Certain species of sponge and gorgonian have direct economic value as sources of biologically active substances, and the coral reefs give shelter to species such as lobster and fish. Some 150 species have potential fishery value. Moreover, approximately 60 species live in coastal lagoons, which are strongly affected by industrial and household waste.

Cuba has many beaches - around 1200 km long - of high aesthetic-environmental quality. They constitute the main tourist resource. In the last few years, some signs of shoreline backward movement (the narrowing of the sand fringe) and natural profile change are evidenced by increasing sand losses.

This phenomenon is caused both by natural and human actions. The latter is due to sand extraction from the beaches and platform, the building-up of dunes, the clearance of natural vegetation and the establishment of inadequate vegetation.

Natural phenomena giving rise to beach erosion, are not exclusive to Cuba. They happen elsewhere in the world. It has been tested, for instance, that the mean sea level in the NW Atlantic Ocean rose over the last 100 years by 1.9 mm/year caused by atmospheric heating. During the last 50 years an increased storm activity has been also observed.

Wetland occupies 26% of forests in Cuba and 4% of the whole territory. The Zapata Swamp is the largest wetland in the Cuban archipelago and one of the most important and better preserved in the insular Caribbean. Furthermore, it contains valuable natural reserves of flora and wildlife and has a high level of biological diversity, specially in terms of water fowl.

Mangroves are the main forest in wetlands. In Cuba there are 4324 km^2 of mangroves, which are of prime importance for coastal protection.

All these resources are threatened by irrational ecological practices causing sometimes irreparable damage.

At present, one of the particularities of geographical sciences is their high level of specialization. We are increasingly far away from the old-fashioned research based on generalization. Now, we are able to study the scientific problems by multidisciplinary teams, integrated by different specialties such as hydrology, climatology, etc.

However, geographic research has been increasingly concerned with inland and high mountain problems, while oceanographers do more investigations on the open sea than they do on the shoreline. That is why some peculiarities of the coastal geosystems such as the dynamics, the preservation mechanisms and other processes related to them are neglected when man tries to transform them with the subsequent negative results on their long, medium, and short term profits.

WHAT IS A COASTAL GEOSYSTEM?

From 1902 until now there have been different coastal classifications. In the early 1970s the littoral geomorphology of Cuba experienced an important scientific development through studies carried out by Russian scientists (IONIN, PAVLIDIS, LEONTIEV, ZENKOVICH). Preference was given to coastal morphodynamic classification (SUAREZ, 1976).

Such classification divided the coasts into two large groups:

- an abrasion shore and an accumulative coast; and
- a very important sub-group, the abrasive-accumulative coast.

A coastal geosystem is not merely a coastal type. It is the result of the interrelationships and the interactions between nature and society, giving place to different environments.

In turn, the environment of a territory is viewed as a historically-shaped open system, resulting from the bilateral relationship between the nature-economy-population subsystems and the inner relationships within the society and nature. It is integrated by biotic, abiotic and socio-economic elements, which man, through his activity, contacts, modifies and uses in order to meet his necessities, elements to which man adapts himself (Nuevo Atlas Nacional de Cuba, 1989).

When considering the complex relationships, it is important to bear in mind that only a systemic approach, allowing us to provide the adequate management and protection to the coastal geosystems, can have good results. From such a systemic approach, the geosystem is a space-temporary unit consisting of a stable type of environment, from which the spatial boundary is determined by the territorial use and function (NANC, 1989).

The environmental map published in the New National Atlas of Cuba (NANC) in 1989 shows these Cuban coastal geosystems. However, this classification and delimitation was not very complete and less precise than expected. Such a cartographic representation has been also used by other authors (Marqués, 1988) to describe coastal types, for instance, in Spain.

In general, a lack of delimitation of coastal geosystems occurs partly because a wrong choice is made for the scale of the cartographic representation and partly due to the difficulties of an actual, comprehensive knowledge of what coastal geosystems really are. Coastal geosystems may undergo impacts, provoking changes in nature. And the consequences may cause the occurrence of ecological stress and variations of stability.

Sometimes, the ecological stress may be regulated (nature may be able to restore those changes in the long run) for the geosystem itself, which regenerates the former conditions, to similar or even new ecological forms. This shows a higher developmental level of the geosystem.

On the other side, the sources of ecological stress are not only caused by human activity. They may be produced by natural causes, by the impact of a given phenomenon, which may provoke changes in the geosystem with similar effect.

If the impact is produced by a combination of natural and anthropogenic factors, the recovery of the geosystem is doubtful and can happen only through the natural mechanics of self-regulation. Consequently, it is mankind that should help the geosystem to recover its former steady state, or to adapt himself to a new situation, useful to society.

Usually, beach coastal geosystems are the most fragile, because their main component, the dunes, are deposited on the littoral or migrate to the beach by winds, waves, and sea currents seasonally. This responds to a normal and well delimited dynamics in the northern shoreline of Cuba. Thus, there is an erosional period -from October to March - as a result of the cold fronts from the North (Fig. 1) with a light sea level increasing and the undercurrent phenomenon. This coincides with the period of low water. A recovery period is present from April to September.

Among the most frequent sources of ecological stress to the coastal geosystems of beaches from the human activity there are:

1) sand extraction,
2) clearance of dune vegetation,
3) building on the dune,
4) mangrove cutting, and
5) hydrotechnical works on the shoreline.

As far as natural ecological stress is concerned it may be produced by the occurrence of:

1) frequent cold fronts over the mean hyperannual (20) during the winter season,
2) sea-swell,
3) hurricanes with strong winds and/or heavy rains over 110 mm in 24 hours during the mean maximum hyperannual (PEREIRAS, 1989).

When both natural and anthropogenic factors are combined, changes may be irreversible for such a geosystem. As a consequence, man will have to use very expensive techniques when recovery of original systems is required.

A coastal geosystem is a littoral geographic geosystem, indicated by the geographic feature of the environment to which, it is assumed, its natural or socio-economic activity is of high importance. Its limits or boundaries are:

- through the ocean, to the edge of the influence zone in the littoral stream and
- the morphology of the submarine bottom which in turn strikes on the type of wave beating on the coast;
- through the land zone, the limit of the saline river wedge, the specific coastal vegetation or the salpeter influence, by the relief morphology or changes in the natural or anthropogenic landscape delimiting the boundaries; laterally, by the geographic feature of coastal type or by its functionality.

These transitional boundaries or edges are, in general, common to each other and they are not rigid.

Doubtless, within the coastal geosystems, those of higher importance to Cuba are the beaches. The interrelationship of the sea, the littoral zone and the inland waters, and their transformations under the influence of both extreme meteorological events and anthropogenic impact, determine the dynamics and preservation of such a coastal geosystem. Hence, the necessity of knowing these processes in order to conduct the efforts to counteract their negative consequences on our beaches becomes obvious.

One of the most important coastal forms in Cuba, like in the rest of the Caribbean Basin islands, consists of specific hydrogeomorphologic systems with the following main components:

- submarine platform,
- beach,
- littoral dunes, and
- coastal lagoons with mangroves habitats.

The main factors influencing the shape and the dynamics of such systems are geologic-historical factors which characterize recent stages of neotectonic processes and oceanic eustatic oscillations, solid and liquid fluvial runoff, and surges acting on the coastal zone.

Each component plays a specific role in the dynamics and the development of the coastal geosystem. Hereby the dunes are the most dynamic and influencing components in beach preservation.

Dunes guarantee beach stability, width, height, and slope, and protect the sand dune field.

Coastal lagoons are typical of such low coasts, inhabited by mangroves. To these lagoons drain in general small rivers, crossing through low coastal lands, where also sea water exchange occurs. A typical example of such a coastal geosystem is observed in Playas del Este (Eastern Beaches), as it is shown in Fig. 2. From the 1950s, this zone has experienced a steadily increased tourist-leisure activity.

For developing tourism in Playas del Este the first need was to urbanize the area with the aim of creating minimal necessary conditions for a tourist infrastructure (roads, hotels, restaurants, snack bars, etc). This caused impacts on the natural landscape, just like a trigger for a series of chain reactions, which were difficult to extrapolate to the future. The list of impacts may be summarized as follows:

- Lagoon dredging and canalization;
- Destruction of mangroves and coastal dry forest;
- Road system and building construction;
- Low zone filling-up; and,
- Waste solid and liquid dumping in the river and the lagoon.

In the following six schemes we can recognize the modifications to the coastal beach geosystem of whole profile in the third lower section of Itabo river.

- *Natural state*

The influenced area of the third lower section of Itabo river (Fig. 3) in its natural state was made up by an accumulative plain stretching about 500-900 meters width, limited to the S by the Alturas del Norte de La Habana (Northern Havana Heights), with a slope of about 10 meters height. Two zones are differentiated in the plain: one, to the north, in the shape of a coastal fringe, made up by sandy grounds with a vegetation common to low sandy coasts; and the other, southwards and lower, a swampy zone covered by a mangrove vegetation possibly reaching to the sea when the sand dune field is flattened during the great floods.

In its natural state, the area is featured for being a whole profile beach.

Studies allow us to distinguish the following different stages:

February 1956

In this stage (Fig. 4) considerable variation was observed in the marine accumulative plain. The zone corresponding to the mangrove lagoon was completely reworked, due to filling-up and building construction in the area of Boca Ciega.

In Santa María del Mar there was a similar situation. Private clubs, linked to each other by a longshore pedestrian way, were built on the dune field. As it is observed, the riverbed became more definite and divided into two main branches that joined again near the mouth. However, the fluvial water keeps flowing through the lagoon, which makes easier the mangrove growing.

On the other hand, the first trend during the beach parcelling was to eliminate the dune field, lowering and terracing by the area. The main road, conceived as a principal artery for the future urbanization, was traced behind the dune field. Finally, both sides of the main road were built-up. When this step was adopted, the beach lost almost a third part of its inland extent and a similar quantity of its sand reserve besides the whole destruction of the beautiful and useful vegetation typical of this shoreline (SUAREZ MORE, 1976).

November 1970

During that time (Fig. 5,) urbanization was expanded throughout the area. The lagoon was dredged in its central part for recreational purposes and it was then when the plan of the communication channel to Mégano was made. This channel is in the shallow zone and drains the fluvial water across the mangrove.

Ground was also filled-up in other parts. Communication to the lagoon was reduced and even stopped for one of the possible riverbeds observed in the previous scheme.

New roads and pathways were traced, among them the one giving access to the site where later the Itabo Hotel was constructed. Such changes do not represent only a more extended territorial urbanization, but also provoked a relief modification, since the areas surrounding the main course, already well defined by other civil constructions of Itabo river, were filled-up.

The main road constructed on the sand dune field was extended until linking Santa María del Mar to Boca Ciega. In that period there was a major sand extraction for building purposes.

Original vegetation was cleared away and casuarine forests were planted. Casuarine grows easily in every soil. The trees reach over 25 meters height, by which they become wind breaker curtains, making it difficult for sand

accumulation on the dune fields and the free passage of the sea wind landwards.
Other difficulties related to casuarines were their features such as the trunk weakness of their upper portion; insufficient rooting on the sand; and the thin branches, make them not very resistant to hurricane winds. A complete forest may be uprooted with the subsequent danger to buildings, aerial electric facilities and human beings. Also, their thin branches and filiform leaves fall down all over the year to result in a dense carpet of fallen leaves covering the sand. They are very difficult to pick up. Moreover, the flattening of the dune field and the planting of such a tree on the fringe provoked growing losses of sand with the subsequent beach deterioration.
During these years there was again a strong activity of sand extraction of the littoral dune.

June 1982
This state (Fig. 6) corresponds to the situation brought about during the passage of a cyclone on June 18 and 19, when rainfall was registered over 700 mm for a period of less than 24 hours and affecting the whole area of Playas del Este.
This was the most important meteorological event ever recorded in the zone under study. High flooding was experienced, and the level of the Itabo river rose up to 6.225 meters above sea level under the Vía Blanca bridge. The flatness of the relief and the low capacity of the river basin to drain water produced extensive inundation of the locality which was completely flooded. The water level reached, for instance, to a maximum height of 1.40 m in the middle of the residential neighbourhood of Boca Ciega. Needless to say that catastrophic effects on the landscape and the facilities occurred. Even though such extreme meteorological events show a low probability of occurrence, they mostly result in a disaster.
As it was calculated, more than 90,000 m of sand (Institute of Geography, unpublished) were removed to the sea and the mouth of the Itabo river shifted westward from the former one. Some 200 meters of the main road were completely wrecked. The shoreline and the beach profile were reshaped. Consolidated sand underlying the littoral sand dune was exposed.
Other effects were the transport by the flood to the coast of different materials such as clays, stones, vegetation, etc., that decreased the beach quality.
The strength of the fluvial water damaged the approaches of the wooden bridge in Boca Ciega. Water flowed away by the streets perpendicular to the beach just like riverbeds on street intersections. The littoral sand dune was broken in different parts, several houses collapsed with the subsequent deaths of their residents as a result of water action on the foundations.
As referred by some people living there for many years, this is a zone of frequent floods; however, they are of higher magnitude since the road leading to the Itabo Hotel was constructed.

April 1993
Since 1982 until present, the area has experienced some alteration (Fig. 7). Some of them are caused by the need to recover from the damage by the cyclone, including the continuation of beach improvement, and others by tourist development. When comparing this scheme to the previous ones some changes can be noticed:
- The beach partially reestablished its balanced profile. Sand was protected by sacks placed in the manner of a "fence" in order to avoid aeolian movements of particles until the new vegetation planted grows up.
- The road section, wrecked when the 1982 flooding occurred, was reconstructed.
- The Itabo Hotel construction was completed. For operating purposes it was necessary to fill up some sections of the ground under the hotel and the road leading to it. This road crosses over the pluvial drain channel of Santa María del Mar, allowing the water to pass through concrete pipes; it runs parallel to the channel and bifurcates to surround the mangrove situated to the SW of the Itabo Hotel. As a consequence, the water circulation to such vegetation is avoided.
- There is a cleared and flattened area -shaded on the map by inclined lines - that is becoming a garbage dump. We found different kind of waste materials such as rubbish, debris of casuarines, etc. Therefore, the channel is almost filled up in certain sections.

- In general, all these modifications (particularly the roads) caused some relief variations that, in turn, influenced negatively on the natural conditions of the territory.

Despite the steps set about for recovery purposes, this area still has some problems such as:

- prone to flooding;
- a low water circulation into the lagoon (facilitating the annoying proliferation of mosquitos);
- the mangrove death, etc.

Taking into account the territorial evolution from its natural or semi-natural state until April 1993, a map on the state predicted for the third lower section of the Itabo river (Fig. 8) was prepared. Such a cartographic expression shows some proposals for a solution besides the steps already taken by the tourist chains and the municipal authorities which must be revitalized.

Our proposals are:

1) To open another outlet seawards. In case of heavy rains this outlet will avoid both the area surrounding the hotel and the residential zone of Boca Ciega becoming flooded. This outlet must be opened by itself and only in case of extreme floods. It will be located in the place where the littoral sand dune was broken in 1982 (Fig. 6).

2) To eliminate the road section between Santa María and Boca Ciega, and facilitate the access to the residential part of the latter through an extension of the road to the Itabo Hotel (the construction of a bridge is required).

3) The sand retention must be continued, using textile fences or palisades, etc., in those places in which vegetation, preventing the inland sand migration by winds, is not established yet.

4) To eliminate the dead mangrove in order to improve the environmental aesthetics of the area.

5) To improve the water circulation in the lagoon by both the cleaning the margins of waste materials which are accumulated during the construction of the hotel and the roadway, and a better location of the drainage and communication pipes o the roads leading to the hotel.

6) To reforest the river and lagoon margins with mangrove species in order to avoid fluvial erosion and the sediment migration.

7) To solve completely the present problems of the sewerage system and the pluvial drainage in urban zones.

Note: The English translation was fulfilled by María Teresa RODRIGUEZ COPPOLA from the Institute of Geography of Cuba.

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Fig. 1. Annual cycle of the general profile of the eastern Havana Beaches.

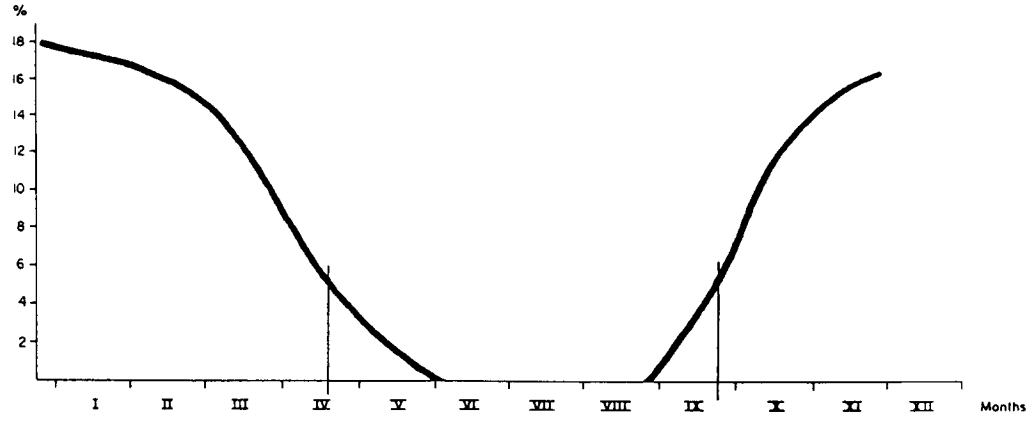
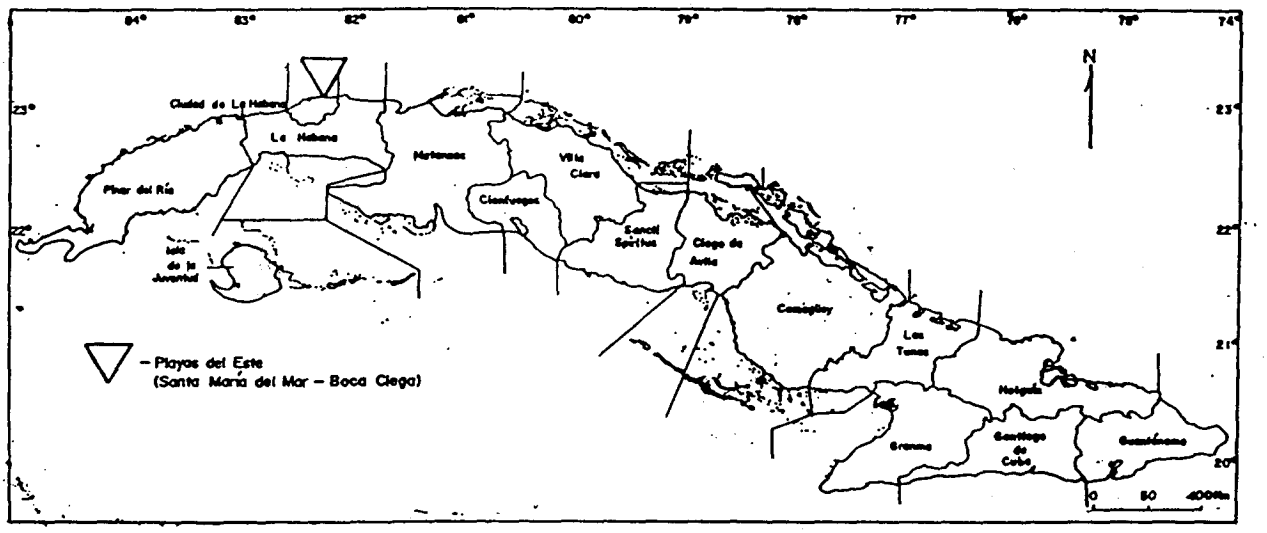


Fig. 2. Locations of the studied zones



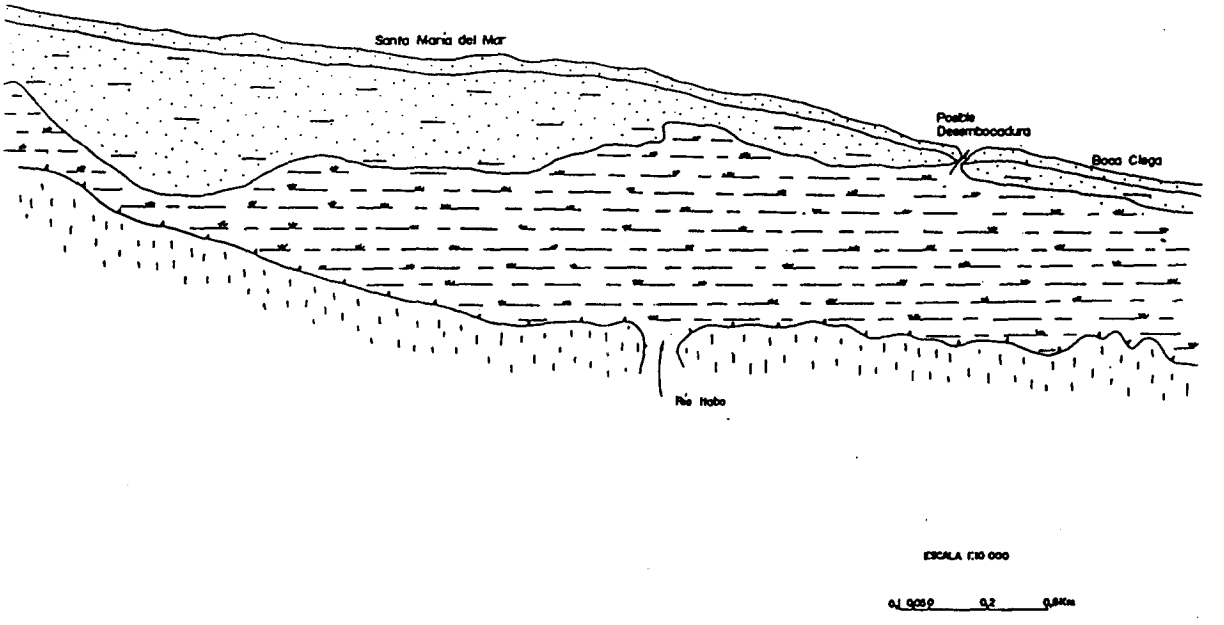


Fig. 3. Natural situation of the Itabo river discharge area (Río Itabo).

Fig. 4., 5 & 6. Situation of the Itabo river discharge area (Río Itabo, low third) of February 1956, November 1970 & Juin 1982.

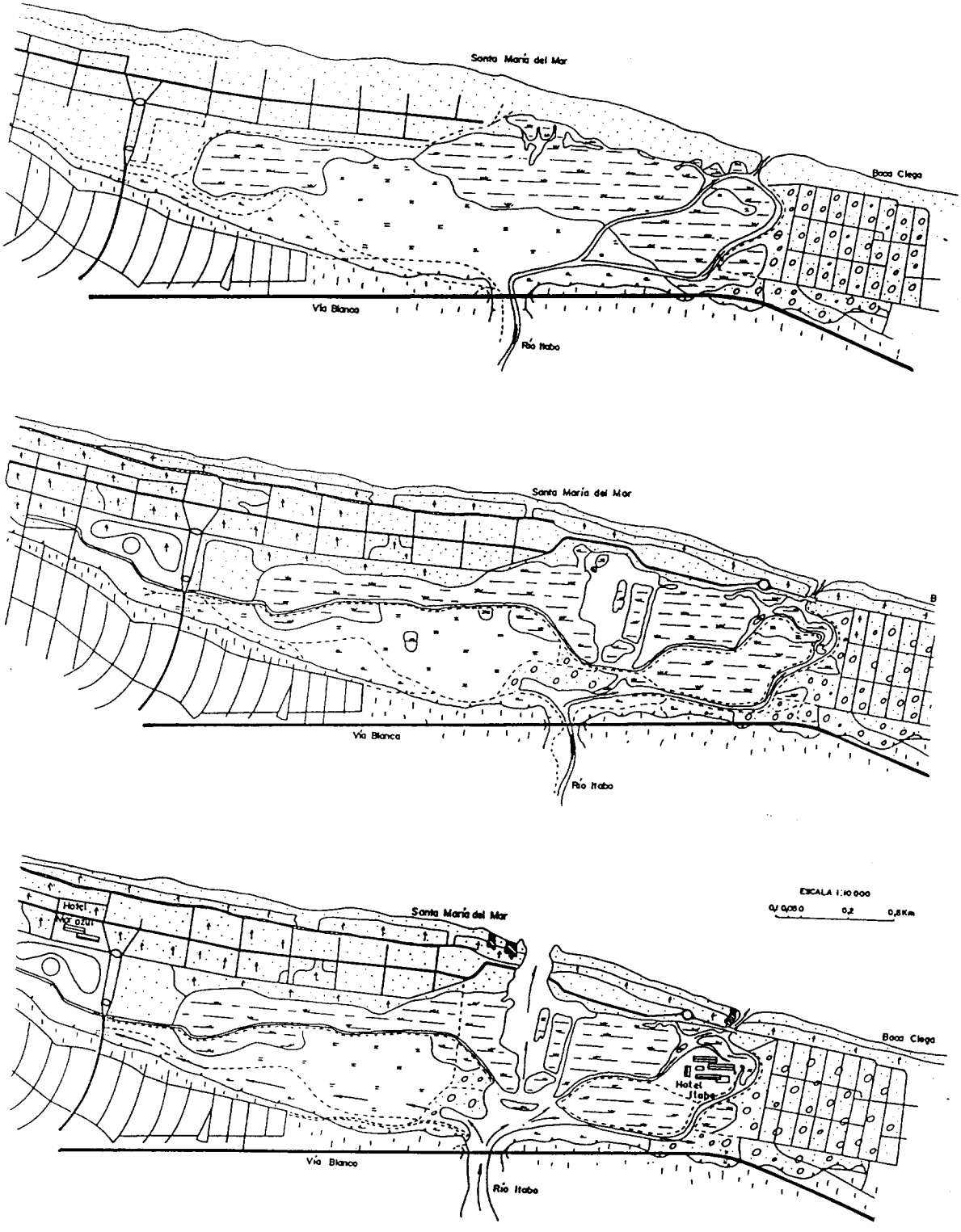
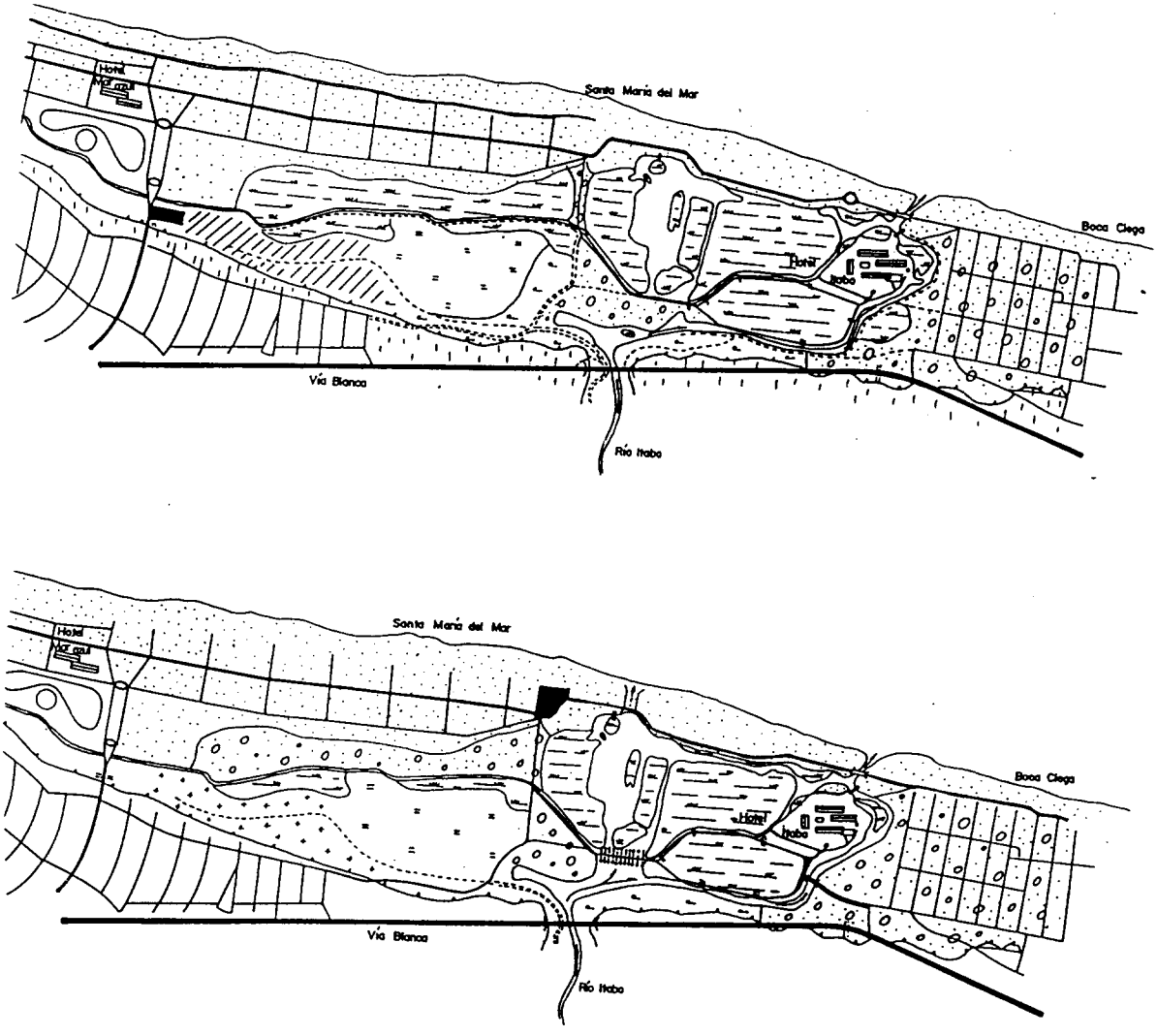


Fig. 7 & 8. Situation of the Itabo river discharge area (Río Itabo, low third), April 1993 and predicted situation.

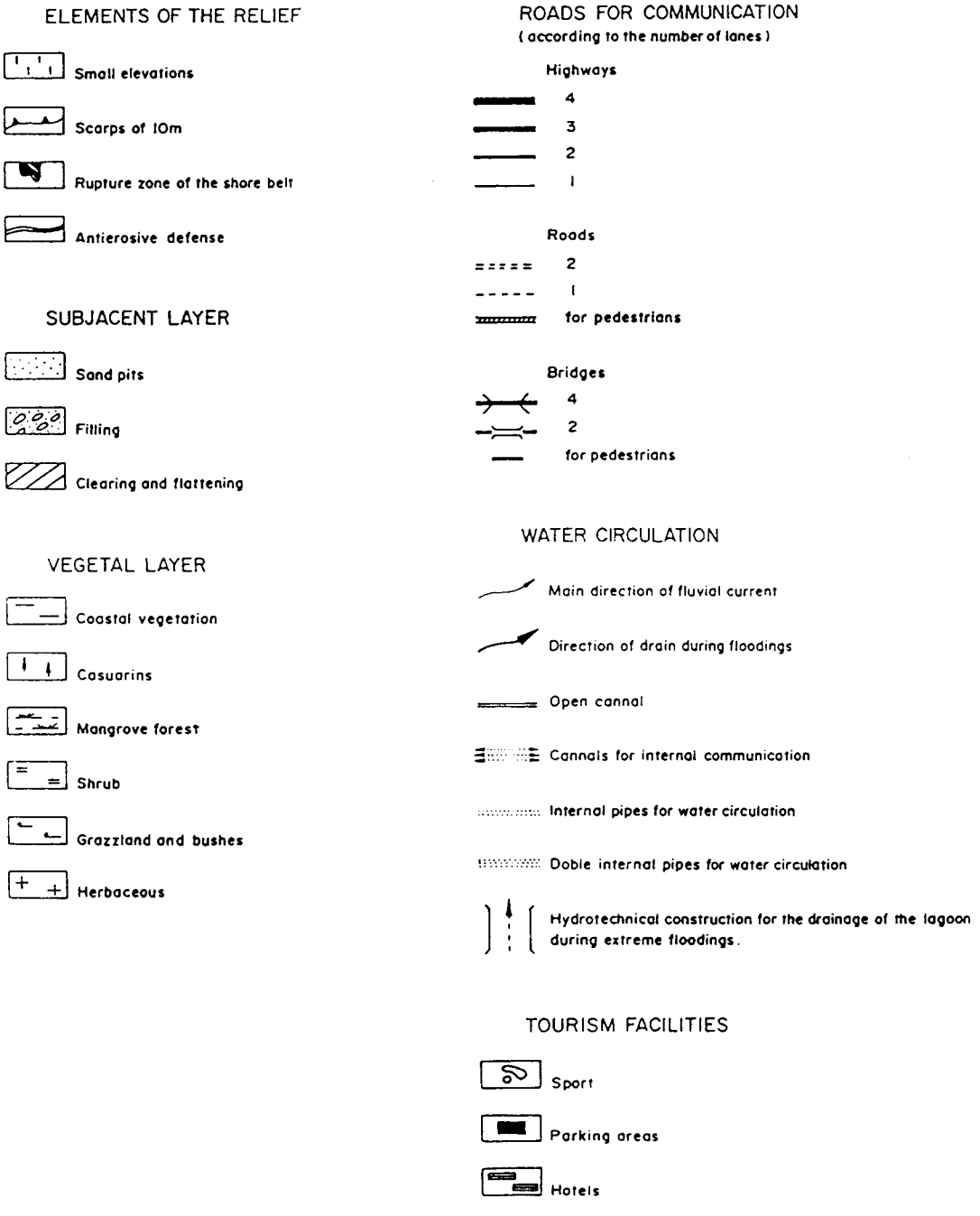


Forecasted condition of Itabo's river low third.

ESCALA 1:10 000

0,1 0,050 0,2 0,3 Km

Key (same for all figures)



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IMPLICATIONS OF PHYSICAL ENVIRONMENTAL CHANGE FOR COASTAL ZONE MANAGEMENT[1]

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KEYWORDS: Coastal Zone Management, coastal erosion, coastal defence, conservation, natural resources, socio-economics.

ABSTRACT

The effective management of physical environmental change in the coastal zone requires a balanced evaluation of the resources at risk, taking into account the geological and sedimentary inventory, the socio-economic interests at local to regional scale and wider conservation and environmental concerns. The chosen remedial solution should be appropriate both to the value of the threatened resources and to the forecast of future change derived from the scientific analysis and understanding of the processes of change within the coastal zone.

INTRODUCTION

The coastal zone occupies the triple junction of the earth's atmospheric, marine and crustal components and is subject to physical environmental change over a wide range of time-scales. The interaction of these components has a major impact on this complex boundary zone. For example, torrential rainfall over the hinterland may lead to enhanced soil erosion and increased sediment delivery to deltas, and coastal waters; submarine earthquakes and their consequent tsunamis may result in the catastrophic marine flooding of low-lying coastal land; and changes in the regional climatic regime may lead, through a modification of the wave climate impacting on the shore, to net erosion of beach material and subsequent coastal recession.

The natural variability of physical interaction in the coastal zone is becoming increasingly complicated by Man's exploitation of its material inventory and his disruption, both locally and remotely, of the natural sedimentary processes affecting that inventory. Coastal construction such as breakwaters and other hard-engineered coastal defences, and reclamations for port and airport development may have a significant impact on the natural sediment transport regime, restricting the provision of sediment to previously well supplied shores. The practices of coral rock and beach sand mining, and sea bed dredging for aggregate production and navigation may similarly alter the natural sedimentary regime. Degradation of the health of coral communities and other carbonate-fixing biota as a result of tourism-related activities and unsustainable fishing practices is another of Man's unwitting contributions to coastal change.

This paper focuses on the implications of physical environmental change in the coastal zone that may reasonably be measured and forecast by scientific study and analysis. The paper stresses the importance of understanding these changes not only in the local context but also within regional and even global perspectives. Finally, it considers the options open to coastal managers in controlling, and remedying the effects of, coastal change, taking into account both the asset value of the coastal resource under threat and the coastal population dependent upon that resource.

MANAGEMENT OF CHANGE

Catastrophic events impacting on the coastal zone such as tsunamis and cyclonic surges cannot be predicted with accuracy and are difficult, if not

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impossible, to plan for, other than with arrangements for the emergency evacuation of the coastal community at risk. Other changes, such as coastal recession, the saline intrusion of a coastal groundwater resource, or the degradation of coral health are more gradual and measurable over the longer (perhaps decadal) term. Their consequences are thus predictable. These latter changes may present serious potential problems in their cumulative effects, but they do allow the possibility for the management of their consequences and, in some cases, the opportunity to carry out remedial or regulatory actions to control their causes.

Physical coastal change - the issues

- *Catastrophic flooding*
- *Loss of beach material*
- *Coastal recession*
- *Siltation*
- *Saline intrusion in groundwater*
- *Deterioration of coral, mangrove*
- *Demand for construction aggregates*

Knowledge of the nature and scale of physical changes in the coastal zone and an understanding of the processes that are forcing those changes are prerequisites for effective coastal environmental policy-making and management. Without such knowledge the consequences of the changes on the coastal resource cannot be properly foreseen, nor can sensible measures for remedying their effects and, if possible, controlling their causes be implemented. It is important that proposals for such remedies or controls are formulated with a knowledge of the value of the coastal resource that is at risk or otherwise subject to change mindful of the regional or even international perspectives as well as the local.

Proposed options for solutions to assist in the management of physical environmental change should be based on the best possible information of the geological (including sedimentary) inventory and an understanding of the processes acting on that inventory. The information should relate not only to the site, but also further afield to the district or region, for example to the adjoining hinterland where land-use changes may be contributing to significant changes in sediment delivery to the coastal zone. If the inventory has been inadequately surveyed and the processes and their causes have been misunderstood or misinterpreted leading to the provision of misguided, if well-intentioned, advice, then, at best, the financial outlay on remedial or controlling actions may be wasted or, at worst, such waste may be compounded by aggravated problems of coastal change.

The worldwide spend on attempts to control coastal change and remedy its effects is enormous, running to billions of dollars annually. The budget for the Netherlands alone, where there is a national policy of maintaining the coastline in its 1990 position, runs to US$ 30M (Rijkswaterstaat, 1990). Annual capital expenditure on coastal defence in England runs at some US$ 150M, while spending on coastal defence in the United States of America probably exceeds US$ 1,500M. Some defence schemes in the United States are on the grand scale and reflect the perceived high value of the real estate that they are intended to protect. Many of these schemes, however, have been unsuccessful and have themselves contributed to the deterioration of the resource value of the real estate that they were designed to protect.

INVENTORY AND PROCESS

The occurrence of physical change in the coastal zone is the norm. The physical inventory of the zone is being modified continually, responding to the interaction of forces within its component marine, crustal and atmospheric environments. Not all changes are necessarily for the worse, although this is a common perception of any departure from the *status quo.* In reality what is bad news for some people may be good news for others. For example, the loss of land through the erosion of soft cliffs may provide the beach materials that will, in due course through the process of longshore drift, protect an adjoining shore. Even the net erosion of beach sand may simply lead to a redistribution of these materials, with accretion on an adjoining shore. On balance, however, coastal change is disruptive and there are many changes affecting the coastal zone which provide cause for our concern. That concern may take various forms. It may be the threat to coastal

infrastructure or tourism investment due to coastal recession, or the reduction in the recreational value and aesthetic quality of a tourist beach through beach erosion. It may be a fear for the loss of what is perceived to be a conservation site of international importance. At the other end of the scale, it may be a realisation that the safety and livelihood of the coastal population is under threat as a consequence of sea level rise.

Physical coastal change - the scientific analysis

- Determine the geological/sediment inventory

- Identify the processes of change

- Determine the dimensions of change - spatial and temporal, past and present

- Identify the factors forcing or contributing to change

- Forecast the dimensions of future change

It is a task for the scientist to establish the inventory of the coastal zone and to develop a knowledge of the processes, establishing the spatial and temporal dimensions of change, and an understanding of the forces controlling that change. In particular, the scientist needs to distinguish clearly between the natural forcing and the contribution or disruption due to Man's activities. The scientist should consider the scale of the forcing and its possible disruption by Man, whether global, as in eustatic sea-level rise; regional, as in significant land-use changes; or local, as in the effects of Man's structures or activities in the coastal zone itself. An assessment of the variability of the various forcing factors is also important, whether tidal or, seasonal, or extreme events such as cyclones, which may be particularly significant in bringing about coastal change in some parts of the world. The task for the scientist is to quantify the physical manifestation of coastal change relating to a range of time-scales and analyze its causes. On the basis of this information, he should aim to predict future change and estimate the spatial and temporal limits within which such change is likely to occur.

VALUATION OF THE COASTAL RESOURCE

It may be important to ensure that the identified concerns relating to coastal change attract the attention of the appropriate policy-makers, and through them funding agencies. If so, there is a need to prepare a clear statement that spells out the risk to the coastal resource, the geographical extent and time-scale of that risk, and its likely socio-economic and environmental consequences. There is also a need to stress why coastal change is a matter of concern. Establishing the asset value of the coastal resource is an essential step in assessing the justification for expenditure on works designed to control the threat presented by coastal change, and to remedy the effects of change on that resource. While the valuation may be dominated by local and district socio-economic interests, such as agriculture in deltaic areas or tourism development on reef-fringed, tropical shores, there may be instances where the valuation is strongly influenced by wider, national and even international interests. Examples of the latter are the marine park conservation areas of the East African coastal zone, and the Karavasta lagoon and similar wetlands in the Adriatic coastal zone of Albania. The value attached to conservation sites of international importance can be gauged by the substantial level of funding for research and management that they attract from donor agencies.

The asset value of the coastal resource may change significantly with time. In north-western Europe the value of agricultural land has declined in recent years and policies towards its defence from erosion and marine flooding in the coastal zone are under review. In the United Kingdom the economic and legal implications of releasing previously reclaimed salt marsh currently in grazing or arable use back to the marine environment by the engineered breaching of sea defence embankments that would otherwise require expensive maintenance are being investigated.

A prime task for the socio-economist is the preparation of a statement of the wealth of the coastal community upon which the coastal change is impacting or could be expected to impact.

Another is the estimation of the economic consequences of coastal change covering a range of temporal and spatial scenarios within the limits specified by the scientific study results. The economist is also involved in the costing of proposed remedial or controlling measures. It may be that the cost of any such measures, whether within or without the coastal zone, would outweigh the projected economic loss in the coastal zone arising from coastal change. For example, deltaic environments in many parts of the world are deteriorating as a result of Man's engineered control of rivers for irrigation and related hydroelectric schemes, thus markedly reducing river flow and the discharge of sediment to the delta. The cost involved in the reinstatement of natural levels of sediment discharge through the major redesign of schemes is likely to rule out such an option, whatever the forecast economic losses to the coastal community.

THE MANAGEMENT SOLUTION

The coastal manager needs to know what can realistically be done about coastal change, and what the options are. The 'do nothing' option deserves careful consideration. While this may be perceived as leading to economic losses, it may be the most attractive option from an environmental viewpoint. In some situations the manager may have no alternative but to follow such a course. In cases of coastal recession, this option may involve the implementation of a planning policy of restricted development within the coastal fringe. The coastal district of North Norfolk in the United Kingdom provides an example of such a planning set-back policy.

Physical coastal change - management questions

- Is remedial action essential? desirable? undesirable?

- Who is concerned? Who would lose and who would gain?

- Can the forcing/contributing factors be controlled or regulated?

- Is a remedial solution technically feasible?

- Is the solution a local matter only?

- Does the solution involve regional, or even international cooperation?

- Is the solution affordable? sustainable? environmentally sound?

Controlling the forces responsible for coastal change may be a possible option, at sites where the natural processes have been disrupted on a local scale. Examples of such sites are those where beach erosion has been exacerbated by inappropriately designed concrete sea walls, or by local activities such as beach sand mining and nearshore dredging. Mostly, however, the forces are likely to be regional, for example, climatic variability; or even global, notably eustatic sea-level rise. These forces are well beyond the manager's capacity for control.

In cases of coastal erosion, the manager may consider the option of engineered defence. This is by nature a local solution and needs to be matched not only to the value of the resource subject to change and the variability of the forcing processes but also to the availability of suitable materials for coastal defence engineering. If the defence option involves soft engineering, the works may comprise both restoration and maintenance, the latter of particular importance if there is a need to take account of anticipated extreme forcing events. Finally, there needs to be consideration of the environmental impact of works associated with the coastal defence programme.

CONCLUSION

Responsive management actions can be carried out at all scales, from local coastal defence schemes, to policy changes seeking to modify land-use practice in the hinterland, and international initiatives designed to temper Man's disruption of the global climatic regime. The success of any such initiative as it relates to local coastal management depends on the correct scientific analysis of the coastal change processes, the realistic assessment of the resource value, and the relevance of the chosen remedial and control measures.

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LITTORAL CELLS AND BUDGET ANALYSIS FOR SEDIMENT MANAGEMENT IN WEST DORSET, ENGLAND

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KEYWORDS: cliff, bluff, erosion, shingle, beach, shoreline Chesil.

ABSTRACT
This paper illustrates systems approach to managing littoral sediment for coastal defence. Changes are characterised in terms of inputs, transfers, storage and outputs of sediment within a process unit or littoral cell. It identifies appropriate methods of investigation, data analysis and element coupling needed for quantification of a sediment budget. In the West Dorset study area, complex links have been demonstrated between eroding cliff sediment sources and the beaches that they supply. In particular, the status of Chesil Beach is re-examined. The impacts of past human activities and possible future interventions are assessed using the results produced. Details are provided of the ways in which this information has assisted management.

INTRODUCTION

Management strategies based upon traditional structural means of coastal defence implemented at site-specific scales are increasingly being questioned in terms of their functions, environmental impacts and costs (Pilkey and Howard, 1981; Nordstrom, 1994). In identifying alternatives, most authorities advocate maintenance of a stable natural process system, assuming that this is known or can be reinstated. For example, a healthy beach is often cited as the best form of coastal defence (Brampton, 1992), that also has amenity value. However, such features frequently depend upon continued erosion of adjacent coasts. It is also necessary to consider the historical legacy of past activities that in many cases has modified natural systems and significantly constrains future options. Long-term sustainable occupation and use of shorelines without recourse to widespread hard protective structures therefore demands innovative management founded upon sound process and landform understanding. Littoral sediment must be managed as a valuable resource so as to minimise needs for costly and potentially harmful engineering interventions.

In working towards these objectives, this paper (Brunsden and Thornes, 1979) in which coastal changes are characterised in terms of inputs, transfers, storage and outputs of materials and energy. The method is based upon the identification of relatively independent littoral sediment cells and partially dependent sub-cells according to transport boundaries (Bray, et al., 1995). The sediment sources, stores, sinks and linking pathways are investigated to develop a geomorphological interpretation of the long term trends that the processes are working towards. A final stage is to quantify the components and formulate a sediment budget (Clayton, 1980). Future conditions can be estimated by extrapolation of contemporary trends and adjustments are possible to incorporate the effects of changing environmental conditions, or management (e.g. coast protection structures).

This paper presents a case study covering the West Dorset coast of southern England. It has been developed from work initially financed by local authorities to investigate sediment supply (Bray, 1986) and transport (Bray, 1990). It identifies dependent sub-cells, the elements of their budgets and outlines appropriate methods of investigation, data analysis and element coupling needed for quantification.

The impacts of past human activities and possible future interventions are examined using the results produced. Such information is essential to address

growing conflicts between the needs for conservation of this coast and its coast protection functions. The diverse nature of the coastal study area means that the methodology and results are potentially of wider significance and their applications elsewhere are discussed.

THE WEST DORSET STUDY AREA

Attention is focused here, on a series of linked process units in the eastern part of the Lyme Bay "macro-cell" (Motyka and Brampton, 1993).

Bounded to the east by the major transport boundary of the Portland Bill headland and to the west by harbour structures at Lyme Regis, the shoreline comprises discontinuous shingle beaches with contrasting character either side of West Bay (Fig. 1). Chesil Beach, a linear shingle storm barrier extends 28 km eastwards from West Bay to the Isle of Portland and is for 13 km backed by the shallow Fleet Lagoon (Plate 1). Rising to over 15 m above mean sea-level and exhibiting exceptional longshore pebble size grading (Carr, 1969), the beach is of international scientific importance and also defends vulnerable low-lying land from flooding (Bray, 1992a). It is thought to be a finite product of the Holocene Transgression that exhibits reworking and slow onshore migration as present relative sea-levels rise (Carr and Blackley, 1974). By contrast, the coast to the west is fringed by much smaller pocket beaches at Charmouth, Seatown and Eype, separated by high headlands and backed by high eroding cliffs. The geology comprises impermeable Jurassic clays overlain by permeable Cretaceous sands in a classic landslide generating sequence (Plate 2). Its spectacular landslide topography is of great geomorphological value and is internationally important for its geological exposures.

Oriented to face the south west, the site occupies one of the most exposed locations on the southern English coast. Predominant wave direction is from the south west coinciding with the maximum fetch which extends into the Atlantic. Maximum wave heights approaching 9 m have been recorded during severe storms (Hardcastle and King, 1972; Draper and Bownass, 1983). The difference in the nature of the coast to the east and west of West Bay reflects the degree of protection afforded by the shingle beaches. The huge volume of Chesil Beach almost completely protects the land behind, so cliffs only exist close to West Bay where the beach is lower. To the west, the pocket beaches offer only partial protection so the coast is highly dynamic and a product of contemporary landsliding, sediment input and littoral transport. The majority of the study area remains natural and unprotected, but with some notable exceptions. Small parts have been developed as harbours or seaside resorts resulting in provision of sea-wall and breakwater structures at Chiswe, West Bay and Lyme Regis (Fig. 1). Not only do such practices incur significant expense, but they interfere with natural sediment transport and can result in detrimental effects elsewhere. Two piers modified in 1866 to protect the harbour entrance at West Bay are especially important because they have intercepted shingle transport and formed a new littoral transport boundary (Brunsden, 1992). There has also been a long history of beach shingle extraction from the Chesil (over 1.1 million m^3) and Seatown (up to 200,000 m^3) beaches. It has long been suspected that this practice was harmful, but hitherto it was hard to demonstrate whether Chesil, or the other pocket beaches were actually closed systems (finite and very sensitive to mining), or whether they might be open to sediment inputs (renewable and able to sustain mining at an appropriate rate). Thus, it was essential to understand the nature and extent of process modification so as to effectively manage the remaining natural beaches.

THE STUDY METHODOLOGY

A phased study method is outlined indicating the sequence of investigation from initial definition of objectives through to application of results towards sustainable littoral sediment management (Fig. 2). Spatial limits were ascertained by defining the local dependent littoral sub-cells according to known or probable sediment transport connections (Bray et al., 1995). Within the major spatial unit (Lyme Regis - Isle of Portland), five sub-cells comprising Chesil, Eype, Seatown , Charmouth and Spittles Beaches were identified. Neighbouring littoral sediment systems could then be excluded safely from detailed

analysis. The main objective was to relate the rapid sediment inputs from the dynamic sub-cells between Lyme Regis and West Bay to the comparatively stable and apparently closed sediment circulation system of Chesil Beach.

When compiling a sediment budget, a necessary task is to identify its elements to form a qualitative model of all sediment inputs, stores, transport and stores (Fig. 3). This is best accomplished by reviewing existing literature in combination with a brief site inspection and geomorphological landscape assessment e.g. Jacobsen and Schwartz (1981). In West Dorset, cliff erosion is an obvious input and supplies material to the beaches following storage in large landslides. Fluvial inputs are limited by the absence of suitable rivers. Fine sands, silts and clays are winnowed rapidly from cliff toe debris and lost offshore. Gravel remains to contribute to the beaches where it is subject to longshore transport and loss by attrition and beach mining (Seatown). This material (>2 mm diameter) is therefore the focus of attention. Landslides that surge across the foreshore at headlands form temporary longshore barriers to beach drift, but are eroded periodically to permit connections between beaches. Losses to, or gains from, submerged offshore banks were not known at this stage. Artificial beach replenishment has not been practised.

A second step is to quantify the main fluxes and flows of materials and analyze the timescales over which they operate. Therefore, research had to examine the qualities and quantities of sediments yielded from cliff erosion, together with its fate once it reached the shore. A holistic approach is advocated that includes intensive searches for relevant data coupled with original field investigations to fill gaps. This entailed investigations of cliff geology, rate of retreat, beach character and volume together with assessment of transport rates. It was important to identify possible losses, so investigation of the offshore zone was also necessary. Integration of research on the landward and the seaward sides of the of the shore is therefore essential in compiling the sediment budget. Although this work is aimed primarily at shingle, broadly similar methods are appropriate for all non-cohesive littoral sediments.

INVESTIGATION OF SEDIMENT BUDGET ELEMENTS

Cliff Erosion Input

All possible sources of beach material were examined, but the most significant inputs are provided by coastal cliff erosion. In simple terms the total volume of sediment yielded by cliff erosion is calculated as follows:

$$Q_e = L \bullet H \bullet R. \quad (1)$$

where:

Q_e is cliff erosion sediment yield ($m^3\ yr^{-1}$).

L is length of eroding cliff (m),

H is height of cliff (m),

R is mean recession rate ($m\ yr^{-1}$)

Sediment yield is therefore a function of the cliff geometry and rate of recession. The types of sediment liberated are also important because this affects their fate once they reach the beach. The geology comprises Jurassic clays, marls and sands dipping very gently to the south east. On the major hill tops these strata are unconformably overlain by Cretaceous sands including the Upper Greensand Chert Beds, a major source of beach forming gravel (Fig. 4 and Table 1). Variable superficial deposits mantle the cliff-tops and contain chert and flint gravel. The quantities of the different material types that would be released per unit of cliff retreat were determined by examination of the existing geological maps (6" Geological Survey fieldsheets) and literature (e.g. Wilson et al., 1958, followed by detailed field section mapping of selected geological units. A programme of sampling and sediment analysis were necessary to accurately profile these source materials. Results revealed that the thickest and richest gravel deposits existed in the backscars at Black Ven and Stonebarrow Hill.

Cliff erosion rates have been determined from analysis of changes in the backscar (cliff-top) and sea-cliff positions plotted from aerial photographs, old maps and a recent field survey, together covering the period 1901-87 (Fig. 4). Results revealed major zones of persistently rapid retreat

at the Spittles (2.2 m yr^{-1}) and Black Ven (0.9 m yr^{-1}) systems, where ground conditions are especially favourable and massive landslide embayments have formed (Plate 2). Elsewhere, backscar recession was intermittent and cyclic with single failures involving up to 30 m of retreat being followed by long periods of relative stability (Brunsden and Jones, 1980). Sea-cliff erosion is more steady and continuous, but over a complete erosion cycle, a similar amount of retreat is achieved so that the two cliff lines remain in equilibrium. Using this data, long term retreat in the order of 0.3 m yr^{-1} to 0.5 m yr^{-1} was calculated for the whole coast between Lyme Regis and West Bay. However, increased rates of retreat are generally noticeable since 1960, especially at Black Ven where a phase of intense landsliding has persisted since 1957 (Brunsden and Goudie, 1981).

The study area was divided into some 180 longitudinal segments of 100 m. Precise details of the nature and occurrence of ground forming materials (size lithology, cross-section area etc.) were summed within each segment and entered in a spreadsheet together with the appropriate segment erosion rates. Integration of these parameters produced sediment supply rates (compiled in Table 2) that were then plotted using a standard graphics package (Fig. 4). It should be noted that on a complex (compound) cliff coast, the supply process comprises three distinct phases:

(i) release from the backscar;

(ii) transport through the landslide system;

(iii) deposition on the beach from landslides (Bray, 1992b).

This means that short term variations in the material actually reaching the beach are possible due to storage within landslide systems. In fact, only 50% of gravel released by rapid retreat at Black Ven since 1957 has yet reached the beach. A further 15 to 20 years of rapid supply are probably required for equilibrium to be established. Nevertheless, results over the full 87 year study period showed that an approximate balance should exist between material inputs from the backscar and outputs from landslides to the beach when the full erosion cycle is covered (parallel retreat model).

Overall material yields are substantial, amounting to over 300,000 m^3 yr^{-1} (Table 2). Clay is the dominant material type (78%) with significant quantities of sand (17%), but only very small proportions of limestone (3%) and chert and flint gravel (2%). Yields are strongly concentrated in western parts (Fig. 4 reflecting their more rapid rates of retreat. Especially important are the high, rapidly eroding cliffs of Black Ven (Plate 2) that account for 50% of total yields. Particle size and abrasion resistance of the different material types determine their fate once supplied to the shore.The sandy and clayey strata are poorly consolidated and easily disintegrate to their constituent particles which are transported offshore by wave action. Only chert, flint and occasionally limestones are sufficiently coarse and durable to form pebbles and boulders that contribute to beach. Long term gravel supply is estimated as 6,362 m^3 yr^{-1}, although, a slight adjustment for storage within landslide systems was necessary to determine yields to the shore over the period 1901-87, giving a rate of 4,900 m^3 yr^{-1}. Gravel yields are concentrated almost exclusively in western parts and are negligible eastwards of Golden Cap where gravel bearing deposits are thin. The landslide complexes of Black Ven (61%) and Stonebarrow (28%) form the major sites of input and reflect the distributions of the thickest gravel bearing deposits and the zones of most rapid retreat. All sediment inputs should increase in the near future as large volumes of material within the Black Ven landslide systems reach the coast.

The landslides along the west Dorset coast can therefore be considered in terms of a flow of materials from backscar to the shore. Most material is rapidly lost offshore, but debris remaining on the foreshore affords protection against marine erosion to the cliff toe, thus instigating negative feedback and self-regulation of retreat. Only at the toes of very active landslide systems is debris supply sufficiently rapid to temporarily exceed removal and material accumulates on the foreshore as mudslide lobes that form new littoral transport boundaries. At

most points on the coast, marine erosion exceeds sediment input, fines are lost offshore and shingle beaches develop. The complete nearshore sediment circulation system is therefore characterised by complex interactions between the coastal landslides and littoral transport of the materials that they deliver.

Beach Storage

The quantities and nature of the shingle on the beaches represents the net result of the various fluxes and flows within the study area. The beach store was therefore investigated by a series of measured beach profiles and an intensive pebble sampling programme that involved analysis of 12,000 beach pebbles across 14 transects (Bray, 1990). Results are summarised in Table 3 and compared with corresponding details of the cliff gravel samples and also with data from Chesil Beach obtained from the literature (Carr and Blackley, 1974; Carr, 1983). These calculations suggest that coastal landsliding could easily be the source of all shingle on the three pocket beaches. In fact, a much larger accumulation of beach shingle would be expected if cliff input had been maintained at current rates since sea-level approached its present position 4000-5000 years ago. Since cliff erosion appears long established on this coast, the mismatch between cliff input and beach volume clearly suggests that major losses (output) must occur and Chesil Beach is the only substantial deposit in the area. It is also shown that pebble lithology and longshore size grading were similar on all West Dorset beaches including Chesil Beach. Slight variations are attributable to short-lived limestone pebbles supplied directly from the eroding cliffs. The beach pebbles are of similar lithology and size range to gravel supplied to the coast by landslides. Clast roundness and sphericity are greater at sea level due to marine sorting and attrition. Roundness and sphericity both increase to the east, perhaps indicating progressive abrasion of the angular cliff gravels as they are transported in this direction. Results therefore suggest that the west Dorset beaches, including Chesil, were previously connected, and shared a common shingle source.

Littoral Zone Shingle Transport

Littoral drift was measured directly by a series of experiments employing aluminium tracer pebbles (Bray, 1990). The tracers were efficiently recovered to a maximum depth of 0.45 m beneath the beach surface using metal detectors. Recovery rates approaching 100% were achieved. Tests were conducted simultaneously on 100% shingle (St Gabriel's) and mixed sand and shingle (Charmouth) portions of Charmouth Beach during high (storm) and low wave energy conditions. Tracer recoveries were undertaken on 40 sampling dates covering a year so as to encompass a wide and representative range of conditions. The data were analyzed using multivariate techniques to relate tracer transport (dependent variable) with size, shape and position variables. Results indicate that shingle transport is most rapid on the upper beach near the high water mark. The larger tracers were the most rapidly transported. The observed increase in pebble size from Charmouth to Golden Cap could therefore have developed by preferential transport of larger pebbles during eastward littoral drift. Similar results are reported from Chesil Beach and have been used to help explain its unique size grading (Carr, 1971; 1974).

Longshore transport volumes were calculated from the velocity, thickness and width of the moving shingle layer as defined by the tracers. The volumes varied from 2 m^3 day^{-1} to 22 m^3 day^{-1} during frequent periods of low wave energy westward drift, increasing to a maximum of 168 m^3 day^{-1} during less frequent periods of high wave energy eastward drift. Results were used to calibrate sediment transport equations e.g. Nicholls and Wright (1991), so as to aid shingle transport prediction at the two sites. Integration of results with a representative wave climate for West Bay over a 10 year period (Hydraulics Research, 1985) indicates a net eastward drift of 3447 m^3 yr^{-1} at St Gabriel's. At Charmouth, net eastward drift is estimated at 4710 m^3 yr^{-1} but 40% of the material is composed of sand and grit; shingle drift is 2825 m^3 yr^{-1}. Drift of the entire beach sediment size spectrum decreases towards the east due to the progressive offshore loss of fines. It should be noted that the long term

validity of these values might be questionable because of growing evidence that wind and wave regimes can shift over decadal timescales (Bacon and Carter, 1991; Brampton, 1993). Virtually no beach monitoring has been undertaken in this area so it is not possible to independently check the values against long term volumetric changes.

Onshore-Offshore Transport

Investigations of the offshore and nearshore zones were undertaken to identify any submerged gravel deposits that might offer evidence of onshore feed or offshore loss (Bray, 1986). Intertidal and nearshore diver inspections revealed relatively little gravel seaward of the well defined beach toe, but several zones of large interlocking limestone and sandstone boulders (boulder aprons) were located. These had trapped small quantities of gravel and appeared to act as transport barriers, effectively isolating the beaches from the offshore zone. An offshore hydrographic and sediment sampling survey also failed to locate any significant gravel deposits, but again identified boulder aprons and revealed that they extended to a point some 3-4 km seaward of Golden Cap. These are interpreted as the residue of ancient mudslides that operated on an earlier retreating coast. Other surveys of the wider offshore area of Lyme Bay and also off Chesil also failed to locate gravel banks (Darton et al., 1980; Dobbie and Partners, 1981; British Geological Survey, 1983), so it is concluded that most of this material must have remained on the shore as the coast retreated.

Outputs by Attrition and Entrapment

Impacts between pebbles during transport by wave action result in fractures and the grinding off of small surface irregularities (attrition). Losses occur as pebbles reduce in size and fines are transported seaward. Laboratory simulations suggest that rates of loss vary directly as a proportion of gross transport, and inversely, according to the amount of attrition a pebble has already undergone (Kuenen, 1964). These parameters were estimated in the field using the tracer data (gross transport estimate) and pebble sampling data rates of rounding estimate) to prepare a site-specific calibration of the laboratory studies (Bray, 1990). Results suggested that freshly supplied angular gravel suffers an approximate 10% loss within its first year, whilst well rounded pebbles are abraded very slowly.

Gravel that becomes trapped within the boulder aprons is immobilised and lost from the beach system as the coast retreats (entrapment). The quantities involved have been estimated by integration of measurements of the extent of the boulder aprons and their gravel trapping capacity with long term coastal retreat rates. Results reveal entrapment losses to be very slow. Although relatively small, attrition and entrapment outputs are both important because they result in losses from otherwise closed systems.

Outputs by Beach Mining

Seatown Beach has been the main focus of activity with substantial undocumented losses during World War II for airfield construction. Eyewitness reports state that the beach was stripped to bedrock, so that at least 170,000 m^3 must have been removed depending on past beach volume. Operations resumed in 1950 and involved removal of a further 34,000 m^3 of the largest, best rounded pebbles for use as grinding media for the ceramics industry. Mining ceased in 1987 following a Public Planning Inquiry (Brundell, 1985). Unlicensed removal of some 8,000 m^3 of shingle is estimated from Eype Beach between 1954 and 1974.

BEACH SEDIMENT BUDGET ANALYSIS

A Flow Model for Charmouth Beach

The Charmouth Beach system is examined in detail here, because it is the most dynamic and receives by far the greatest inputs from cliff erosion (Fig. 4). In compiling the budget, it is necessary to integrate various elements, including the differing magnitudes and frequencies of their component processes. This is accomplished by modelling the flow of gravel through the system over the study period 1901-87 (Fig. 5). Inputs are primarily from cliff erosion in western parts. Net littoral transport is to the east and consequently the western part of the beach is subject to slight depletion despite its proximity to supply.

Accretion (an output in terms of flow) is concentrated on the eastern part of the beach, explaining the eastward increase in beach volume (Fig. 5). Output of gravel from the beach by offshore transport is assumed to be negligible, as suggested by the tracer experiments and sea floor sampling. Other gravel outputs from the beach by attrition and entrapment are comparatively small. If Charmouth Beach were a fully closed system, substantial accretion should have occurred since 1901. This is not supported by the comparison of old maps, field reports and the contemporary volume of the beach. The imbalance can be explained by intermittent pulses of eastward littoral drift (output) beneath Golden Cap. Major mudslides at the headland currently act as a total barrier to transport. Observations along the West Dorset coast indicate that mudslides evolve by active phases of surging (Plate 2), separated by long phases of low activity and marine erosion. The barriers formed are liable to retreat. Old photographs show that landslide debris blocking the foreshore beneath Golden Cap became eroded between 1934 and 1949 to allow a continuous beach to exist from Charmouth to Seatown ("open" transport condition). Thereafter, minor mudslide surges intermittently cut the beach until a major phase of surging activity finally severed all connections in 1962 (Brunsden, 1985). During "open" transport, the Golden Cap headland operates as a one way valve. All shingle drift is eastward at rates equivalent to the gross transport in this direction estimated by the tracer experiments. An analysis of shoreline orientation and dominant wave approach directions (Hydraulics Research, 1985) indicates that westward drift should be minimal. Charmouth Beach therefore alternates between being an open and a closed system and its beach volume fluctuates accordingly. The model indicates significant beach accretion due to its "closed" system state since 1962. Attention is drawn to the importance of establishing such understanding because the likely responses to intervention could differ significantly according to the system state. The model also demonstrates that the spatial distribution of cliff inputs and beach accretion zones are themselves important regulators of the coastal system. Beaches afford protection to the cliff toes. If retreat accelerates, gravel supply increases, so in theory beaches should accrete and marine erosion should reduce. This idealised negative feedback mechanism cannot operate efficiently on Charmouth beach because eastward littoral drift prevents shingle accretion on the foreshore beneath the major landslide supply areas. The western part of the beach system is therefore characterised by high sediment throughput and relatively low volumes of shingle. Clay and sand are supplied in large quantities but are easily eroded and transported offshore. Limestone boulders, chert and flint gravel provide only temporary protection because of the low durability of the former and the potential for longshore transport of the latter. The active phase of landsliding initiated at Black Ven in the late 1950's is therefore likely to continue because natural basal protection cannot to keep pace without additional landslide throughput. It must be considered as an inherently eroding site that functions as a valuable sediment source.

Gravel Budgets for Seatown and Eype Beaches

Gravel budgets have been compiled for Charmouth, Seatown and Eype beaches (Table 4). They reveal that the intermittent littoral drift outputs from Charmouth Beach comprise the main inputs to neighbouring Seatown Beach, so that it too fluctuates between closed and open states according to conditions at the Golden Cap headland. In spite of these contributions, a net shingle loss has prevailed due to substantial mining outputs. Transport connections around Golden Cap are unlikely to be restored until 2020, when landslide activity should have diminished allowing mudslide barriers to be eroded. The scientific evidence of net loss and closed system status (since 1962) was critical in proving damage and led to revoking of the long-standing planning permission for mining (Brundell, 1985).

Eype Beach is isolated from all sediment sources and is an entirely closed system suffering net loss. Present trends for increasing cliff erosion are therefore likely to continue, but gravel inputs cannot increase accordingly because no suitable material is present in these cliffs.

Long-term Coastline Evolution

The three pocket beaches have been studied by sediment budget analysis for an 87 year period, long enough to significantly reduce variability arising from spatial and temporal changes in budget elements. Budgets must be considered over longer periods to understand the implications of this research for Chesil Beach. Retreat of the West Dorset coast has undoubtedly been long established as indicated by the submerged boulder aprons that extend 3 km to 4 km seaward of the present coast. Although difficult to date, it is suggested here that they represent the amount of cliff recession since sea level approached its present elevation in this region approximately 5000 years ago (Heyworth and Kidson, 1982). If this is correct, coast retreat based on the position of offshore boulder arcs has averaged 0.6 m yr^{-1} to 0.8 m yr^{-1} over the last 5000 years. Since this long term mean rate is comparable with present day values, current shingle budgets might be projected back over this period (Table 4).

Harbour structures at Lyme Regis and West Bay are recent developments on this timescale so shingle inputs would have been possible from the eroding East Devon coast (Bray, 1990) and Chesil Beach itself would have extended at least as far westwards as the Doghouse Hill headland. The combined cliff yields from the East Devon and West Dorset coasts are considerable (Table 4). Assuming that losses by attrition and entrapment have remained constant through time, 58 million m^3 of gravel could have been produced as these coasts retreated. Present day shingle storage between Lyme Regis and West Bay is estimated at less than 1 million m^3, so again there is a disparity between input and storage.

It seems likely that surplus gravel could have drifted eastwards along ancient pocket beaches to accumulate on Chesil which thus operated as the main sediment sink. There are no alternatives either in the region, or offshore in Lyme Bay. Chesil Beach is the closest shingle deposit of any size, its volume is estimated at 16 to 63 million m^3 (Carr and Blackley, 1974) and the characteristics of its pebbles are virtually identical to those produced by the eroding cliffs. Whilst the cliff erosion is clearly significant by comparison with the present volume of Chesil Beach, it is unlikely to have been the formative process. Chesil had already formed by 7000 years B.P. (Carr and Blackley, 1974). Input from cliff sources would therefore have nourished and enlarged the beach in spite of continuous attrition losses. The original source was probably fluvial, periglacial and perhaps ancient beach deposits on the floor of Lyme Bay, which gradually decreased in importance as the rate of sea level rise slowed down. The finite status of Chesil Beach is therefore a recent phenomenon and derives from alterations to the West Bay piers in the mid 1860's that effectively isolated it from its remaining shingle source. Substantial wartime mining of Seatown Beach has depleted the supply pathway making transport impossible around the Doghouse Hill headland (a relict beach indicates the former connection). Renewed inputs to Chesil are therefore unlikely in the foreseeable future.

MANAGEMENT APPLICATIONS OF THE BUDGET ANALYSIS

In treating the coast as an integrated process system, the research has indicated the impacts of past activities and provides a basis for anticipating the likely effects of future interventions. Pocket beaches such as Seatown have been identified as closed systems over planning timescales so a strong basis is established for identifying and controlling damaging practices such as beach mining. This has assisted Dorset County Council in their minerals planning process. Perhaps the most damaging interventions have been the harbour structures at Lyme Regis and West Bay that intercept littoral drift and isolate beaches from their natural sources of supply. Well maintained structures form permanent transport boundaries. Headlands also act as barriers, but periodically allow pulses of shingle to pass so their long term effects are less damaging. Downdrift beaches thus affected suffer net loss and become sensitive to further interference and the cumulative effects of rising sea-level and storm activity. Crest lowering and retreat have recently been recorded from Chesil Beach (Carr and Seaward, 1990) and numerous flooding events have occurred over the past 30 years at Chiswell

and West Bay (Jolliffe, 1979). The shortage of beach shingle is clearly identified as a major problem, but the changes to the transport pathways for fresh shingle are such that the natural system is not easily re-established. Shingle bypassing systems might have reduced early problems, but at West Bay, serious beach loss has occurred on both sides of the artificial barrier (Brunsden, 1992). The alternative option at Chiswell has been to adopt various engineering measures to reduce flood hazards (Hook and Kemble, 1991), but this further interferes with natural processes and could reinforce commitments to intervene more widely (Brunsden, 1992).

Research should inform management to avoid future actions that interfere with key natural processes so that the difficult problems outlined above do not develop. The present study has identified the importance of cliff erosion in yielding much of the region's beach forming sediment. Coastal planners might therefore formulate setback zones (Kay, 1990) to ensure that the main source areas e.g. Black Ven, remain free to erode. However, such policies should also consider the transport pathways and process timescales so that the potential benefits of these actions might be evaluated. It is important to ensure that pathways linking sediment sources and sinks remain free to operate. Shingle bypassing should therefore be included as an essential part of the operation of any new structures that might form artificial boundaries. Using the budget model it is possible to assess possible future changes. For example, an empirical model study of the effects of sea-level rise on the West Dorset cliffs indicates that erosion might double by 2050 (Bray and Hooke, 1994). The fates of resultant increased sediment yields can then be traced though the coastal process system to estimate impacts.

CONCLUSIONS

Improved understanding of coastal processes, landforms and landscapes are needed to manage littoral sediment in a sustainable manner and minimise needs for structural interventions. In working towards these objectives, a geomorphological systems approach has been applied successfully to investigate a complex and dynamic coastal system at a variety of scales. At the strategic level, it is sufficient to identify independent cells and partially dependent sub-cells for shoreline management units. At regional and local levels of operational responsibility, it is important to apply a more rigorous approach to quantify a littoral sediment budget. Analysis of the processes, rates and timescales of material flow can then be integrated with details of the resulting landforms to identify the long term trends that the landscape is evolving towards.

In West Dorset, complex links have been demonstrated between eroding cliff sediment sources and the beaches that they supply. Boundaries to sediment transport systems are not always clearly defined and can evolve naturally in a complex manner, as at Golden Cap. Others can be produced artificially, as at West Bay. Failure to recognise these features has resulted in human interventions having serious unintended knock-on effects that have modified the natural littoral sediment system. Although it has been possible to control damaging beach mining, shortages of shingle remain a major problem. Current trends for increasing cliff erosion are unlikely to replenish the depleted beaches in the short term due to lags in the process system.

These examples demonstrate the differences between geomorphological and planning timescales. It should be appreciated that management based on natural process systems demands forward planning over longer intervals than hitherto contemplated. Coastal managers should realise that this type of approach is not simply a research tool, but has practical management value and is widely applicable elsewhere. Many coastal other environments have been modified by human activities or face imminent interventions and it is valuable to understand the spatial and temporal dimensions extent of such modifications when planning future management strategies.

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Table 1. Geological Succession of the West Dorset Coast

Period	Series	Formation	Lithology	Maximum Thickness at Coast (m)
Quaternary		Superficial Deposits	Angular chert and flint in a sandy clay matrix. Perturbated and fissured.	5
Cretaceous	Upper Greensand	Chert Beds	Yellow-grey chert bands in coarse sandy clay matrix.	10
		Foxmould	Fine, yellow silty sand.	35
	Gault	Gault Clay	Soft, silty clay.	13
			UNCONFORMITY	
Jurassic	Middle Jurassic		Clays, shales and limestones.	74
	Upper Lias		Yellow sandstones.	64
	Middle Lias		Soft clays, marls and hard sandstones	130
	Lower Lias		Soft clays, marls and thin, limestones	150

Table 2. Long Term Sediment Yield

Material	Lyme-R. Char		Stonebarrow-Golden Cap		Golden Cap and Seatown		Doghouse Hill-West Bay		Total	
	m^3a^{-1}	%	m^3a^{-1}	%	m^3a^{-1}	%	m^3a^{-1}	%	m^3a^{-1}	%
Gravel	3,890	1.21	2,291	0.71	141	0.04	40	0.01	6,362	1.97
Limestone	7,801	2.42	843	0.26	116	0.04	741	0.23	9,501	2.95
Sand	17,604	5.47	14,647	4.55	5,821	1.81	17,045	5.30	55,117	17.13
Clay	134,706	41.86	76,506	23.79	17,134	5.33	22,415	6.97	250,761	77.95
Total	164,001	50.96	94,287	29.31	23,212	7.22	40,241	12.51	321,741	100

Table 3. The West Dorset Shingle Beaches

Beach	Size Grading	Sorting	Roundness and Sphericity	% Chert and Flint	Volume (m^3)
Cliff gravel input		very poor	unabraded and very angular	99.5	*32 million
Charmouth	eastward (well defined)	very poor in west, but improving eastward.	improving eastward, very angular in west.	94.4	277,000
Seatown	eastward (slight)	improving eastward	slight eastward improvement	98.5	167,000
Eype	eastward (well defined)	improving eastward	slight eastward improvement	96.1	164,000
Chesil	eastward (exceptional)	good, throughout, but improving eastward.	not studied	98.5	**16 - 63 million

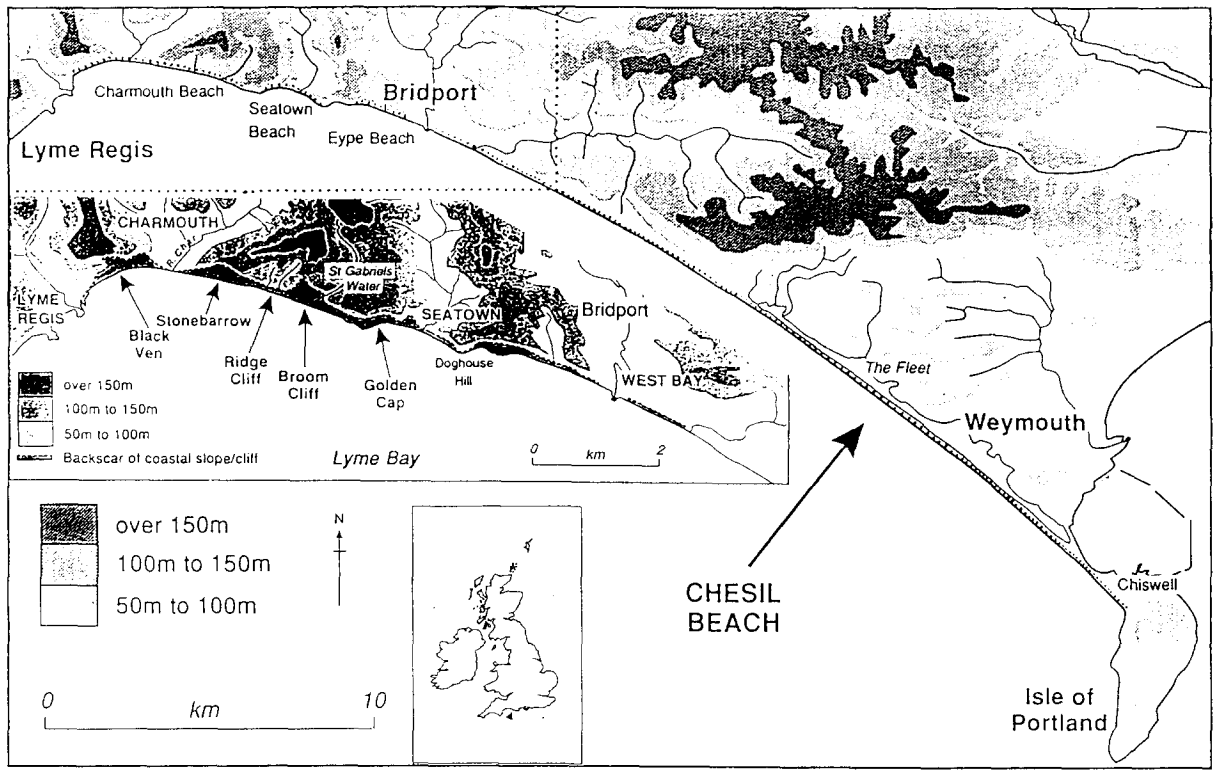
* long term supply extrapolated over past 5,000 years.
** imprecision caused by variable thickness and composition at depth.

Table 4. Beach Gravel Budgets 1901-1987

Budget Element		Charmouth Beach	Seatown Beach	Eype Beach	Whole area (long term assuming no human intervention)
Inputs ($m^3 a^{-1}$)	Coastal Erosion	4,870	34	negligible	6,362
	Fluvial (River Char)	240	-	-	240
	Littoral Drift	-	2,150	small	from East Devon 6,700
	Onshore Transport	-	-	-	-
	TOTAL	**5,110**	**2,184**	**-**	**13,302**
Outputs ($m^3 a^{-1}$)	Attrition	1,260	84	82	1,426
	Littoral Drift	*2,150	-	-	to Chesil 151,590
	Entrapment	190	45	51	286
	Beach Mining	-	2,371	93	-
	Offshore Transport	-	-	small	-
	TOTAL	**3,600**	**2,500**	**226**	**13,302**
Beach Store ($m^3 a^{-1}$) (1987)		277,000	167,000	164,000	500,000 - 800,000
Balance ($m^3 a^{-1}$)		+1,510	-316	-226	0

* pulsed input beneath the Golden Cap headland

Fig. 1. Locations of the shingle beaches of Southwest Dorset



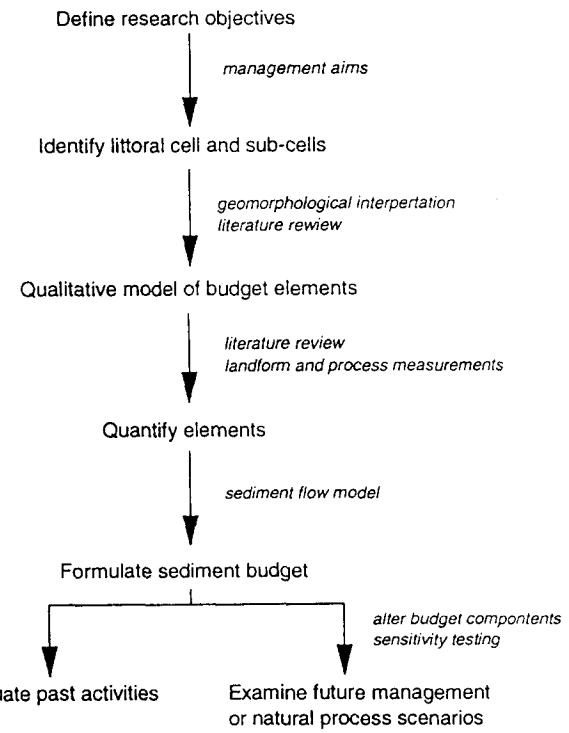
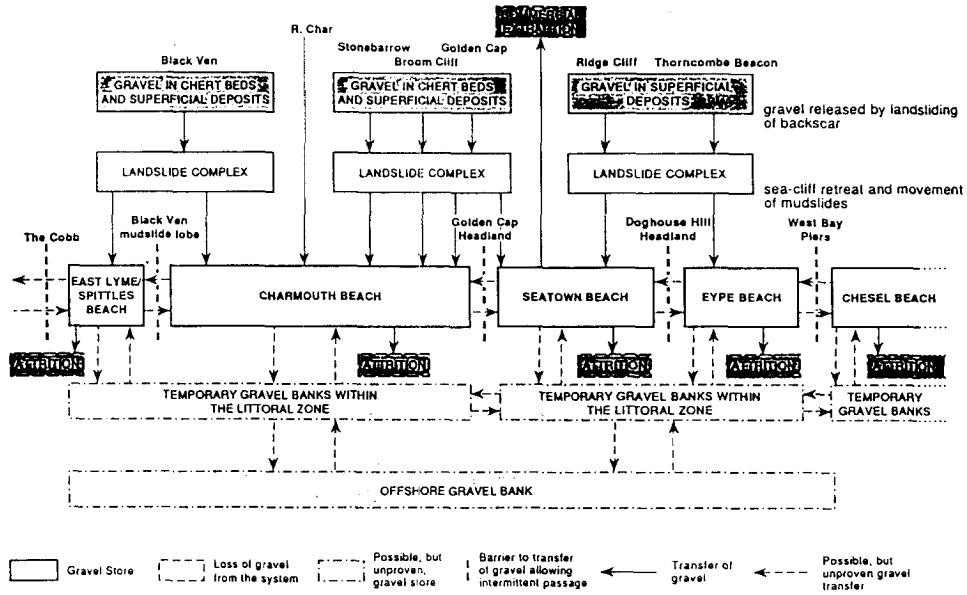


Fig. 2. Systems methodology for development of sustainable sediment management.

Fig. 3. Sediment budget model of the West Dorset littoral cell. This forms a valuable framework within which to identify the component elements and their interrelations. It facilitates the planning of research to quantify the budget.



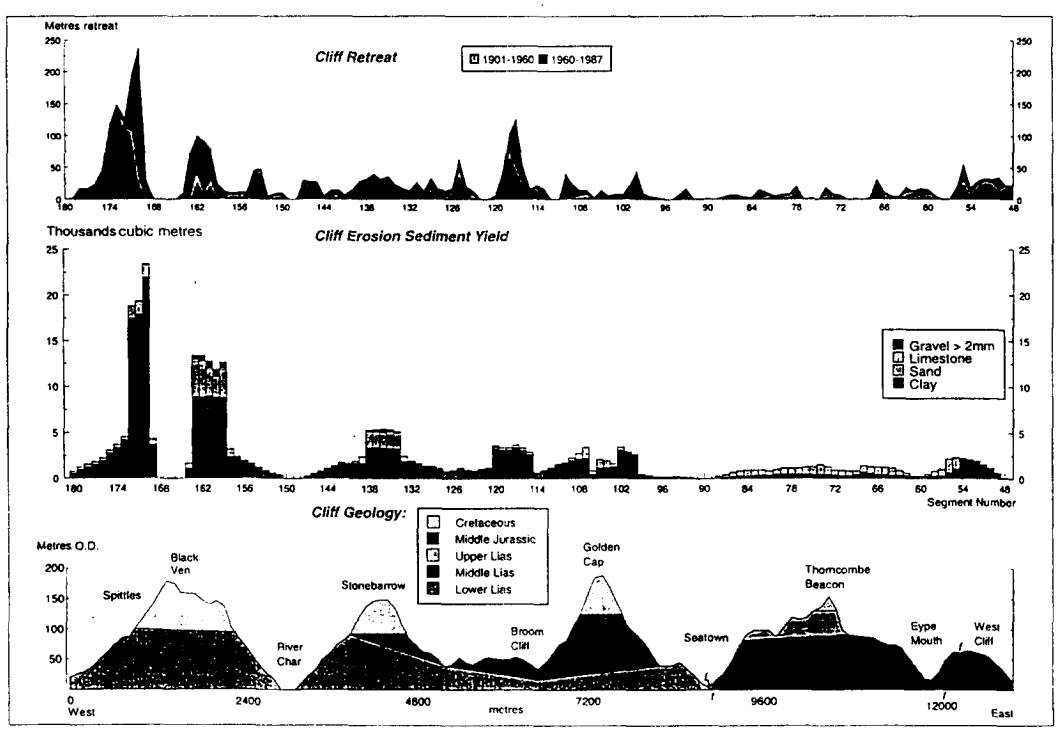
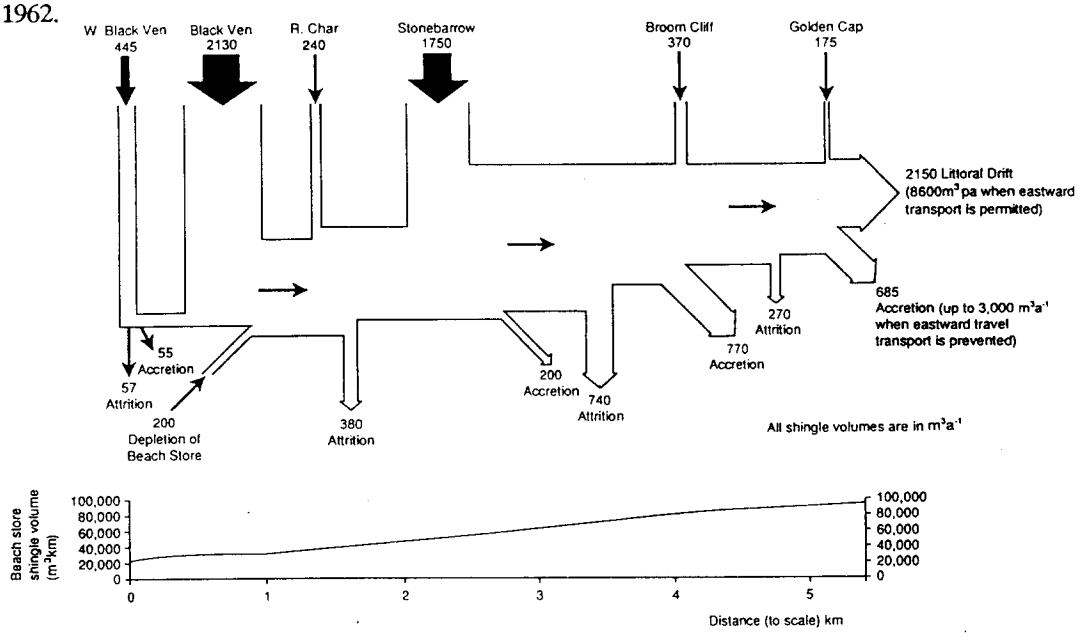


Fig. 4. Analysis of ground forming materials: geology, cliff retreat and sediment yield.

Fig. 5. Shingle flow model of the Charmouth Beach sub-cell. Inputs from cliff sources in the west are transported eastwards towards the one-way valve of the Golden Cap headland. Beach volume fluctuates according to whether transport is "open" (output and beach depletion), or "closed" (storage and accretion). The recorded improvement in beach volumes eastward reflects the closed condition that has prevailed since 1962.



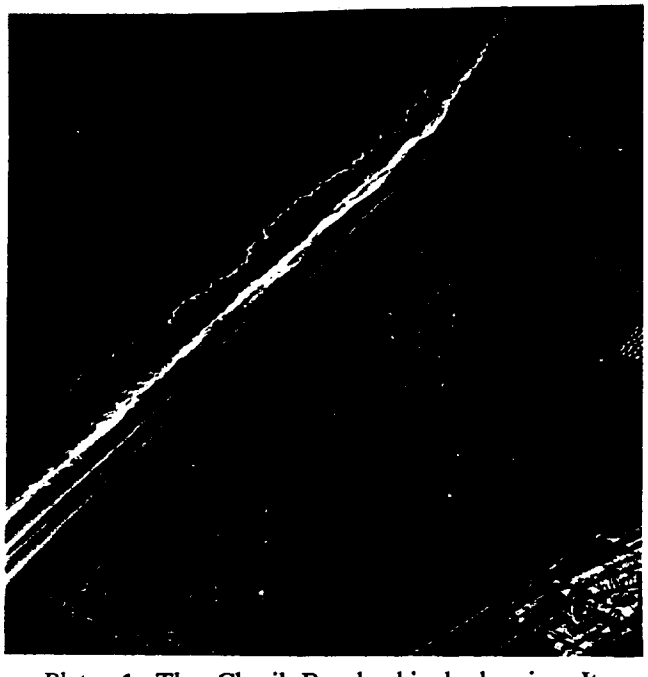


Plate. 1. The Chesil Beach shingle barrier. It extends some 28 km westwards to West Bay in the distance. Note that the beach affords protection to the Fleet Lagoon and a low-lying hinterland.

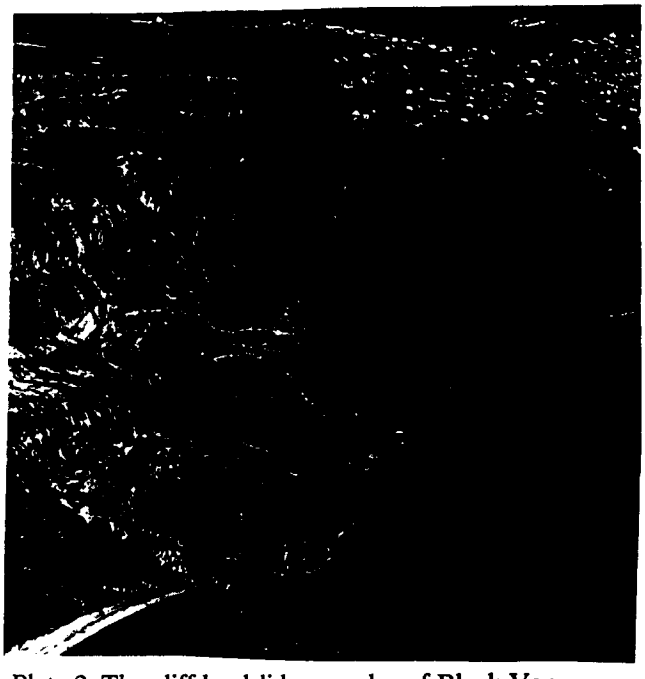


Plate 2. The cliff landslide complex of Black Ven. Major failures involving massive mudslide surges deliver lobes of sediment to the shore. Their erosion produces characteristic boulder aprons. Note that the lobes cut the beach and intercept littoral drift.

Proc. Int. Conf. 'Coastal Change 95' Bordomer-IOC, Bordeaux, 1995, p. 781 - 791

LES EFFETS DU TOURISME SUR LA ZONE CÔTIÈRE: LE CAS DU COULOIR TIJUANA-ENSENADA (CTTE) À LA FRONTIÈRE NORD DE MEXIQUE

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MOTS-CLÉ: tourisme, zone côtière, littoral, développement, aménagement, différenciation urbaine, fidéicommis, trailers park, ejidos, population locale, impacts sociaux, écologiques, économiques

RESUME

L'objectif du présent document consiste à présenter un panorama des principaux facteurs qui ont contribué à configurer le littoral Tijuana-Ensenada en tant qu'espace orienté vers le tourisme. En présentant les différents impacts de l'activité touristique sur la zone côtière. Le démarrage de cette région a été si rapide et non planifié, ce qui a provoqué une croissance anarchique de la zone. Par conséquent, les problèmes urbains, sociaux et écologiques se sont accentués. Dans ce contexte, on essai d'attirer l'attention sur la nécessité de protéger, d'aménager et de développer le littoral mais grâce à une exploitation optimale des ressources pour atteindre un développement soutenu.

INTRODUCTION

Comment développer le littoral et en même temps protéger son milieu naturel? Cela est un défi que doivent affronter tous les pays qui, comme le Mexique ont un littoral important. Les zones côtières deviennent des espaces d'une incalculable valeur pour le développement de certains activités comme le tourisme, c'est pour cela ces espaces sont fortement convoités.

L'attraction que signifient les zones littorales pour le tourisme, représente en soi une arme à double tranchant. D'une part, il existe de grands intérêts économiques orientés vers un rapide et progressif développement foncier, d'où un aspect environnement et une configuration du paysage assez négligés et; d'autre part, il y a aussi des intérêts à ce qu'un développement écologique équilibré soit fait.

Dans les décades antérieures, la balance penchait plus vers l'aspect économique, même si pendant les dernières années, à un niveau mondial, la conservation de l'environnement est devenue cruciale à cause de sa situation critique. Dans le secteur touristique cette situation n'a pas été l'exception. Par la suite sont apparus de nouveaux courants de planification du tourisme, considérant le milieu naturel et sa conservation comme base pour obtenir un développement soutenu.

Dans ce contexte, le document présent a pour objectif d'attirer l'attention sur les effets dus au tourisme dans une région côtière qui se trouve au nord-ouest de la frontière du Mexique. Région où, malgré l'existence de nouvelles orientations, le développement touristique s'implante toujours sous de vieux schémas. Ensuite on verra quelles en sont les répercussions négatives sur la nature.

LE MILIEU PHYSIQUE-NATUREL

Le couloir touristique Tijuana-Ensenada (CTTE) se trouve au nord- ouest de l'état de la Basse Californie. Il est contigu au nord avec l'état de Californie, Etats-Unis, au sud avec petits "rancherías" (ranchs), à l'est avec les municipalités de Tecate et Mexicali et à l'ouest avec l'Océan Pacifique (Fig. 1).

On appelle couloir touristique la portion côtière de forme longitudinale qui part du quartier Playas de Tijuana (municipalité de Tijuana) et qui continue vers le sud jusqu'à la Bufadora (municipalité de Ensenada) suivant un trait

imaginaire d'à peu près 2 kilomètres à partir de la ligne de côte vers l'intérieur des terres. Cette frange varie en épaisseur selon les caractéristiques topographiques. La longueur du couloir est d'environ 140 kilomètres et comprend une surface de 59 474 hectares (594,7 km²).

Selon le recensement de 1990 (INEGI), dans cette surface, il y avait 67 130 personnes qui habitaient dans la zone rurale, c'est-à-dire, sans compter la population des villes de Tijuana et Ensenada ni inclure celle des centres touristiques, mais on sait qu'en 1992 il y avait 16 147 personnes qui résidaient dans le couloir. Au total la population était d'environ 83 277. (Fonatur-Colef, 1993).

Pour bien aménager la zone côtière il faut connaître le milieu physique, avec la finalité de déterminer les caractéristiques naturelles qui limitent ou permettent le développement urbain-touristique et surtout, pour sauvegarder les zones fragiles pour la conservation.

La majeure partie de la péninsule de la Basse Californie se trouve dans une zone aride (SPP, 1981; INEGI-SPP, 1984), mais on peut y distinguer deux provinces ou "régions physiographiques", une appelée province du Désert de Sonora (Desierto sonorense) et l'autre dénominée région de la Basse Californie (región californiana).

C'est dans cette région que se trouve le couloir touristique Tijuana-Ensenada qui se reconnaît par la présence de fortes pentes qui s'adoucissent tandis que s'approche la côte. Il y a un type de plateaux et des montagnes de basse altitude où passent des ruisseaux. (Roberts, 1989).

Le relief du littoral Tijuana-Ensenada est formé de plateaux de basalte, de plaines côtières et de montagnes. Les plaines côtières s'étendent parallèlement à la côte entre Playas de Tijuana et Rosarito; dès El Médano jusqu'à la Misión de San Miguel à Ensenada et au-delà de El Sauzal juste avant l'espiguette de l'estuaire de Punta Banda. On trouve à Punta Banda des montagnes basses avec de pentes abruptes et des zones plaines. Le reste du couloir se compose de pentes qui finissent en vallonnements.

D'après la classification des climats de Wylwly Koppen (1936), classification modifiée par Enriqueta García (1973), le climat qui prédomine dans le CTTE est du type sec, le subtype est méditerranéen sec tempéré. Ce type de climat existe depuis les zones qui se trouvent au niveau de la mer jusqu'à celles situées 2800 mètres d'altitude. (INEGI/SPP, 1984).

La saison de pluie est en hiver, de décembre à février, dans cette période tombe 36 % du total des précipitations annuelles. La période la plus sèche correspond à la saison chaude, c'est-à-dire, pendant les mois de juin, juillet et août, là où normalement il n'y a pas de précipitations. La moyenne des précipitations annuelles dans le couloir connaît une variation comprise entre 160 mm et 400 mm. (INEGI/SPP, 1984).

Les températures que prévalent dans la région enregistrent des taux variant de 23• C en août à 10 et les 11•C dans les aires proches de la côte pendant le mois de janvier. La moyenne annuelle oscille entre les 15 et 18•C (INEGI/SPP, 1984).

Contrairement à ce qu'on pourrait penser, les zones arides du Mexique contiennent une grande quantité d'espèces de végétaux. Dans la Péninsule de la Basse Californie cohabitent environ 3000 espèces; 23 % de sa flore sont des espèces endémiques (Wiggins, 1980). Ses caractéristiques d'aridité ont engendré cette grande nombre d'espèces endémiques mais quelques d'unes sont menacées par les voitures de sable (buggies).

Très schématiquement, dans la zone côtière Tijuana-Ensenada on peut distinguer trois grandes types de végétation. (Bringas et Ojeda, 1991). La plus importante est le buisson côtier (matorral rosetófilo costero) qui se trouve dès le niveau de la mer jusqu'à 900 mètres d'altitude. Il s'étend vers la frange de la côte dès le sud-ouest californien jusqu'au nord-ouest de la Basse Californie.

Dans la partie de Tijuana cette végétation est répandue de Punta Bandera à Los Medanos. Dans la partie d'Ensenada on la trouve incluse de façon disséminée autour de La Misión de San Miguel, Salsipuedes et Punta Banda. Ce type de végétation est plus basse (2 mètres d'hauteur) et se caractérise par des arbustes et quelques types de cactus, lesquels survivent malgré les vents et le brouillard maritime. (Roberts, 1989).

Une autre genre de végétation qui se trouve dans la région est le bosquet d'yeuses (chaparral) qui couvre de grandes étendues de montagnes dans le nord et sud du couloir. Cette végétation pousse à une hauteur comprise entre 1 et 4 m. Moins abondante, mais non pas moins importante est la végétation qui existe sur les massifs dunaires. Celle-ci permet la fixation du sable. On peut mettre en évidence l'importance de la végétation dunaire avec un seul exemple: les dunes de Punta Banda à Ensenada qui dans 0.8 km² abritent une espèce en danger d'extinction, 3 espèces endémiques et 13 plantes d'utilité. (Espejel, 1993).

Dans les "canons" qui sont l'endroit où confluent les écoulements naturels des monts et des parties hautes, existe la végétation que l'appelle "riparia", très différente des autres car elle pousse dans les microclimats qui la rendent plus feuillie (Bringas et Ojeda, 1991).

En ce qui concerne la faune côtière, on y trouve 448 espèces différentes. Parmi elles se distinguent les invertébrés et les oiseaux. Il existe aussi une espèce endémique et quatre espèces en danger d'extinction. Dans le domaine de la mer, on sait maintenant qu'il existe environ de 524 espèces de poissons et six de mammifères, tels que les baleines grises, les dauphins, les phoques, les éléphants et les loups maritimes. (Sedesol-Sectur-Fonatur-Gobierno del estado de B.C.,1993).

Tout l'ensemble des facteurs naturels ci-dessus, en plus des mesures légales prises par le gouvernement pour appuyer le développement touristique et, en même temps, l'introduction d'infrastructures et les services publics ont mis en valeur la région et l'ont transformée en un espace géographique unique. Pour cela le littoral a été et continue à être fortement demandé et convoité surtout par le tourisme américain.

LE TOURISME DANS UN CONTEXTE RÉGIONAL

On va démontrer ensuite, l'importance que revêt le tourisme étranger pour la région Tijuana-Ensenada. Depuis le début du siècle l'Etat de Basse Californie et notamment la ville de Tijuana, occupe une place particulière grâce à la visite quotidienne de milliers d'étrangers. En 1992, on a enregistré 30,6 millions de passages d'étrangers aux différents postes frontaliers de l'Etat dont 19,7 millions ont eu lieu à Tijuana, c'est-à-dire 64,5 % des passages. (SIN, 1992).

L'affluence constante de visiteurs que reçoit Tijuana a placé cette ville à la première place des traversées frontalières de l'Etat. Il faut signaler que Tijuana est la principale porte d'entrée pour les touristes qui se déplacent vers le sud de l'Etat et tout particulièrement vers le littoral.

Le fait d'être contigu à l'Etat de la Californie, un des plus riches des Etats-Unis, a contribué, sans doute, à augmenter l'affluence touristique vers la Basse Californie. Il est reconnu que le Texas et la Californie sont les états les plus importants en ce qui concerne les flux touristiques qui arrivent au Mexique. De ces deux états proviennent respectivement 16 et 34 % des touristes américains (SECTUR, 1992).

Nous allons présenter maintenant un panorama des principaux facteurs qui ont contribué à configurer l'espace littoral entre Tijuana et Ensenada, en présentant les différents acteurs qui se partagent le littoral et les impacts du tourisme sur la région.

Eléments qui ont favorisé la constitution de la zone côtière entre Tijuana et Ensenada en tant qu'espace orienté au tourisme

Le peuplement de la zone littorale Tijuana-Ensenada, obéit à une politique fédérale menée depuis le siècle dernier comme une mesure préventive pour éviter que les Etats Unis ne s'approprient une portion du territoire mexicain. C'est pourquoi l'Etat offrit des concessions de terres aux compagnies étrangères afin d'urbaniser la région (Aguirre, 1975)

Les résultats de cette politique ne furent pas ceux escomptés puisque les intérêts étrangers s'approprièrent une partie plus grande du territoire. Depuis lors, jusqu'aux années 70, la majorité de la population tirait ses richesses du secteur primaire (Piñeira, coord., 1985).

La Constitution mexicaine de 1917 interdit aux étrangers l'acquisition des biens fonciers et immobiliers sur une frange de 100 kilomètres à

partir de la frontière et ce, sur une frange de 50 kilomètres à partir de la côte. Ces franges s'appellent officiellement "zone interdite aux étrangers".

Cette mesure tentait de sauvegarder la souveraineté nationale. Malgré cette interdiction, il existait encore en 1923, près de 32 millions d'hectares de propriétés rurales appartenant aux étrangers, dont plus de la moitié étaient des étrangers d'origine américaine (Tannenbaum, 1979).

Ensuite, dans le cadre de la Réforme Agraire, le Gouvernement Fédéral expropria les terres qui étaient aux mains des étrangers et les distribua aux paysans sous le régime des EJIDOS (Aguirre, 1985). La Réforme Agraire de Lázaro Cárdenas (1936-40) fut la première mesure sociale provenant de l'Etat, mesure bénéfique pour les paysans des ejidos.

Cette mesure nationaliste du gouvernement mexicain d'attribuer la jouissance de terres littorales aux paysans eut des effets contradictoires dans la pratique, car en même temps on établit le cadre juridique qui permit aux étrangers d'exploiter et d'avoir en usufruit les côtes et les frontières mexicaines sous la forme de fidéicommis.

Sous la présidence de Luis Echeverría (1970-76) des échanges sont intervenus dans la politique touristique, car on a reconnu l'importance du tourisme comme facteur de développement. A partir de ce moment-là, le rôle de l'Etat n'a cessé de croître.

Le tourisme a été considéré comme un moyen important pour faire rentrer des devises, de plus, on a vu en lui également une activité qui intégrerait d'autres secteurs de l'économie et donnerait une impulsion au développement régional. On l'a considéré aussi comme moyen de diversification de l'économie agricole. C'est à partir de cette idée que l'on a cherché des investissements étrangers en matière de tourisme.

L'offre touristique s'est orientée vers les étrangers, on a donc modifié des dispositions juridiques afin de contourner les restrictions constitutionnelles à l'usage de certaines zones (Jiménez, 1984).

C'est ainsi, qu'en avril 1971 ont été créés les mécanismes légaux, à travers les contrats de fidéicommis (Ley de Titulos y Operaciones de Crédito) qui ont permis aux étrangers l'usage des biens fonciers et immobiliers sur les côtes et aux frontières mexicaines pendant une période de 50 ans. Il faut souligner que, jusqu'à 1989, la période maximum de durée du contrat était de 30 sans prolongation.

Un des objectifs pour lesquels ont été créés les fidéicommis était d'incorporer les paysans à l'activité touristique pour qu'ils profitent des avantages générés par le "développement touristique". Mais la réalité a démontré qu'ils ne furent pas incorporés, pire ils furent écartés de l'activité, leurs terres leur furent prises et ils ne créèrent pas d'autre activité pour survivre.

Au début des années 60, l'espace littoral était rural et il fut facile de l'aménager à des fins touristiques et récréatives car elles étaient plus rentables que les activités agricoles. Malgré cette situation, le gouvernement ne donna pas de crédit pour les infrastructures à ceux qui avaient intérêt à changer l'activité de leur ejido. C'est pourquoi quelques-unes cherchèrent du travail dans le service domestique ou la construction.

D'ailleurs, la population locale n'a pas profité non plus des bénéfices économiques du tourisme, par contre, les inégalités de niveau de vie entre la population et les touristes sont chaque fois plus grandes.

De plus, cette situation a engendré une zone d'isolement et l'exclusivité pour les étrangers -la plupart américains- où ils reproduisent à grande échelle le mode de vie de leur pays.

De plus, des dispositions juridiques ci-dessus mentionnées, un autre facteur qui a facilité l'expansion des centres touristiques dans les années 60 fut la construction de l'autoroute à péage, qui a permis un peuplement rapide et l'intégration de la région.

Dans la même période furent construits d'autres infrastructures comme l'aqueduc "La Misión" qui fournit de l'eau à la zone côtière de Tijuana. A Rosarito la Commission Fédéral d'Electricité (CFE) et les Pétroles Mexicains (PEMEX), fournissent des services au couloir.

A partir de ce moment-là a commencé une grande lutte par rapport à l'usage du sol, lutte dans laquelle les centres touristiques ont gagné du terrain pour l'usage agricole ou ejidal. De cette façon l'idéal qu'arborait la Réforme Agraire périt face à l'attrait des gains rapides d'argent grâce à la location de lots pour les étrangers. C'est ainsi que commencèrent les luttes entre différents groupes économiques, politiques et sociaux pour s'approprier les titres des terrains côtiers.

Il faut signaler que la demande d'espace littoral de la part des étrangers a été fondamentale pour la configuration du CTTE comme espace orienté vers l'activité touristique. Parmi les facteurs les plus importants on trouve: la proximité de la mer, le paysage, le climat méditerranéen et, en général, les attraits naturels. L'accessibilité, le bas prix du terrain et des services ont attiré aussi les étrangers, surtout si on considère qu'aux Etats-Unis il existe des restrictions écologiques pour utiliser le littoral.

La proximité géographique avec le pays d'origine et la tranquillité de la région ont joué un rôle important dans l'acquisition du terrain, et la majorité des résidents du couloir sont des personnes très âgées, retraitées et qui font une grande partie de leurs achat aux Etats-Unis.

A notre avis, tels sont les principaux facteurs qui ont favorisé l'existence de centres touristiques dans la région littorale. C'est ainsi, que le couloir a commencé à être connu et qu'il est devenu le lieu de développement touristique le plus important de la frontière nord, malgré les grands différences parmi les services et infrastructures qu'ont les quartiers populaires et les centres touristiques.

Différenciation urbaine

Le développement de la zone côtière Tijuana-Ensenada a signifié la transformation accélérée des usages du sol. Ils sont passé d'une étape agricole et d'élevage vers un processus de rapide urbanisation qui s'est caractérisée par l'occupation d'espaces orientés vers la construction de résidences secondaires.

Cette urbanisation a donné naissance à deux types d'emplacements bien différenciés, l'un destiné à la population locale et l'autre orienté vers le tourisme où l'espace est perçu de façon différente.

1) Pour ceux qui habitent les centres touristiques, le littoral fonctionne comme un espace de loisir: c'est un endroit de détente, loin de la vie quotidienne, de la monotonie du travail, où les touristes sont au contact avec le milieu naturel.

Dans le couloir on trouve aussi différents sortes de centres touristiques mais tous s'implantent de façon contiguë à la côte. D'une part, on peut trouver l'existence de zones exclusives et très chères comme le sont les fidéicommis (ou fractionnements résidentiels) qui de fait, sont le fer de lance d'un processus d'occupation territoriale qui est soutenu, surtout par le pouvoir d'achat important qui possèdent les touristes étrangers par rapport à la population locale.

Ceux-ci sont apparu comme des enclaves longitudinales par rapport à la côte. Ils offrent diverses options: lots urbanisés, résidences nouvelles ou anciennes. Normalement ce type de centres bénéficient des services publics, eau (87%), électricité (97%), tout à l'égout (54%) et quelques-uns ont une station d'épuration des eaux usées. (FONATUR-COLEF, 1992).

En 1992 il y avait dans le couloir 39 centres touristiques sous cette catégorie, dans lesquelles il y avait 5 602 lots, dont 3 157 étaient bâtis. La plupart des centres se concentrent entre Rosarito et la Misión dans la municipalité de Tijuana.

D'autre part, on trouve aussi un type d'emplacement touristique que l'on appelle "trailers park". En 1992, il existait 79 centres destinés aux campements ou aux caravanes. Au total il y avait 4 280 espaces, 65 % à Ensenada et 35 % à Tijuana. Par rapport aux fidéicommis, ces centres comptent avec une moindre couverture de services et un équipement urbain minimum. Seul 66 % d'entre eux ont l'eau, 77 % l'électricité et le 15 % ont le tout à l'égout. La partie de Punta Banda à Ensenada, est celle qui compte le moins de services publics (FONATUR-COLEF, 1992).

2) L'importance que prit l'espace littoral pour la population locale est tout à fait différent. Pour

eux, il s'agit d'un lieu urbain pour habiter et travailler, et surtout cela leur permet d'avoir des ressources pour survivre. Dans ces espaces on trouve des aires "ejidales" dédiées à l'agriculture, l'élevage, la pêche et la floriculture et aussi des petits commerces qui sont utilisés pour satisfaire les besoins de la population native et étrangère.
On peut distinguer ici de petits villages (communautés de pêcheurs, des ejidos et des ranchs) avec leurs quartiers populaires et un grand manque de services publics. Il n'y a pas d'homogénisation par rapport à la couverture de services car on y trouve des différences même entre villages. Cependant la plupart des villages ont l'électricité et dans une moindre mesure l'eau courante par canalisation et évacuation par des égouts.
La concurrence par rapport aux services et aux infrastructures entre les centres touristiques et la population locale se traduit par les inégales conditions de vie de chaque groupe. La distribution de l'eau est le plus claire exemple des inégalités.
Dans cette zone il y a de gros problèmes de manque d'eau et un pompage excessif des nappes phréatiques, en plus des difficultés de distribution de l'eau.
La distribution de l'eau pour la zone comprise entre la partie de Tijuana et celle de Rosarito provient de l'Aqueduc La Misión et de trois puits qui donnent 130 litres/sec. Seulement 25 % de cette eau est destinée à la population locale et le reste va aux centres touristiques. C'est-à-dire, qu'il y a 20 500 habitants qui n'ont pas accès à ce service. Dans le cas d'Ensenada l'eau vient de diverses sources: 200 l/sec. proviennent des puits de Valley de Guadalupe, 100 l/sec. du barrage López Zamora, 110 l/sec. de sept puits de la zone urbaine d'Ensenada et 250 l/sec. viennent de quatre puits placés dans la Valley de Maneadero. Au total il y a une disponibilité de 660 l/sec., cependant 23,000 personnes n'ont pas l'eau courante (Sedesol-Fectur-Fonatur-Gobierno del Estado de B.C., 1993).
En résumé, on peut dire que les inégalités urbaines existent selon le type d'usager et selon les bénéfices économiques que produit le type d'activité dans laquelle est orienté l'espace littoral. C'est pour cela que l'on trouve des différences entre les fidéicommis (tournés vers un tourisme haut de gamme), les trailers park (plus axés vers un tourisme populaire) et la population locale.

Bénéfices économiques contre coûts sociaux et écologiques

a) L'aspect économique

Le flux de touristes vers la zone littorale Tijuana-Ensenada en 1990 (FONATUR-COLEF, 1991) fut d'environ 17,6 millions dont 96 % se sont déplacés vers la ville de Tijuana, 4,8 % vers Rosarito et 3,7 % vers Ensenada. Pour 47 % des ces personnes, il s'agissait de la première visite dans le couloir. Parmi ces touristes 32,4 % provenaient de San Diego, 20,2 % de Los Angeles, 15,4 % d'autres parties de la Californie et 20,1 % d'autres régions des Etats-Unis.
Les recettes touristiques de 1990 furent d'à peu près 740 782 millions de dollars et les dépenses moyennes par touriste ont été de 42 dollars. La plupart de ces dépenses (51 %) ont été consacrées aux achats de produits artisanaux; 29,3 % aux restaurants et aux bars; 6,6 % au logement; 4,2 % aux jeux de hasard comme les paris aux courses de chevaux dans l'hippodrome; 2,6 % aux cinémas et aux théâtres; 1,4 % aux événements sportifs et le reste 4,9 % dans d'autres services non touristiques.
D'autre part, il y avait en 1992 un total de 16,283 résidents dans les centres touristiques du couloir , dont 6 682 avaient des résidences secondaires dans les fidéicommis. 2 418 propriétaires y vivaient de manière permanente, c'est-à-dire, qu'ils habitaient plus de six mois à la suite dans le couloir et 4 156 étaient des résidents saisonniers. Dans les trailers park, résidaient 9 601 personnes; 2 398 de façon permanente et 6 594 de façon saisonnière. Parmi ces résidents 59,5 % étaient d'origine anglo-saxonne et 29,2 % étaient d'origine mexicaine (COLEF-FONATUR, 1993).
Il n'y a pas d'information sur les dépenses de ces touristes qui ont leur résidence secondaire dans le CTTE, mais il faut signaler qu'ils doivent payer la taxe d'habitation et le permis de construction à côté de la plage.

Cependant l'importance économique du tourisme à simple vue, au moins dans le couloir, ne montre pas l'effet multiplicateur de cette activité dans les zones voisines. Celles-ci continuent à être en marge des bénéfices économiques que le tourisme engendre. Donc la question qui se pose est: où vont ces revenus?, qui en est bénéficie? Y a-t-il vraiment une redistribution des rentrées d'argent?

b) L'aspect social

D'un point de vue social, l'un des apports du tourisme est la création d'emplois, surtout dans les régions où les opportunités de travail ne sont pas suffisantes. Dans ces endroits, l'activité touristique absorbe une part de la population active ce qui contribue au bien-être social.

Malgré les emplois créés dans le couloir, la plupart sont saisonniers et ne requièrent pas de main d'oeuvre qualifiée, comme les emplois de jardiniers, de plombiers, de charpentiers, de serveurs, de femmes de ménage et d'ouvriers de la construction. Cependant, ces emplois allègent le poids du chômage dans la municipalité.

En 1992, il y avait dans le CTTE 116 établissements de logement, soit 4 741 chambres (COLEF-FONATUR,1992). Si on considère les paramètres urbains du FONATUR, selon lesquels pour chaque chambre se créent 1,8 emplois directs et 5 indirects, le tourisme aurait créé 8 534 emplois directs et 23 705 indirects dans le couloir.

Dans la région convergent les intérêts de l'Etat, des "développeurs" et des agents immobiliers pour obtenir les meilleurs gains possibles. C'est pourquoi l'amélioration et l'urbanisation des centres touristiques se sont faits plus vite que dans les villes de Tijuana et d'Ensenada.

Un des principaux problèmes non résolus a été le recul des ejidos face aux centres touristiques. Ils ont perdu leur fonction agricole pour satisfaire les échanges mercantiles, à travers la location de lots pour le tourisme étranger. De cette manière, on a subordonné l'ejido au développement touristique.

D'une part, le tourisme a aidé le développement d'infrastructures bénéfiques non seulement pour les touristes mais aussi pour la population locale, comme par exemple les autoroutes, les aéroports, les installations de loisir, etc. Les investissements nécessaires au tourisme sont si chers que seuls les petits groupes à hauts revenus ou l'Etat lui-même peuvent les réaliser.

D'autre part, l'introduction de services publics comme l'eau, le tout à l'égout et l'électricité dans les zones rurales du couloir dépendait majoritairement des agents touristiques et non des municipalités.

Par conséquent, il y a des niveaux d'urbanisation et d'équipement très différents entre les centres touristiques et les communautés de résidents locaux. Mais, en même temps, ils ont ouvert la possibilité d'introduire des services à prix plus bas dans le futur.

D'ailleurs, les propriétaires fonciers spéculent souvent sur la valeur du sol littoral, c'est ainsi qu'ils ont provoqué l'accaparement des espaces côtiers, augmentant de façon significative leurs prix et qu'ils ont marginalisé aussi la population locale à moyen et bas revenus pour avoir accès à cet espace.

Les prix des lots sont variables, tout dépend de leur taille, de leur localisation, des services qu'ils offrent pour la zone et surtout de la vue sur la mer. Ainsi tandis que le mètre carré de terrain le moins cher coûtait, en 1992, environ 70 dollars, le plus cher coûtait à peu près 1 200 dollars. Généralement sont les constructeurs et les agents immobiliers qui obtiennent la plupart de bénéfices, puisque le prix moyen d'une habitation dans la région littorale était d'environ 165 000 dollars (COLEF-FONATUR,1992).

La construction anarchique et non réglementée des centres touristiques dans le couloir a provoqué de fait la privatisation des plages, puisqu'il y a des bâtiments contigus qui empêchent le libre passage de la population locale vers celles-ci. En dépit des dispositions légales qui imposent l'accés à la plage tous les 500 mètres.

Les irrégularités de la propriété des terres est un autre problème aussi grave du couloir. En effet, la délimitation de quelques sites est imprécise quand il y a plus d'un propriétaire, comme par exemple à Rosarito, Primo Tapia, Esteban Cantú entre autres.

Le démarrage du couloir a été très rapide et non planifié, ce qui a provoqué une croissance anarchique de la zone touristique. Par conséquent, les problèmes urbains se sont accentués et la dotation de services publics est à chaque fois plus difficile pour la population locale. Tel est le cas de l'eau insuffisante dans la région. En été, l'eau doit être rationnée aux communautés locales mais est distribuée dans les centres touristiques.

c) L'aspect environnement

Les effets du tourisme sur l'environnement normalement sont négatifs. Surtout si on considère que l'urbanisation du littoral s'est développée sans frein. Les centres touristiques s'étendent, les résidences secondaires se dispersent sans ordre, entraînant des changements qui dénaturent son paysage.

La fréquentation massive de milliers de touristes sur un espace réduit, qui négligent les richesses naturelles en risquant de saccager le littoral est devenu le noyau d'une concentration humaine démesurée et dangereuse, surtout pendant l'été et les fins de semaines. Un autre problème aussi grave est celui de la pollution résultant tant du piétinement des plages que du rejet à la mer des eaux usées.

Comme résultat de l'évacuation des eaux usées vers la mer on trouve de véritables contraintes dans la qualité de l'environnement. Les eaux du couloir sont polluées à cause de la négligence des entrepreneurs touristiques et industriels et le gouvernement lui-même n'a rien fait pour sauvegarder l'équilibre écologique de la zone.

Les sources de pollution du couloir sont principalement le rejet des eaux usées vers la mer sans traitement, pas seulement des centres touristiques mais aussi des centres urbains comme Tijuana, Rosarito, Ensenada et l'écoulement des eaux usées par la station d'épuration de Point Loma, Californie qui arrive vers la zone à causes des courants marines (Sedesol-Sectur-Fonatur-Gobierno del estado de B.C., 1993).

Dans la zone de Ensenada, en plus s'ajoute le rejet vers la mer de gaspillages organiques des industries de conditionnement de poisson et aussi de déchets industriels des bateaux qui arrivent au port. A Rosarito on trouve aussi des problèmes dûs aux les déchets industriels des Pétroles Mexicains (PEMEX) et la Commission Fédéral d'Electricité (CFE) émet des fumées et gaz par l'utilisation de "fuel" à cause duquel l'air est pollué.

Malgré le développement accéléré du couloir rien n'est ni maîtrisé ni organisé. La multiplication d'immeubles de tout type consomment de larges espaces tout en dégradant irrémédiablement l'harmonie du paysage naturel sans aucun effort pour maintenir l'équilibre écologique du littoral.

CONCLUSIONS

Dans le contexte de l'urbanisation ci-dessus mentionnée on peut identifier quelques tendances qu'il faut remarquer. Tout d'abord, on trouve une demande très forte de l'espace littoral de la part des touristes étrangers. On peut prévoir que cette situation va continuer dans la mesure où le gouvernement élimine les barrières légales qui actuellement interdisent d'acquérir des biens fonciers aux frontières et sur les côtes mexicaines. Ainsi, on peut craindre que la frange placée entre l'autoroute à péage et la plage accélère la formation d'une connurbation linéaire étendue dans tout le couloir. Par ses propres caractéristiques ce type de développement crée de forts coûts d'urbanisation, car l'usage des infrastructures et des services est comparativement bas par rapport à l'intensité de l'usage.

En face de cette demande qui va en augmentant et face au manque d'espaces disponibles à côté de la plage, qui est la zone plus demandée et la plus privilégiée on peut prévoir deux cas de figures, ou bien s'ouvrent de nouveaux fractionnements avec les mêmes caractéristiques sur les collines adjacentes ou bien, commence à surgir une croissance verticale face aux plages, qui obstruera le paysage naturel.

Maintenant on sait que les flux constants de touristes vers le couloir ont abîmé de façon irresponsable l'espace littoral. Il faut donc minimiser les coûts écologiques et sociaux du tourisme et de l'urbanisation en créant des mécanismes pour assurer son développement optimum. On peut reprendre les expériences de

l'Espagne et du sud de France pour éviter de commettre les mêmes erreurs en ce qui concerne la conservation du littoral. (Colloque Franco-Espagnol sur les Espaces-Littoraux, Madrid, 1981; Arroyo Ilera, 1980; Michaud, 1981; Jurdao Arrones, 1983; Cendrero et al, 1982; Cazes, 1972; Cazes et al., 1993).

Il faut mettre en place de manière urgente, un plan d'action pour défendre et assurer une protection efficace du littoral grâce à une politique nationale. Cette politique doit d'abord définir des objectifs et créer les instruments nécessaires pour son application (lois, réglementation, application et contrôle).

La tâche n'est pas facile: il est nécessaire de protéger le littoral en conservant ses caractéristiques naturelles. Il faut appliquer des mesures sur certaines zones qui doivent être sauvegardées, comme les sites menacés par la fréquentation touristique excessive, par exemple les massifs dunaires.

Au même temps que l'on protège le littoral, on doit chercher un développement économique non assujetti aux oscillations du marché immobilier ou du tourisme de masse. Le modèle économique du tourisme doit changer parce que l'esprit du touriste est changé et à chaque fois l'environnement est un facteur plus décisif dans le choix du lieu de visite: l'écotourisme serait une alternative viable et rentable.

Pour que les entrepreneurs choisissent d'investir ou de changer ce type de développement il est possible de créer un programme d'impôts "verts", grâce auxquels ils pourraient y avoir certains encouragements.

Mais une politique de telle nature doit engager l'intérêt général, ce ne peut pas être la tâche d'un individu. Cela demande un compromis de tous les acteurs impliqués: les touristes, la collectivité locale, les entrepreneurs et le gouvernement. Il est nécessaire d'assurer les droits légitimes de la population locale, la protection de la nature et les exigences du développement économique régional et national. Il est nécessaire de protéger, d'aménager et de développer le littoral. Mais il faut établir un plan régulateur prenant en compte la croissance du couloir, les usages du sol et une exploitation optimale des ressources pour attendre un développement soutenu.

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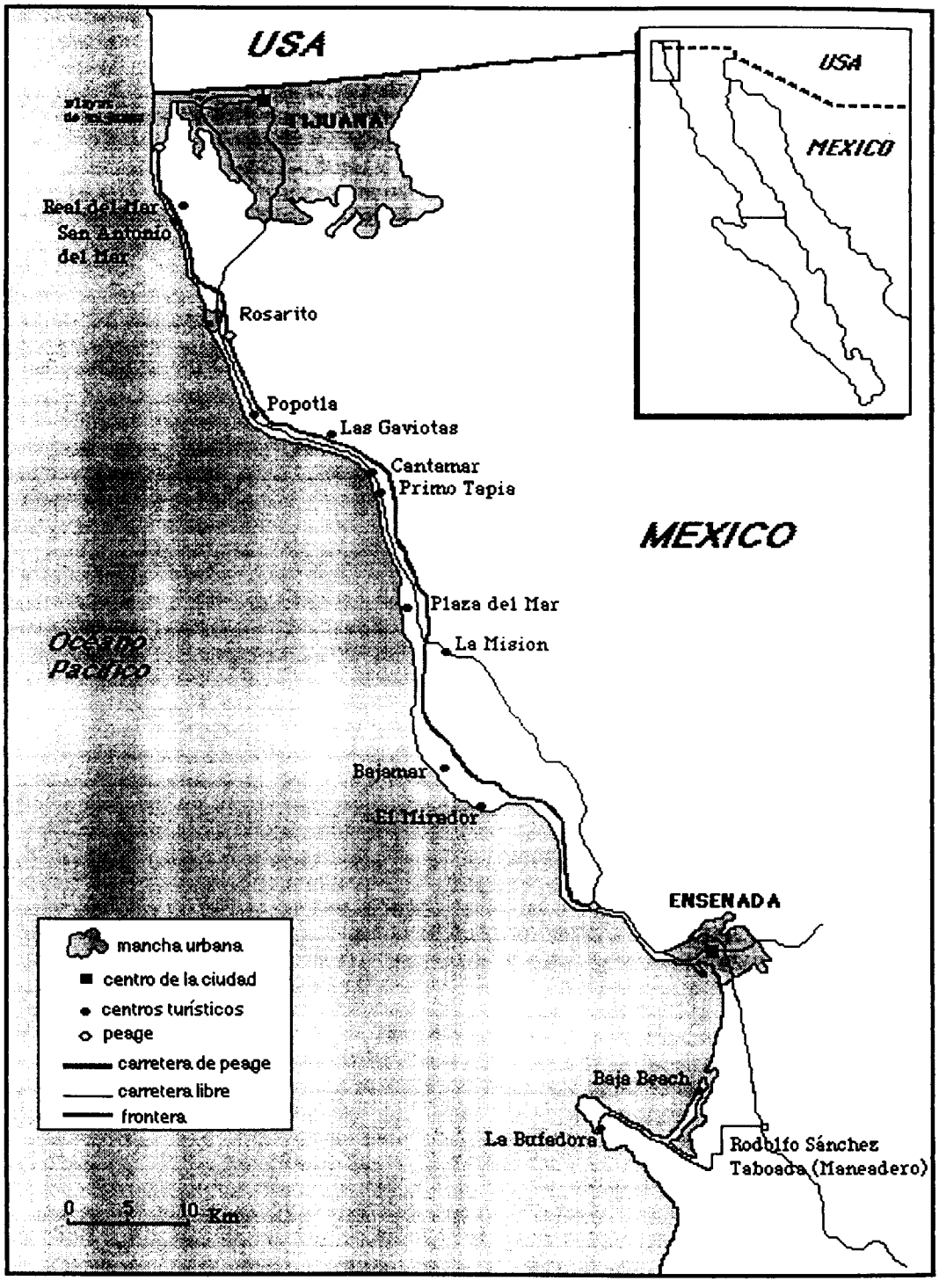

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DURHAM COASTAL MANAGEMENT PLAN

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ABSTRACT

The Durham coastline, in North East England, which naturally consists of limestone cliffs and small sandy coves, was eroding by some 2-3 m/yr until the turn of the century. From that time, and until the early 1990's, colliery waste was tipped onto the beaches in vast quantities, causing them to advance, in some places by several hundred metres. The tipping has now ceased.

This new situation offers major environmental opportunities and challenges in respect of improvements to the natural and socio-economic environment. Any such changes must, however, be carefully managed if different types of environmental degradation are to be avoided.

This paper discusses the preparation of a management plan for the County Durham coast, including the coastal process studies required in order to determine the future behaviour of the tipped colliery waste.

INTRODUCTION

The tipping of colliery waste on Durham's beaches since Victorian times has had a massive impact on the coast. However, the tipping reduced in recent years and ceased in 1994. The consequent changes could be far reaching, both in the quality and use of the beaches as well as in the resumption of coastal erosion. In the light of these major and inevitable changes, the Durham Coastal Management Plan was instigated by a Steering Committee whose aim was to promote the sustainable management of the coast through preparation of a management plan.

Posford Duvivier were appointed to undertake this commission in February 1993. The first stage of the study involved a detailed investigation into the coastal processes and the likely future erosion. An "Issues Statement" was also prepared, describing how the various interests along the coast might be affected by erosion. The second stage of the study involved the preparation of an integrated coastal zone management plan. This was completed in mid-1994.

The Coastal Zone

The coast of Durham (Fig. 1) is a largely undeveloped landscape including the wooded denes. Exceptions are Seaham and the amenity beaches in Crimdon and Seaham. The coastal zone is popular for informal recreation and supports a network of footpaths through the denes and along the cliff tops. The marine environment supports the fishing industry, based in Seaham harbour, and a thriving angling fraternity. The coastal waters are, however, subject to pollution from colliery waste and sewage discharge. The ecology of the County Durham coast is important both nationally and regionally. There are five nationally important Sites of Special Scientific Interest and a National Nature Reserve within the study area, along with five county wildlife sites. The tipping of colliery waste onto the beaches has however led to environmental degradation. For instance, it has caused a reduction in the ecological value of the beaches, intertidal zone and seabed; reduced the value of the coast for recreation and tourism; and seriously damaged the landscape quality of the coastal zone.

In the nineteenth century, Durham's soft rock coast was eroding by some 2-3 m/yr. Colliery waste was first dumped in significant quantities on the beaches in the early 1900's and thereafter increased to reach a maximum estimated as 2-3 million cubic metres per annum after the 2nd World War. For around 50 years, therefore, there have been seriously despoiled beaches and little was done to improve matters until the 1980's. Finally, in 1990 British Coal was informed that the

licences permitting the dumping of colliery waste on the beaches would not be renewed.

The Physical Nature of the Coast

The coast now consists of cliffs, fronted at their base by an artificial beach which is heavily contaminated by colliery waste. The cliffs have been differentially eroded by the sea to form bays and headlands. The upper terrace level of the beach is between 5 m and 6 m above ODN and is up to 150 m wide in places. Chemical degradation of this material has changed its character into a cohesive bank of clay, pebbles and sand together with mining debris. Studies by Sunderland University at Horden beach indicated that the alteration of loose sediments to clay may slow down the rate of erosion of the degraded material compared to its non-cohesive counterpart.

The affected beaches thus comprise two components: a wide terrace of consolidated waste extending from the foot of the cliffs and the lower unconsolidated active beach in the intertidal zone. Within each bay there are often marked variations in the orientation of the coast and shoreline from one end to the other. It is apparent, in the northern part of the study area in particular, that each headland has a containing effect on the beach immediately to the north.

COASTAL PROCESS STUDIES

The Durham Coast is, in one respect, most unusual in that very major changes are virtually inevitable (now the tipping has stopped). The coast has, during this century, developed in response to the tipping of vast quantities of colliery waste - an eroding coast has as a consequence become an accreting one. A management plan could only be based on an appreciation of how the coast would behave in the future. Coastal process studies were carried out in order to gain an understanding of:

- coastal geology and geomorphology
- the action of wind, waves, tides and currents
- sediment transport and sediment balance
- effect on the beaches of colliery waste tipping and its cessation,

and thus to assess:

- whether the spoil beaches would erode
- if so, how fast
- when the previously "cliffed" coast would be exposed to erosion again
- if and when the beaches would become "natural" again (i.e. clean of spoil)
- what form the coast would take in future.

Wave climate was studied thoroughly, using hindcasting and extensive wave modelling, to determine wave conditions at eight inshore locations, these then being used to assess sediment transport. This analysis showed that, between Sunderland and Blackhall, the bays are roughly in equilibrium with respect to longshore transport.

Cross shore transport was also considered but it was not practical to compute it from fundamentals. However, considerations of mass balance (ie. quantity tipped, less quantity which accreted, less quantity lost alongshore) suggested that some 70-90% of material dumped was lost offshore. The distance offshore by which the material is transported is not known but work by MAFF (1992) suggested it was concentrated between Dawdon and Easington and that south of Easington it was in general inshore of the 20 m sea bed contour. The spoil that currently makes up the majority of Durham's beaches is thus but a small proportion of the spoil that has been dumped.

Past Coastal Changes

Up until the turn of the century the coast was eroding by some 2-3 m/yr. During this century the tipping has reversed that trend. A comparison of the shoreline shown on the 1897 O.S. map with that of the most recent series showed erosion to the north of Ryhope (ie. to the north of the study area and of those beaches heavily fed by spoil), but accretion to the south (up to 3.7 m/yr at Horden). Over the last ten or so years the tipping has been progressively reducing, and even before it stopped (based on beach profiles taken by HR Ltd between 1974-1986) erosion had recommenced at Blackhall, Crimdon and Horden. At Horden, very high erosion rates were apparent immediately following the closure of Horden Colliery in the mid 1980's - the rate exceeded 10 m/yr. This was characteristic of the erosion of the

unconsolidated spoil. Elsewhere, at Blackhall where tipping stopped in 1974 the erosion had slowed to some 1.5 m/yr, demonstrating the more resistant nature of the consolidated (clay like) material that the spoil becomes in time. Further evidence of the initial rapid rate of erosion was obtained by comparing the 1989 OS maps with a survey carried out specially for this commission in 1993. At Dawdon, where tipping stopped in 1991, an initial erosion rate of 20 m/yr was evident.

Future Changes

From the various parts of the coastal processes study it was deduced that, in future, erosion would proceed in two stages:

- an initial high rate (10-20 m/yr) which appears to last for two years or more
- a subsequent reduced rate (0.5-2.0 m/yr).

When the beach is finally lost, the cliffs thereafter will erode for the most part by some 0.3 - 0.6 m/yr, with the higher figures in the north. On this basis, future shoreline positions were determined for a range of erosion scenarios. Using these erosion rates, the knowledge of the longshore drift pattern and our awareness of the underlying geology, an estimate of the future beach characteristics was made. There is no precise means of predicting this with confidence, but taking note of the time that it will take for the beach to return to its 1896 position (ie. to where the accumulated spoil has been removed), Tables 1 and 2 were prepared.

ENVIRONMENTAL BASELINE DATA COLLECTION

In parallel to the coastal process studies, a major data collection and consultation exercise was undertaken to establish the environmental interests in the study area and to identify the concerns of interested organisations in respect of the long term management of the coast.

Impacts of Stopping Tipping

In the first instance following the cessation of tipping, there will be a number of impacts resulting from the reduction in the amount of sediment entering the coastal system. Water quality, for example, should improve. Some impacts will also occur due to the erosion of the colliery waste on the beaches (eg. a reduction in access due to the "cliffing" of the colliery waste). Finally, in the longer term, the recommencement of erosion of the natural cliffs will cause further environmental impacts such as the loss of cliff top habitats. In addition to these impacts, many of which will require management, a number of other, more general management requirements were identified. These included habitat loss due to development, prevention of anti-social behaviour and landscape rehabilitation measures.

Management Issues

The management response to the above and other impacts will depend on any decision taken to intervene in the natural processes of erosion. In particular, any decision to construct coast protection works and/or to mechanically remove the colliery waste from the beaches (eg. to a land-based disposal site or to sea) could necessitate a very different management response to that which would be required if natural processes are allowed to continue. The decision on a shoreline management policy was therefore of fundamental importance to the development of a coastal zone management plan.

ISSUES STATEMENT

The completion of the first stage of the work culminated in the production of the coastal processes report and the preparation of an "Issues Statement" describing likely future management requirements. On the basis of the results of the coastal process studies, the Steering Committee determined that, in the short term at least, there would be no intervention with the natural coastal processes. There would, therefore, be no large scale artificial removal of the colliery waste from the beaches and no coast protection or erosion prevention schemes would be constructed. The management plan was prepared on this basis.

MANAGEMENT PLAN

The project Steering Group identified a "vision for the coast" which described the type of coastal environment the respective organisations would like to see in the future:

The sponsors of this Management Plan envisage the Durham Coast of the future to be environmentally healthy, open, accessible, cared for and well managed. We want to see the natural landscape restored, clean beaches and bathing waters, healthy marine habitats, a semi-natural cliff top with magnesian limestone grassland thick with flowers, lush wooded denes rich in wild life, essential development sited sensitively and blending into the landscape, eyesores cleared and a comprehensive footpath network. Above all, we want to see local people and visitors enjoying the peace and natural beauty of the Durham coast once again.

The ultimate intention of the overall Durham Coast Management Plan study was to prepare a management strategy to achieve this vision. This involved identifying mechanisms for maximising enhancement of the coastal environment and landscape and developing the potential for tourism and recreation, while protecting the conservation value of the unspoilt coast. The overall image of the Durham coast could be improved through the implementation of the strategy, not least to attract sustainable industry and tourism to East Durham and thus to regenerate the local economy. The Durham Coast Management Plan therefore documents the management strategy and the mechanisms required to achieve its aims.

Management Plan Framework

The Management Plan contains guidance and prescriptions for the management of the coast. When it is implemented, the Plan will become the focus of a dynamic management planning process. A framework for management was therefore developed, comprising goals, objectives, policies and actions.

The Management Plan goals identify the long term aims or principles for which the Plan strives. The objectives set out targets which are achievable in the short to medium term. Objectives are important because, unless management successes can be clearly achieved in the short to medium term, the management of the coast may lose its focus and future successes will not be easily determinable.

The Management Plan then sets out policies which are statements intended to guide any future decisions relating to the management of the coastal zone, ensuring that the achievement of objectives is not threatened by poorly based decisions. Finally, the Plan defines actions (or activities) which must be carried out by the organisation(s) identified as being responsible for their implementation, in order to achieve the objectives of the Management Plan.

There are three main aspects of the Management Plan, which have been developed in the goals, objectives, policies and actions in order to reflect the fact that the coastal zone is an integrated system. The three aspects, which are further discussed below, are as follows:

- Resource protection
- Resource use and ownership
- Co-ordination, research and education

Resource Protection

Within the terms of the management philosophy and to achieve a coast which resembles the Steering Group's "vision", the Management Plan acknowledges that the natural resource (nature conservation, landscape, geology etc) on the Durham coast is already very valuable in regional and national terms. There is also a very great potential both for its protection and its improvement. This potential for enhancement arises primarily as a result of the historic degradation caused by and associated with colliery waste tipping on the beaches. Environmental quality has also been reduced by factors unrelated to the tipping of colliery spoil, such as sewage pollution, inappropriate development, fly tipping, motor cycle scrambling and uncontrolled access over sensitive nature conservation areas.

While human activity has historically damaged the environmental quality of the Durham coastal resource, it is not the intention of the Management Plan to prevent human activity on the coast. On the contrary, the Plan aims to encourage and promote activities such as leisure and tourism, given that they are carefully controlled to ensure that they do not unduly damage the natural resource. Where appropriate,

however, enhancement of the natural resource will take priority.

The resource protection goal seeks to protect, enhance and maintain the natural value of the Durham coast. The policies and actions therefore intend, inter alia to recreate and restore coastal habitats, for example through the conversion of the agricultural land at the top of the cliffs to permanent pasture. In the denes, where areas have been deforested, replanting of native species is recommended. Various site specific projects such as the control of scrub to prevent its invasion of grassland habitats, and careful management of the coastal environment will also achieve enhancement of its natural value.

While habitat creation and enhancement projects will help to improve the overall image of the coastal zone, other landscape improvement activities are also recommended. For example, landowners are encouraged to join together to identify and undertake projects to improve the landscape value of their land, working towards an upgraded appearance of the coast.

In order to improve environmental quality and reduce pollution, the Management Plan supports the current and ensuing sewerage improvements and recommends the ongoing removal of debris and broken structures, particularly those being exposed as the colliery waste erodes. Although local, small scale removal of colliery waste was not favoured as an option for regeneration of the beaches, the Management Plan recommends examination of potential opportunities to tidy up small areas of the beaches. Such options would help to enhance the image of the coast.

Resource Use and Ownership

It is recognised in the Management Plan that environmental enhancement must not preclude sustainable human activity in the coastal zone. Clearly people own and make a living out of the coastal resource and this must not unnecessarily be threatened. Indeed, the Plan aims to enhance the value of the coast to its users. However, the type and extent of use must be carefully and sensitively managed in order that the resource protection goal can be achieved.

Enhancement of the coast's value to users need not conflict with the resource protection goal. The type of use to be promoted should be targeted to be compatible with the protection of an enhanced environment. For example, tourism should be targeted to attract visitors who are interested in the open landscape and educational value of the coast. The Management Plan intends to maximise the realistic tourism potential of the coast. Commercial and recreational use of the coast should be controlled so as to be sensitive to the important environmental quality and landscape value. Necessary development should be designed to be compatible with the character of the coast. Many of the current activities on the coast are uncontrolled and were identified in the Issues Statement as requiring careful management. The Management Plan therefore aims to regulate coastal development to prevent unnecessary threats to the natural value of the coast and particularly to prevent the need for coastal protection structures in the future. Intensive development should therefore be concentrated in Seaham with the rest of the coast being designated as being appropriate for mainly low intensity tourism.

Access to the coast, particularly vehicular access, will need to be controlled thus preventing damage to the coast by sea coal lorries and motor bike scramblers, and reducing incidences of vehicular crime on the coast. The Plan promotes the use of the coast by pedestrians for example by encouraging the provision of car parks adjacent to the coastal zone and the promotion of foot access within the coastal zone.

The Management Plan intends to reduce risks to public health and safety hazards by regularly surveying existing coast protection structures and carrying out works as required. Where paths are threatened by erosion and collapse of cliffs, regular works should be undertaken to protect walkers' safety and notices should be displayed warning of any potential dangers.

Co-ordination, Research and Education

In order to achieve protection and sensitive use of the resource, it is important to co-ordinate all management activities in the coastal zone.

Successful management of the coast relies on co-operation and co-ordination between and within the various organisations with management responsibilities. That is, the various organisations and the users of the coastal resource including the public should be aware of activities occurring on the coast which may affect their respective interests.

It is also necessary to further develop understanding of the natural systems and their interactions. This is important in order both to target management, and to educate the users of resource, thus gaining their support for management. Successful management of the coast will also rely on a comprehensive understanding of the state of, and interactions between, environmental parameters. The effectiveness of management can be improved by increasing public understanding and awareness of the issues, objectives and policies pertaining to their use of the coast. With a better understanding of the sensitivity of the resource and the reasons for controlling activities on the coast, user co-operation with the policies is often more readily achievable.

The Management Plan therefore recommends that a Management Committee is set up consisting of representatives of all the organisations with management responsibilities on the coast. All management should be coordinated by a Coastal Officer and a formal coastal forum will help to involved the local users of the coast in the management of the resource. A programme will be devised and implemented to encourage the participation of teams of local volunteers in the implementation of the Management Plan. The Plan also promotes the provision of information and the education of users of the coast by means of an Information Office and information boards. Research and monitoring programmes recommended in the Management Plan include the ongoing monitoring of the erosion of the coastline and the dispersion of the eroded minestone on the seabed. Various research projects have been recommended to record the recovery and maintenance of the ecological value of the coastal zone and to improve the information base relating to the coast. It is also recommended that all data and results of research and monitoring projects are held in a centrally located databank to facilitate the exchange of information amongst those involved in the management of the coast.

Reviewing the Management Plan

Having developed the Management Plan, it is important to ensure that the actions are being carried out; policies are being adhered to; and objectives and goals are being achieved. Research and monitoring actions are intended to help identify areas where the plan will need to be modified. The research will help to avoid further conflicts by early definition of management issues, while the monitoring will determine whether the actions are achieving the intended objectives. Both the research and monitoring should illuminate any shortcomings in the effectiveness of the plan and modifications can therefore be made to the plan as necessary. Indeed, as actions are completed, these will need to be replaced by new actions to take the plan one step closer to achieving the objectives.

Once objectives have been achieved (most likely in the medium to long term) new objectives will need to be identified which will bring the coastal zone closer to the vision and closer to achieving the Management Plan goals.

Eventually, a holistic overview of the Management Plan will be needed. Within, say, ten years, the majority of the objectives may have been achieved, or political priorities may have changed or the Management Plan may have become outdated. A comprehensive review of the state of the coastal zone will then be required to assess the progress of the Plan and determine the way forward in the future. It is anticipated that it will only be possible to achieve many of the objectives and actions identified in the Durham Coast Management Plan in the longer term.

CONCLUSIONS

The coastal process studies demonstrated that the tipping of colliery waste onto Durham beaches led to accretion of a previously eroding coast. With the cessation of that tipping, the accumulated spoil beaches are already beginning to re-erode in

two stages. The first is rapid and removes loose unconsolidated spoil at a rate of maybe 10-20 m/yr, the second stage is slowed, by the consolidated clay-like nature of the older spoil, to some 1.5 m/yr. The timescale for the beaches to regress to a more natural state has been estimated.

The Issues Statement identified the potential environmental impacts associated with the cessation of tipping colliery waste and also more general management issues in the coastal zone.

The Management Plan for the County Durham coast identifies actions to achieve management objectives in the short term and provide a decision making framework to facilitate the integrated, sustainable management of the coastal resource into the foreseeable future.

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Table 1. Summary of future beach characteristics.

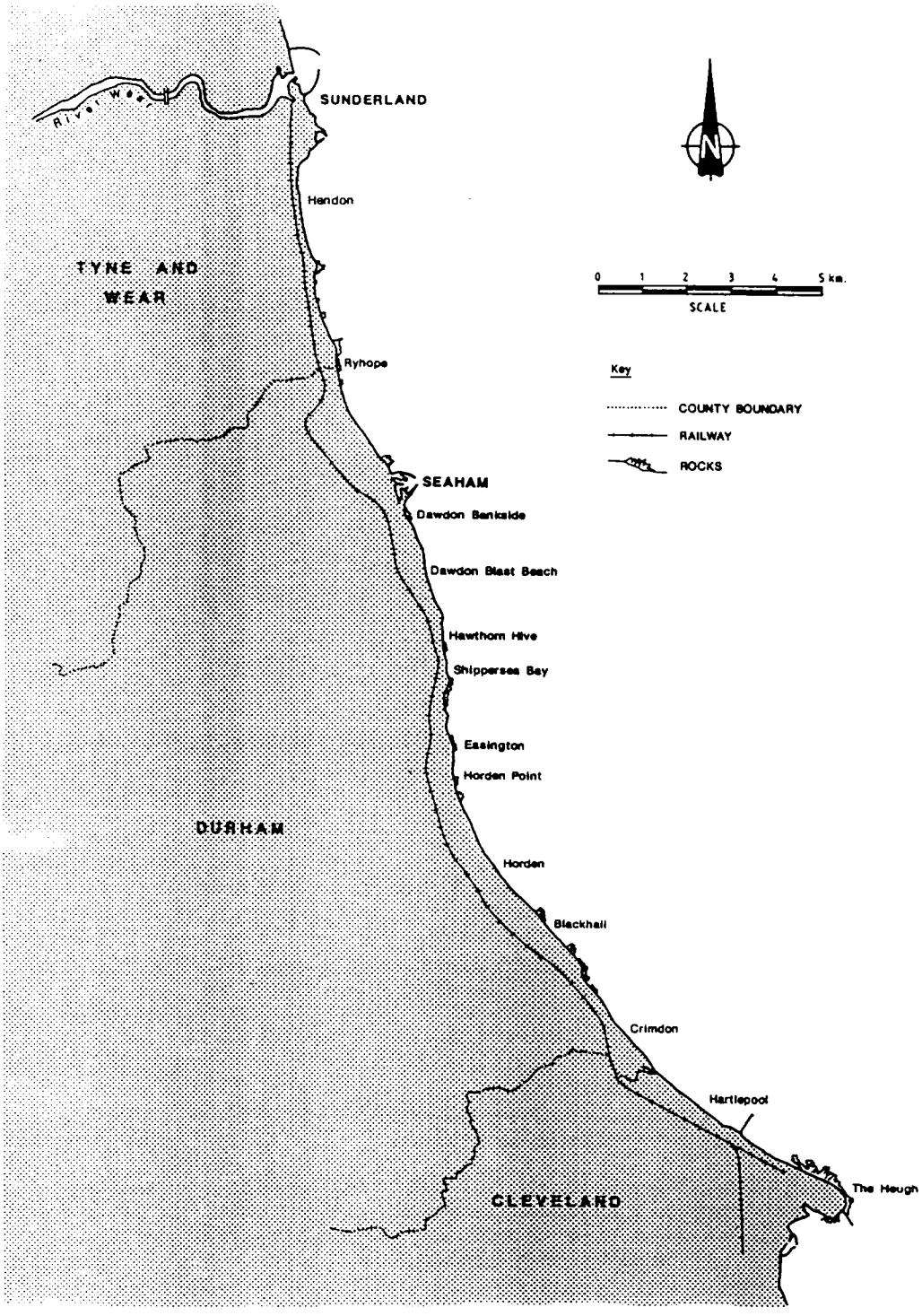
Location	Retreat Period for Spoil (years)	Future Erosion Rate of cliff m/year	Future Beach Characteristics
Dawdon Bankside	4 to 102	0.3	steep, gravel/little sand, rock outcrops and rock stacks
Dawdon Blast Beach	25 to 242	0.3	steep, gravel/some sand, rock outcrops, possible marsh area some 50m wide between highwater and cliff
Hawthorn Hive	9 to 142	0.3	steep but flatter than Dawdon, sand and gravel, rapidly deepening water (seabed excavation), residual contamination likely
Shippersea Bay	3 to 82	0.3	steep, gravel/little sand, rock outcrops, residual contamination likely
Easington	5 to 143	0.3	steep, gravel/little sand, rock outcrops
Horden	52 to 210	0.3	flatter beach, sand and gravel, rock outcrops in north, residual contamination likely
Blackhall	40 to 160	0.3	flat, sand, residual contamination likely

Table 2. Predicted shoreline positions.

	Beach Width from Cliff in 1896	Present Beach width from cliff	Initial Rapid Erosion Rate	Time of Rapid Erosion	Final Erosion Rate	Future Beach Width from Cliff (m)			
						5 yrs	15 yrs	25 yrs	50 yrs
	(m)	(m)	(m/yr)	(yrs)	(m/yr)				
Dawdon Bankside	30	100	20	5	2	30*	-	-	-
			10	2	0.5	78	73	68	55
			15	3	1.5	52	37	20*	-
Dawdon Blast Beach	80	220	20	5	2	120	100	80*	-
			10	2	0.5	198	193	188	176
			15	3	1.5	172	157	142	104
Hawthorn Hive	90	180	20	4	2	98	90*	-	-
			10	2	0.5	158	153	148	136
			15	3	1.5	132	117	102	90*
Shippersea Bay	40	100	20	4	2	40*	-	-	-
			10	2	0.5	78	73	68	56
			15	3	1.5	52	40*	-	-
Easington	20	120	20	5	2	20*	-	-	-
			10	3	0.5	89	84	79	66
			15	4	1.5	58	43	28	20*
Horden	20	125	0	0	2	115	95	75	25
			0	0	0.5	122	117	112	100
			0	0	1.5	117	102	87	50
Blackhall	20	100	0	0	2	90	70	50	20*
			0	0	0.5	97	92	87	75
			0	0	1.5	92	77	62	25

Notes:

Fig. 1. Map of Durham coast, UK.



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COASTAL CHANGE: ITS IMPLICATIONS FOR TAIWAN ISLAND'S COASTAL ZONE MANAGEMENT

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ABSTRACT

On a world-wide scale coastal zones are under stress. Many countries experience environmental degradation and their coastlines suffer from significant erosion. Equal problems threaten Taiwan's coasts enhanced by industrial development, recreation, aquaculture, and waste disposal practices. In order to avoid negative effects, effective coastal management has become a key issue on the environmental agenda in Taiwan.

IMPLICATIONS FOR COASTAL ZONE MANAGEMENT

Taiwan's economic success is due to much industrial research. However, there are many impediments to Taiwan's sustainable development. Large-scale land reclamation in tidal areas is a significant example (Fig. 1). Each of fifteen major reclamation projects involved more than 1,000 ha. Moreover, the most ambitious project is larger than 15,000 ha (Chiau, 1993). Since these projects often do not take into consideration long-term natural processes, such as the movement of drifting sand, and show a lack of coordination among other projects in the same region, their artificial structures have caused tremendous problems (Fig. 2), such as serious erosion of the coastline, unwanted accretion, wetland losses and a general degradation of the near-by marine environment. As is shown in Fig. 3, a notable part of Taiwan's shoreline is receding.

In addition to natural factors (e.g., strong summer storms, current patterns, and coastal topographic features) and dam constructions on each of the major rivers, a decrease of sediment supply along the coast was observed. Moreover, due to numerous inadequate structures, sand drift has been blocked, which aggravated the situation. According to a report, the shoreline at Pali beach, on the north-west coast, retreated 500 m during the past twenty years.

Due to the lowering of ground levels, as a result of uncontrolled groundwater abstraction, the south-western low-lying coast faces the threat of increased flooding at higher sea-levels. When typhoons struck Taiwan in the summer of 1994, that region suffered from serious flooding and property loss. On the other hand, rapid land development in the coastal zone may bring some benefits to Taiwan's economy. However, this development will also change its natural environment and lower the quality of life in the coastal zone.

"Integration" of coastal affairs will be one the most important and challenging tasks for Taiwan. The major governmental agencies associated with coastal zone development and management include:

(1) The Council for Economic Planning and Development, Executive Yuan (Cabinet);
(2) The Ministry of Interior;
(3) The Environmental Protection Administration;
(4) The Council of Agriculture:
(5) The Ministry of Economic Affairs (Industrial Development Bureau);
(6) The Ministry of Finance (National Property Bureau); and
(7) The Ministry of Communications.

Among these agencies, the Ministry of Interior has been designated to be the future authority on coastal zone management. In response to the problems arising in the coastal zone, the Ministry of Interior is actively undertaking several programmes for better management of this critical and fragile area.

Three major works currently undertaken by the Ministry are the following:

(1) Enactment of the coastal zone management Law;
(2) preparing the integrated coastal zone management plan, and
(3) establishing a permit system for tidal land reclamation.

However, the complete authority on the protection of the marine environment is still spread among a number of central and local agencies. Without coordination, all related projects in the coastal zone are based on individual or subjective considerations. The essential data for marine engineering, on the other hand, are collected by non-continuous projects and scattered between research institutions. Since an exclusive law on coastal zone management is still in preparation and may take several years to enact into law, the dispersed existing regulations inevitably limit the performance of the management of the coastal zone in Taiwan (Chiau, 1994a, 1994b). Therefore, integration of coastal affairs, strengthening the coordination among all related agencies, and involving environmental considerations will be the themes of coastal management in Taiwan in the future.

The innovation of coastal management by management institutions must properly consider the interaction between the coastal physical environment and human activities. Although few international organizations exert influence on environmental, safety and health requirements, the policies and legislation in Taiwan follow in general the established international practices. A national environmental programme as a follow-up to UNCED has been proposed by Taiwan's Environmental Protection Administration recently. In order to overcome the problems of coastal change in the area, Taiwan should consider preparing national programmes focusing on the integrated coastal management and sustainable use of coastal and marine resources as early as possible. It is believed that the following policy recommendations are essential in response to the changing coast of Taiwan:

(1) establishing a national marine information centre to provide scientific and reliable data for coastal research and integrated management;

(2) systematic observation of Taiwan's coast to address promptly the problems of coastal erosion;

(3) providing a forum to facilitate an effective communication between scientists and user community;

(4) strengthening the coordination between coast-related agencies;

(5) applying the principles of environmental planning and assessment for avoiding environmental problems which may arise from development programmes;

(6) promoting education and training programmes on coastal issues for informing and training officials and the general public; and

(7) promoting regional and international cooperation for exchange of experience in the field of coastal zone management.

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Fig. 1. Location of reclamation projects.

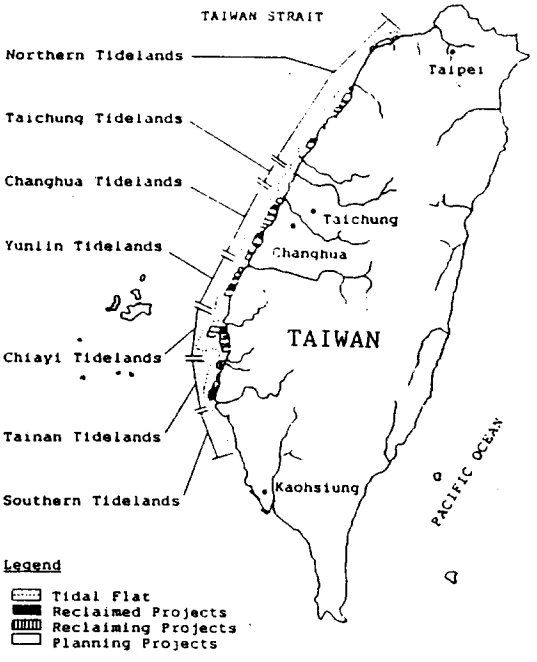
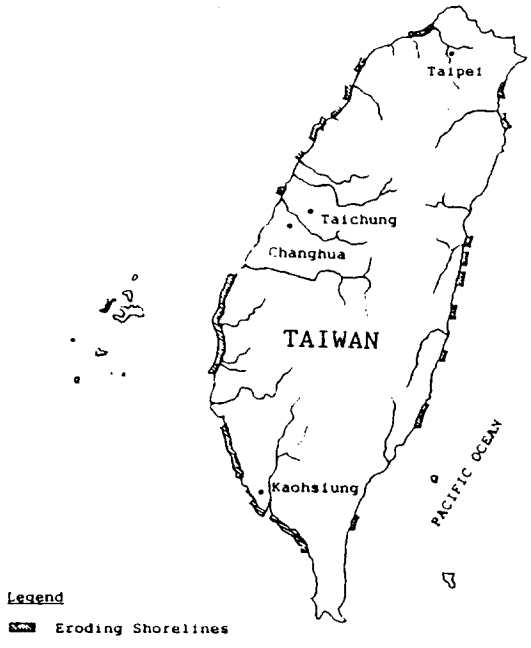


Fig. 3. Eroding shorelines in Taiwan.



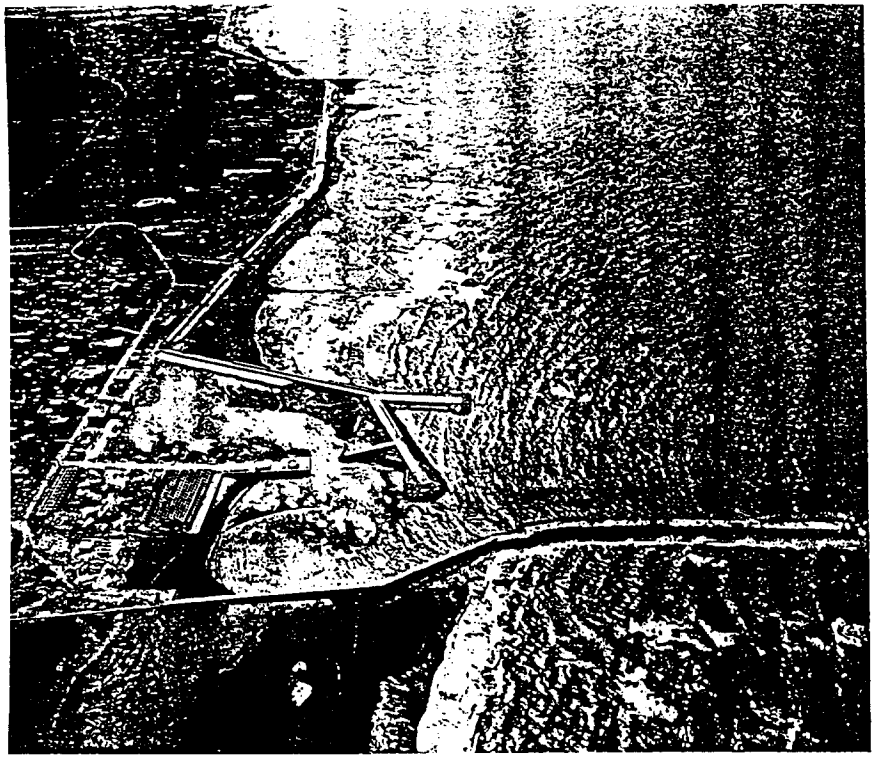


Fig. 2. Erosion and accretion caused by artificial structures.

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METEOROLOGICALLLY INDUCED CHANGES ALONG THE NIGERIAN COASTAL ZONE AND IMPLICATIONS FOR INTEGRATED COASTAL ZONE MANAGEMENT PLAN.

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ABSTRACT

The narrow, low-lying Nigerian coastal zone is dominated by a dense human population, socio-economic facilities and vast natural resources. This coastal zone experiences two types of meteorologic conditions. The rainy season (May-Nov.) when storms, characterised by high winds are more frequent, and a dry season when meteorological conditions are much more subdued. Though coastal changes resulting from coastal erosion, flooding, subsidence and deforestation are caused by other forces, harsh meteorological conditions especially during the months of May - September, help to aggravate these coastal hazards. For example, rates of coastal erosion at Victoria beach and the Mahin mud coast peak annually during these months. This paper utilizes the meteorological factors which influence the above coastal hazards. A detailed analysis of wind and other meteorological parameters as they influence wave energy and coastal processes resulting in coastal changes are discussed. An effective Integrated coastal zone management plan for Nigeria should include knowledge of the meteorological parameters which exacerbate coastal changes.

INTRODUCTION

The Nigerian coastal zone spanning about 853 km of low-lying coastline (with nowhere above 3 m of low water) is bordered in the west by the Republic of Benin and in the east by Cameroon. Its width ranges from a few kilometres in the west to 150 km in the Niger delta. It lies generally between 4°10' and 6°20' N latitudes and 2°45' and 8°35' E longitudes adjacent to the Gulf of Guinea (Fig. 1). The Nigerian coastal zone can be distinctly classified into four geomorphic units with different configurations. A 200 km long barrier lagoon coast in the western part is followed by the 75 km of Transgressive Mud Coast which tapers into the dominating 450 km long arcuate Niger Delta. To the far East is the 85 km Strand coast where mangroves fronts the sea.

SOCIO-ECONOMIC SETTING

The Nigerian coastal zone with an estimated population of 20 million (Awosika et al. 1992), constitute an area of intense human activities. Population densities of more than 400 persons per square kilometres have been recorded in urban cities of Lagos (former capital of Nigeria), Warri, Port Harcourt, Calabar, Sapele and Uyo.

The coastal zone is a bee hive of activities because the countries economy is closely tied to it. A significant proportion of Nigeria's resources is located there. The most important is oil and gas which constitute well over 90% of Nigeria source of foreign exchange earnings. Large cities such as Lagos with concentration of industrial establishments, Port Harcourt and Warri with the oil infrastructure are within the coastal zones. The coastal zone is also constituted by other human activities including agriculture, fishing, mining, manufacturing and tourism.

CLIMATE

The climate within the coastal zone can be described as sub-equatorial mainly under the influence of the North-east trade winds and the south-west monsoons. Two main seasons characterise the Nigerian coastal climate. The first is the dry season which starts around November and ends in April but its effect on the coastal areas is mildly felt as a result of marine influence. The second season is the rainy season which occurs during the months of May to October with a short

dry spell between the months of August and September (Fig. 2).

Dry Season

The dry season is usually characterised by dry, dust laden North East trade winds which are dominant in the northern part of Nigeria. Temperatures during this period range between 26°-28°C. Higher temperatures are usually recorded in the months of February, March and April, which coincide roughly with the passage of the overhead sun. On-shore north east winds reaching the coast attain speed ranging from 2 to 7 m/s. Towards the late dry season, the south westerly winds have not brought their rains which usually lower coastal temperatures, thus temperatures could peak to 31°C in some places. From December to February when the coastal areas are under the influence of the Tropical Continental air masses, average relative humidity of between 60 and 70 per cent at about 9.00 GMT is usually recorded. As from April, temperatures decrease steadily while relative humidity rises steadily. In February for example, the mid-latitude trough may be extended as far south as Northern Nigeria. This may induce the development of vortices in the coastal areas. The Inter Tropical Discontinuity (ITD), a zone which forms a wedge under a dry relatively warm air with a northeasterly component, may move for a brief period to the sea thus causing a wind shift from north-westerly which can be observed at such times in Port Harcourt. In April, a number of factors lead to the formation vortices and fluctuations in the position of ITD.

Rainy Season

The amount and type of rainfall experienced at any place in the coastal areas at any time of the year depends on its position in relation to the Inter Tropical Convergence Zone (ITCZ). The predominant winds during the rainy season are the south westerlies which are moist laden. Maximum wind speed during the rainy months usually range from 6 to 9.5 m/s and could be well over 17 m/s during storms. The rainy months of May to September are characterised by heavy rains with a short dry spell between the months of August and September (Fig. 2).

Coastal temperatures during the rainy months of May to July are between 27°c and 28°c. During this months, the southwesterly winds tempers temperatures down, so that daily temperatures are usually more regular than in some places inland. During the rainy period, the southwest monsoons are dominant, intensive line squalls reaching several areas like Port Harcourt are experienced. The ITD fluctuates between 15°N and 20°N or higher. Vortices develop around west of Lagos, east of Calabar and in the Cameroon. Under such conditions, numerous line squalls are induced in the coastal areas. During these line squalls, wind speed could exceed 20 m/s. Coastal humidity at this period could reach a maximum of 90 to 95 percent between June and September.

In July, the south Atlantic high pressure gradient steepens towards the Gulf of Guinea. Sometimes, the ITD is pushed back to 8° N by a sudden anticyclonic blocking. A semi-permanent high pressure is usually established at the Bight of Biafra at this time. Line squalls are more frequent in the country during this period. There is at least one line squall a month and as many as six or more in the same month. One line squall may cover a distance extending from 120 to 240 km or more, while its speed may vary from 48 to 120 km/hr. The squalls are sometimes dry, at other times they are accompanied by violent storms which may last several hours at a stretch. In July, which represents the peak of the rainy season, a large part of the coastal area is affected by the humid maritime air mass and so relative humidity is quite high averaging about 90% while rainfall also averages more than 3500 mm/yr. About 80 per cent of the total annual rainfall in the coastal zone occurs during this month.

The monthly distribution of rainfall for many coastal stations (Fig. 2) show that there is a long wet season from April to July where most of the states record about 80-90 per cent of their total annual rainfall. In the south especially along the coast, the constant convectional rains and winds from the sea ensure that there is no dry period in August. Instead, there is only a slight decrease in the heavy precipitation. The short dry spell (which

is the coldest) experienced in August loses much significance in some coastal areas where there is continuous rainfall. In Lagos where this period is rather felt, there is still a degree of cloudiness which deflects incoming solar radiation. From September to November, relative humidity decreases while temperatures increases, by December, high temperatures are again accompanied by low relative humidity and the continental air mass has become dominant once more. The ITD at this time begins its southward retreat, its position averaging 15^0 N latitude. November sees a dramatic shift in the ITD The oscillation of the ITD continues into December until the end of the month when it reaches its southward limit at 6^0 N.

IMPACTS OF METEOROLOGICAL FORCING ON THE COASTAL ZONE

The Nigeria coast is usually impacted by wind generated southwesterly waves. The intensities (height, period) of these waves are usually under the influence of the wind and the fetch. During the raining months of May to September when harsher meteorologic conditions persist, the south westerly waves are more intense. Mean wave heights along the Nigerian coastline range from a few cm's along the Mahin mud coast to about 1 to 1.5 m along the western part, the Niger delta and the Strand coast. During the months of April to May and August to September mean wave height could exceed 2 m. Fig. 3 shows typical wave characteristic off Forcados (Awosika et al. 1995). The low lying nature of the Nigerian coastline as well as the nature of the sediments make the coastline very vulnerable to erosion and flooding especially during these months of harsh meteorological conditions and high waves. Other adverse effects of these meteorologically induced conditions include deforestation and increased salinity of groundwater. The result of these is an apparent change is coastal morphology.

COASTAL EROSION

The entire Nigerian coastline is very erosive. Typical annual rates of erosion include more than 18 m at Ugborodo/Escravos, 20 m at Forcados, 6-19 m at Brass, 10-14 m at Imo River entrance and 25-30 m in Lagos (Ibe et al., 1988). The prime function of wind in relation to beach migration is in the generation of wind waves which result from kinetic energy transfer from the wind to the sea. Wave and wave induced current are the most important force which shape and determine to a large extent beach erosion.

During the rainy months of May through September when southwest winds are predominant, wave heights of more than 2 m are recorded in Lagos, Forcados, Brass and other coastal areas. During storms when wind speed could reach over 120 m/s wave height could reach 4 m (Ibe, 1988). Such phenomenon are frequent during line squalls. Critical analysis of erosion rates along the Nigerian coastline, indicate a strong correlation between rates of erosion and meteorological forcing especially during storms. At Awoye along the Mahin mud beach coastline, erosion rates averaging 13.26 m between August and October (predominantly during the stormy months) have been recorded (Ibe et al., 1985). Along the Victoria beach and on the 24th August 1990, during a storm, large parts of the back-beach was flooded. Wave heights of well over 4 m were recorded during the storm and about 7 m of beach was eroded within 12 hr during the storm. Following the beach nourishment of 1990/91, Awosika et al. (1994) also found that erosion rates were faster along the nourished Victoria beach during the rainy months as against the dry season. Table 1. shows that between August and September 1991 when wind speed averaged 4 m/s, 2.5 m of beach was eroded as against 0.5 m of beach eroded during the calm months of October to December 1991. Also, 15 m of beach was eroded during the months of June and July 1992 when wind speed exceeded 4 m/s as against 6 m of beach eroded between April and May 1992 when wind speed was about 1.8 m/s. These seasonal erosional trends are shown graphically in Fig. 4.

FLOODING

Flooding is an environmental phenomenon that is widespread all along the Nigerian coastal area. Flooding leads to loss of agricultural land, property, socio-economic structures and even life.

This phenomena is more prevalent during two climatic regimes of the rainy periods of (May to October). During the rainy season, the intricate network of coastal river systems especially in the Niger delta, estuaries, creeks and fringing lagoons get flooded and overspill their banks.
Also there is a prepondance of high waters which generally coincide with storm surges prevalent during the rainy months. The low lying nature of the coastline makes it very vulnerable to flooding. Such is common along the Mahin mud beach where a large part of the backshore is perpetually under water during the rainy months. The problem of flooding of coastal areas is also more apparent especially in Victoria Island Lagos. During storms which again mostly coincide with high waters, storm drainage systems are usually backed up resulting in the flooding of many of the roads and even houses. Such was the case on 24th August 1992 when a storm surge which had its origin from roaring forties of the Atlantic flooded a large part of the island.

SALINISATION OF GROUND WATER

The ground water potential of the coastal areas is very high with a yield of several hundred thousand gallons per hour due to high permeabilities, considerable thickness of the aquifers and high recharge potentials due to heavy rains. During the rainy months of May-October, wind generated waves cause large piles of coastal sea waters to flood extensive low-lying areas of the coast (Calabar, Awoye, Forcados, Brass etc). The flood water would stagnate and seep into the water table which is often very shallow in the coastal areas. This increases the salinity of the groundwater. More often, deep aquifers which are known to have potable fresh water also gets contaminated from sea water.

DEFORESTATION

The coastal areas have a remarkable diversity of vegetation ranging from coastal forests to the swamp vegetation and mangroves which in most cases cannot tolerate very high salinity. Human activities like clearing of vegetation, oil and gas exploration and exploitation especially in the Niger Delta have resulted in the loss of primeval coastal vegetation. Increased flooding resulting in increased salinisation of groundwater, coastal erosion have also led to the loss of coastal vegetation which is usually faster during the rainy months This situation is wide spread in the Mahin coast.

INTEGRATED COASTAL ZONE MANAGEMENT AND IMPLICATIONS OF EXTREME METEOROLOGICAL CONDITIONS.

Integrated coastal zone management (ICZM) is a governmental process consisting of legal and institutional framework necessary to ensure developmental and management plans for coastal zone. The purpose of ICZM is to maximize benefits derived from coastal zone and minimise conflicts and harmful effects of coastal processes. In the formulation of ICZM, issues that affect coastal zone must be understood. Such issues must include coastal erosion, flooding, salinization of coastal lands and decimation of coastal vegetation. While a large part of these coastal problems are cause by anthropogenic activities natural forces like storms derived from meteorological forcing cause very drastic changes along the coastal zone. The lack of adequate knowledge about some of these natural phenomena that periodically inundate coastal areas especially low lying ones lead to the haphazard response measures. Incorporation of some of the causative agents of coastal hazards into ICZM will ensure an effective plan. National recognition of these issues are important processes in institutional arrangement in the process of ICZM implementation.

CONCLUSION

The Nigerian coastal zone constitute an important economic nerve centre for the nation. However, conflicting uses of coastal resources as well as natural forces are causing wide spread coastal degradation. Though the Federal Environmental Protection Agency (FEPA) is saddled with the task of enforcing environmental policies, there is no ICZM plan in place that will incorporate coastal issues embodying such natural events as storms. ICZM programme in Nigeria hence calls for collective efforts of concerned agencies and

institutions in developing management measures to resolve resource uses, preservation of coastal areas and adverse effects of coastal changes.

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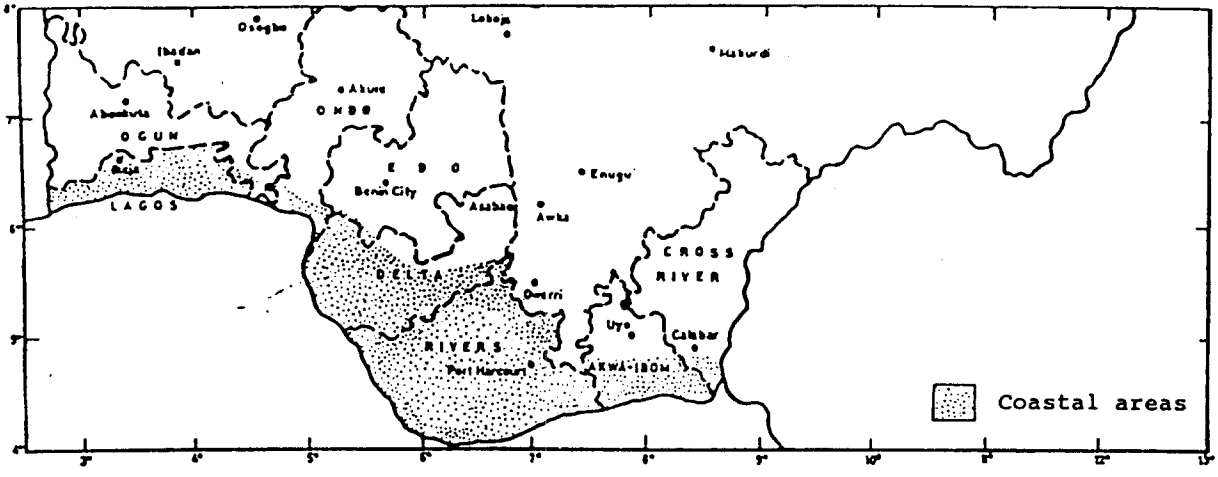
Table 1. Erosion rates (at station 1 on Victoria beach Lagos) versus monthly mean wind speed between August 1991 and September 1992.

MONTH	MONTHLY MEAN WIND SPEED (m/s)	RATE OF EROSION (m)
August 1991	4.62	2.5
September '91	3.926	
October 1991	3.982	0.5
November 1991	2.833	
December 1991	2.224	
April 1992	1.847	6.0
May 1992	1.847	
June 1992	4.775	15
July 1992	4.892	
August 1992	5.251	10
September 1992	4.753	

Fig. 1. Map showing coastal areas with the coastal States of Nigeria.



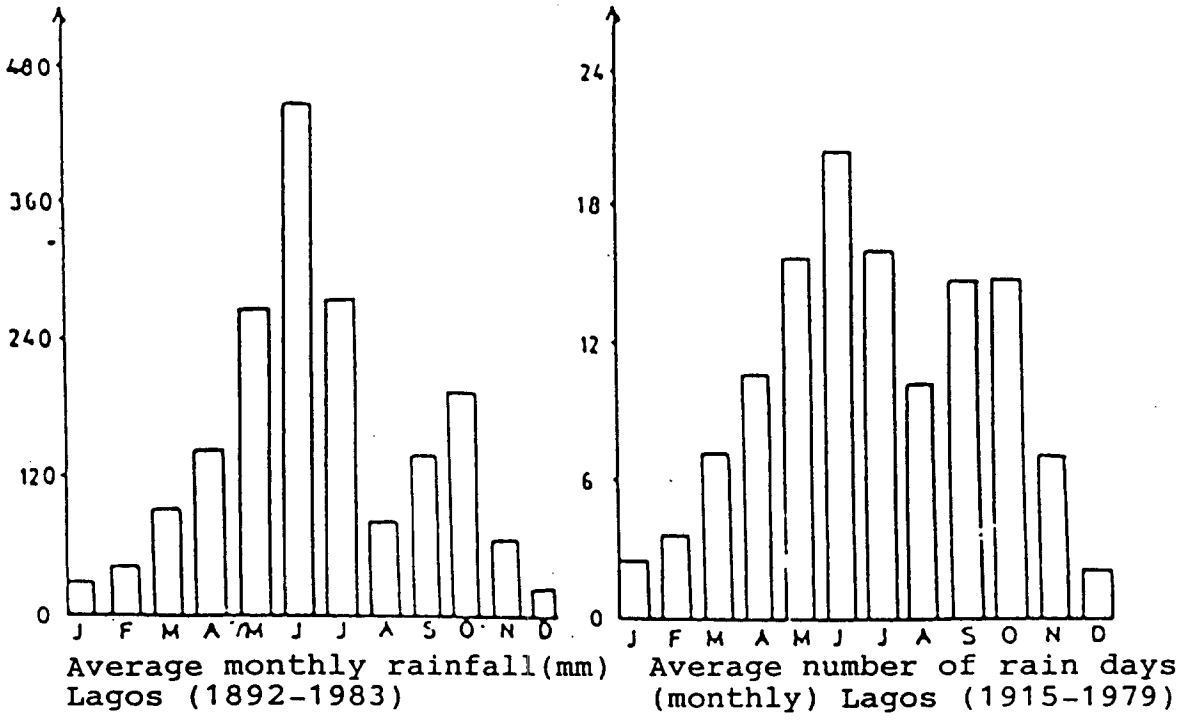
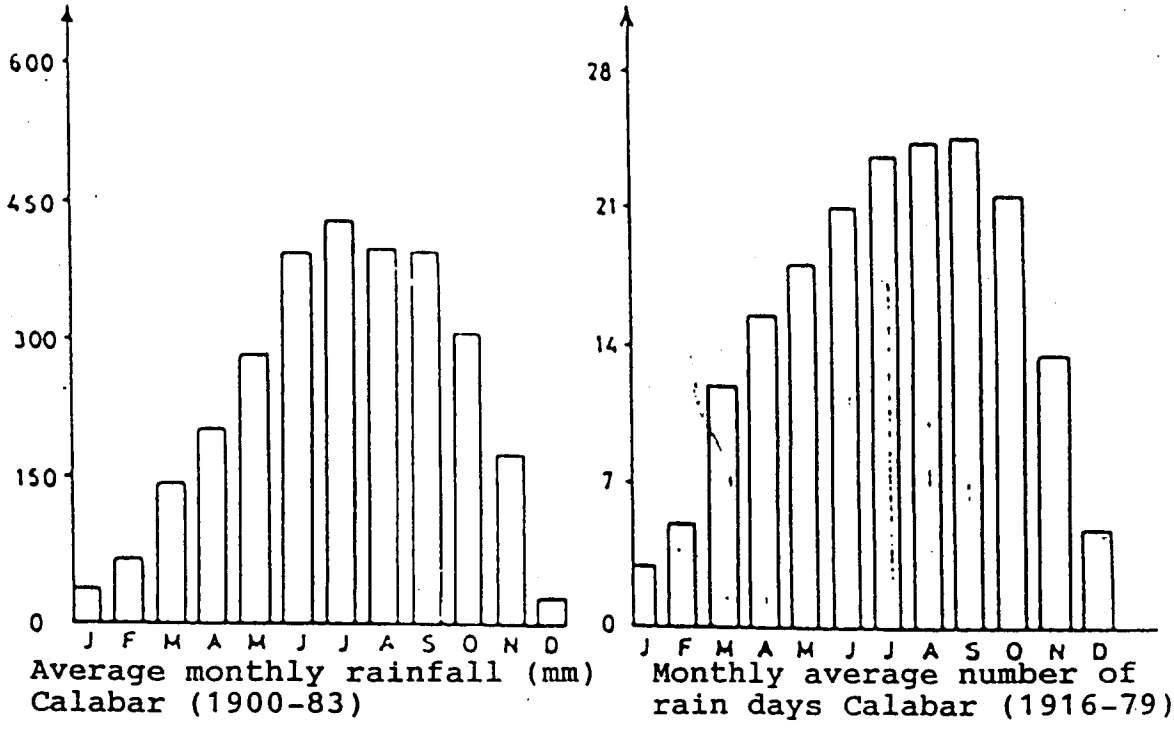


Fig. 2a. Rainfall data for Lagos.

Fig. 2b. Rainfall data for Calabar.



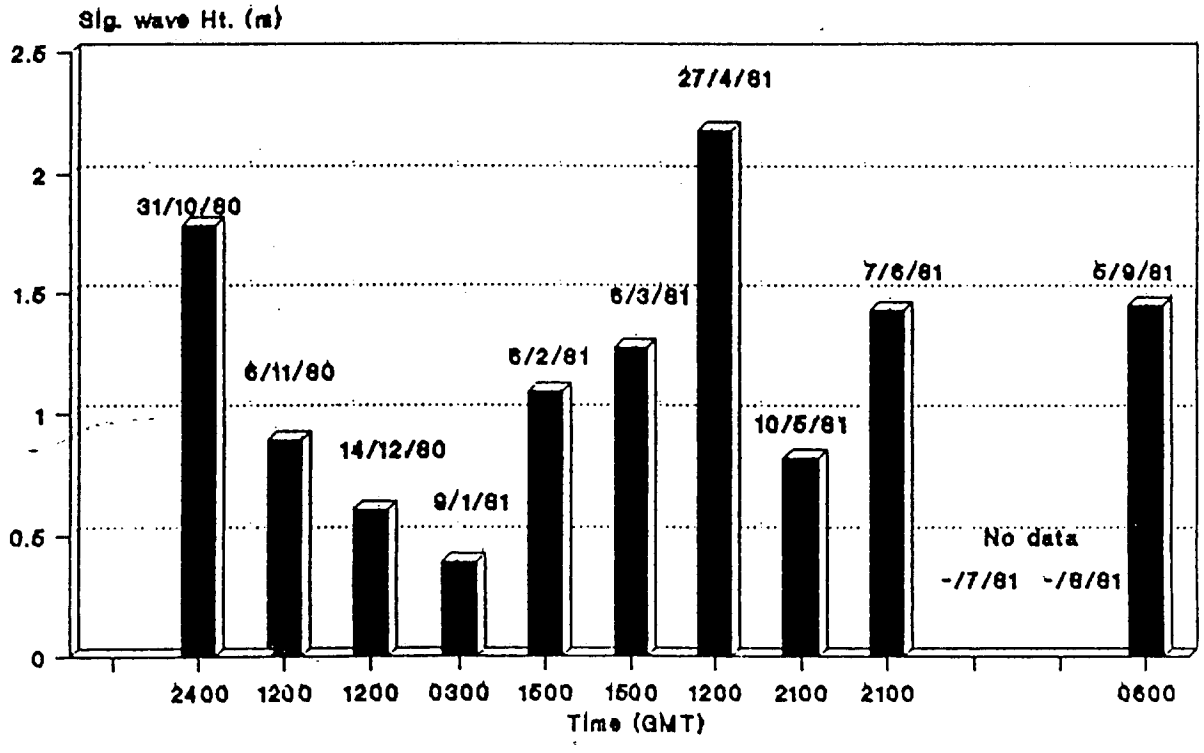
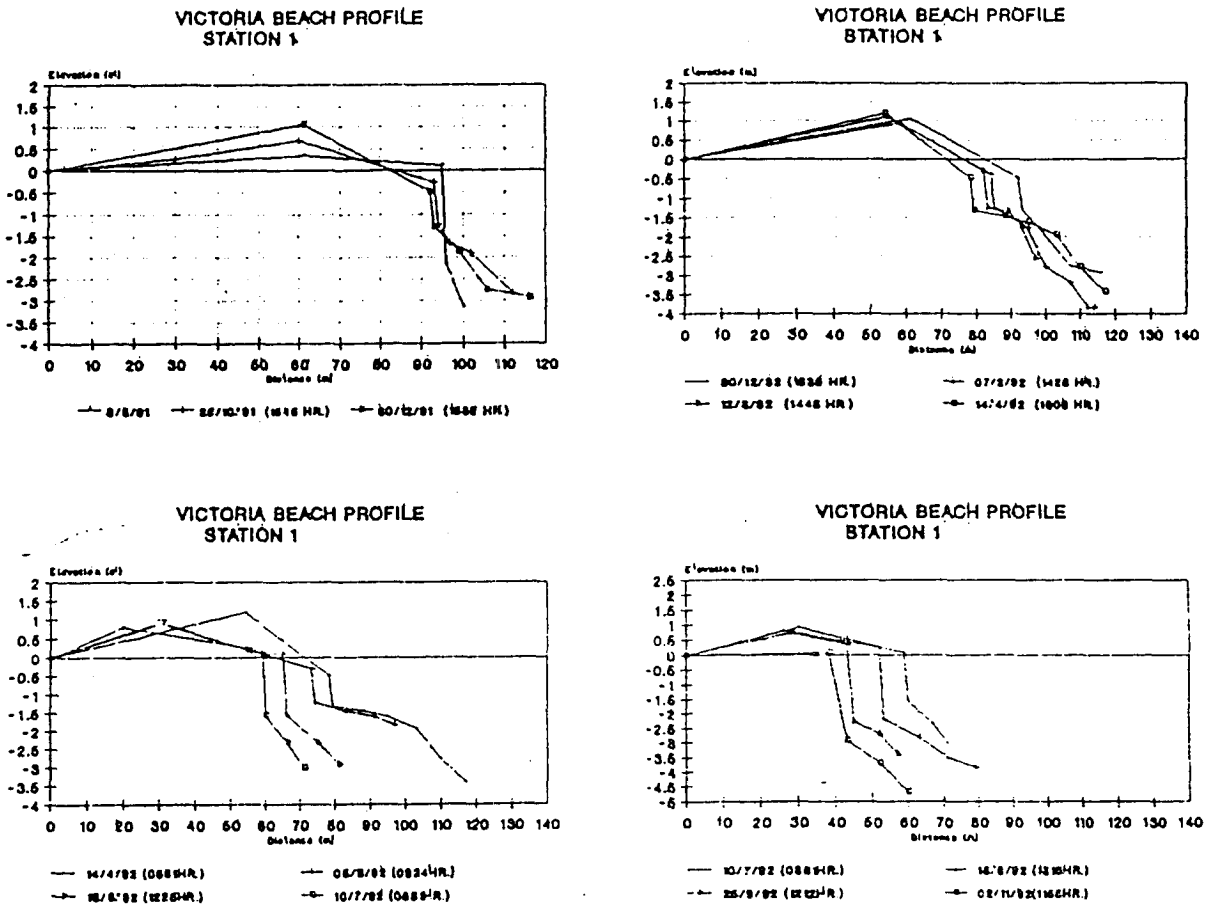


Fig. 3. Wave heights, recorded off Forcados (Awosika et al. 1995).

Fig. 4. Beach profiles at station 1 (Victoria Beach) showing beach migration trends between 8.8.91 and 02.11.92 (Awosika et al., 1994).



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CONFLICTING USES OF COASTAL WETLAND: IMPLICATION FOR INTEGRATED COASTAL ZONE MANAGEMENT IN NIGERIA.

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ABSTRACT

The Nigerian coastal and marine environment consist of lagoons, mangrove swamps, estuaries and low lying wetland. The Niger delta, second largest in the world, covers a large percentage of the Nigerian coast with an area of 16,340 km^2 of which 2,370 km^2 is permanently waterlogged by upstream rivers, creeks and tidal waters. Other geomorphic zones are the barrier lagoon, the Mahin mud coast on the west and the Strand coast in the east. Activities in the hinterland and along the coastal areas have affected the natural dynamic processes and caused imbalances in the processes and coastal configuration. Increase in oil and gas extraction has increased industrial development creating adverse effects on coastal areas. The annual rates of retreat along the coast in Nigeria varies between 16 and 30 m/yr, in especially the Niger delta due to flooding and erosion by natural and anthropogenic activities. Between 1976 and 1986 there were 2,005 reported cases of oil spill of which only 26% were recovered while 74% were retained in the environment causing severe ecological damage. More than 2,000 trees are cut daily for wood-based industries and fuel wood. The rate of deforestation far outstrip the rate of afforestation leading to extinction of wildlife and loss of genetic diversity. Increasing population and poverty has led to increased demand for cheap sources of protein from fisheries resource. Sand mining and dredging have destroyed the habitat of wetland flora and fauna. This paper looks into these conflicting activities in the coastal areas as they impede the implementation of coastal zone management strategies designed for these dynamic but highly productive environment.

INTRODUCTION

The Nigerian coastal wetland consists of mangrove and brackish water swamps. Natural vegetation are mainly the strand vegetation of coastal thickets made of herbaceous strand, coastal thicket and undifferentiated coastal forest and the mangrove forest. Also, freshwater swamps and the lowland rain forest are found farther away from the coastline. The Nigerian mangrove forest extends from Badagry in the West to Cross River in the East. Only about 3.14% of the mangrove forest fall within the gazetted forest reserve. The fresh water swamp forest are non peaty and occur on landward side of mangrove forest (Fig. 1), covering an estimated area of 21,134 km^2 (NEST, 1991). Of these, only about 11.5% of the fresh water swamp forest falls within the gazetted forest reserves. Vegetation of the fresh water swamp forest consist of aquatic grassland and herbaceous swamp forest and undifferentiated inland swamp (NEST, 1991).

The most important resource derived from these areas by the Federal Government, is oil and gas which have to a great extent degraded the area. Management conflicts arising from increasing population pressure, transportation, oil and gas exploration/exploitation, fishing, urbanization (with its inherent associated problems such as waste disposal, sand mining and deforestation) have exerted pressure on wetlands leading to changes in the coastal areas.

FISHING

The dependency of coastal population on fish as their major source of protein and livelihood, have serious impacts on fish stocks, (Figs. 2 and 3). Decrease in stock abundance due to over fishing,

pollution by petroleum activities, loss of wetland due to sand filling, have restricted fish migration and reduced fish stock abundance. Artisanal inshore catches have been on the decline over the years despite increasing number of canoe fishermen (Fig. 2). On the industrial sector (Fig. 3), catches from the inshore waters have been declining even with increase in the number of vessels (about 300 and 400 between 1989 and 1994 currently operating) in Nigeria. Installation of fish nets across river channels result in capture of small sizes of fish which otherwise would have grown to adult. Pesticides, herbicides and insecticides from agricultural farmlands get washed into the water and the soil killing aquatic life. Chemicals such as DDT, Gammalin 20 and Aldrin are also introduced directly into water bodies by fishermen to kill fish. All these as well as bad fishing procedures are causing rapid depletion of fish stock. All these as well as bad fishing procedures are causing rapid depletion of fish stock.

OIL AND GAS EXPLORATION AND EXPLOITATION

Oil and gas represent about 90% of Nigeria's total revenue and source of foreign exchange. Oil investment in the Niger Delta is estimated at about more than 13 billion US$ (Awosika et al., 1992). Between 1978 and 1986, there were about 2,005 reported cases of oil spills involving about 2,038,211 barrels of which only 513,716 barrels were recovered with the rest retained in the environment. Oil spillages are still on the increase due to neglects, accidents and sabotage. During an oil spill in 1980, about 57,600 acres and 836 acres of mangrove were destroyed, (Ekekwe, 1981). Gas flaring in the wetland areas have serious impacts on the biota. This activity increases the temperature of the air, exerts stress on plants and animals, disrupting the photo-periodicity of plants. Withdrawal of fluids (mainly oil and gas) induces subsidence aggravating coastal erosion, flooding inundation.

LUMBERING AND FOREST HARVESTING

Forest resources of the coastal wetland includes high quality forest products such as mangrove, various species of tropical rain forest trees, oil palm and raffia palm. Adegbenhin and Nwaigbo (1990) estimated that over 200,000 poles and other wooden items such as logs and billets (about 4 million m^3) are extracted annually by inhabitants for various purposes. Most of these poles are used as fuel wood for cooking and drying of fishery products. Various species of forest trees estimated at about 2,000 trees (75,000 m^3), for timber, ply wood and other wood-based industries are also felled daily. The removal of mangrove plant (red mangrove) from the edges of the estuaries and coastline makes the area more vulnerable to coastal erosion and flooding.

Clearing of vegetation for pipelines and electric power lines leads to fragmentation of forests. However, deforestation far exceeds afforestation. This also leads to extinction and loss of genetic diversity

HUNTING

Various species of animals in wetlands are hunted for meat, hides, skins (Alligator) and their plumage (birds). Such species as Pigmy Hippopotamus, Manatee and Chimpanzee are classified by the International Union for Conservation of Nature (IUCN) as endangered, while the Hippopotamus and Mona Monkeys are classified as threatened species. Many of these species are almost extinct in the Nigerian coastal areas.

POPULATION

Population growth in coastal areas have been on the increase over the years (Table 1). This is mostly due to migration from rural to urban centers in search of employment opportunities. This population growth in urban centers has led to the clearing of forest, sand filling, and sand mining.

Mangrove and freshwater swamps provide a variety of products such as fuel wood, food, drugs, household items, construction materials, tannin and manure for the local population. Other products are fish and shellfish, birds, reptiles and mammals, feather, leather and fur. The demand for good road network, housing, water and other social amenities for the increasing population with

its inherent problem such as waste disposal has exerted excessive pressures on the environment.

WASTE DISPOSAL (DOMESTIC AND INDUSTRIAL)

Disposal and collection of waste is a major problem affecting the environment. Accumulation of waste far outstrip the collection with the result that, wastes spill into drainage systems, rivers, creeks and lagoons, often leading to blocked drains. The Federal Ministry of Housing and Environment estimated that 20 kg(/month?) of solid waste is generated per capita per income in Nigeria. Two categories of solid waste are observed, the industrial, domestic/commercial and solid waste.

Domestic wastes are those from housekeeping activities, they are mostly plant materials while some are toxic and not biodegradable. Domestic waste has increased with increase in population as observed on Table 2 below.

Industrial waste consist of scrap metals, chips, grit from machine shop, saw dust, waste paper and pieces of glass, chemicals, both organic and inorganic and gases.

More than 4,000 industrial establishments are in Nigeria, of these, about 70% are located in the coastal wetland, with Lagos accommodating about 60% of these industries, (Osibanji, 1992). Table 2 shows the quantity of actual waste collected, excluding waste dumped on empty plots, or directly into drains and the aquatic environment. The 8 landfill sites in Lagos State has capacity for about 11,080,000 m^3 as at 1990 and are actually used as dump sites. At present, there are no proper landfill or waste pile and neither incineration practised.

Industries discharge their effluence into rivers, streams, lagoons and or the sea. Most of these effluence such as dyes, mercury, cadmium, iron, copper, zinc, lead, DDT and sodium compounds are toxic. The temperature of most discharged effluence are often higher than the normal surrounding water body, destroying the nearby vegetation and sedentary organisms. This has adverse effect on both the flora and fauna in wetlands that cannot absorb rapid increase in temperature in their niches. Mobile fauna on the other hand are forced to more away from the surrounding areas.

Between 1987 and 1988 foreign businessmen imported into Koko port terminal (on the Benin River) 900 tonnes of toxic waste of which 150 tonnes contained polychlorobiphenyl (PCB) from Italy. Also 1,800 tonnes and 3,000 tonnes containing hazardous compounds such as methyl melamine waste from Norway, dimethyl and ethyl acetate formaldehyde from Italian manufacturers as well as x-ray radioactive waste (West Africa, 1988) were dumped in the area.

TOURISM

Recreational activities especially on beaches contribute to the degradation of the aquatic environment. Littered beaches has adverse impacts on tourist. The beach clean up exercise carried out on Victoria Beach (a Lagos beach) in 1994 gave the results in Table 3.

The most predominant waste on the beach were polythene which constituted about 37% of total debris collected from the beach as shown on Table 3. Polythene bags/sheets are used for almost everything in Nigeria, (wrapping food, to packaging water or lollies to sweets). These waste eventually end up in the marine environment.

AGRICULTURE

Large areas around the fringes of the forest flanking major rivers are used as farmlands for cash crops, such as palm oil and rubber. The increasing demand for food by the teaming population has made farmers with small land holdings abandon traditional methods of fallow system and crop rotation for yearly planting. To increase productivity local farmers have embarked on indiscriminate use of fertilizers. The by-products of these activities leads to pollution of surface, soil and ground water.

Phosphates, nitrates and other forms of fertilizer and detergents find their way into the water bodies leading to phytoplankton and algal bloom which deplete the dissolved oxygen content causing eutrophication. The excessive bloom of water hyacinth in Benin River, lagoons of Ogun, Ondo and Lagos may be due indirectly to agricultural fertilizer.

TRANSPORTATION

Large areas of the wetland have been channelized to provide access for oil operators, settlements and the sea. Some of these canal have been linked to the sea, resulting to increase in the salinity of fresh water habitat. Highly saline waters are harmful to fresh water wetland fauna and flora which can only survive under brackish systems. Heavy traffic of cargo vessels entering and leaving the ports and terminals contribute to pollution either by discharging ballast water, washing of tanks or the release of petroleum products into aquatic environment.

CONCLUSION

This paper has highlighted some of the conflicts and changes that arise when coastal resources are exploited. It is an acceptable fact that Nigeria relies heavily on coastal resources. Exploitation of these resources are usually accompanied by environmental degradation. The main constraint on environmental issues has been the slow response to environmental protection by the government and the private sector.

The coastal zone needs an integrated management strategy to sustain long term utilization and reduction of adverse coastal changes. However, for such long term plan, legislation would be required for effectiveness. The Land Use Degree of 1978 of Nigeria, states that all land and waterways resides with the Federal government. The Decree provides for statutory rights of occupancy over land and customary rights of occupancy over rural land. This means that Integrated Coastal Zone Management (ICZM) should be embraced by the Federal Government. Towards an effective implementation of integrated coastal zone management policy for Nigeria has been the creation of Federal Environmental Protection Agency (FEPA) in 1988 to take care of all environmental issues in Nigeria. With regards to the coastal wetland, FEPA's priority area include: Coastal erosion, flood control, abatement of pollution by industrial effluence, improve the quality of the unique environmental resource. Also FEPA is saddled with the preparation of an ecological master plan to ensure rational exploitation and avoid the diverse use and often conflicting industrial and social activities.

The cost of inaction in the long term to reverse and avoid environmental degradation and natural resource depletion was estimated at 5.1 billion dollars per year. This estimated cost of unsustainable development was made by the World Bank 1990 Report on "Towards the Development of our Environmental Action Plan in Nigeria".

Therefore an integrated coastal zone must start with a complete knowledge about the state of the environment, resources, existing conflict in uses and coastal changes. Such knowledge can form the recipe for an ICZM of coastal wetlands.

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Table 1: Land area and population density of coastal states in Nigeria. Source: National Population Bureau, 1992.

STATE	1963 Population	1992 Population	Area (km^2)	Density ($/km^2$)
Akwa Ibom and Cross River	3,478,000	4,225,340	27,237	155
Delta and (Edo)*	2,161,000	4,730,029	35,500	133
Rivers	1,444,000	3,983,857	21,850	182
Ondo	1,551,000	3,884,485	20,959	185
Ogun	2,729,000	2,338,570	16,762	140
Lagos	1,729,000	5,685,781	3,345	1,700
Total	11,792,000	22,688,214	125,653	

* *State without a coastline*

Table 2: Annual solid waste collection and disposal in Lagos state. Source: Lagos State Waste Disposal Board Report, (1991).

Year	Domestic (metric tonnes)	Industrial (metric tonnes)	Total Waste (metric Tonnes)
1986	1,169,215	98,306	1,267,521
1987	1,473,144	78,247	1,543,391
1988	2,630,613	118,720	2,749,333
1989	3,194,148	119,390	3,313,545
1990	3,518,684	260,000	3,778,684
Total	11,985,804	666,670	12,652,474

Table 3: Summation of the debris from the Victoria beach. Source: Awosika et al., 1994 (In Press).

Types of debris	No. of debris	composition %
Plastic	3,974	37
Foamed plastic	1,129	10
Glass	730	7
Rubber	785	7
Metal	1,393	13
Paper	1,755	16
Wood	785	7
Cloth	335	3
Earthen ware pot	12	0.1
Total number	10,872	100.1

Fig. 1. Ecological zones of the Nigerian coastal wetland.

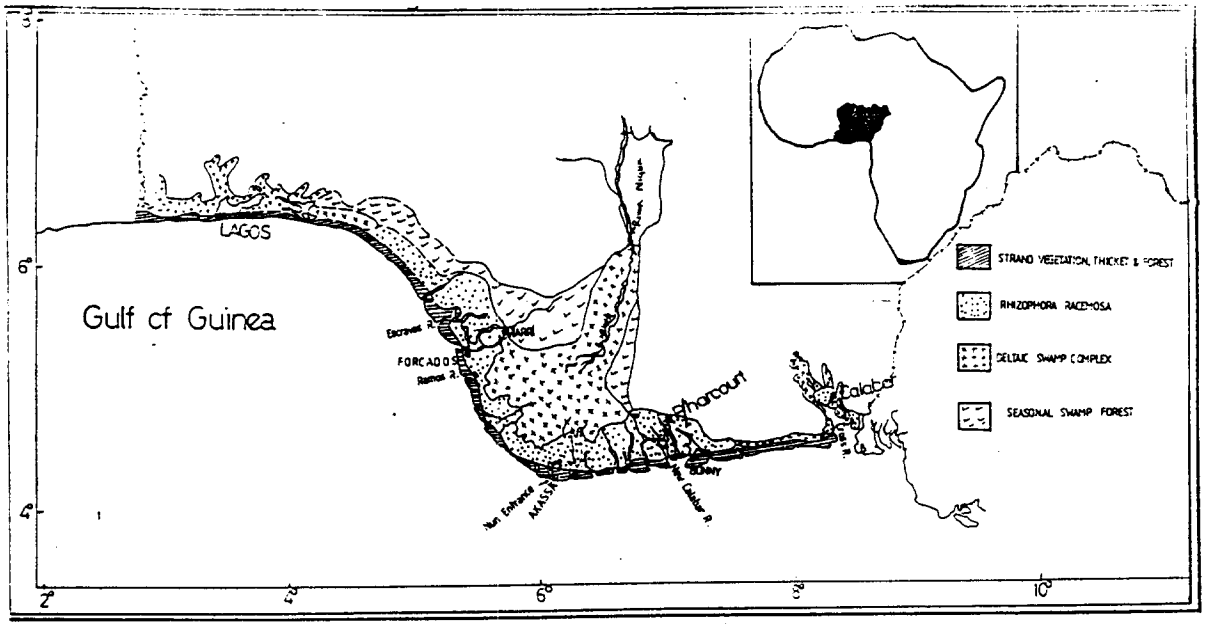
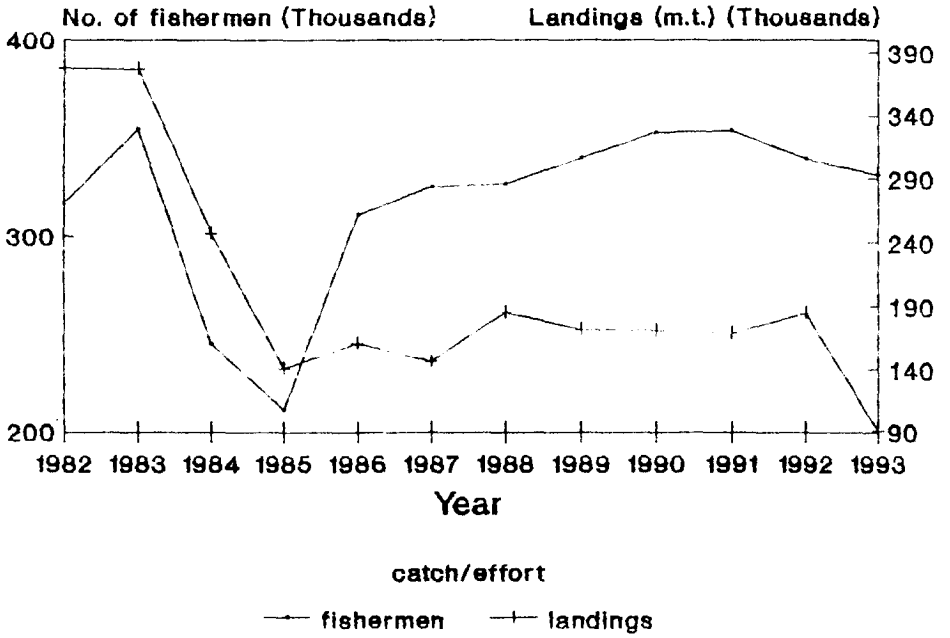


Fig. 2. Number of fisherman and landings (metric tonnes).



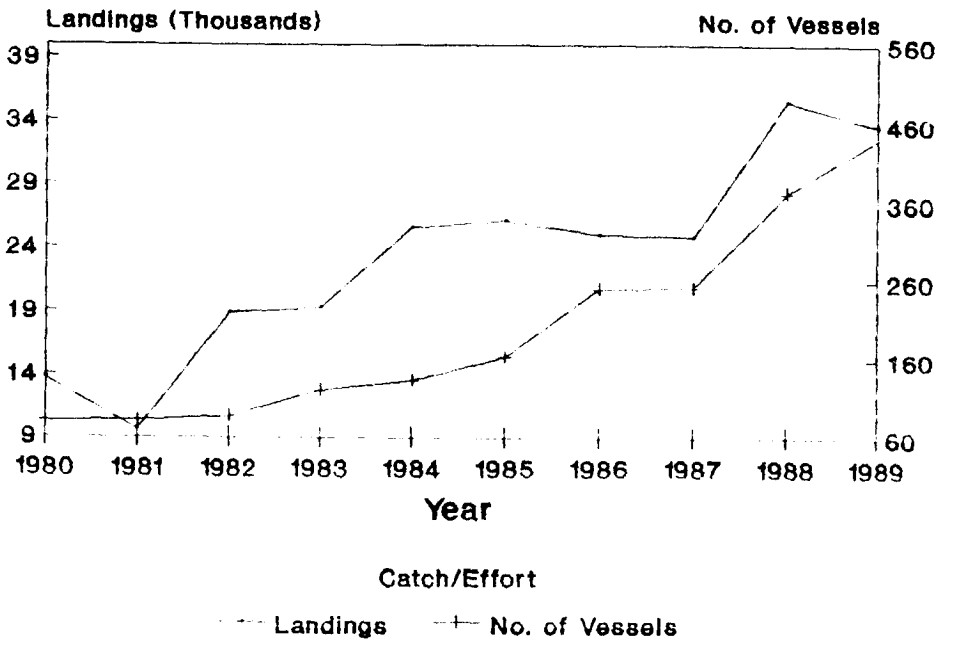


Fig. 3. Number of fish and shrimp vessels and landings (metric tonnes).

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STRATEGIES FOR THE COASTAL MANAGEMENT OF VILLA GESELL, ARGENTINA

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ABSTRACT

A fast growing population and a lack of adequate control, planning and policy in the management of the coastal areas of Villa Gesell have modified the natural ecosystem. A lack of compatibility between human activities and the geomorphological setting, has intensified two problems during the last years: beach erosion, and pollution of the aquifer. Recently, an erosive stage is registered because the equilibrium between the dune system and the beach has been broken when buildings spread over the coastal areas. Several human activities are accelerating the beach erosion. They are:

- Destruction of coastal dunes,
- mining of sand from beach and dunes, and
- inadequate urban planning.

Geologic and geomorphologic analyses of this coastal area were developed to evaluate the critical requirements for assessing the effects of human activities on the environment and for developing management strategies to deal with environmental problems.

INTRODUCTION

Important littoral changes have affected the coast of Buenos Aires State during the last 30 years as a result of rapid population growth and a lack of adequate control, planning and policy concerning the management of its coastal areas. Villa Gesell was established in 1931. It is one of the largest centres of summer tourism in the Buenos Aires state.

The natural ecosystem of coastal dunes was perfectly conserved in the urban planning when the city was established in 1931. Development was slow and steady until 1970 when a dramatic boom in construction began. Additional facilities for transport, potable water and waste disposal were required as the coastal population increased, in particular during summer.

Recently, an erosive stage has been registered, because the equilibrium between the dune system and beach has been broken since buildings spread over the coastal areas. López (1994), detected a similar effect in the localities of the Municipio de La Costa, located 80 km northward. Marcomini & López (1993a), described an erosive event along the Buenos Aires coast with large rates of erosion in Mar Chiquita (6 m/yr).

The purpose of this study is:

- to analyze the physical processes that have formed the beaches,
- to relate the effect of urbanism on the natural coastal ecosystem of Villa Gesell and
- to determine a management plan for sustainable development of this locality.

Geologic and geomorphologic analyses of the coastal area of Villa Gesell were developed to evaluate the critical requirements for assessing the effects of the human activities on the environment and for developing management strategies to deal with environmental problems.

Beach profiles and field conditions, monitored at four sites provide an opportunity to characterize the beach response to urbanisation and storm surges.

A policy in the coastal management should be applied by Government agencies to remedy the harmful effects of the inadequate equilibrium between population growth and the coastal environment.

GEOLOGICAL SETTING

Villa Gesell is situated on the coast of Buenos Aires state, 411 km southward from Buenos Aires

city at latitude 37º22'S and longitude 57º02'W. The studied area covers about 30 km^2 for a length along the coast of 10 km. The coast is sandy and has a micro-tidal regime with a moderate wave energy. The beaches are composed of medium grain-sized sand. The beach sand is composed of quartz, feldspar, lithic fragments of volcanic rocks and shells. The sand has 2% of heavy minerals. The dune sand is of fine to medium size and contains 8.5% of heavy minerals (Teruggi, 1959)
Most waves approach the coast from the southeast. Shoreline orientation and seasonal winds cause a littoral drift from which the direction reverses periodically. The net littoral drift at the Buenos Aires coast is northward (Mazzoni and Spalletti, 1978, Codignotto and Aguirre, 1993). It ranges between 300,000 and 1,000,000 m^3/yr (Caviglia et al., 1991).
Astronomical tides at Villa Gesell are semidiurnal and have a mean range of 0.76 m (SHN, 1994). The wave-induced changes in sea level are larger than those caused by astronomic tides. Wind from southeast coupled with spring tides, causes the sea level to be raised as much as 1 meter over the mean sea level.
The tide gauge at Puerto Quequen, shows a relative rise of sea level of 1.6 mm/yr (Lanfredi et al., 1988) for the last century. This rate coincides with the global eustatic sea level rise, which averages between 1.5 and 2 mm/yr (Gornitz and Lebederef, 1987).
The area is tectonically stable. Coastal movements during the Holocene were associated with the reactivation of the coastal basins such as Colorado, Salado and Parana (Codignotto et al., 1992).
The region is a coastal plane on the southern flank of the Salado basin. Two synchronous littoral barrier systems have developed in opposite directions against a headland formed by Pleistocene sediments between Villa Gesell and Pinamar (Tricardt, 1967; Dangavs, 1983; Codignotto and Aguirre, 1993; Fig. 1). The southern barrier system, over which the city is emplaced, is characterized by a Holocene transgressive barrier as well as by a regressive environment such as lagoon and ponds. The Holocene transgression reached its climax in this area between 5200 and 4600 years BP, when the sea was nearly 2 m above the present level (Violante, 1992). The Holocene system is covered with a thick sequence of dunes of 20 m, formed of medium and fine sand. The dune sand has a similar mineralogic composition as the beach sand, with higher contents of heavy minerals (8.5%).

METHODS

Aerial photography, determined beach profiles, historical dates and field observations, were used to realize the geomorphologic analysis of the coastal landscape and to evaluate the urban growth and beach changes since the city settlement.
The morphology of this coastline has been determined from aerial photography at a scale of 1:20,000 edited by INTA and GEODESIA for the years 1967 and 1981. Four beach sites, given in Fig. 2, with a length of about 2.5 km, were chosen for beach morphology investigation. The sites are numbered 1 to 4 from north to south, with site 1 being on the northern edge of Villa Gesell. Beach profiles at the sites were obtained with a Level instrument.
Two parameters were used to evaluate the urban density and population growth since 1967. They are called NCS and PCS, where:
- NCS: Number of constructions/Surface unit
- PCS: Constructed area x 100/Surface unit

NCS is the number of constructions per surface unit and the PCS index represents the percentage of constructed area per surface unit. The unit considered, is a square of 20,000 m^2. These indexes were surveyed by aerial photography for the years 1967 and 1981. The results are shown in Fig. 2.
The PCS was estimated parallel with the coastal site observations (Fig. 2). Two profiles are seen in Fig. 6, where this index is compared for the year 1967 and 1981.

GEOMORPHOLOGY

Marine and aeolian processes have controlled the coastal landscape of the studied area since the beginning of the Holocene. The fluvial processes are of limited importance. The fluvial channels

are ephemeral with an anarchic pattern due to the flat slope of the area. They present scarce length. The rainfall water is rapidly percolated in the sand dunes and the runoff accumulates in the low interdunes, so there is no development of fluvial channels to evacuate excess rain water.

The most characteristic geomorphologic feature on the coastal landscape between Mar Chiquita and Punta Rasa is the presence of dunefields. The formation of dunefields took place during an arid period of the upper Holocene. Large dune fields extend over a belt of about 100 km length and 3 km width of the actual coastline. The majority of dunes are barjanoid crests although some are barchans, parabolic and compound dunes. The maximum height reached is 30 m.

The dunefield in the surroundings of Villa Gesell has been altered since the settlement of the city in 1931. The geomorphologic study by aerial photography of 1967 (Fig. 2, map A), distinguished three sectors with different dune features. The southern sector is characterized by barchans and barchanoid crests with a main crest alignment from N90W landward to N55W near the coast and thus required prevailing winds from south and southwest for their formation. The dune ridges are strongly asymmetrical, the windward sides are between 100 and 150 m width. The interdunal valleys are narrow, up to 40 m wide. Dunes are not covered with vegetation. The sector located westward of Villa Gesell (Fig. 9a), is composed of inactive dunes. The dunes are of parabolic size, with a chaotic orientation of branches and no dominant wind blown direction can be deduced. The sand supply to this sector is restricted by the Villa Gesell village. This area remains on the lee side of the city, so predominant winds are not affecting these dunes. The winds, blowing from different directions, modeled these dunes so that no particular orientation prevails on their branches, with a result that the vegetation is densely spread.

The northern sector presents barchan, barchanoid crests longitudinal and compounds dunes. In northern boundaries of the city, sand mounds are observed, the interdunal valleys are large and vegetated.

Near the coast the dunes are barchans and barchanoid crests. Landward the landforms are not well defined. Two scales of dunes are joined. The interdunal spaces are larger and partially vegetated, and the dunes faces are narrow which implies a decrease in the sediment supply.

The beaches are sandy, extended laterally, with a variable width of about 140 m. They present a berm of about 20 m and a submerged bar that outcrops during low tides. The backshore continues landward with the foredune. The medium beach slope is 1º15'. The beaches present changes in their profiles depending on their location along the city (Fig. 2). Four beach profiles are shown in Fig. 3. They present different features although they are located along a straight coast and formed under the same littoral processes.

Profile 1. Is located in the northern boundary of Villa Gesell. It is under low human impact. The foredune is conserved. The beach is broad and has a berm of about 25 m and a submerged bar. The slope is 0º44' (Fig. 4a).

Profile 2 (Fig. 4b). It is in the centre of the city. The dune was destroyed and replaced by a coastal avenue. The beach is narrow, 44 m width. It has one berm. The beach slope is 2º43'. Several resorts, with protection structures and a vertical seawall are placed on the berm. A scarp of about 0.50 m is cutting the berm (Fig. 5). The streets, perpendicular to the coastline, drain the rainfall water to the street which erodes the berm and backshore.

Profile 3. The dunes are partially conserved. The beach has a berm of 25 m. The beach slope is 1º25' and the beach width 90 m. Beach resorts are over the berm and dune.

Profile 4. The profile is on the southern extreme of Villa Gesell. The beach width is 90 m. The foredune is conserved and is not artificially cut. The beach slope is 1º32'. The slope in profile 4 is higher than in the other ones and is representing an increase in erosion due to urbanization. A scarp over the berm, the high slope, and narrowed beach width are a clear indicator of erosive wave action along the coast where the city is situated.

COASTAL CHANGES

The increase of the coastal population and buildings was estimated with an aerial photography survey of the city for the years 1967 and 1981 (Fig. 2). The NCS (number of constructions per surface unit) is considered high when the square has more than 10 constructions, moderate for 5 to 10 constructions per square and low when it has less than 5 construction per square. In Fig. 2 an important increase in the number of constructions is observed, as well as an increase of the urbanized surface, especially near the coastal areas between 1967 and 1981. Nowadays the increase is even higher.

The PCS (percentage of constructed area per square unit) is a significant index to evaluate the impermeabilization of land surfaces. This parameter impacts directly on the aquifer recharge. Two graphs showing the PCS versus the distance to the coastline for two observation sites are exposed in Fig. 6. A considerable increase of this index was registered for both profiles since 1967, with a higher index up to 1200 m from the coastline.

An increase of NCS and PCS is observed in the centre area of Villa Gesell up to 1200 m from coastline. The backward movement of the coastline during the last 35 years was estimated considering historic data, aerial photographs, and beach profiles.

A sequence of the coastal recession between 1950 and 1995 is pointed out in Fig. 7 for the reference point (a) Atlantic Hotel, near profile 2 (Fig. 2). The erosional rates obtained for the observation sites ranged between 1.23 and 2.35 m/year (Fig. 8). The higher rate of erosion and the increase in the beach slope (Fig. 9) are directly related to the innermost part of the city, where foredunes were broken down by the construction of buildings.

An erosive wave action, focusing on the central beach resorts of Villa Gesell city, is detected. Evidence of this erosive event is: An increase in the rates of coastal recession, an increase in the beach slope and a decrease of the beach width. This erosive event is directly related to the higher values of number of constructions per surface unit (NCS) and with an increase in the percentage of constructed surface (PCS) or increase of population growth, replacement of dune areas with buildings and others human impacts.

Another remarkable impact of the city settlement is the alteration of the dunefield, because the constructions and trees act as a barrier for the principal winds and interrupt the sediment supply. A diminution of the sand supply changes the dune forms which is observed in the northern sector of the city between 1967 and 1981 (Fig. 10).

COASTAL MANAGEMENT

A lack of perception between human activities and the geomorphological setting modified the ecosystem and increased beach erosion rates. The issues involved are: Dune management, aquifers capacity, mining activity and urban design.

Dunes

The destruction of coastal dunes is one of the principal factors that generates damage to the natural ecosystem. The dune ridges have a principal role in maintaining the equilibrium of the coastal system and its conservation. The coastal dunes supply the sand which is necessary for beach nourishment. During south and south-east storms (storm surges), the backshore and dunes are eroded and sand is transported northward by littoral drift and seaward by the backwash, leading to the formation of offshore bars. So dunes acts as a natural and flexible protection of the coastline. Otherwise, winds blowing from west supply large quantities of sediments to the dunes and the backshore area. Nowadays, the foredune ridge is replaced by buildings, coastal avenues, and the backshore is covered with beach resorts, so the equilibrium between dunes and beaches is severely altered, resulting in large rates of erosion, which increase drastically during storm surges. The subsaturated wave flow has not enough material to remove from the dune area, because the dune ridges were destroyed by buildings.

Future urban planning should conserve and reconstruct the coastal dune area. It is suggested that the nourishment and reconstruction of the dune area should be envisaged, even when this implies the destruction of the coastal avenue.

Stick parapets, perpendicular to the most frequent wind directions, and specific types of vegetation could be used to reconstruct the dune area.
The riding of motor-cycles over the coastal dunes in central zones, where the dune width has been narrowed by anthropogenic action, must be restricted.

Aquifers
The aquifer is composed of a sequence of aeolian sands, overlying marine sands of successive coastal deposits. The marine sequence includes clayey intercalations of 3 to 5 m width which represent ancient coastal lagoons and tidal flats. Sometimes these interlayers are associated with ferrous ions in the underground waters. The sand represents a typical aquifer and the clayey intercalations act as aquitards.
The morphology and unimodality of the dunes help the fast infiltration of the rainfall, without changing the chemical quality of the fresh water. The infiltrated rain is kept in the sand dune as a suspended lens of fresh water, lying over brackish water on the continental side and bounded by salt water to seaward (Sala, 1982).
The active and inactive dunes constitute a free aquifer, which provides potable water to the population, which is another reason to preserve the natural topography and surface of the coastal dunes. Buildings and houses should be built only on the surface of ancient dunes (López and Marcomini, 1993, Marcomini and López, 1993b).
The change in permeability of the dune surface by asphaltic paving, concrete or other constructions, impede rain infiltration, restricts the natural feeding of the aquifer and reduces the water-saturated thickness.
The chemical pollution of the groundwater is due to the presence of high concentrations of NO_3^- NO_2^-, because some houses have cavities for sewer residues, and contaminants are introduced directly in the aquifer. Natural contents of $CaCO_3$ and ferrous ions are high in the water and the excessive exploitation of the aquifer increases their concentration. The content of $CaCO_3$ of the groundwater is caused by shells of marine origin.

Urbanization design
Artificial drainage was designed to evacuate the rain water from the streets to the sea, introducing a new cause of erosion to the system. The artificial drainage of rain water dissected the dune ridge and increased the erosion of the beach areas, where streets drainage ends (Fig. 11). Also, the runoff of pluvial water along the streets perpendicular to the coast by natural or artificial processes diminish the groundwater infiltration in the interphase between salt and fresh water, and a landward movement of the fresh water aquifer can be observed.
Streets and avenues should end at a distance of 150 m from the line of Spring high tides, and the dunes must be kept intact to accumulate the rain water between dunes and streets, increasing the infiltration in the aquifer interphase and stopping the drainage of rain water to the beach.
Some areas of the beach (backshore) are cleaned during summer season. The sand is removed and the beach slope is levelled (Fig. 12). The cleaning work modifies the equilibrium between the natural beach profile and the hydrodynamic conditions and increases the erosion during storms.

Mining activities
Mining of sand from beach and dune areas has affected the coastal area of Villa Gesell increasingly and caused increased rates of erosion. The extraction of sand for construction purposes is partially controlled by Governmental agencies. Several individual beach-sand mine workers are not prosecuted by the Government, so the sites and volumes of sand extraction can not be estimated accuracy.

CONCLUSIONS
It was estimated that the rate of retreat of beaches occurred at rates between 1.23 and 2.35 m/yr. The higher rates are found in the centre of the city where the difference of NCS and PCS between 1967 and 1981 is high. The beach slopes are higher at the shores of the urban area, showing a larger erosion in the centre resorts. They remain flat in the neighbourhood. This implies that beach stretching is directly

related with an increase in number and area of buildings, with the consequent destruction of the foredunes.

Changes in morphologic features of the dunefields were detected since the settlement of the city, because the constructions act as a barrier for the predominant winds.

In summary, the following steps must be implemented to prevent further increase in the erosional rates as registered during the last years, and for diminishing the environmental impacts:

- Conservation and restoration of the dune areas.
- Suppression of sand mining activities on beaches and coastal dunes.
- Ban the construction of bathing resorts on the beach.
- Elimination of rain water outlets on the beach.
- Cut out roads and streets which directly end on the beach.
- Prohibit the removal of sand on the emerged and submerged beaches.
- Conserve the natural environment of the beach and dunes in a ridge extending to 150 m landward from the Spring high-tide line.
- Enhance the construction of houses and buildings over the dune topography without extraction of sand to level the land.
- The construction of roads and streets should respect the natural slope and topography.
- Restrict the asphaltic paving of avenues and the impermeabilization of the coastal dunes.
- Pluvial water accumulations near the beach should not be drained to the sea nor directed laterally.

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Fig. 1. Location of studied area.

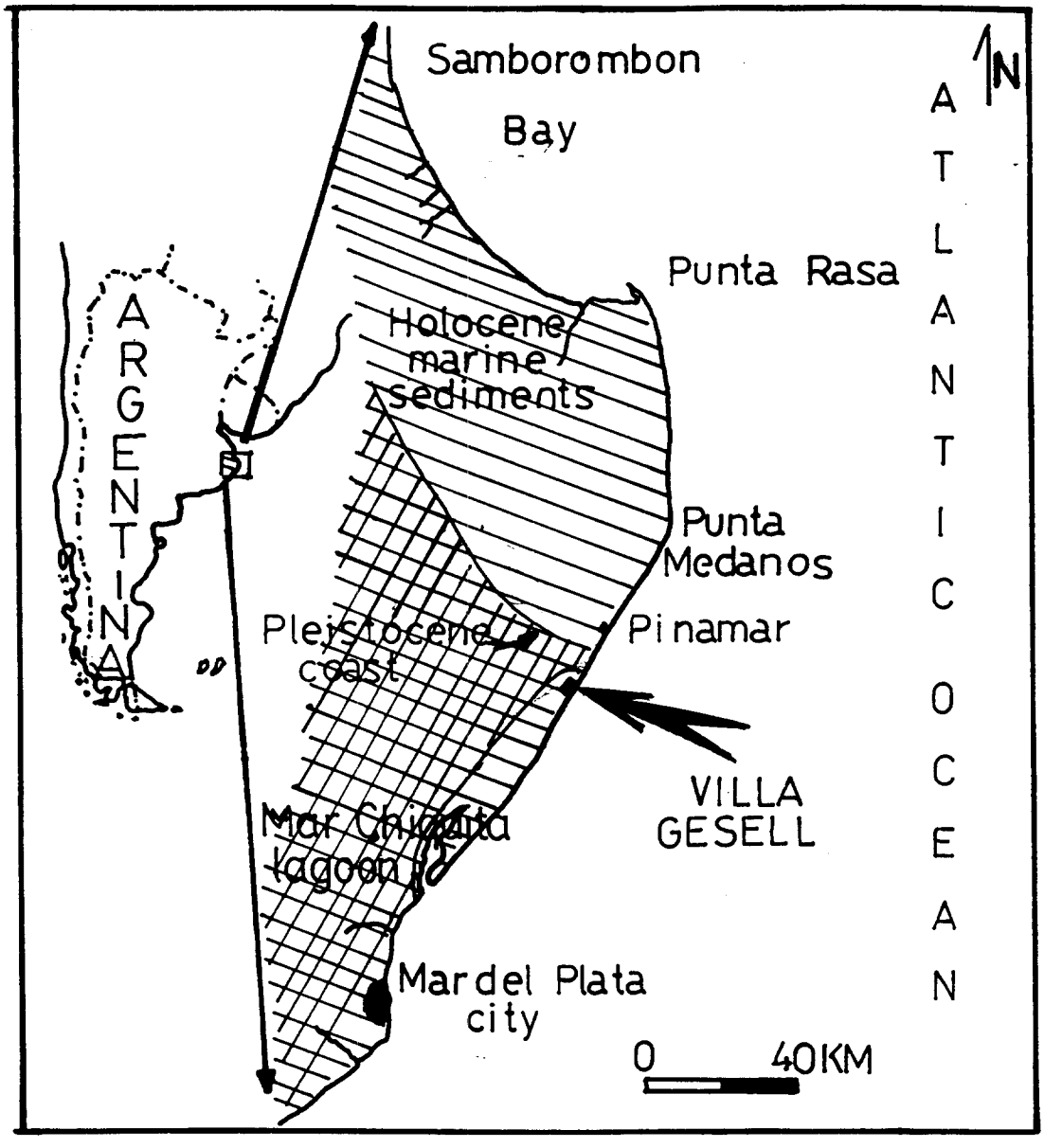
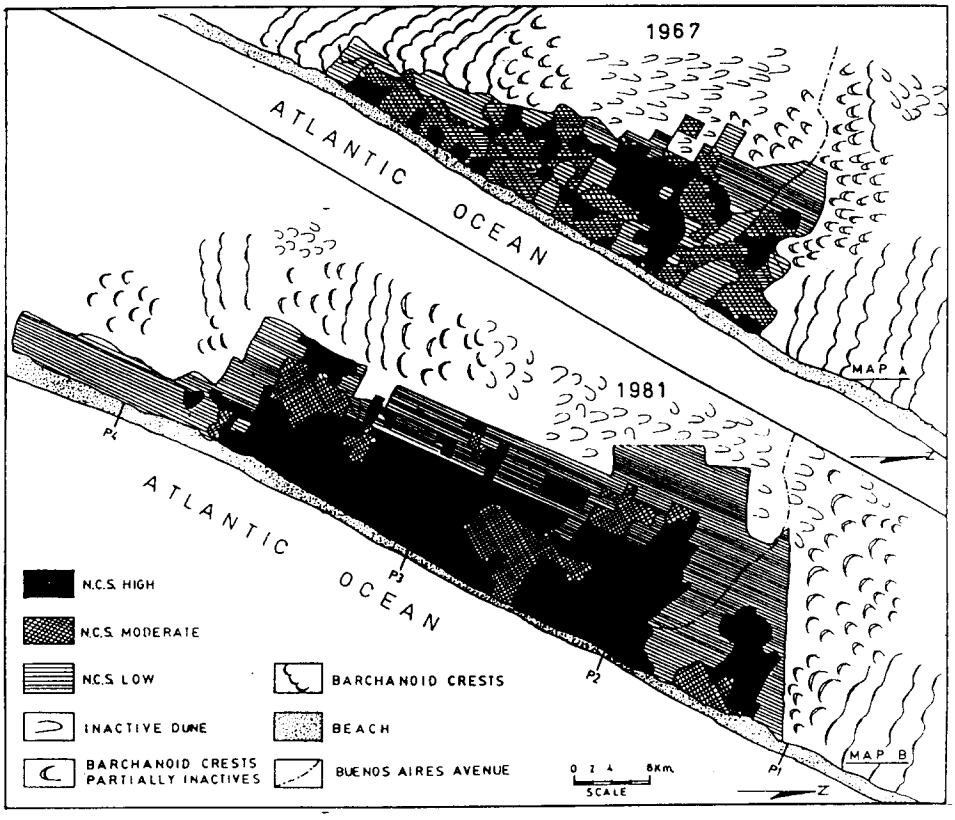


Fig. 2. Geomorfologic features and urban area with number of constructions per square patterns (N.C.S), in 1967 (A) and 1981 (B).



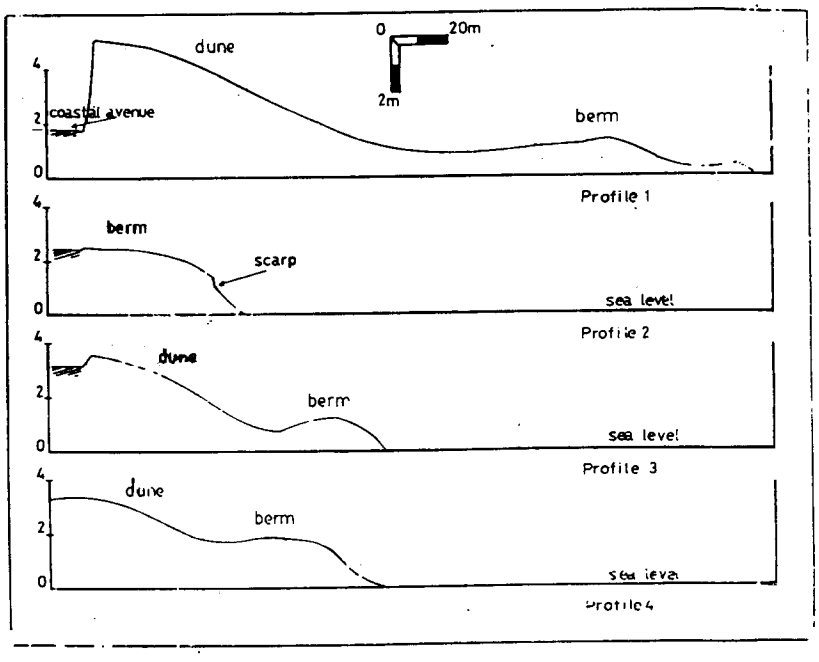
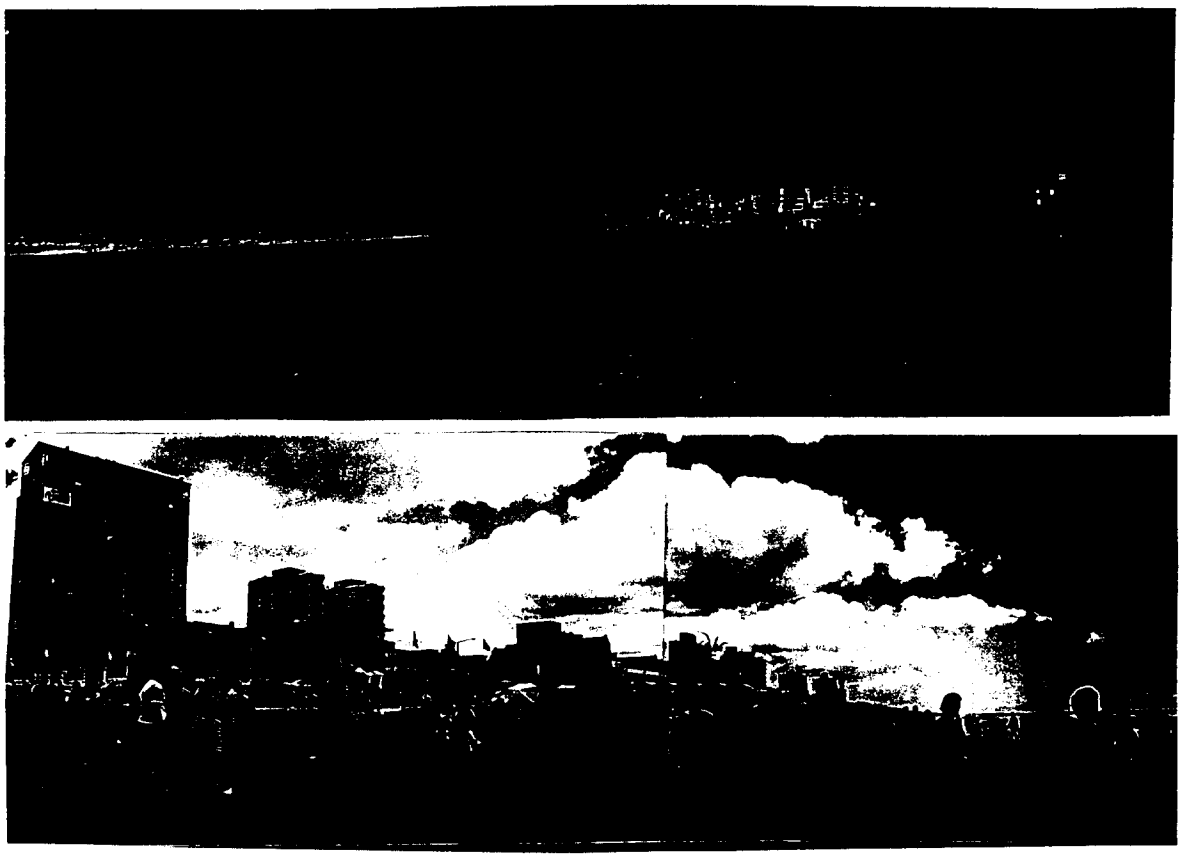


Fig. 3. Beach profiles (m).

Fig. 4. Beach features for two observations sites in Villa Gesell. A. Beach erosion profile altered by human activities at the centre of Villa Gesell (coincident with profile 2, figure 2). Beach profile with scarce human alteration in the northern boundary of Villa Gesell city (coincident with profile 1, figure 2).



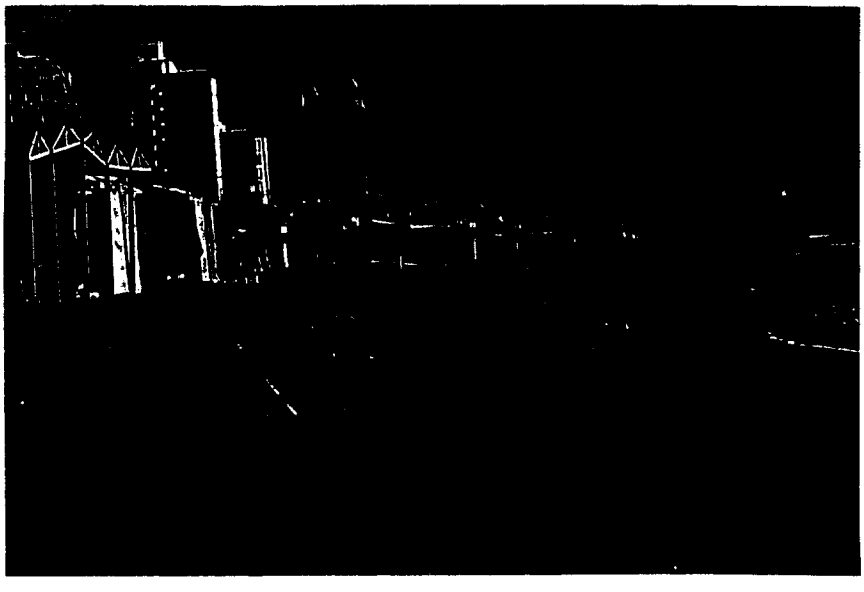
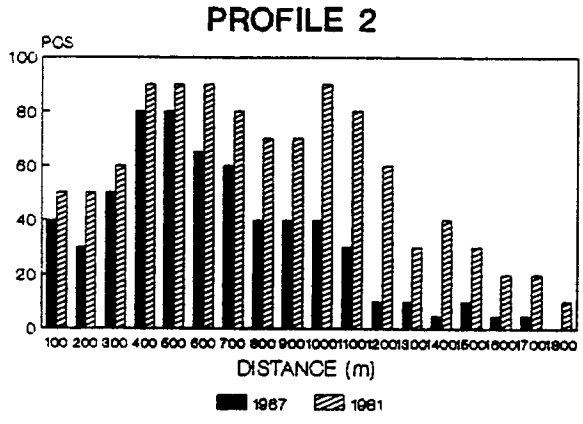


Fig. 5. Scarp of the beach berm after a surge storm (January 1995), in the centre resorts.

Fig. 6. Comparison of the PCS (Percentage of surface constructed per area unit) between 1967 and 1981, for the coastal profiles.



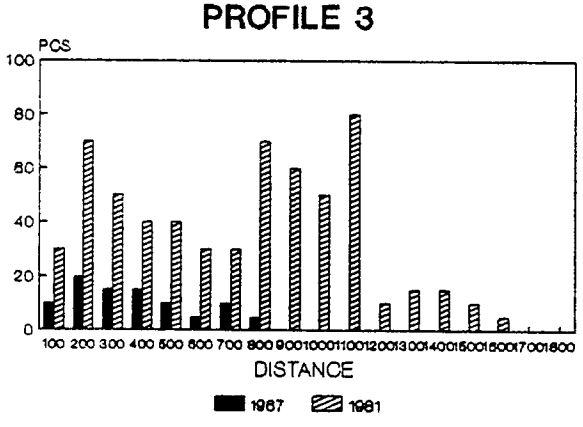


Fig. 7. The photographs show a view of the coast and beach for 1950, 1960 and 1995. The reference point is the Atlantic Hotel (a) located in the profile 2.

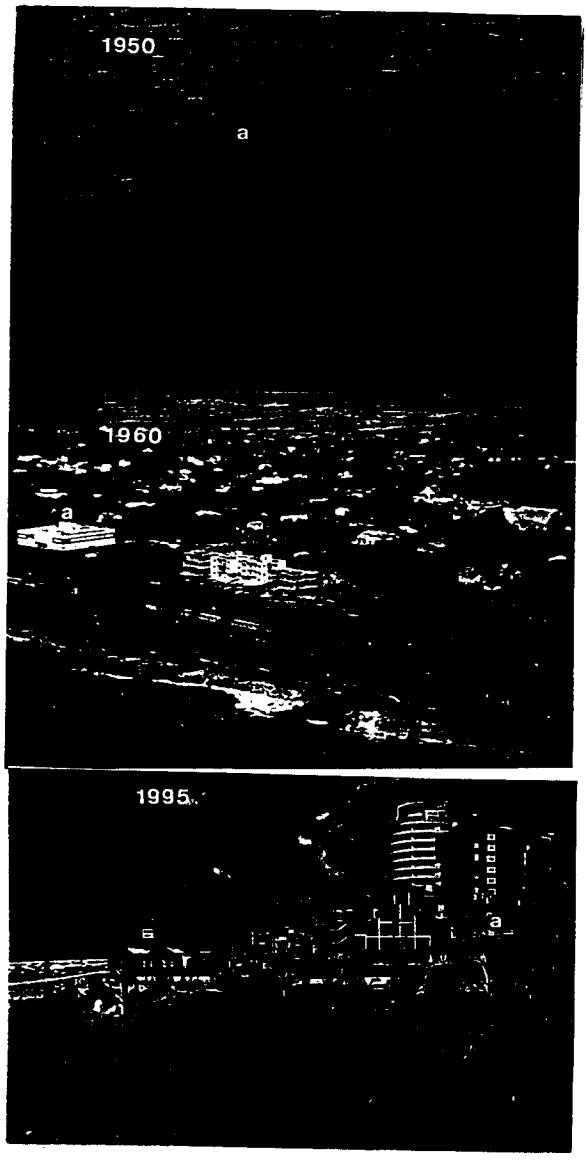


Fig. 8. Rates of beach erosion since 1960 for the observation sites.

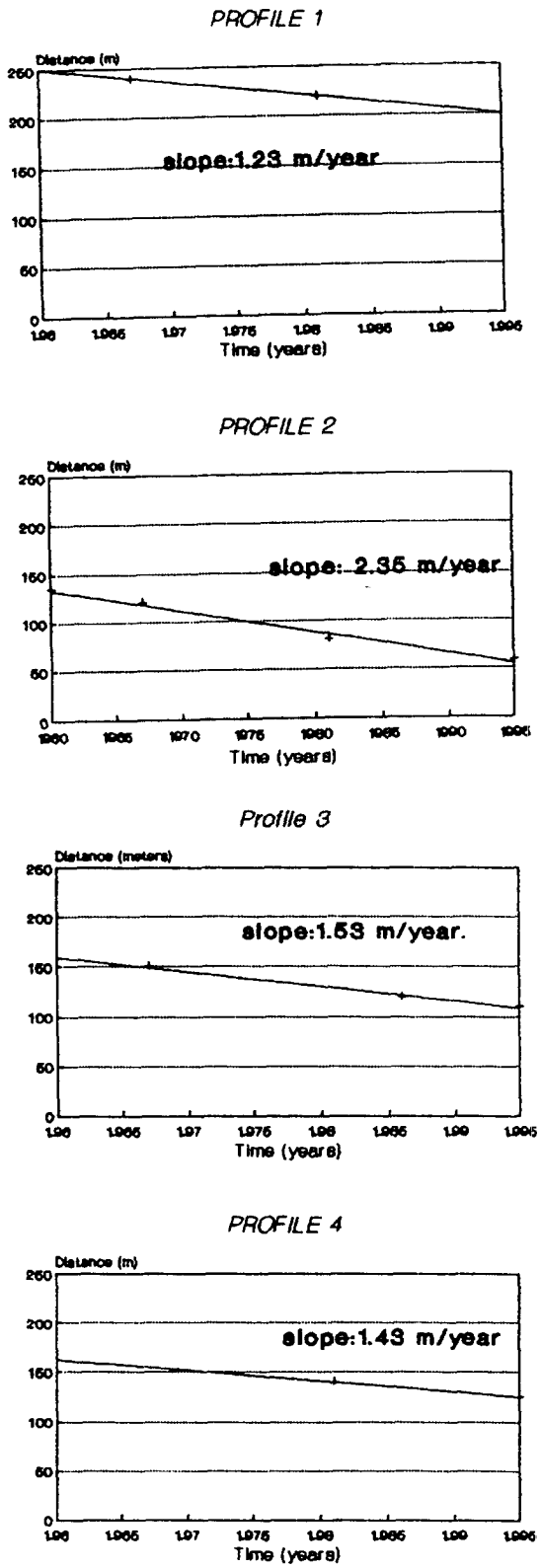


Fig. 9. Rates of erosion and beach slope along the beach for the observation profiles.

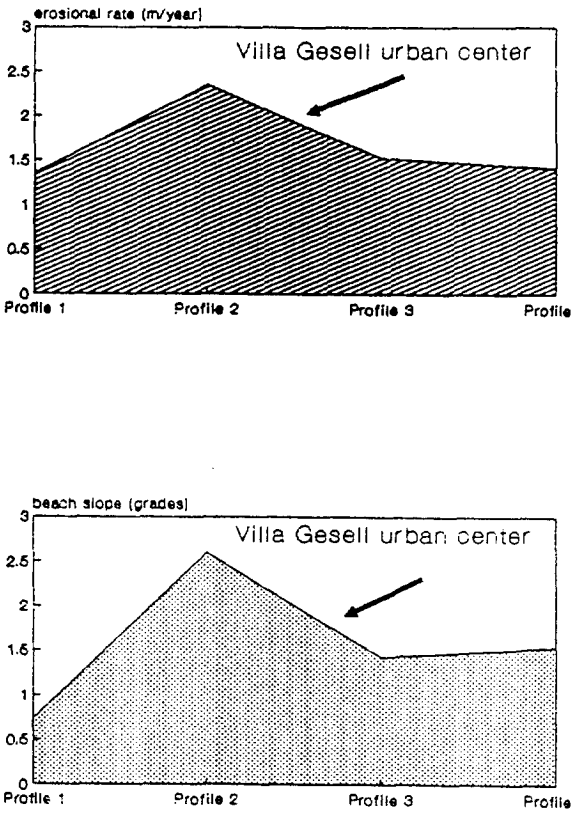


Fig. 10. Partial reproduction of aerial photographs edited by GEODESIA and INTA in the northern edge of Villa Gesell. The photographs show a variation in the morphology of the dunefields between 1987 and 1981. The growing of Villa Gesell city provoked a decrease in the sand supply because the city act as a barrier for the south and southeast winds.

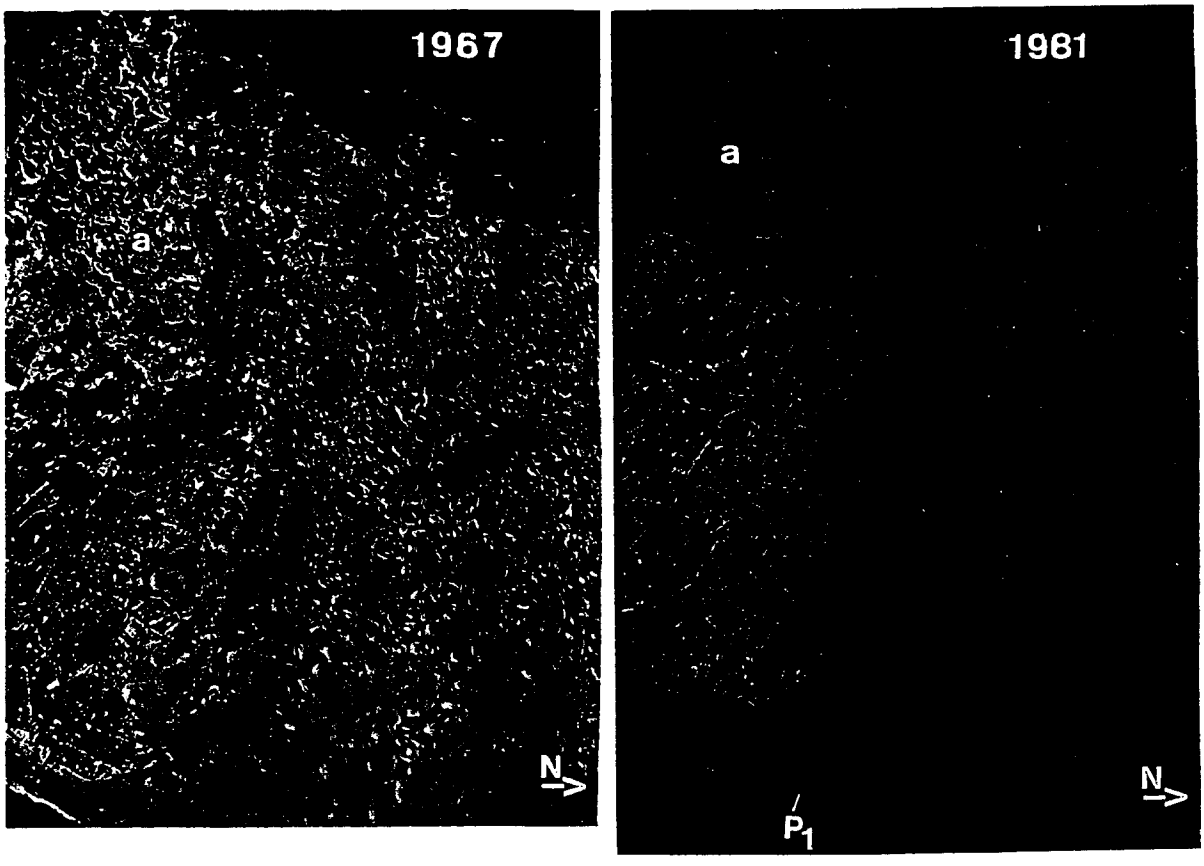
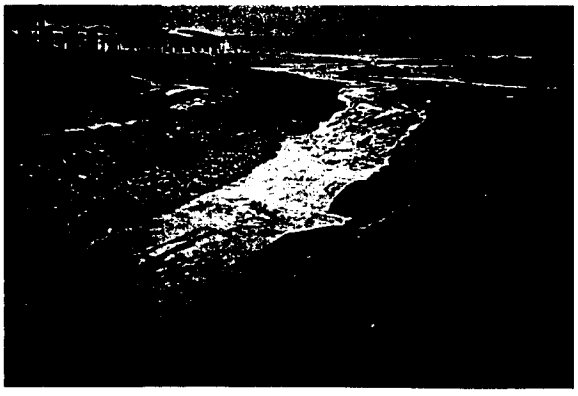


Fig. 11. Artificial drainage of the rainfall water along the streets perpendicular to the coastline, produces the beach and dune erosion during storms.



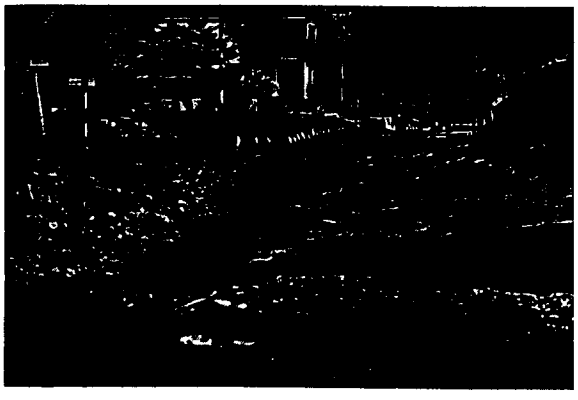
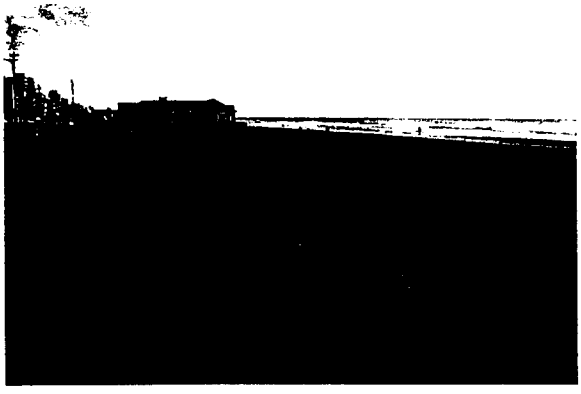


Fig. 12. Clean workings of the beach.



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COASTAL ZONE MANAGEMENT IN ITALY (AND ELSEWHERE): PLANNING THE COASTAL ZONE *vs.* PLANNING COASTAL ZONE MANAGEMENT

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ABSTRACT

In the specialized literature, the terms Coastal Zone Planning and Management are often taken to be synonymous, or as slightly different with a similar meaning. But the implicit contrast in these two terms actually reflects two completely opposed ideas of the planning process: the rational-comprehensive approach versus the incrementalist approach. A question arises over what methodological issues are at stake when trying to adopt an approach which is both holistic - as required by the emerging concept of the coastal zone - and an effective management of the critical problems. This paper attempts to address the issue by focusing on some aspects of the Italian situation.

INTRODUCTION

Planning of the coastal zone is still synonymous, at least in most southern European countries (but the same can be said of countries where public policy thinking in a inter-organizational setting is not highly developed), with appointing someone to make a plan (or several plans) for the 'rational' exploitation of coastal zone resources, as well as to draft consequent regulations to ensure plans are enforced. Today, however, there is widespread dissatisfaction with this approach, mostly because of inevitable shortfalls in implementation. If the forces (public bodies, organizations, groups of interests, individuals, etc.), which might contribute to the implementation of an action, do not take part in the design stage, they will certainly not contribute in the most effective way to its implementation, if they do not actually block it. Nor can the controllership function be conceived in simple terms; the central *v* local powers controversy now intensifying in most countries, gives an idea of just how much of a hot issue legitimation (who has the controlling power?) is. Opposed to this concept of planning is management. This is the fragmented, day after day activity taking place in individual organizations or even in a single organization unit. Management is usually highly effective in implementation, but fails when it comes to dealing with long-term large-scale closely interwoven issues, which often require overall reorienting in practice. A new method for dealing with the coastal zone issue is therefore required, and there is some evidence that a new "middle way" is emerging between the two approaches, a kind of "planned management" or "strategic incrementalism". Although this trend is to be found in most public policy domains (and corporate business) with planning processes, the coastal zone provides a particularly good case for highlighting the shortcomings of other approaches and the possibilities offered by this new middle way.

DEFINITIONS OF COASTAL ZONE MANAGEMENT AND PLANNING

Updated definitions of the coastal zone stress its dynamic nature and consequent hazards involved. As regards its substance, it is represented as a series of interlinked physical systems, functions, resources and uses. What is considered as being within the coastal zone, is a matter of debate. While Vallega (1985) suggests abandoning the - over narrow - concept of the coastal zone in favour of the concept of a coastal region, the OECD (1993) points to how the definition of the

coastal zone not only depends on the purpose at hand, but must also be comprehensive: "*the extent of the zone will vary according to the nature of the problem, the extent of the resource and the boundaries of governments with jurisdiction and responsibility for management in the coastal zone. Commonly, a variety of governments have jurisdiction in the coastal zone, none of which coincides with an ecosystem or a topographic definition of the coastal zone. The boundaries of the coastal zone should extend as far inland and as far seaward as necessary to achieve the objectives of the management programme; in most cases this means that the management programme should be based upon an ecosystem approach and the definition of the coastal zone should extend into the watersheds of rivers discharging to coastal waters*" (OECD: 1993, p. 10). Note that the seaward boundaries are no better defined than those on land! Close attention must be paid to the consequences arising from the choice of definition: the boundaries attributed to the zone and the way of describing its "nature" sets the - at times very binding - framework for the kind of actions to be developed. Since this arbitrariness cannot be avoided, it must be contemplated explicitly. In other words, any person contributing to the choice of action has to be aware of the "reality building" aspect of his or her role. The nature and role of planning and management are closely linked to or dependent on the relations included in describing the coastal zone. ORiordan et al. (1994), for instance, notes that "*as coastal zones are generally dominated by large-scale natural processes, such as tidal movement and sediment transport, major projects are required to deal with these processes, in order to protect ecological and socio-economic values. As a result of the increasing vulnerability of coastal zones, large-scale projects will therefore be an important feature in long-term coastal zone planning. These projects function as a framework in which, in a flexible way, smaller-scale and more manageable projects can be placed*" (ORiordan et al., 1994, p. 20). This is just one of the possible definitions of the scale and scope of planning for the coastal zone. If large scale natural processes, for instance, are considered to be outside the scope of any feasible planning effort within given circumstances, such efforts may thus consist of small-scale government, adaptive responses to the risks associated with these natural processes, and so on. Traditionally, planning corresponds to statutory activity projected onto and justified by the future, whereas management is less related to statutory powers and more short-term oriented. However, the boundaries between planning and management have recently been subject to some change, and some inter-merging: incrementalist representations of the planning process consider management actions to be the basic elements in planning, whereas management theories now look to strategic orientations. Nonetheless, the most traditional interpretation still survives with all its limits: "*coastal planning and management are not synonymous. Planning relates to the operation of the statutory planning system. The planning system is entirely capable of taking into account the human, natural heritage and physical elements of the coastal environment. However, there is a difference between what can be achieved within the present framework and what is achieved by many local planning authorities*" (DoE, 1993, viii). We might well wonder about the relation between the two phenomena mentioned here: planning authorities cannot achieve what they might because planning is conceived of either as a regulatory power over future developments - i.e. planning performs a pure controllership function - or as an exercise in strategic thinking about the future. These two interpretations of planning can hardly be reconciled, since a strategic approach involves a clear, thoroughly analyzed vision and set of purposes, but avoids specifying a particular set of tools too early in the decision-making process, and also recognizes that both the strategic programme and the vision itself may be improved as new information becomes available. The fact planning is subject to change is widely recognized, as is its dependence on the whole system, but the related difficulties in designing well-defined effective guidelines in advance are not: "*Planning forms only one of a number of control and regulatory systems in the coastal zone, which are concerned with the 'management' of a wide range of activities from port and harbour*

operations to oil and gas exploration. However, the wide range of policies, decisions and management practices adopted by each of the bodies with a responsibility in the coastal zone can have a direct effect on planning objectives. The role of regulating change and improving environmental conditions in the coastal zone is split between many authorities and bodies. Powers generally relate to a requirement to perform specific duties" (DoE, 1993, ix).

The framework for coastal management can be viewed as a complex system; change in one area (e.g. increased demand, intensification of use or change in management practice) will often lead to change and tension elsewhere. In general, the framework comprises three key components:

- legislation and regulations which define responsibilities and provide powers;
- policy advice which sets the management context; and
- linkages between authorities, managers and users through which decision makers can take into account the views of other interests.

With separate legislation and policies for many of the different types of coastal activities, the linkages provide the means for:

- anticipating problems before they arise;
- coordinating management decisions to ensure that uses do not interfere with other interests;
- ensuring that coastal management reflects local needs as well as national policy;
- resolving conflicts when they arise (DoE, 1993, x).

Setting up linkages as a separate task is nevertheless highly unsatisfactory, as is shown both by most participatory planning experiences in the 1970's-1980's and by the attempts to create formal coordination spaces between different authorities, such as the Italian "conferenza di servizi". The interest of Coastal Zone Planning and Management as a more general case for reflecting on planning rationality and methods lies rather in the fact that there are so many very different responsible and affected bodies, interests and people, that they call for planning activity which is not done on their behalf - even with linkages - but with them. Management context design is perhaps the most delicate task; linkages recognition or construction has to be fully acknowledged as a fundamental part of it, not as a separate function. This has even been recognized by the World Bank: "*all stakeholders in the coastal zone at all levels of government must be consulted and involved in the planning, implementation and operation of the ICZM program*" (World Bank: 1993). At the same time, a general aggregation into a single massive decision-making matrix where all factors can be treated relatively simultaneously in order to arrive at a holistic optimum is not at all manageable. There are both "cognitive limits" - i.e. human capacity - and "process limits" (Quinn: 1989) - i.e. the timing and sequencing imperatives necessary to create awareness, build comfort levels, develop consensus, select and train people, etc. - that constrain the system and ultimately determine the range of possible decisions. So the problem with managing and planning the coastal zone may be defined as that of finding a "satisfying" compromise (not the right compromise, not even the most satisfactory one, but one which satisfies most participants in the specific local context) between a framing phase which has to be as holistic and participatory as possible, and a phase where issues are dealt with by studying the feasibility of different solutions and putting into practice different actions.

REFERENCE FRAMEWORK AT INTERNATIONAL LEVEL

As implicitly evidenced by the various reports cited above, the reference framework at international level dealing with coastal zone management and related issues has attracted a considerable volume, quality, and variety of information. UNEP, WB, OECD, EU, as well as associations with a more limited scope have all contributed to the production of a highly valuable body of knowledge. What this knowledge lacks, however, is full acknowledgement of the need to develop site-specific methods, i.e. problem setting and a range of tools to deal with these issues defined with - and therefore more than just agreed to by - all relevant local stakeholders. This procedure does not exclude the use of scientific expertise in setting the general problem, segmenting it and finding satisfying solutions:

rather, it represents a challenge towards more reflective and self-aware scientific practice, especially where there is a lack of scientific certainty about the causal relationships between the factors that the institutional system is supposed to govern. As already mentioned above, at international level some moves seem to have been made in this direction. Let us hope it can become a mainstream tendency. On the other hand, the contribution of the reference framework developed at international level is already quite satisfying for the segmentation of the overall problem into more manageable limited issues. Here the only criticism to be raised concerns the limits encountered at some times and in some places in providing free and user-friendly access to information.

RELEVANCE OF THE COASTAL ZONE FOR ITALY

The coastal zone is an important issue in Italy, since the country has over 6000 km of coast (including the two major islands, Sicily and Sardinia). If a comprehensive definition of the coastal zone were adopted, i.e. extended to the watersheds of rivers discharging to coastal waters, then the whole of Italy would be considered a coastal zone. Consequently, the Italian coastal zone is generally a more limited area, more or less corresponding to the land interested by water outflows discharging directly into the sea plus the coastal waters, i.e. sea waters directly affected by input from coastal land. In 1989, 17.2 million people lived along the coast, a rise of 4.5 million since 1951. Although in absolute terms this figure is not apparently very significant, in terms of land-use density it has meant an increase from 297 inhabitants/km^2 in 1951 to 402 in 1989, a much higher average density growth than any other kind of area. Particularly rapid in the 1950's and 1960's, this nationwide growth pattern has slowed down in recent decades. There are, however, broad regional differences: in the South the high trend has persisted; in Central Italy the presence of Rome tends to distort the general pattern, while the North has seen a more moderate and evenly spread increase. In peak holiday periods, however, the overall figure of coastal inhabitants is estimated to rise by around 14 million due to tourism. Settlements for urban and recreational activities are not the only structures along the Italian coast: manufacturing plants, ports, infrastructures etc., also compete, at times fiercely, for coastal land use. Some years ago an Italian National Research Council survey valued coastal land in the Emilia-Romagna region at around 1,800 US$/m^2 (quoted by La Repubblica, 6 May 1994, p. 23). This figure is several times higher than the average inland value and close to the price of city-centre plots.

THE CASE OF THE "GENERAL PLAN FOR THE COAST" AND OF SOME OTHER PLANS: RATIONAL PRESCRIPTION TOOLS IN HIGHLY FRAGMENTED PROCESSES

Unlike city centres, coastal zones have almost no tradition of land-use planning and development control. At present, however, a number of tools have been introduced to design coastal zone uses, as well as to safeguard its landscape, morphology, etc. Beyond a number of different local and regional initiatives, a National Plan for the Defence of the Sea and of the Coastal Areas against Pollution and for the Sea Environment Conservation (Piano generale di difesa del mare e delle coste marine dall'inquinamento e di tutela dell'ambiente marino) was introduced by a 1982 Law (no. 979). Promoted by the Merchant Navy Ministry (a Ministry for the Environment was created only in 1986), this plan - which was never approved (Marson, 1994) - is a good example of the kind of planning which does not work. In addition to coastal protection from the sea, the Ministry of the Merchant Navy is responsible both for managing Coastal State Property and regulating various activities on or in territorial waters, such as fishing, shipping, offshore constructions, etc. The Ministry's view is that sea protection structures always defend from erosion, despite the fact that the evidence suggests in some cases the opposite may be true. In preparing the Plan, which attempts to deal with a much broader issue than what falls within its statutory powers, this Ministry does of course define actions to be taken by other bodies as well. This form of internalization in the name of public interest

proves very difficult to achieve. In this specific case, the Plan was even to be rejected by a body which did not exist when it was promoted, the Ministry for the Environment; in the years to come this Ministry was to block any attempt to amend or approve the Plan. This case was generally characterized by very tough inter-institutional competition and conflicts over power and resources. In inter-organizational settings none of the bodies has the necessary power to design and manage an integrated coastal approach without the cooperation of other public and/or private subjects. It is crucial, then, that the fact many subjects are involved in the management of the coastal zone - and should therefore define policy together - is recognized. A recent institutional reorganization in Italy first combined and attributed the powers for the Sea and sea transport to the Environment Ministry, and then merged the Environment Ministry into the Public Works Ministry. But this has not solved the problem, even at central government level. The Public Health Ministry, the Foreign Affairs Ministry, National River Basin Authorities, Regional Administrations, State Property, Harbour and many other authorities at local level are all greatly affected by any efforts at implementation. On the other hand, when one of these organization promotes a plan or a series of actions, which are more limited in scope, mainly or completely within its area of competence, implementation will certainly be more effective, but its contribution to the coastal zone issue will be rather limited, if not in conflict with overall, medium- to long-term interests. Thus despite the number and variety of tools currently addressing the coastal zone management issue, the overall picture is highly fragmented and irregular. At a time when there is a general lack of confidence in centrally planned economies, most actors acknowledge the presence and effectiveness of more subtle and complex forces like information, trust, identification, satisfaction, etc., as well as of individual and collective strategies in playing roles, relating to others, and anticipating future actions and outcomes. Consequently, we should at least begin to recognize the importance and try out these tools.

SEGMENTATION IS UNAVOIDABLE, BUT SEGMENTING THE PROCESS OR THE PROBLEM IS NOT THE SAME THING, AND SEGMENTING BOTH, HAS A NUMBER OF CONSEQUENCES

The Italian Coastal Zone plans would seem to address many issues. If, for instance, we take the more representative National Plan for the Defence of the Sea and Coastal Areas - but any other plan on a national scale would prove to be quite similar - we find it is divided into six themes: shoreline and maritime works; coastal zone uses; marine resource exploitation; sea pollution; critical environmental situations; and coastal zone environmental decay. These are very different themes: some are concerned with the management of emergency and or risk detection; some with long-term physical processes influenced by human impact; most have problems which are so broadly defined they inevitably involve many stakeholders and different institutional areas of competence. The Plan must thus deal with a very complex situation. But at the same time this situation is reduced to a sort of functional space in which competing tendencies are represented as "natural" processes and the real actors are completely concealed. So much for the descriptive aspect of the Plan, which turns out to be rather rhetorical in tone, since the themes addressed are clearly too broad and complex to be effectively tackled by this kind of plan. The next step is the definition of objectives. What the document describes as "strategic objectives" more or less coincide with the six themes mentioned above, and consequently can hardly be described as being very strategic in nature. The "specific objectives" are a little more clearly defined. Thus for the theme of shoreline and maritime works, the proposed objectives are:

a) promotion of research and experimentation to find solutions to coastal erosion phenomena;

b) an environmental revision of defense works; and

c) encouraging the sedimental equilibrium of the shorelines. If the processes involved are described as "natural", then the methodological approach to the solution is of course typical of the natural sciences (at least it was in the past; now major

transformations seem to be underway in this field too): the definition of the problem is taken for granted, the dynamics of the undesired phenomena are explored and the most efficient solution is put forward. This solution is then formally recommended or imposed. Human factors play an important role in the processes the Plan claims to tackle. But at the same time the main actors are not involved when the objectives are identified by the Plan. This means that the objectives of the Plan are not acknowledged as being of sufficient strategic interest to the national or regional community and therefore the Plan fails to warrant technical decision-making by a single institution (in this case, the central government Ministry, but the same applies at regional level), affecting overall social, economic and bureaucratic practices. At the same time, such practices often surreptitiously anticipate many of the actions envisaged by plans. Thus not only does the optimal rational solution usually encounter strong opposition in introducing the process because it fails to take into account the many "social" constraints and has to face a very different context when actually being implemented, in most cases it is sub-optimal anyway, because it does not use local knowledge and forces. By 'local' we mean within the processes that a plan claims to shape, and thus opposed to the knowledge produced by a supposedly impartial external rationality. The sequence of actions envisaged by the Plan also follows a rather outmoded rational scheme as regards public/collective action for the future in a complex and dynamic domain such as coastal zone management. The sequence may be summarized as follows: increase knowledge, describe in detail the action to be taken and the technical support required, build new works and tools, and organize their maintenance and/or management. This is all rather wishful thinking. In practice no single action can be implemented purely on the basis of the Plan, since it requires the approval of other institutional organizations, especially the Ministry for the Environment. But the Plan already includes schedules and deadlines, thus anticipating these formal agreements (on the basis of whose authority or leadership is far from clear!). The estimate cost of the proposed actions is equally detailed: around 3,500 million US$ in five years to be assigned to different institutions according to their areas of competence, with priority given to actions already underway promoted by the Ministry of the Merchant Navy. Actors, therefore, are not considered explicitly in the various phases of the Plan but surreptitiously re-introduced at the very end: one might wonder, therefore, what the initial, larger section of the Plan had been dealing with. It might be tentatively argued, therefore, that as a minimum requirement in segmenting the problem, the process should be widely representative, i.e., a large number of stakeholders should be involved in setting the problem and specifying its segmentation and simplification. In this way agreement may be reached about who is going to be in charge - and how - of dealing with such matters.

RATIONAL-COMPREHENSIVE V INCREMENTALIST "MODELS" OF PLANNING AND MANAGEMENT

But in actual practice what usually happens is exactly the opposite. First partial solutions are chosen (by those in charge of planning) - either because these are the best known, or because they are at hand, or because the planner has experience in that field, and so on. Such solutions are then justified through the ritual construction of a purely fictitious ideal rational-comprehensive model of planning. This model leaves no room for the acquisition of further knowledge and information, nor for the development of the best solutions *in situ*. In a concise and effective account, ORiordan et al. (1994, p. 52) express a number of concerns which apply particularly well to the Italian situation: "*The reasons for the failure are several. The attempt to a comprehensive planning cannot withstand the combined pressures of scientific uncertainty and institutional fragmentation. The result is endless disagreement and even misunderstanding about the priorities to be address, and the issues to raise. The best international experience available suggests that the goal of comprehensiveness and clear hierarchical linkages is not only futile but also quite dangerous.*

It leads to administrative cumbersomeness and eventually to regulatory inertia. To pursue the illusion of a binding, static and comprehensive plan for the formulation and implementation of the different policies, programs and projects, could be very dangerous". Critics of rational-comprehensive planning usually advocate a method that is known under different names: "incrementalism", "mutual adjustment", "power-behavioral approach". Among other things, this method stresses "the multiple goal structures of organizations; the politics of strategic decisions; executive bargaining and negotiation processes; satisfying (as opposed to maximizing) in decision making; the role of coalitions in strategic management; and the practice of muddling in the public sphere" (Quinn, 1989). Although very powerful in analyzing processes, the incrementalist approach, in turn, is criticized for being essentially conservative and short-term oriented, and for offering no guidelines for future action. Nevertheless, although not considered a panacea, this conceptual model is at least viewed as a more fruitful starting point for ideas about planning than the more widespread rational-comprehensive approach.

A COMMON MISUNDERSTANDING: PLANNING AS A CONCEPTUAL FRAMEWORK FOR DEVELOPING SATISFYING SOLUTIONS AND AS AN EXTENSION OF THE CONTROLLERSHIP FUNCTION

Traditional (mostly statutory) planning is not very successful not only because it addresses too many objectives, is static and so on, but also because it tries to combine two quite irreconcilable tasks: suggest ideas able to guide innovative change, and at the same time attempt to inhibit change (but often let more dangerous marginal action take place) through an extension of the controllership function. Of course ambiguous ill-defined medium- to long-term objectives help legitimate the control function. A "school" of planning has even developed in recent years, which views public planning as mere rhetoric. In any case, the growing production, in different domains, of non-statutory planning exercises as a means to developing new solutions and fostering their implementation seems to highlight both the usefulness of planning, beyond purely rhetorical purposes, and the dangers of combining it with extended control. These two tasks require such different time references and definition levels that they can hardly be combined. Thus on one hand, are the issues of establishing the procedural or general conditions for change, leaving the "how" to further developments, interactions, fresh knowledge, etc.; and on the other, the totally different questions involved in detailing the conditions without knowing "who"-"when", under what changed external conditions, etc. - is going to introduce change.

SOME METHODOLOGICAL STEPS TOWARDS EFFECTIVE CZM

What is the way out of this deadlock? As always, only time will tell, although in some respects the answers it will eventually provide may come too late. Half-way between the two models of planning described above, that is the rational-comprehensive and the incrementalist models, a kind of new model is developing, basically starting from incrementalist assumptions. This new model is based on a belief in loose fragmented incremental actions as the only method reflecting actual behaviour, and on the search for purposeful effective proactive strategic management. It calls for a closer focus not only on human dynamics, power relationships and organizational processes, but also on the "constructive" use of data and data analysis in order to shape crucial aspects in decision making. The basic requirement for Integrated Coastal Zone Management is a holistic long-term view of all factors involved in the coastal zone. At the same time, the experience acquired so far by system engineering demonstrates how trade-offs between conflicting objectives cannot always be solved in a technical way. Project financing, too, is becoming increasingly less frequently an external variable, and is now considered a constituent part of the feasible alternatives. Holism, therefore, must be seen as a framework of reference for acting on the smaller action/actor combinations and on the resulting network, rather than as a means of

justifying a rigid technocratic style of intervention, which has turned out to be rather fragile over time in uncertain or turbulent situations. Thus as a test case for verifying the latest styles in planning and management, the coastal zone is a very challenging prospect.

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ASSESSMENT AND MANAGEMENT OF DIVING RELATED TOURISM IN THE RAS MOHAMMED NATIONAL PARK, RED SEA, EGYPT

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ABSTRACT

(1) Diving related tourism is an increasingly common cause of damage to coral reefs in tropical tourist resorts. At the same time income from tourism can be important to the local economy and may provide the incentive for government to protect and manage reef areas. The need to strike a balance between tourist activities and reef conservation is particularly demonstrated in the management of the Ras Mohammed National Park.

(2) The Ras Mohammed peninsula and adjacent coastline were first given protection in the 1970's. It was established as a National Park in 1989 and subsequently enlarged to cover 52% of the Egyptian coastline of the Gulf of Aqaba, equivalent to 2,000 km^2 surface area (marine, coastal and terrestrial). By 1994 the area included 36 hotels (with 8,234 beds) and 26 diving centres attracting an annual total of 220,000 visitors, a seven-fold increase since 1988.

(3) The National Park has initiated a programme of research designed to (a) monitor the conditions of the reefs and associated habitats, (b) determine the extent of impacts due to hotel development and tourists' use of the shore, (c) monitor specifically the impact due to SCUBA diving and (d) examine factors underlying the maintenance of biodiversity.

(4) This paper describes key issues and findings. Coral cover and integrity has decreased at some of the most heavily used sites. Observations on divers have shown that they impact corals approximately 9 times per dive but that this rate can be reduced considerably by pre-dive briefings. Damage caused by snorkellers walking on the reef flat can be reduced by the construction of walkways, jetties and the demarcation of entry points. However, structures built or floating over the reef may cause coral mortality by shading.

INTRODUCTION

Coastal zones have been managed more or less successfully for millennia. It is only recently though that the link between coral reefs and their associated marine environments and tourism development objectives has been fully appreciated. Ideally, tourism should be the most environmentally benign way to generate income from coral reefs. This is true only under carefully controlled conditions of resort development. It is the recognition that resource based tourism is limited by the condition and health of the resources themselves that has, in many cases, led to the establishment of marine reserves, biospheres and national parks. A recent report lists some 353 protected reef areas world-wide (Wells & Spalding, 1995, in prep.). A number of these lack the adequate funds and/or personnel for management and law enforcement to be implemented as a TMRU/IOC survey recently revealed (Medio, in prep.) but many have succeeded in creating a balance between local economic aspirations and the conservation of delicate marine ecosystems. The island of Bonaire for example relies almost exclusively on diving tourism: a reef tax levied on all tourists entering the country finances the high costs of park management (Dixon et al., 1993). The Galapagos Islands have relied on ecotourism since the establishment of a national park: tourists can only access the sites with the assistance of a highly trained guide (Salm, 1985, 1986; Kenchington, 1989). An example from an industrialised nation

sees the GBRMPA in Australia managing a multiple use protected area through intensive and extensive consultation with the public (Kelleher, 1986).

Sinai and its protected areas

The uplifted Sinai peninsula, located at the northern-most part of the Red Sea (between 27°N and 30°N), is embraced by the Gulf of Suez to the west and that of Aqaba to the east. The latter, a segment of the Afro-Syrian rift system, is 170 km long, 14 to 26 km wide and close to 2,000 m deep, and separated from the Red Sea proper by the straits of Tiran, a 250 m deep narrow passage. The Gulf of Aqaba is bordered by a luxuriant fringing reef which extends along almost the whole 200 km shoreline from Eilat (Israel) in the north to Ras Mohammed (Egypt), the southern most tip of the peninsula, interrupted only by shallow bays. The width of the fringing reef flat depends on the steepness of the inorganic slopes on which the corals rest. At most sites this base line is formed by the descending and submerging mountains of the uplifted Sinai peninsula. On several northern sites such as between Dahab and Ras Abu Galum and on the eastern shores of the Ras Mohammed peninsula, these rocks descend directly into the sea thereby presenting a very narrow reef flat (1-5 m) and an abrupt drop off into deep waters. In more southern parts however, such as north of Sharm el Sheikh, the mountains retreat revealing uplifts of coral reefs often exposed above the current coastline. These exposed terraces are between 20,000 and 200,000 years old (Friedman, 1965).

The reefs of the Gulf of Aqaba are subject to few natural disturbances. The Red Sea is a narrow and enclosed body of water with generally small waves and very rare storms; the lack of river runoff, low planktonic primary production and extremely low rainfall result in very clear water. These features have all contributed to the biological uniqueness of the area; a high diversity of corals (Loya, 1972, 1976; Sheppard, 1980) and over one thousand species of fish (Randall, 1981) living in transparent, warm waters have formed the basis for the region's popularity as a tourist destination. This became evident in the late 1970's and in a preliminary study on the proposed establishment of protected areas in Sinai, Fishelson (1980) stressed the fact that it was possible to develop a tourist industry centred around Sinai's coral habitats so long as these were actively protected and that benefits would eventually outweigh the costs of reef conservation. "This concept", he emphasised, "should be the basic premise for developers".

Ras Mohammed Marine Protected Area: its evolution

The Ras Mohammed Marine Protected Area at the southern extremity of Sinai, Egypt, was declared in 1983 (Law 102) and covered 97 km^2 and 0.6% of the Egyptian littoral on the Gulf of Aqaba and the island of Tiran. The rapidly encroaching tourism led the Egyptian government to request a study in order to determine the feasibility of and the technical assistance for the development of the RMMPA. Its recommendations proposed upgrading its status to that of National Park, increasing its area to cover 210 km^2, the establishment of a coastal zone management plan and a monitoring programme to evaluate and modify management measures (Pearson, 1988). As a result, technical assistance from the EU led to the establishment of an initial development phase which provided essential equipment, recruited and trained local staff and introduced a basic monitoring programme. This first phase, lasting two and half years, demonstrated, among other things, that strict management of marine resources was not meant to hinder development in South Sinai.

One of the objectives of the management in place at Ras Mohammed was to show that all development in the area was resource dependent and that the degradation of coral reefs and other marine ecosystems would limit the area's economic potential. Subsequently, in 1992, following acceptance of the second phase of the development for the National Park, the government of Egypt extended the boundaries even further to include:

(a) the National Park, a coastal and terrestrial protected area with very limited access, about 70% is still off-limits, and no development. Since it was

declared (1989), the park area has been provided with a visitor centre and a laboratory complex: this includes state of the art laboratories, a workshop, a diving centre for park staff and accommodation for visiting scientists.

(b) the coastal areas, the jurisdictional limits of which are defined as the highest equinox tide line, fronting the Sharm el Sheikh development zone. These include the military and commercial harbours, the larger proportion of built-up areas and ca. 90% of hotels in the area. This section of the protected areas has witnessed the greatest tourism development expansion and most of its 24 km coastline northeast of Sharm el Sheikh has been sold to developers. The park, responding to the regulatory procedures established by the Egyptian Environmental Affairs Agency (EEAA), has effectively regulated tourism activities and related development. All development projects such as hotels and diving centres must be approved by the EEAA through its Park management: some of the constraints include minimum distances from the shoreline, maximum height of buildings and the inclusion of walkways or promenades to guarantee public access to the State owned shores. Waste water discharge into the sea from urban or development areas, for example, is absent from the Egyptian Gulf of Aqaba. All sewage is treated either at municipal biological facilities or by individual hotel operators. In order to implement this and other regulations in place within the protected areas continuous patrolling by park staff and monitoring programmes have been established by the park management.

(c) the Nabq and Ras Abu Galum Managed Resource Protected Areas : two multiple use areas, with a preliminary zoning plan comprising scientific reserves, buffer zones, controlled access zones, traditional settlements and tourism development areas. These areas are linked by the Dahab Coastal Managed Area. This network of protected areas is presently known as the Ras Mohammed National Park Management Sector (MNPMS) covering 2,000 km^2 of surface (marine, coastal and terrestrial) and 52% of the Egyptian Gulf off Aqaba (Fig. 1) (Pearson, 1995).

The oasis of Nabq contains the northern-most mangrove forests of the Red Sea (vicennia marina), further emphasising the uniqueness in biodiversity of the Gulf of Aqaba. Apart from the sparse mangrove at Ras Mohammed, four mangrove stands of considerable density are found along a 20 km stretch of coast northeast of Sharm el Sheikh. The mangrove oasis of Nabq is a critical zone which includes dunes, seagrasses, lagoons, coral reefs and most important, Bedouin settlements which have used Nabq as a fishing area for centuries; the nearby wadis are currently used to graze sheep, goats and camels. Its recent protection is part of the commitment by the Egyptian authorities to preserve critical marine environments and all Bedouin settlements.

The area of Ras Abu Galum contains unique back reef areas with important mollusc and invertebrate populations. Much of the area remains unknown but those parts which have been explored and inventoried do have an economic value both in terms of artisanal fisheries and tourism. By including Abu Galum Sin the Management Sector, the authorities have, de facto, efficiently separated two development areas (Dahab and Nuweiba) with large Protected Areas providing space, undisturbed natural systems and economic resource based opportunities.

Tourist development

The vicinity of Sinai's reefs to the European tourism market and Egypt's economic needs have led to an unprecedented increase in tourism and associated infrastructure. Since 1988 the number of hotels has increased from 5 to 36, the number of diving centres from 5 to 26 and the number of boats from 23 to over 200 (Table 1). The rate of development in the past two years has increased even further: the % increase from 1988 to 1995 has been almost twice that of the period between 1988 and 1993. The number of visitors to the Sharm el Sheikh area in 1994 was 220,000; if the development ceiling for this area, currently set at 23,000 beds in 1996 and the average annual occupancy rate of 70% (National Park Survey, 1994) are reliable statistics, then the expected number of visitors for 1995 will be in excess of 500,000.

These figures do not include the newly developed areas of Dahab and Nuweiba.

Hotel development is taking place albeit at a different pace from that seen in the Sharm area. The EEAA has acted promptly in creating two large protected areas (see above) and linking them by a Coastal Managed Area such as the one in place at Sharm el Sheikh.

Such an increase in tourism related development can have several direct and indirect impacts on coral reefs and other delicate marine ecosystems. Some of the more common effects are siltation due to construction as seen at Eilat in the Gulf of Aqaba (Mergner, 1981) and in the Caribbean (Stafford-Smith, 1990), and Waste water discharge as highlighted by White (1987) in the Philippines. Altering the coastline by constructing artificial beaches can also have devastating effects. A particular case in Sinai involved a sand-fill in order to create a 4,000 m^2 beach. The consequences, which are still being investigated, include Increased sedimentation, beach erosion and possibly an altered fish community structure (Medio, pers. comm.). Damage from collecting, fish feeding, over-fishing, anchoring and diver damage has been reported from numerous locations world-wide (Davis, 1977; Neil, 1990; Rogers et al., 1988; Salvat, 1981; Tilmant, 1981; Tilmant & Schamahl, 1982; Ward, 1990; Wood and Wells, 1989). In the case of Ras Mohammed we shall be looking at the damage caused by divers and snorkellers and at ways of reducing this perhaps less well documented form of abuse.

Monitoring: results and applied management solutions

Some data are available on the reef community structure in the Gulf of Aqaba (Mergner, 1971; Loya, 1972, 1976; Sheppard, 1980, 1991; Kotb et al., 1991). Very few studies however have dealt with the impacts of human activities on coral reefs and their complex linkages with the associated ecosystems present in the Ras Mohammed protected area : in particular, no data are available as to their degree of tolerance from human interference i.e. a reef's carrying capacity. In the light of this, the Park management has established, in collaboration with the Tropical Marine Research Unit (York University), a coral reef monitoring programme to assess, scientifically, the effectiveness of its coastal zone plan and some of its policies in place within the park and the Sharm el Sheikh development area.

Observations have been made with the aid of fixed belt transects and permanent photographic stations to evaluate the health of reefs in selected parts of the park sand in recently built up areas. The objective was to create a data-bank on overall coral cover and coral damage at selected sites which could then be monitored for change in the short and long term. Furthermore, the introduction of management techniques such as entry points - walkways on the reef flat which allow easier access to the reef edge -, jetties and permanent moorings - fixed anchoring at selected sites (anchoring is prohibited throughout the area) - in various parts of the protected areas has been shown to be beneficial to the coral reefs at Ras Mohammed.

SCUBA is an increasingly common yet poorly documented cause of damage to coral reefs. Hawkins and Roberts (1993) showed that there were more broken corals and loose coral fragments at popular dive sites than at undived ones within the MNPMS. At the time of their research (1989, 1990) relatively low tourist numbers led them to conclude that the damage caused had more aesthetic rather than biological implications.

In a recent experiment designed to quantify the actual rates of damage by SCUBA divers at Ras Mohammed, Medio et al. (1995) concluded that the current rates of impact were not sustainable. The data show how a single diver impacts the reef at least 8 times per dive. Hence the 200 boats operating in the area and carrying between 2,000 and 3,000 divers lead to at least 32,000 impacts a day. On a smaller scale every dive site is battered about 500 times a day and every m^2 15 times a year. The experiment was also designed to verify whether diver education could reduce the rates at which the reef was being damaged. A single environmental briefing reduced the number of impacts from 1.5 to 0.3 per diver per observation period; further data analysis showed that the number of real damaging impacts (those contacts

actually breaking or abrading live corals) following the briefing was in fact 0.07 per diver per observation period. The one-hour interactive lecture on reef biology, diving techniques and park management, made the divers aware of the different reef elements. In the 11 experimental weeks the change in the number of impacts following the briefing was significant (t-test, P=0.09 to 0.001) while this was not the case in the control weeks where no briefing took place. The experiment also confirmed that underwater photographers are the worst offenders: representing only 23 of all divers they are responsible for over 70% of all damage.

The Park management at Ras Mohammed was quick in responding to the findings of the above study. A training programme designed to provide the diveguides operating in the area with an adequate amount of information on coral biology and park management was established in late 1994. With over 90% of all diving in South Sinai taking place from locally chartered boats, where at least one diveguide is compulsory, such a training scheme should be highly beneficial and, in the short term, greatly reduce damage to coral reefs. Reef walkers and snorkellers represent 60% of all tourists in the Ras Mohammed area (Pearson, 1995). According to the latest estimates, the narrow fringing reefs in the area will attract about 300,000 users in 1995. The damage caused by visitors on a reef flat has been well documented in Sinai (Hawkins and Roberts, 1992) and elsewhere (Bryceson, 1981; Kay and Liddle, 1989). These authors were unanimous in concluding that overall coral cover decreased on the reef flat and crest at popular sites. The results also indicated that trampling affects the various coral genera and growth forms in different ways (Woodland & Hooper, 1977), the massive and encrusting forms and those found on the reef crest showing less damage. The studies conducted in Sinai however found no significant changes in species diversity. The recommendations made included the use of walkways i.e. well marked routes for reef walkers, snorkellers and indeed divers.

In an experiment designed to test the benefits of such a walkway, a rudimentary entry point was installed at a recently opened tourist village in the Sharm el Sheikh development area. Divers and snorkellers at this site left the shore line and spread out over a wide area before reaching the reef edge causing extensive damage to the coral community. Coral cover and coral damage were evaluated using three parallel 70 m belt transects on the reef flat at 20, 30 sand 40 m approximately from the shore line (prior to the installation of the walkway). The flat was also subdivided into three equal portions (left, centre and right) in order to confirm an even distribution of the resort's users. Analysis of the data showed no significant difference between the three transects nor between the theoretical left, centre and right portions of the reef flat: users did spread out evenly on the reef flat.

A year after the entry point was put in place the same area was re-monitored to test for changes in coral damage. The overall incidence of broken, abraded and knocked over coral due to trampling had decreased significantly on the reef flat area fronting the tourist village as most of its guests made use of the easier access to the reef crest and the open sea. The beneficial effects of the walkway were further demonstrated by the analysis of the data. The theoretical central portion of the reef flat was significantly more damaged than the right or left portions (Mann Whitney U test, P=0.008) and more importantly, a significant proportion of damage was confined to plus or minus 2 metres on either side of the walkway (Mann Whitney U test P=0.001) (Medio, in prep.).

The findings of the above study have had management implications in the Ras Mohammed area. Arguably the largest tourist resort in Egypt applied for a number of floating jetties and walkways which have since been installed on the reef flat fronting their 1,400 m beach. These are being carefully monitored by Park staff. An independent survey has shown that 90% of the resort's guests make use of these access points and the same reduction in the amount of damage can therefore be expected. The only drawback to one of the floating structures in place at this resort is the 1,600 m^2 floating swimming pool. Its extensive use by most of the guests has surely limited damage to the reef crest itself. However,

a preliminary study into its shading effects has revealed a higher coral mortality due to bleaching (Medio, pers. comm.). As a result new surface designs, allowing more light to penetrate, will have to be developed before similar floating structures can be approved by the Ras Mohammed management. The results highlighted by the experiments described above have further justified park policy on the number of accessible dive sites in the management Sector and in particular at traditionally popular areas. Since 1988 the number of boats has increased ten-fold. In order to efficiently distribute divers and hence reduce damage to coral reefs more than 120 fixed mooring buoys have been installed in the past 2 years. Furthermore, at the more popular dive sites a timetable determines the maximum number of boats allowed in one place at any given time.

Ras Mohammed in a regional context: future prospects

The creation of marine protected areas can lead to the preservation of coral reefs and, at the same time, achieve long term economic development especially in developing countries. Furthermore, the purely financial benefits derived from effective conservation can outweigh the costs of managing protected areas. The Bonaire example, whereby the costs of managing the Marine Park are provide by a reef tax, is a case in point. At Ras Mohammed, a recent survey (TMRU, 1995) has shown that at least 90% of the park's users would be willing to contribute to the financial needs of the park. In the very near future the park will have to become financially autonomous and the authorities are in fact looking at the most feasible way in which to raise the necessary funds: if the visitor data and the surveys are reliable the issue is close to being resolved.

The Park management has initiated a monitoring programme to assess the validity of its policies and its recommendations have in some cases already been applied.

The authorities have also been active in a public awareness campaign: regular seminars inform the public (Hudson, 1988) on topics such as basic coral biology, sound diving techniques and park regulations. The diving and tourist industries are kept updated on management policies and key issues by park staff at monthly meetings.

The protection of the Gulf of Aqaba is now at a critical stage. Much effort has gone into the extension of the Egyptian protected areas in the past ten years.

Two key issues are at stake: (a) further enlargement to cover the remainder of the Egyptian littoral on the Gulf and (b) a more regional approach to the conservation of Red Sea reefs.

(a) The current trend in tourist development is now occurring along the 70 km stretch of coastline between Ras Abu Galum and Taba near the Israeli border. A new protected area between the tourist resorts of Nuweiba and Taba would complement the Nabq and Abu Galum sections in regulating development activities.

(b) The geo-political situation in the region, recently boosted by the peace process, may further exacerbate the current pace in tourism development. The regional market may not be as large as the wealthier European one but, with far higher population growth rates in the countries bordering the Red Sea it may soon become so. A global consensus by Egypt's neighbours (Israel, Jordan and Saudi Arabia) of the need for an effective coastal zone management strategy is mandatory. Failure to address this issue may lead to considerable degradation of the region's marine resources and an inevitable reduced economic potential for the countries concerned.

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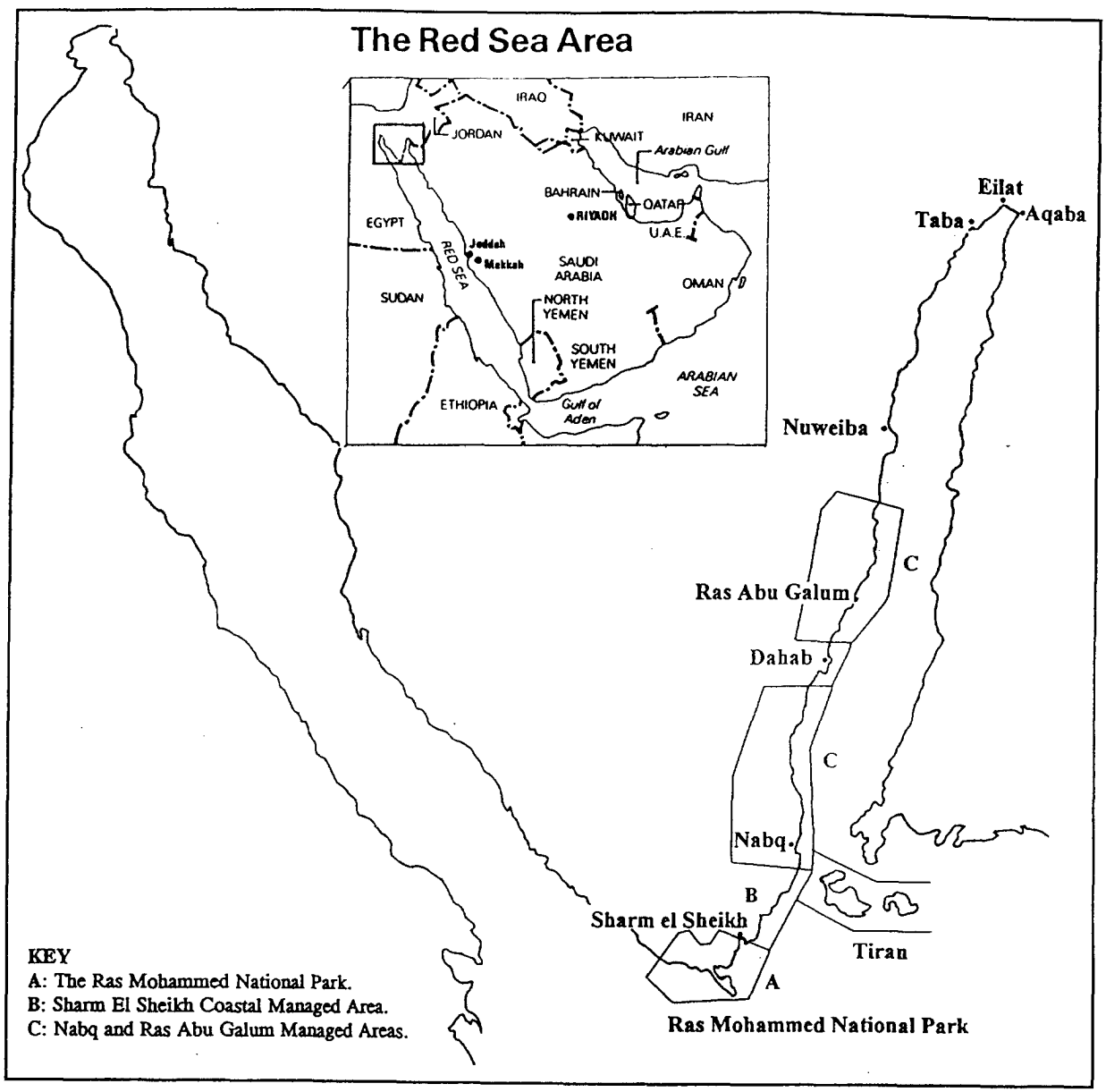
Table 1. Tourism development trends. Sharm el Sheikh, Sinai, Egypt

YEAR	1988	1989	1990	1991	1992	1993	1994	1995
No. Hotels	5	7	8	15	18	27	36	40
No. Rooms	565	694	805	1492	1662	2578	4050	6124
No. Beds	1030	1276	1358	2906	3306	5190	8234	12248
Dive Centers	5	6	10	14	16	18	26	30
Shore Diving Sites	22	22	18	14	10	6	4	1
Dive Boats	23	25	47	60	89	120	200	240

Fig. 1. The Sinai Peninsula and its protected areas.



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LA GESTION INTÉGRÉE DE LA ZONE CÔTIÈRE EN RELATION AVEC LE CHANGEMENTS PHYSIQUES; CAS DU BASSIN MÉDITERRANÉEN

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Lieu de rencontre des trois éléments de la nature que sont, la lithosphère, l'hydrosphère et l'atmosphère, la zone côtière dispose des ressources naturelles parmi les plus importante et les plus attrayante du monde. Milieu très sensible à l'action de l'homme, elle est enfin l'objet d'une attention particulière de la communauté internationale et de plus en plus des pouvoirs publics.

La Conférence de Rio n'a-t-elle pas statué dans le chapitre 17.1 de l'Agenda 21 que "le milieu marin y compris les océans et toutes les mers et les zones côtières adjacentes, forme un tout et constitue un élément essentiel du système permettant la vie sur terre".

Les 500 000 km de côtes, qui parcourent le Globe sont néanmoins distribués d'une manière inégale. La Méditerranée - Mer au milieu des Terres - Comme son nom l'indique, ne dispose que d'à peine 7% du total. Elle abrite, par contre, prés de 15% de la population littorale mondiale et produit annuellement prés de 15% des richesses crées sur la planète. Elle est aussi le siège de prés de 16% de l'ensemble des échangés de marchandises.

C'est pourquoi les pays méditerranéens dans leur ensemble devront prendre conscience que seule une gestion rigoureuse et intégrée de la zone côtière pourra garantir un développement durable de ses ressources sans rompre l'équilibre naturel de l'écosystème.

L'objectif du présent papier est de contribuer à la sensibilisation du littoral méditerranéen. Trois volets seront développés:

- La première partie comprendra une revue globale de la zone côtière méditerranéenne incluant les contextes physique et socio-économique de cette région.
- La deuxième parie présenterai différentes approches lancées ou en cours de lancement dans plusieurs pays Méditerranéens en matière de gestion intégrée de la zone côtière GIZC.
- La dernière partie traitera une méthodologie de prise en charge des travaux de préparation, de conception et d'exécution du programme GIZC.

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ASPECTS OF PHYSICAL AND CULTURAL PARAMETERS ASSOCIATED WITH COASTAL ZONE MANAGEMENT ALONG THE CEREDIGION HERITAGE COAST, WALES, UK.

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ABSTRACT

The Ceredigion Heritage Coast (CHC), Wales, UK comprises some 34 km of coastline and is a major tourist attraction to the area. Some 45 Heritage Coasts currently exist in England and Wales occupying 34% of the coastal fringe. The prevailing philosophy of such areas is to conserve for posterity beautiful stretches of natural coastlines. This is achieved by low key management approaches incorporating community involvement and the leaving of land in public ownership. Utilisation of the Tanner abc model indicated several 'high and low' beaches together with fifteen sediment cell distributions. Active erosion sites were compared to sites postulated by wave refraction models and a correlation was found. Seven beaches were studied in detail as these form the economic heart that has been part and parcel of the tourism fabric in this sector of Wales. These beaches were Aberporth, Tresaith, Llangranog, New Quay, Cei-Bach, Aberaeron and Aberystwyth. These were all 'high' beaches. In addition 1053 visitors at these beaches were questioned regarding beach visit patterns. Beach visitors came from a wide area (54% outside Wales, with the West Midland region of England being the major component) and in frequent visits - less than 5 times per year - were the rule. The car was the most popular form of transport (79%) and the caravan (trailer) the most popular form of accommodation (47%). People over 40 years of age, tended to stay at the larger towns of Aberystwyth and Aberaeron in hotels and guest houses Eighteen percent of the visitors were classed as Socio-economic Status group 1, i.e. the professional class. Awareness of the fact that the area was a Heritage Coast was low (40%). This could be a result of the low key management approach and the fact that coastal visitors originated from a wide inland hinterland. Escalating pressures of pollution, fishing, leisure, conservation and farming are all interlinked. Sun bathing, swimming, children's play all take place around the beach fulcrum and it is the stability, cleanliness of the beach, beach facilities, that determines a major part of the economic prosperity of the area Coastal zone management is vital for this area as it helps resolve conflicting issues associated with the coastal zone. For effective management, information about the natural and cultural processes (e.g. sediment cell circulation and tourism), at work in the region are imperative.

INTRODUCTION AND BACKGROUND

In 1970 the Countryside Commission published the results of a comprehensive survey of the England and Wales coastline in "The Coastal Heritage" Thirty-four coastal areas were given the new definition of "Heritage Coasts" (Williams and Howden, 1985), with three of these being designated as pilot schemes for special study (Glamorgan, Dorset and Suffolk; Williams and Howden, 1979). At present 45 Heritage Coasts have been established and these now cover approximately one third of the coastline of England & Wales This approach is internationally recognised as an effective and efficient method of coastal management (Williams and Howden, 1985).

The primary management aim for Heritage Coasts is to conserve the quality of coastal scenery in its natural state, and secondarily to facilitate enjoyment by the public through recreational activities which accord with the primary aim. Where natural beauty and recreation are in irreconcilable conflict, then the former should prevail. In practice however, a balance has had to be struck between developing recreation too far

(so that conservation is impaired), and conserving absolutely (so that tourism declines). Regarding conservation of environmental resources, the aim is 'to make the wisest use of all coastal resources rather than to preserve scenic stretches for their own sake and to discourage access thereto' (Countryside Commission, 1970, p. 16).

Determination of intensity of use at various locations within Heritage Coasts is seen as a valuable aim (Williams, 1987), and management also recognises zones subject to different intensities of usage Landscape and ecological factors are of great importance for zoning policies within the Heritage Coast sand 'intensive', 'intermediate' and 'remote' zones are recognised. At intensively zoned sites, facilities such as car parking, refreshments and toilets are provided, but with the intention of having the minimum effect on the beauty of the coast (Williams and Lavalle, 1990) At these sites in particular, increasing usage may require regulation of the man/environment interaction by means of management policy (Williams and Sothern, 1986). In remote areas priority is given to agriculture, nature conservation and the protection of solitude. These areas are thus maintained in a relatively inaccessible and unspoilt state and the natural amenities of the coastline are safeguarded. Access is limited at sensitive sites by passive means, e.g. limiting car parking and by guiding people to intensively zoned sites by provision of car parks, toilets and refreshments.

Landscape improvements should be in keeping with the environment, e.g. improving footpaths, concealing pipelines, repairing derelict buildings, etc. As far as recreation is concerned, 'passive' activities such as walking and relaxation are encouraged, while water-skiing, motor cycling, etc., are not considered appropriate. Provision of interpretative services aims to promote understanding and interest in the coastal environment, and so use information as a management tool.

The management philosophy aims to establish a close working relationship between management, farmers, landowners, residents and visitors for the benefit of all concerned and the environment. Management plans emphasise the concept of voluntary agreements and rely principally on persuasion of landowners to surrender areas of their land to public usage. There is provision for compulsory purchase to bring key areas into public ownership but this is rarely invoked. Invariably the management authority does not own or want to own, the land for which it takes responsibility.

Heritage Coast status was granted to 4 separate sections, totalling 34 km of the Ceredigion coastline, Dyfed, Wales, in December 1982 (Fig. 1). Together these form the 'Ceredigion Heritage Coast' All the Ceredigion Heritage Coast is within, and is the responsibility of, Ceredigion District Council. A Heritage Coast Project Officer was appointed in 1985, in line with the practice all Heritage Coast schemes. Currently, a move to formulate policies for a Marine Heritage Coast between New Quay and Tresaith and to extend the ethos of the Heritage Coast philosophy into the marine world, is supported by the Heritage Coast policies and priorities document of 1991 (Countryside Commission, 1991).

Recreation, conservation, economic utilisation, pollution control, wildlife habitat, development control, etc., are all facets of any region that wants to be prosperous in the 21st century. The Ceredigion Heritage Coast is no exception. An area of outstanding beauty, it has beaches and resorts that have been part and parcel of the fabric of Welsh coastal holiday making for some 100 years. Water quality in the area apart from Llangranog and Aberporth is good, all other resorts meeting EC Mandatory standards for bathing waters (Council of the European Communities, 1976) The Ceredigion Coast 'can be considered to be the district's most precious resource' (CDCPD, 1979, p.1); so tourism is on the increase. A pilot survey of these increases is becoming increasingly necessary in the context of coastal management decision making. Management is an effective decision making tool which can resolve conflict between competing landusers, e.g., recreation-conservation-agriculture-forestry. Boating, angling and swimming are obvious competing activities common to most sea coast areas. Recently pressure from touring and motor caravans have been predominant within this area.

The aim of this paper was to analyze some of the physical constraints in the CHC and to construct a visitor profile comprising data on visitor origin, age, socio-economic group, mode of transport and Heritage Coast awareness, for seven study beaches (Tresaith, Aberporth, Llangranog, New Quay, Cei-bach, Aberaeron and Aberystwyth; Fig. 1) The results obtained would assist with the development of a new management plan for the Ceredigion Heritage Coast.

Increased pressures - pollution, fishing, leisure, conservation, farming, are all interrelated and there is a need for sound coastal zone management policies to ensure that environmental strife does not occur. Knowledge of the current processes at work in the region is imperative for any effective management strategy. Physical (e.g. wave, climatology, geology), fieldwork was carried out as well as cultural (from questionnaire replies) at the seven beaches considered in this study.

LOCATION

The Ceredigion Coast extends in a 100 km arc which has some 60,000 year round inhabitants. Summer visitors total some 1.5 million, the attraction inevitably being the beaches which are the basis for the tourist economy. The seven study beaches lie within the county of Dyfed, Wales, stretching between Aberporth in the south-west and Aberystwyth in the north-east, a distance of approximately 45 km and within this length of coastline lie two of the four sections of the Ceredigion Heritage Coast (Fig. 1). Therefore, not all beaches investigated fall within Heritage Coast designated areas. Management however, treats all zones as if they have Heritage Coast status.

Between Aberystwyth and Llanrhystud is a 13 km stretch of remote, unspoilt and often rugged coastline containing several Sites of Special Scientific Interest (SSSI's), and also other sites of nature interest. In this area cliffs attain a height of up to 120 m (Jones & Williams, 1991). South of Llanrhystud an undeveloped shoreline of cliffs and banks of boulder clay subject to erosion leads to Llanon. Immediately south of Llanon the beach gives way to high cliffs composed of Aberystwythgrits. Near Aberaeron several caravan developments occur. The 8 km stretch between Aberaeron and New Quay has several visitor access points, amongst which is Cei-bach This stretch also remains relatively undeveloped, with attractive coastal scenery and sites of conservation interest. Coastal cliffs rise to 80 min height south of New Quay, and over 100 m south of Llangranog, before becoming lower and disappearing towards the dune system at Penbryn near Tresaith. The resorts of Tresaith and Aberporth are connected by a coastal footpath, frequented by residents of nearby caravan developments.

METHODOLOGY

Theoretical modelling of predicted onshore and longshore wave power was used to indicate potential erosion-deposition points on sediment cell boundaries (May, 1974). The WAVENRG Programme (May, 1974) was used to simulate wave refraction and potential longshore transport pattern. This programme computes orthogonal wave pathways and determines the transformation of wave parameters using linear wave theory. Orthogonals were generated for each specific wave directions from positions at the bathymetric grid boundary Bouws and Battjes (1983) have argued that wave energy distribution can only be an estimate of reality, suggesting a smoothing of longshore wave power to erase local noise Breaking is assumed to occur when wave height-water depth equals or exceeds 0.78. At this point wave height (hb), wave power (Pb) and the longshore component of wave power (P1) are calculated. A typical plot for an 8.5 s wave moving inshore from a 270° direction is given in Fig. 2. The bathymetric grid extended from Aberporth to Aberystwyth, projecting seawards to a depth of 40 m with a grid spacing interval of approximately 400 m The spatial cell position boundaries dictate the longshore magnitude of beaches (Davies, 1974) and determines their effectiveness against coastal erosion. The whole system can be divided into a number of littoral drift cells covering net erosion, transport pathway and coastal deposition (Tanner, 1974). Tanner's (1974) abc model is characterised by five key points designated 'a' through 'e' (Fig. 3). Some important parameters

vary predictably from point to point. The longshore wave power component P1, is maximum at point 'a' decreasing steadily downdrift to a minimum at point 'e' Between points 'a' and 'e', is an equilibrium position at point 'c', with a value of P1 that is insufficient to maintain the sediment already being transported. Two contiguous cells with common points 'a/a' boundaries result in net erosion and low beach sediment volumes; a common point 'e/e' boundary of two adjacent cells results in net deposition and high beach sediment volume. An 'a/e' boundary marks a sub-cell boundary within a major drift. Topographic profiling at 100 m intervals along the coast between Llanrhystud and Aberaeron and every 200 m between Gilfach yr Halan and New Quay -144 stations - showed longshore variation in beach morphology typifying the above Cliff line erosion rates were also estimated from fixed marker points hammered into the cliff and from overlays of Ordnance Survey maps of 1880 and 1970. Geotechnical analyses were also carried out via pocket penetrometers in boulder clay areas and from Schmidt hammer readings on hard rocks which gave values of unconfined uniaxial compressive strengths for the relevant rocks.

A questionnaire, based on that used by Williams and Sothern (1986), at the Glamorgan Heritage Coast - one of the original Heritage Coast projects - was developed for this study. Surveying was carried out over the period July - September 1993,on varying days in each month. A large variation in the number of questionnaires completed (29 to 358, see below) between the seven study beaches was obtained. However the numbers may betaken as indicators of relative usage levels.

RESULTS AND DISCUSSION

a) Physical Context

This coastal area is an active environment which has experienced almost continuous change over the last century. Long term recession rates obtained from map evidence exhibited considerable spatial variability ranging from 0.06 myr^{-1} in the Aberystwyth Grits south of Aberaeron to 0.65 myr^{-1} in the glacial tills near Aberarth Mean values of 0.16 myr^{-1} with individual peaks of 0.5 myr^{-1} were found for the till sections between Llanon and Llanrhystud. The incidence of cliff erosion within the tills was found to occur under specific climatic and tidal conditions and environmental energy inputs. The investigation time period - 4 years - is short with respect to geomorphological time scales and did not include the extreme low frequency high magnitude event of cliff recession suggested by local residents which remove several meters of till faces. Theoretical wave energy calculations were made by the Sverdrup-Munk-Bretschneider method based on hourly wind data fora 15 year period recorded at the RAE Aberporth. This indicated 33 significant events averaging 2.2 per year and the total wave energy ($Jm^{-1} \times 10^5$) is indicated in Table 1. The maximum predicted storm gave a total wave energy of 47.8×10^5 Jm^{-1} coming from the north-west quadrant, an area which contributes 82% of all destructive waves. The predicted moderate to high storm event may not affect change along the coastline unless such events coincide with periods of high tide. A number of distinctive energy provinces occurred alongshore. Outside the study area exists a low energy zone (4×10^4 MJ $m^{-1}yr^{-1}$ in Aberporth Bay) followed by a high energy zone (12×10^4 MJ $m^{-1}yr^{-1}$) from Llangranog to New Quay New Quay to Llanrhystud is another low energy zone (5×10^4 MJ $m^{-1}yr^{-1}$) of which two-thirds can be attributed to northerly waves North of Llanrhystud average wave energy increases to 9×10^4 MJ $m^{-1}yr^{-1}$ The high recession along the Llanrhystud beach area corresponds to an intermediate energy peak. For similar values of wave power, erosion in the boulder clay tills north of Aberarth is on average twice that of the more resistant. Aberystwyth Grits lying further north. The mean till bulk density value was 2.28 $ton.m^{-3}$ (ranging from 2.15 to 2.4 $ton.m^{-3}$) and the mean moisture content value was 8.7%. Shear strength parameters gave values of ϕ_r^1 (angle of shearing resistance) of 29.5°. The compressive strength of the clays was 250 kN m^2, the liquid limit 36%, plastic limit 20%, with a plasticity index of 16 South of Morfa, high peaks of recession in mixed stratigraphy relate to high intermediate peaks of energy. Generally a poor relationship existed between wave power and

recession rate. This is a function of the beach volume existing at the foot of the cliff line (Jones and Williams, 1991; Williams and Jones, 1991). Field observation of high tide position showed a consistently different value than the predicted one, the height discrepancy being attributed to meteorological conditions. Beach and cliffs at zero metres AOD are submerged for 52% of the time, whilst those at 3 m AOD are covered for less than 1% of the time, indicating that potentially subaerial rather than marine processes are dominant. Zones of deposition and erosion in the form of 'high and low' beaches, obtained by computer prediction and field surveys showed a good correlation (Fig. 4). Fig. 5 shows the longshore component of wave power translated in to a sediment volume using the CERC (1976) transport rate equation:

$$S_l = k P_l$$

where S_l is the sediment transport rate, (m^3 beach volume /m beach width/ day) and P_l is the longshore wave power (J/m/s). The constant (k) is based on many assumptions relating to sediment density, packing and transport efficiency. The largest volumes of potential sediment transport relate to the south-west wave vector (270°), and dominate all other vector's transport volumes. There is a consistent northerly drift direction with strong obliquely impinging waves (north/south) such that littoral drift frequency reversals is maximised with westerly or onshore vectors. Generally littoral drift is to the north-east (Fig. 6). Thirty distinct cells exist within this large area with a mean longshore length of 1.5 km. Numerous cells combine to form higher order cells and four exist between New Quay and Llanrhystud comprising some 80% of the coastline. The New Quay Bay cell indicates potentially high depositional zones building to a 'high' beach at Llanina Point. The largest cell indicates a southerly drift of sediment from Gilfach yr Halan where a potentially 'low' beach is backed by high cliffs of the Aberystwyth Grits (Jones and Williams, 1991). A potential erosion zone south of this beach is followed by a depositional sediment bulge at Graig Ddu Northwards from Gilfach, alternate zones of erosion/deposition result in a 'high' beach at Aberaeron. The model identified a potential erosion stress point at the harbour mouth of Aberaeron and the littoral drift system is influenced by coastal defence structures in the region. The 'high' beach near Aberarth coincides with the southerly drift of material from one cell and northerly drift from another Revetments and groynes have been introduced into this area to counteract some erosional problems. Around Llansantffraid several erosion-deposition subzones occur but a net northerly drift leads to a 'high' beach at Llanrhystud. All refraction programmes depend on bathymetric and wave climate input data. The lack of Admiralty charts in this region at scales larger than 1:75 000 means that grid spacing and therefore wave orthogonal positioning may lack sensitivity.

b) Cultural Context

A total of 1053 questionnaires relating to age, sex, length of stay, mode of transport, purpose of visit, trip origin, accommodation Heritage Coast awareness, occupation, age were completed (29 at Tresaith, 42 at Cei-bach, 85 at Aberporth, 147 at Llangranog, 155 at Aberystwyth, 237 at Aberaeron and 358 at New Quay).

Trip generation

At Aberporth and Aberaeron more than 50% of visitors originated from within Wales, compared to 40% or less at Tresaith, Llangranog and Aberystwyth (Fig. 7d). Overall, 46% of the visitors surveyed were from Wales, the next most important source being the West Midlands.

Mode of transport

As expected, the overall proportion of visitors arriving by car was high (79%; Fig. 7e), a similar level to that found by Williams and Sothern (1986) in their study at the Glamorgan Heritage Coast (GHC). At Cei-bach and Aberaeron the proportion was very high (more than 88%), compared to less than 70% at Tresaith, Aberporth and Aberystwyth. Only 1% of visitors had used public transport to reach the beaches.

Type of accommodation
The remoteness, particularly in terms of journey time of this stretch of coastline from major centres of population is reflected in the finding that only 22% of visitors to the beaches had travelled from their own home on the day of the survey (Fig. 7f). A large proportion (47%), were staying in caravans, reflecting the widespread availability of caravan sites; only 8% stayed in hotels or guest houses. At Tresaithand and Llangranog in particular, high percentages of visitors (35% and 42% respectively), were staying in rented 'holidayhome' type accommodation.

Purpose of visit
In this section, more than one response per visitor was often obtained. Many of the categories could be said to be of a vague and non-specific type, but the bulk of the people were holidaymakers and an 7overall 8% of responses mentioned walking or nature (Fig. 7c).

Visitor frequency
At all beaches except Tresaith, the majority of respondents were either first time or infrequent visitors (less than five visits per year; Fig. 7b). Infrequent visitors formed particularly high proportions at Aberystwyth and Cei-bach.

Heritage coast awareness
Visitor awareness of the Heritage Coast was disappointingly low, being less than 40% at all the study beaches except Tresaith, and less than 30% at Aberporth and Aberystwyth (Fig. 8). Thus awareness of the Ceredigion Heritage Coast amongst its visitors compares poorly with that found at the GHC by Williams and Sothern (1986; 68% and 46% at two beaches), and Morgan et al. (1993; mean 72% at four beaches). This may be due in part to the fact that visitors to the Ceredigion Heritage Coast originate from a much wider area of the country compared to GH-visitors. GHC-visitors are mainly local (Williams and Sothern, 1986) and thus more exposed to publicity concerning the Heritage Coast.

Method of Awareness
At the Ceredigion Heritage Coast a high proportion (74%), of those visitors aware of the Heritage Coast had gained knowledge of its existence through tourist information and various news media, compared to only 13% by word of mouth (Fig. 7a). This has important management implications. Heritage Coast philosophy is based on a 'low key' approach in direct contrast to the Welsh Tourist Board, who aim to achieve a high profile. Conflict sometimes arises between these two viewpoints.

Age breakdown
In terms of age breakdown of visitors, the seven study beaches fell into two distinct groups (Fig. 9). At Aberaeron and Aberystwyth over 40% of visitors were 40 years old or over, while this group comprised 25% or less at Cei-bach, New Quay, Aberporth and Tresaith, and 30% at Llangranog. It appears that Aberaeron and Aberystwyth attract a markedly older visitor profile than the other study beaches.

Socio-economic status (SES)
There were more employed visitors in SES group 3 (OPCS, 1980) than any other group, but a surprisingly large proportion of visitors could be classified into socio-economic group 1 on the basis of their occupations (Table 2). This proportion ranged from 35% at Tresaith (n = 29), and 24% at Cei-bach (n = 42), to 14% at New Quay (n = 358). The mean across all beaches was 18% (n = 1053), which was markedly higher than the 11% found by Williams and Sothern (1986) at two GHC beaches.
It was notable that the two smallest resorts studied (Tresaithand Cei-bach), had the highest proportion of visitors in SES group 1, whilst that with the largest number of visitors (New Quay), had the lowest proportion. At the GHC Morgan et al,(1993), found visitors to be of higher SES at a small, uncommercialised resort (Nash), than at a busier, more commercialised one (Southern-down). As would be expected from examination of the visitor age breakdown, the highest proportion of retired visitors were found at Aberaeron and Aberystwyth (17% and 13% respectively).

The physical and cultural parameters referred to above, are but a part of the myriad parameters needed to be studied in order to embrace a fully integrated coastal zone management (ICZM) plan for the region A current example is that of local government reorganisation - to be completed by 1997 which is being carried out in the UK whereby power is being devolved to new local unitary authorities. The very closeness of a major upheaval regarding policies for the whole region makes coastal management plans difficult, even so an integration of physical and cultural parameters is essential Recent engineering structures at Aberarth have ensured stability in the beach region but the effects on adjacent beaches of revetments and groynes is not clear, although depletion of beach material can be clearly seen. It is likely that the most cost effective measure for this region is beach replenishment. The success of any ICZM depends upon the data base (for example the cell systems, longshore drift, tourism, highways, water supply, sea water quality) being updated on a continual basis. The physical characteristics enumerated within this paper remain in an essentially steady state scenario, but the cultural parameters are more likely to fluctuate with time. For example, in times of economic restraint, more holidays could take place in this region *in lieu* of overseas travel; conversely, in 'boom' times, the opposite could materialise. Additionally, management strategies should be based on a systems strategy requiring a multi-sectoral approach to be used in the design and implementation of such a strategy. Natural and infrastructural systems exist in plenty in the coastal zone and all must be studied. The main aim is to harmonise these activities in such a way that all are consistent with and support a wider set of national goals. Impediments to the practise of environmental planning embrace factors such as:

- The size, complexity and interrelatedness of environmental and public service systems.
- The quantification and social relevance of costs and benefits.
- The time differentials that exist between costs and benefits, and their distribution.

A new management plan for the CHC is currently (1995) being countenanced and it is to be hoped that the fragmentation of the past will be subsumed into a more comprehensive ICZM system.

CONCLUSIONS

The CHC region has been analyzed in the context of sediment cell delineation, fifteen being found in the locality existing between New Quay and Llanrhystud, and thirty within the larger region. Within the sub-region, seven 'high' beaches were found from computer modelling and field surveys. These locations are epitomised by seven coastal holiday resorts; Tresaith, Aberporth, Llangranog, New Quay, Cei-bach, Aberaeron and Aberystwyth. The Ceredigion coast appeared to draw visitors from a wide area of the UK, in contrast for example, to the GHC where most visitors were local (Williams and Sothern, 1986). Perhaps as a consequence of this, at most beaches infrequent visitors formed a majority. As expected, the car was the dominant form of transport used to reach the coastal resorts. The caravan was the most popular form of accommodation amongst visitors, reflecting the high availability along this stretch of coast, followed by holiday homes-flats.

Aberaeron and Aberystwyth appeared to attract a higher proportion of older visitors than the other beaches, while the age profile for the other Ceredigion resorts was not dissimilar to that found by Williams and Sothern (1986), at the GHC. A large proportion of visitors could be classified into SES group 1 (OPCS, 1980) and it was interesting that the two smallest, least commercialised beaches (Tresaith and Cei-bach), attracted a higher proportion of visitors in this group. One may speculate that those in this group, who often have challenging and stressful jobs, prefer to 'get away from it all' to a smaller, quieter resort.

Heritage Coast awareness was disappointing, although not all the resorts were actually within the boundaries of the Ceredigion Heritage Coast Many visitors had travelled a considerable distance to reach the resorts, and presumably would have been unlikely to have encountered

publicity concerning the Ceredigion Heritage Coast.

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Table 1. Cumulative wave energy, generated by storm events, classified by direction.

Total Wave Energy $jm^{-1} \times 10^5$	Direction				All Directions
	202° - 247°	247° - 292°	292° - 337°	337° - 022°	
0 - 10		7	3	3	13
10 - 20	1	6	9	1	17
20 - 30		1			1
30 - 40			1		1
40 - 50			1		1
Total	1	14	14	4	33

Table 2. Socio-economic classification of Ceredigion Heritage Coast visitors - percentages.

	Tresaith	Aberporth	Llangranog	New Quay	Cei-bach	Aberaeron	Aberystwyth
SES-1	35	14	23	13	24	18	20
SES-2	10	7	12	14	19	14	4
SES-3N	3	7	8	7	5	11	10
SES-3M	17	25	16	24	17	22	16
SES-4	10	15	9	11	7	8	11
SES-5	7	2	1	5	0	0	1
Unclassified	17	26	28	24	28	27	29
N/S	0	4	2	1	0	0	0
n =	29	42	85	147	155	237	358

Fig. 1. The Ceredigion coast.

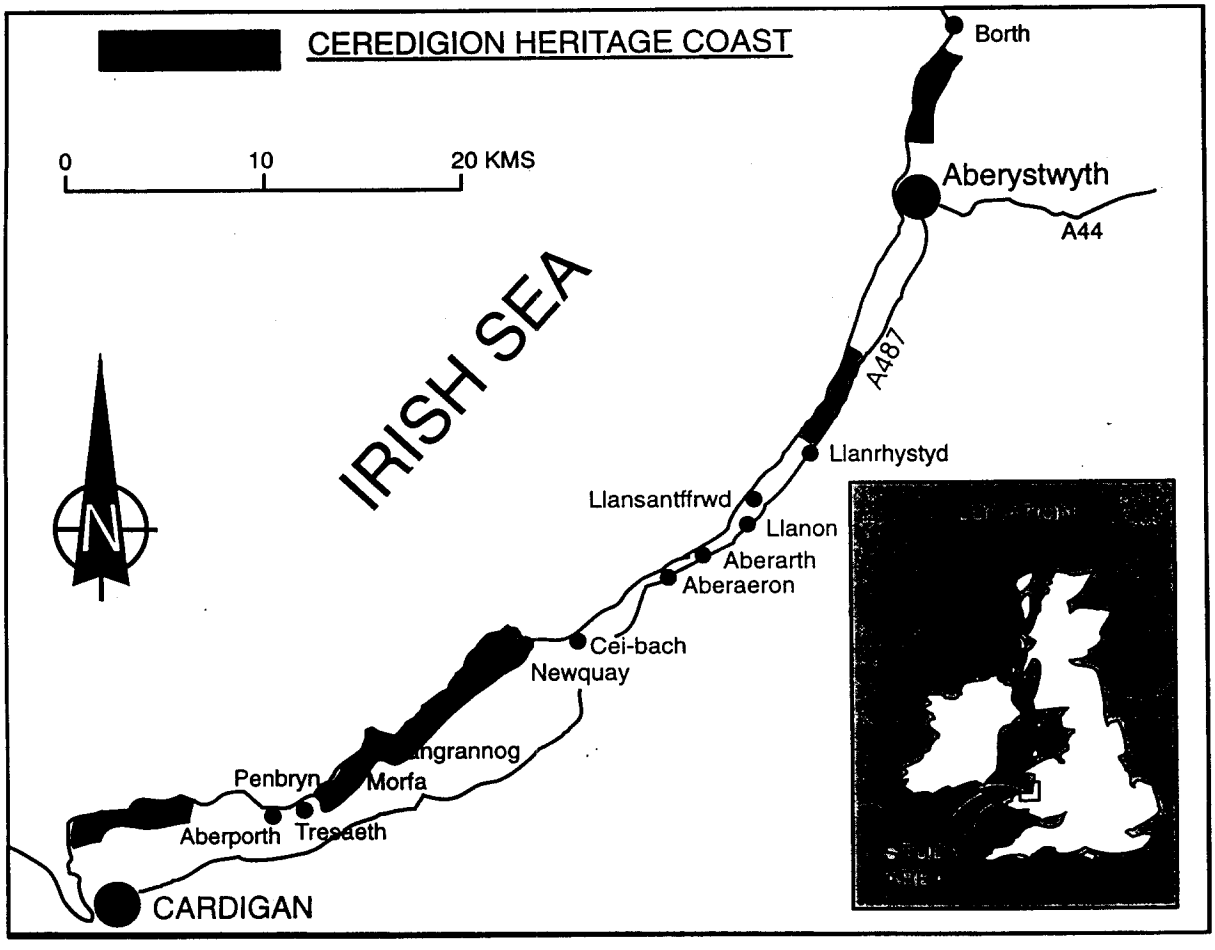


Fig. 2. Wave orthogonals for a 8.5 s wave, 2.06 m in height, moving inshore from the west. (Ll-Llanrhystud; Ab-Aberaeron; NQ-New Quay; Ap-Aberporth).

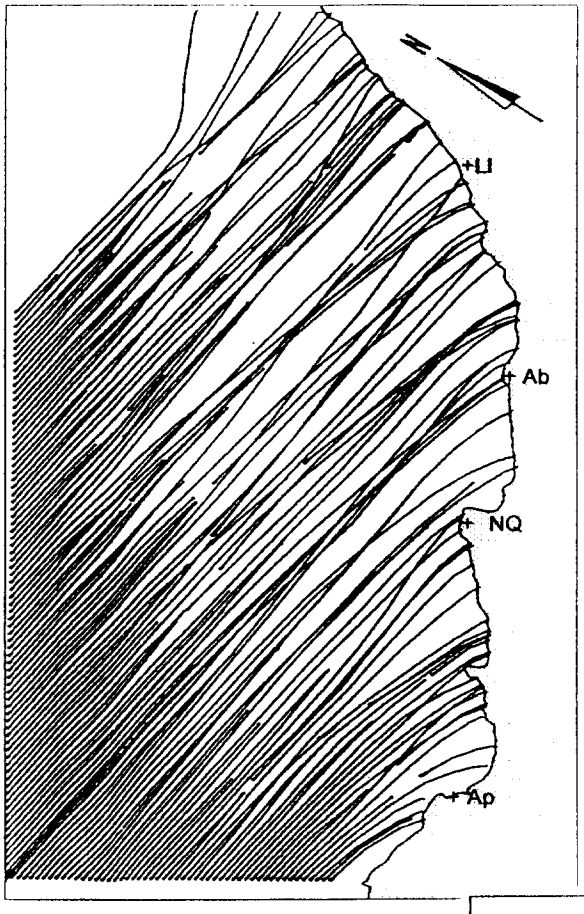
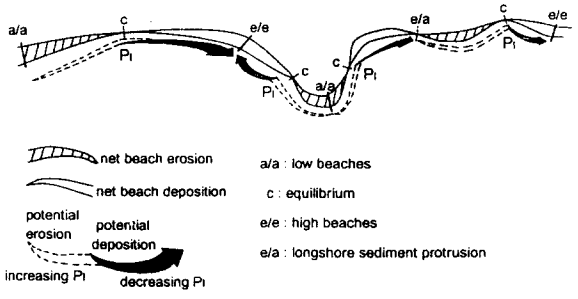


Fig. 3. Principal elements of May and Tanner's (1973) 'abc...' model.



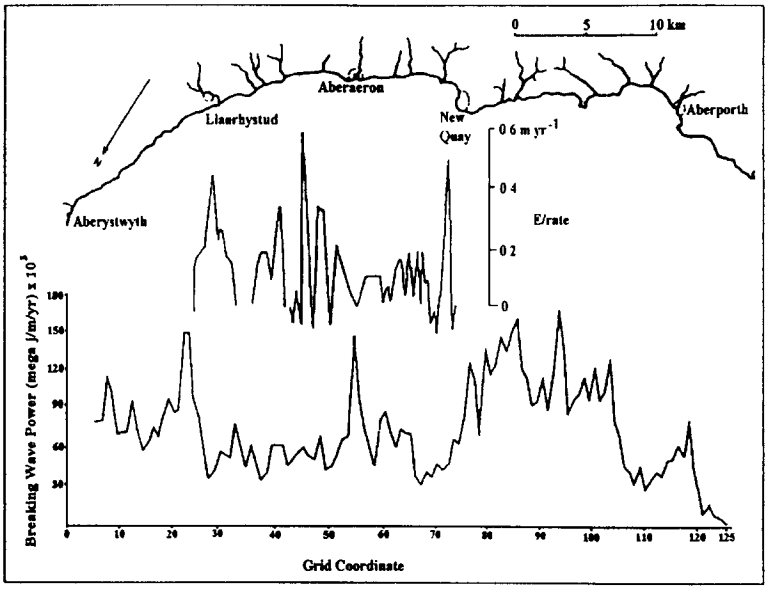
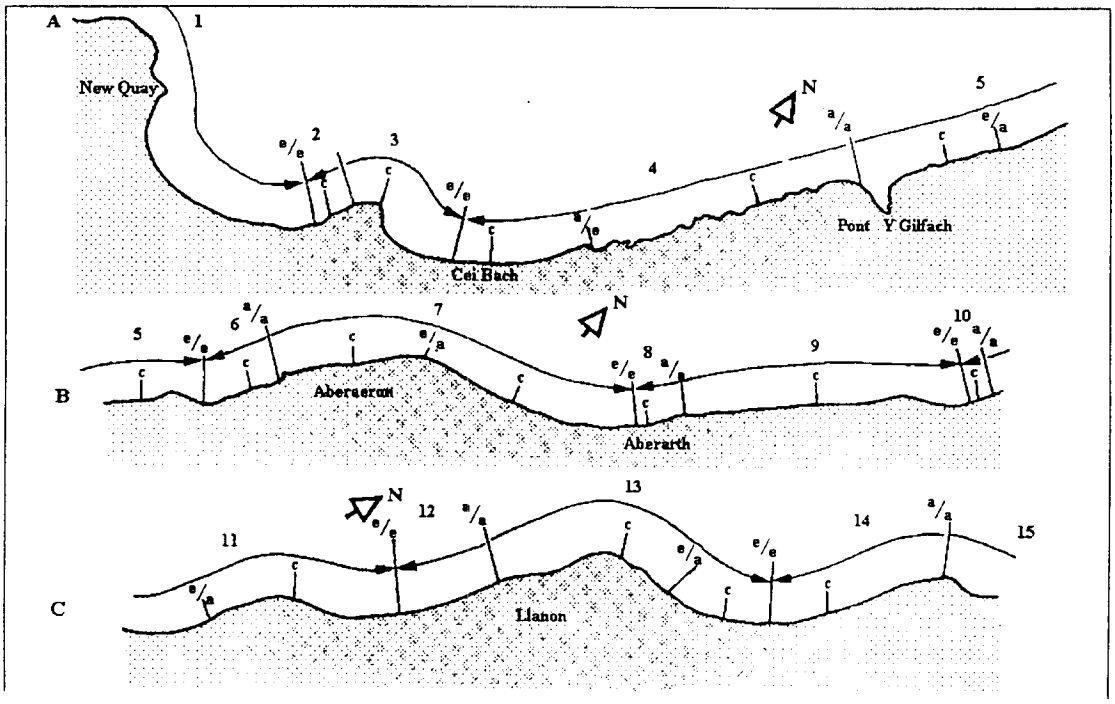


Fig. 4. Longshore variation in total annual wave breaking power.

Fig. 5. Computer prediction of sediment cells along part of the CHC.



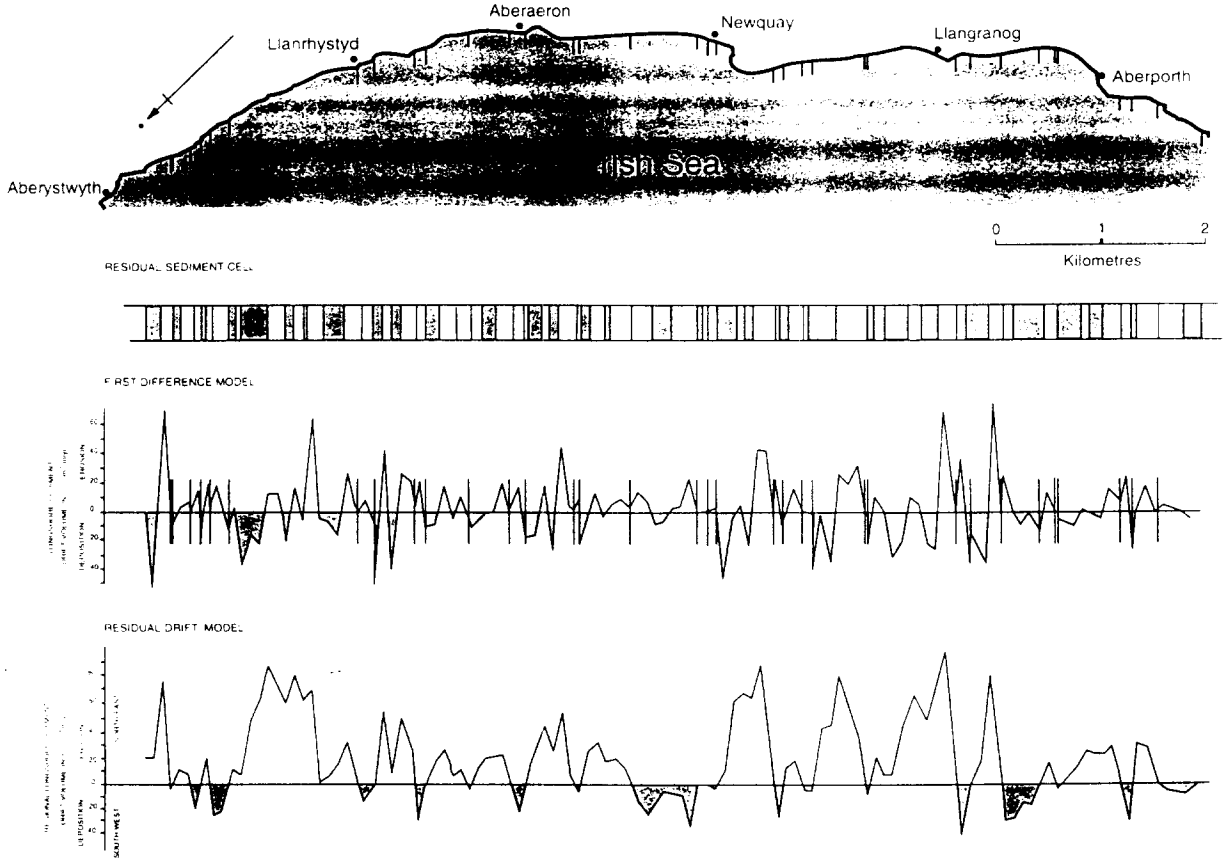


Fig. 6. Smoothed residual sediment cell structure for part of the South Cardigan Bay coast.

Fig. 7. Socio-demographic variables at the CHC.

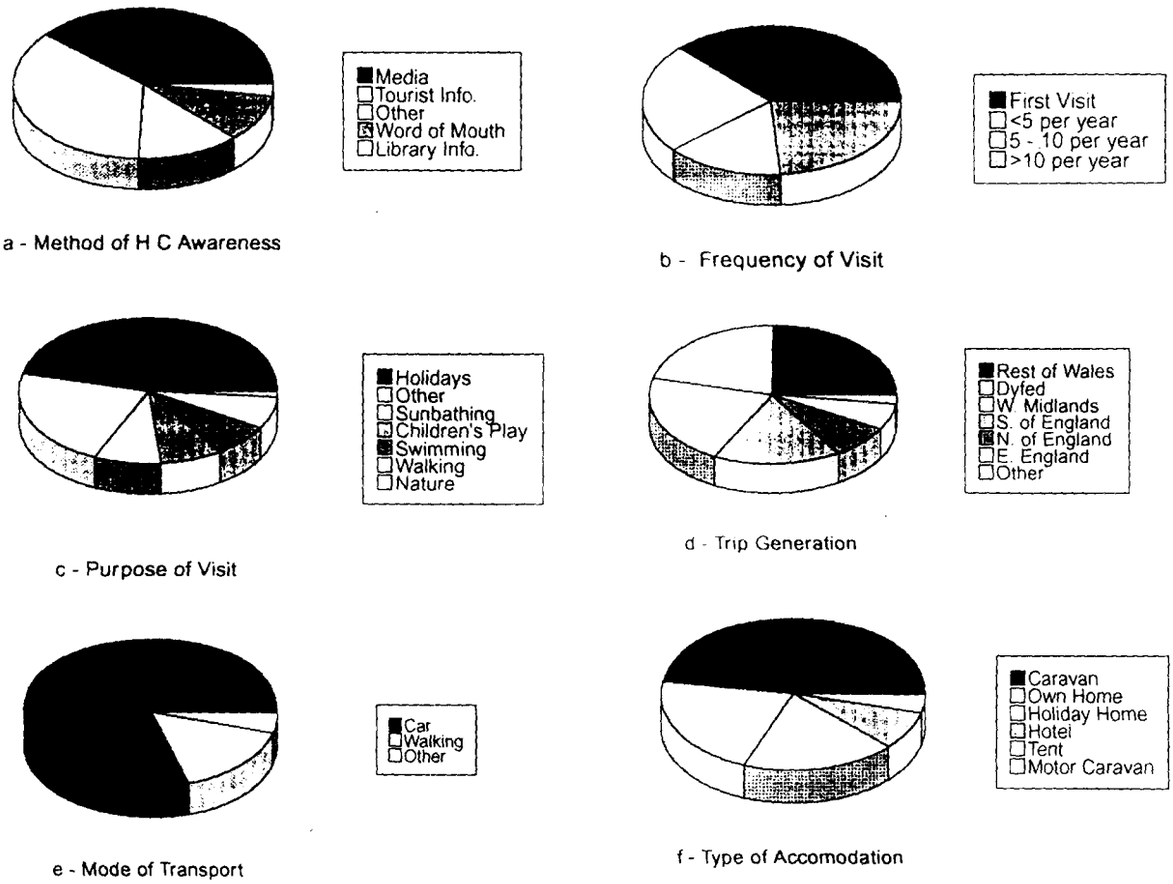
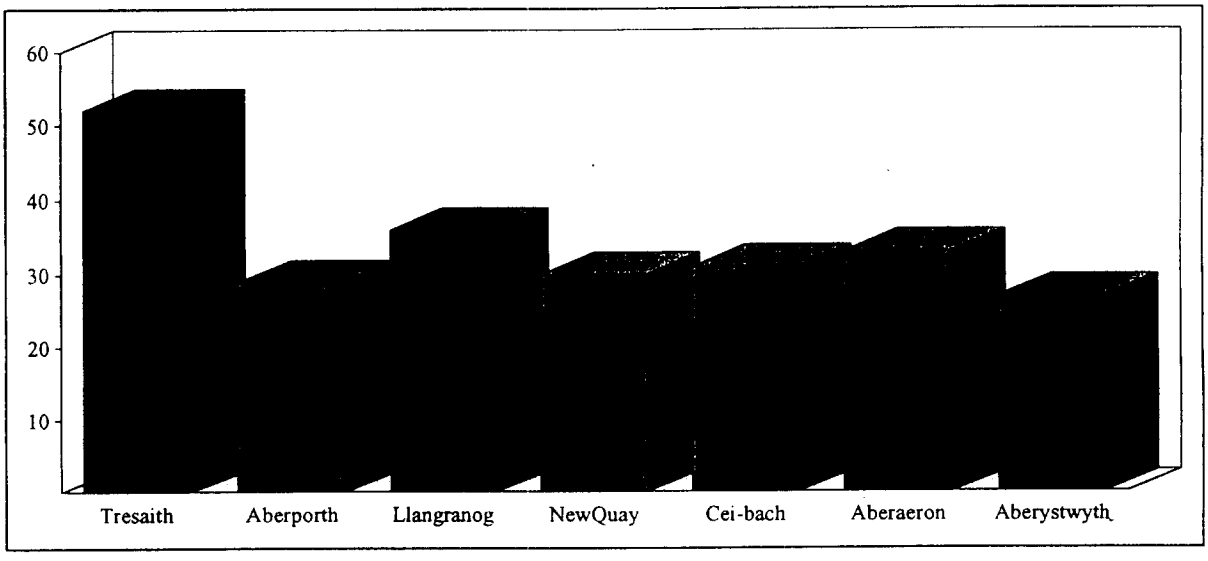


Fig. 8. Heritage coast awareness (%).



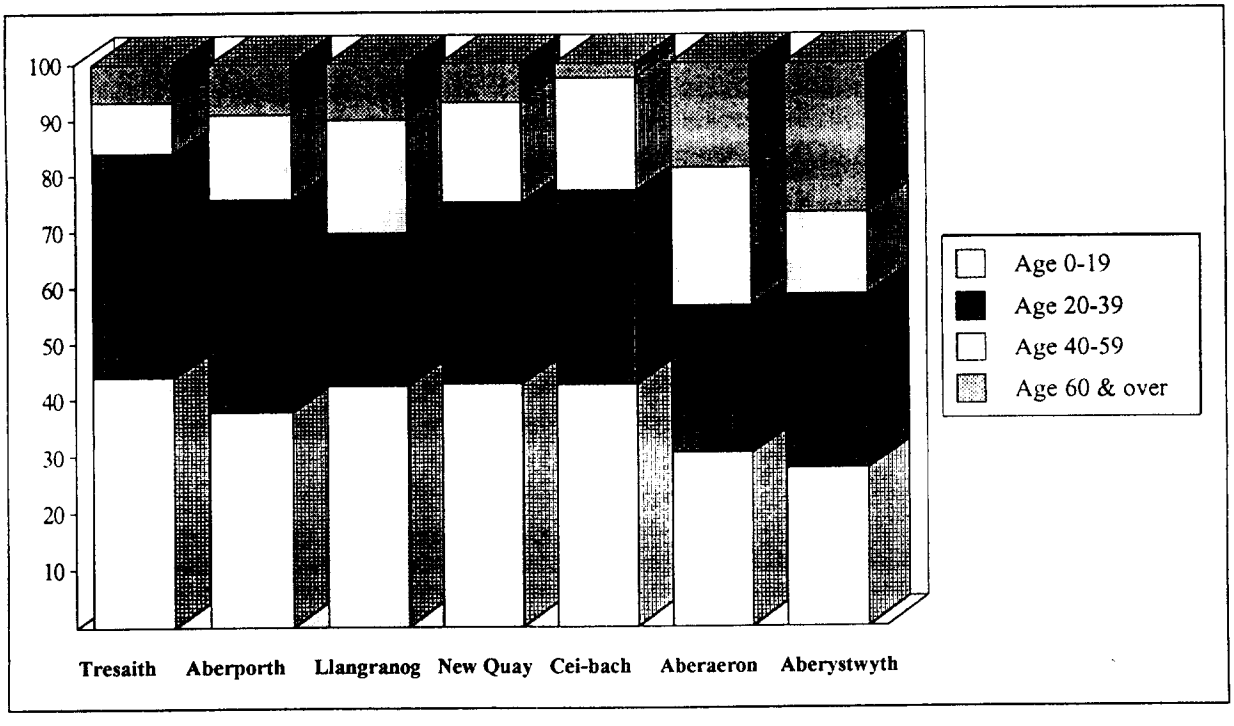


Fig. 9. Age breakdown of beach users (years).

SESSION IX

Conference reports and conclusions

Proc. Int. Conf. 'Coastal Change 95' Bordomer-IOC, Bordeaux, 1995, p. 867 - 875

SUMMARY OF RAPPORTEURS' REPORTS AND A PERSONAL VIEW

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INTRODUCTION

104 papers have been presented in 12 separate sessions, numbered from II-a to VIII-b, for which 12 rapporteurs were appointed. Several additional papers were given in the accompanying sessions and, of these, 7 were accompanied by a written document. The rapporteurs would certainly have liked to present their reports orally. The problem is, however, time. Twelve speakers would at least take 1½ hours of the programme. It was therefore decided that I should summarize their reports in 20 minutes, after which my colleague Russell Arthurton, will focus on the requirements for the manuals, to which reference has been made before this conference.

I will follow the sequence of our sessions, starting with session II-a and ending with session VIII-b. Some additional remarks will be given on the posters followed by a personal view.

I have counted the keywords which were mentioned by the rapporteurs and which can be extracted from the abstracts of the presented papers and posters. They easily come to about 30 to 50, depending what we can define as a key-word. I give 23 of them: erosion, accretion, sea level rise and fall, hinterland effects, storm surges, ownership, currents, mining, tourism, fishery, mangroves, deltas, estuaries, data acquirement, maps, beach and slope profiles, dredging, aquaculture, land reclamation, coastal-zone management, training and capacity building.

SESSION II. Mechanisms & Processes, divided in three sub-sessions on sea-level changes and coastal impact, geological framework and physical oceanographical framework.

II-a. SEA LEVEL CHANGE (Rapporteur: Albert Tolkatchev)

This session was not intended to present a full worldwide overview on sea-level rises, as a consequence of world climate changes, but to present some interesting points with respect to geomorphology of coastal zones. It was felt that there is certainly a need for an continuous assessment of the global, regional and local sea-level changes and associated economic impacts. For that purpose GLOSS (Global Sea Level Monitoring Observing System) has made great improvements with tide gauge techniques, satellite radar altimetry and advanced geodetic methods. The present estimates by IPCC of sea-level rise, range between 25 and 70 cm towards 2100 (105 years from now) which is twice the rise of the last 100 years. A point stressed is the global environmental change caused by the increased frequency of severe and extreme events such as storm surges. A particular case is the large sea level change in the Caspian Sea, also reported in another session. It is clear that events observed in one region cannot automatically be extrapolated to other regions. Storm-surges in the Baltic might present an indication that indeed climate changes are affecting primarily the frequency of extreme conditions. Here in France we have recently had such extreme conditions of flooding and also here the question may be posed whether this is a warning of more frequent extreme conditions in future.

We may be able to learn something from the small ice-ages which occurred in the middle ages and caused changes of sea levels in the Caspian Sea. The response was found to be related to the longer periods of high pressure in east Europe.

Another point, which was presented, was whether mangroves can catch up with sea level rises, since due to peat formation, such sea-level rises should not exceed 10 cm/century. The same is due for coastal lagoons. Can they match sea-level rise sufficiently to be preserved?

Extreme and temporary sea-level fluctuations are also caused by tropical cyclones and the question is posed how this might develop in future. IPCC is involved with these problems for small islands.

II-b. GEOLOGICAL FRAMEWORK (Rapporteur: Richard A.Davis Jr.)

Much can be learned from the natural coastal responses to sea-level changes and land subsidence or uprising since the Holocene. Several examples were presented with results on the sediment balances as related to beach erosion and accretion, their beach profiles, marsh formation and loss, and delta formations. Risk assessments should be carried out for sensitive regions. It is clear that coastal zones are continuously under the impact of natural processes, and these cannot be neglected. Dominant factors are sea-level fluctuations after the Holocene, sediment availability, human intervention in the coastal zones and tectonic activities. A good example is the Yellow River in China with its large sediment load and modifications in the delta and diversions of the main outlets. Human intervention in some regions causes both water quality problems and morphological changes in the coastal zone.

II-c. PHYSICAL OCEANOGRAPHICAL FRAMEWORK (Rapporteurs: Richard A. Davis Jr. & Michel Glass)

In the context of physical oceanography, the forcing functions concern key parameters such as: wave action and run-up, current impact, delta ebb and flood channels, turbulent diffusion and long-shore sediment transport. Some interesting points were discussed in this context. They concern theoretical studies, studies on processes and practical means to preserve beaches. To be identified are process-response variables and their variation in a temporal as well as in spatial context. The clue of a predictive model is to provide some measure of beach retreat under the conditions of specific storms and whether theory offers some guidance to the magnitude of these events. Beach preservation and restoration was executed successfully in Georgia by nourishment at low cost. Also polder management modelling in Bangladesh may determine the limits of tidal channel flushing and siltation. Central themes were directed toward a better understanding of the natural system responses to coastal processes before management takes place.

III. REGIONAL CASES (Rapporteur: Noriyuki Nasu)

Results were presented on scientific, technological and cultural viewpoints, for a major part related to African regions and a few Pacific cases. There were great budgetary difficulties in improving Coastal Zone Management (CZM). Erosion, loss of wetlands (Benin), mass mortality of mangroves (Colombia) by river canalization, loss of beaches due to sand mining and loss of reefs due to coral mining were reported. In some countries (Egypt) Environmental Impact Assessment (EIA) has become mandatory. The case of the impact of the Aswan dam on coastal erosion is almost classic. Also land reclamation (Kenya) are causes of coastal erosion. Possibilities for creating stable beaches by special constructions were presented for Japan.

IV-a. LOW TROPICAL COASTS (Rapporteur: José L.J. Marti)

Low tropical coasts suffer in particular from changes or either natural or anthropogenic origin. For example: mangroves disappeared for 60% in Nigeria due to the needs for fire-wood; seawall and breakwater constructions accelerate erosion elsewhere; coastal aquaculture is in danger (pollution and collection of fingerlings) although being themselves a cause of mangrove destruction. All coasts are subject to erosion and deposition of sediments. Retreats of the shorelines have been observed of 25 m/century (Tanzania), and these may be caused by monsoons (India). Integrated monitoring is required (USA). In summary, man-made causes are: mining, dams, hard structures at the coastline and exploitation of beaches and coral reefs. These have a feedback on human activities. Erroneous environmental planning or improperly implemented works have some of the largest impacts.

IV-b. OTHER COASTS (Rapporteur: S. Resa Pezeshki)

That coasts have been subject to changes is shown for Brazil for the last 7000 years period. Such natural changes are often accelerated by human activities and questionable engineering (Brazil) at the expense of large costs. Industrial and human impacts accelerate permafrost rock erosion (Russia), lagoon deterioration (Mexico), where port-dyke impacts (Morocco) cause erosion-deposition and dune changes (Vietnam). A model was given for the Riau region (Indonesia) for human settlement. No easy solutions could be formulated without a great deal of economic impact in terms of costs. Process investigations, connected with geological studies will provide a sound basis for coastal land-use planning and allow development of suitable preventive measures.

V. AQUITAINE, MEDITERRANEAN AND OTHER COASTS (Rapporteur: Claude Latouche)

A major paper was the one on the evolution from 1705 to present of the Arcachon basin where cycles of about 80 years determine the shifts of sand bars and gullies, with additional shifts from west-east to north-south. The use of specialized atlases is proposed, which can for example demonstrate regions of dune sensitivity. Coastline preservation is in some case possible by applying a vegetation defence, using grasses and forest plantation (France). Erosion can be accelerated due to uncontrolled land reclamation (Albania). Micropalaeontological data can help the understanding erosion and accretion patterns as was shown for the coast of Biscay. Changes in river systems (Rumania, Russia) have a great impact on the Black Sea shorelines. The 1978 unexpected change in sea-level from fall to rise in the Caspian Sea caused problems with coastal sub-soil waters and increased erosion.

VI-a. SHORT-TIME MECHANISMS AND PROCESSES (Rapporteur: Shu Gao)

Similar examples as were given in the former sessions were presented, but accents were laid on designing together with nature. The model TOSCA (U.K.), which consists of currents meters, optical back scatter, instrumentation to monitor sediment movements, can be used for effective high-frequency measurements. Natural radionuclides are useful as tools for sediment source and deposit detection and for measuring sediment transport. Changes of river mouths (Côte d'Ivoire), storm events (Canada), restoration of the natural shoreline drift's balance (Georgia), estuarine dynamics (China) and new regulation for Coastal Zone Defense (Russia) become much better known. An essential point for management (China), concerns the criteria for understanding the stability of natural systems on which the changes are superimposed. Sometimes proper field measurements are more essential than modelling for solving the *in situ* problems (Australia). There should be also further development and application of simple devices to improve beach accretion (France).

VI-b. MODELLING (Rapporteur: Ruben D. Kos'yan)

Some interesting models were given on multi-dimensional challenge (U.K.), storm-model circulation (Russia), effects of river diversion, canalization for navigation and saltwater intrusion (Mississippi, USA) and the stability of beach front slopes (France). Pr. Wang kindly replaced an absent key-note speaker and calculated longshore sediment transport rates and showed the capacity of estimating sediment transport. The anthropogenic impact, also caused in the hinterland of the Danube, was shown for the Russian Black Sea coast. The installation of numerous groynes (dykes into the sea) provoked abrasion of some areas and required even more concrete constructions. The long-term response of estuaries to environmental changes is an essential part of Chinese research. Data on sediment load of the Yellow River and its river tributaries over large distances, are key parameters.

Cores of Atlantic sediment, taken offshore from Morocco, showed heterogeneous profiles which can be related to historical sea level changes. An example from Kuwait showed that rapid development, private ownership of beaches and

illegal dumping, created a major threat to the coast line and the stability of the beaches.

VII. COASTAL AND INSHORE INFORMATION SYSTEMS AND MODELLING (Rapporteur: Jentje v.d. Weide)
There is a need to translate scientific data into information for management use (UK). The application of the Landsat Thematic mapper is proposed (USA), as well as the use of Electronic Navigational Charts (Monaco). Moreover, the use of models, describing physical and biological processes is essential (UK). Examples of the application of GIS-based information systems were given by speakers from the USA and France. Research on basic processes such as cross-shore sediment transport and low-frequency hydrometeorological processes (Russia) were presented. Although modellers may have taken this into account, we have not heard so far the term Coriolis force, which is an essential factor for tidal current effects on coastal zone erosion or accretion.

VIII-a. TRAINING (Rapporteur: A.N. Balchand)
Training and capacity building should be an essential part of CZM. India proposes to set up a centre for SE-Asia. TEMA, (IOC-Germany) concerns training courses in developing countries for CZM. Some of the information should be given through computer automatization of littoral prognosis and management (Russia). There is a need for proper infrastructures in this context for developing countries (UK) and people should be taught on erosion management (UK). Training and capacity building are vital to advance integrated coastal management. Possibilities through international organizations like IOC-TEMA and bilateral programmes are examples. Germany and Australia were active in this aspect, where the receiving countries took part in the organization, like India and Indonesia. Training occurs also through UNEP. Capacity building will not only increase through training, but also through education, which in the long run may give sustainable impact.

VIII-b. MANAGEMENT (Rapporteur: Jorge Foyo)
Proper coastal zone management encounters many difficulties, some of them are related to the fact that parts of the shoreline are private property (California), the large pressure of tourism development (Mexico), key conflicts between polices and practices (Australia), conflicts between the hinterland development and the coastal zone impact (Nigeria), conflicts between diving tourism and reefs (Egypt), socio-economic risks (Nigeria) and former irrational ecological practices. Government measures are now taken (Cuba). There is a tendency to prepare zonation plans for estuarine systems (Sri Lanka) and complete coastal zones (Italy). UK stresses that measures should be taken now, not tomorrow.

POSTERS
A word of appreciation must be made for the posters presented. Data were presented on the changing frequency of extreme and temporary storms and sea-level fluctuations, which are real indicators of global change.
As usual, posters present special cases, related to phenomena and techniques. Some techniques were proposed for changing erosion of sandy beaches into accretion.
Additionally posters create a platform for discussions on a personal basis. In Bordeaux many contacts between participants were established in the poster hall. Thanks are also due to Mr. de Rees for demonstrating the Dutch computerized Coastal Zone Management model COSMO, which was prepared for the Noordwijk 1993 conference on CZM.

PERSONAL VIEW
I think this summary shows in a nutshell the concern on a global scale for the preservation of continental margins and island coastal zones. Nevertheless the total scale in which we have to place the problems is not complete. It looks like we are fighting a withdrawal war in which we try to reduce the damage, by almost not knowing where it will end up. There are a number of factors which should be taken into account and I will illustrate them with the following four figures:

- A coastal zone is in principle the degrading edge of the continent in contact with the sea (Fig. 1). The enormous thick layers of sediment on the shelfs and bordering ocean confirm that these edges have been eroded for billions of years and will continue to erode in future. The forcing functions are *gravity, waves, wind, currents.*
- Only under special conditions of offshore profiles, river sediment supply, wind direction and sand composition, will there becompensation for the erosion of beaches and dunes.
- Sea-level changes are part of the natural changes between glacial and interglacial climatic episodes. At present we are in a post-interglacial, or pre-glacial period (Fig. 2). 6000 years ago the reduction of solar insolation started and will cause a new glaciation period (Milankovitch effect, modelled by Berger et al., 1991, 1993). The tendency to an new glacial period is compensated by the greenhouse effect and the key question is to what extent. Although the small ice-ages of the last millennium have not been repeated in the last few centuries, they are indications that a new glacial period is developing. It is only the green-house effect that has interfered and still interferes.
- Our fossil fuel reserves are sufficient to serve for about 2-3000 years greenhouse heating (Fig. 3), when mined at the present rate. However, reliable extrapolation of present global heating is still dubious since the precise feedback atmospheric processes are known only qualitatively.

The major point for the world coastal zones is *'What impact will this have in the near future on the global atmospheric temperature and the sea level'*. Questions should be asked which zones are at risk in the next 200 years, and are new small ice ages (Fig. 4 and 5) to be feared or is that fiction?

- The message of our conference stresses that there is a need for integrated knowledge which should be translated into practice. On a small scale this can begin with the preparation of practical manuals. The message should, however, be heard by our responsible authorities, which usually have no responsibilities for periods beyond their mandates.
- What is of utmost and urgent necessity at a global scale is: *To understand and predict near-future changes (decades to century) due to conflicting climatic trends*, and for regions: *Integration of investigations and measured to be set up to combat the effects which will be caused by extreme climatic conditions*. For example: France, Germany, Belgium and the Netherlands should take common actions to combat extreme flooding as happened recently (end 1994).

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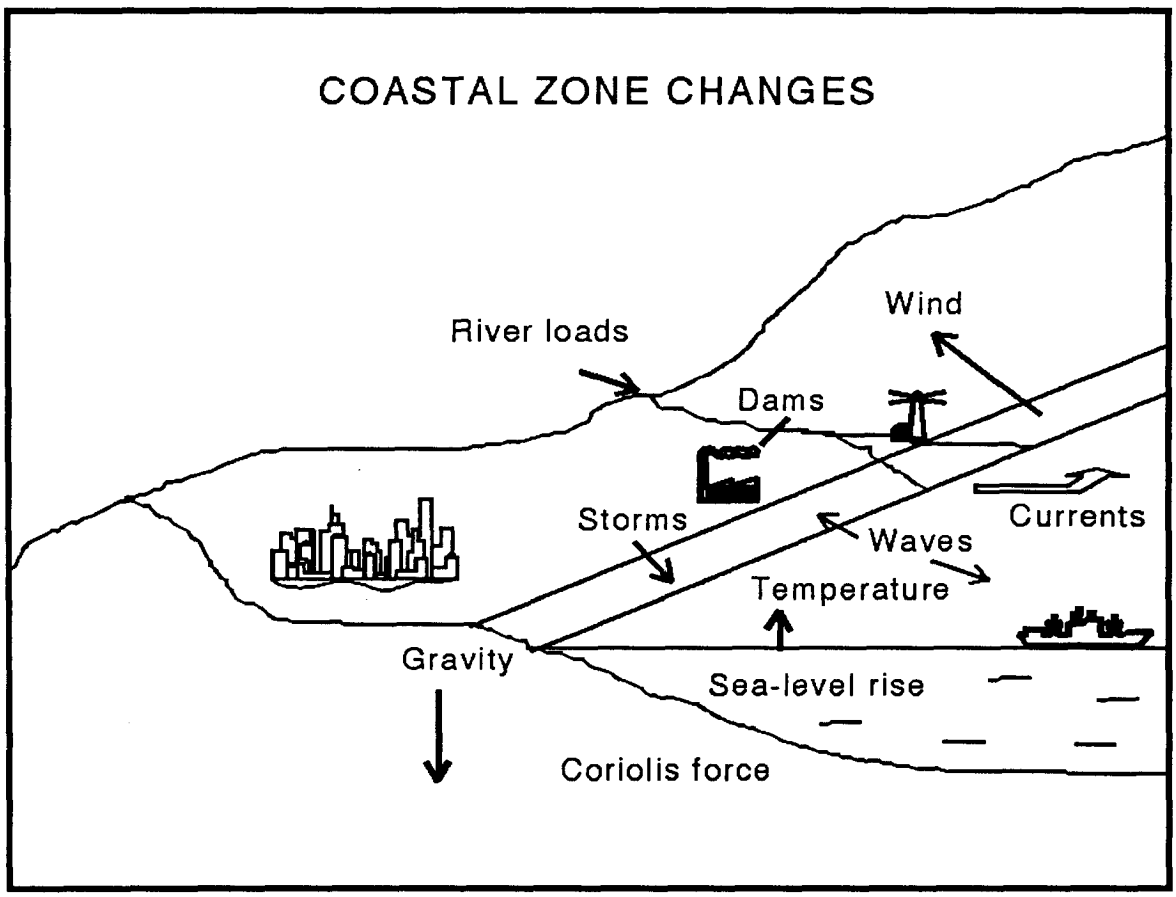

Fig. 1. Coastal zone with forcing functions causing erosion, accretion of coastlines.

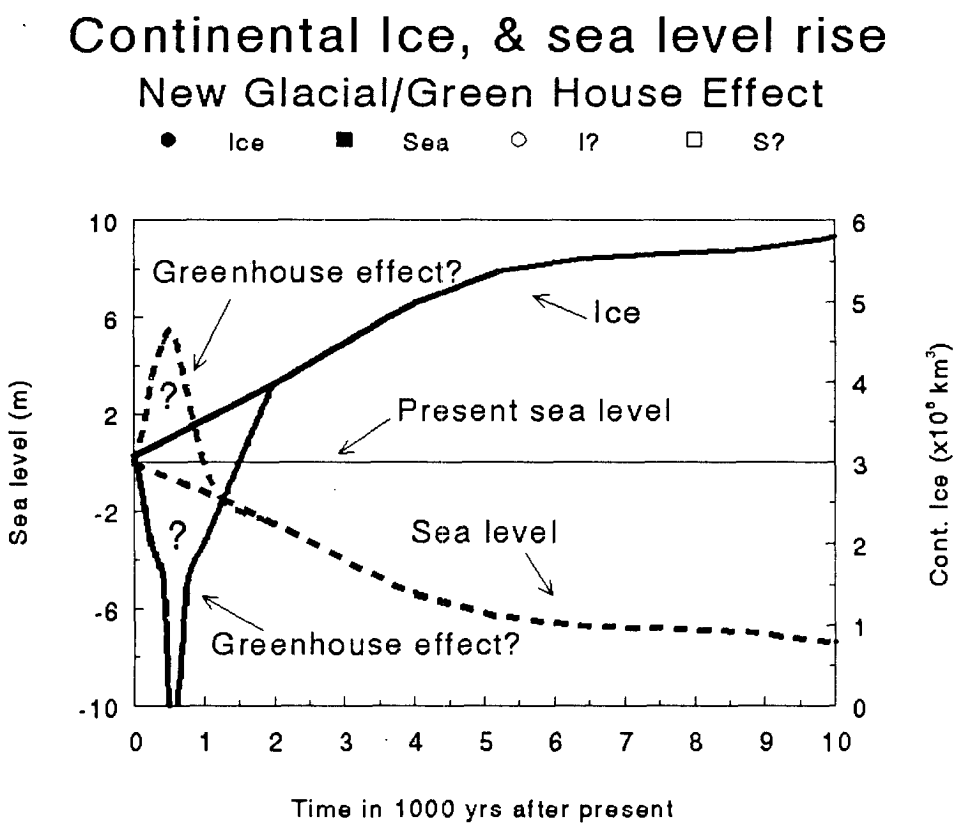

Fig. 2. A sea level rise, due to melting of the Ice cap of Greenland (not Antarctica) and due ocean expansion will occur due to global atmospheric temperature rise caused by the greenhouse effect. This process is partly balanced by the approach of a new glacial period which will have its major effects in the coming millennia (Berger, 199?). Although far away, and small the effect is for decades or centuries, we should know in how far the green-house effect is compensated at present. Conflicting processes cause climatic extremes, with particular emphasis on *storm surges, flooding and dry periods.*

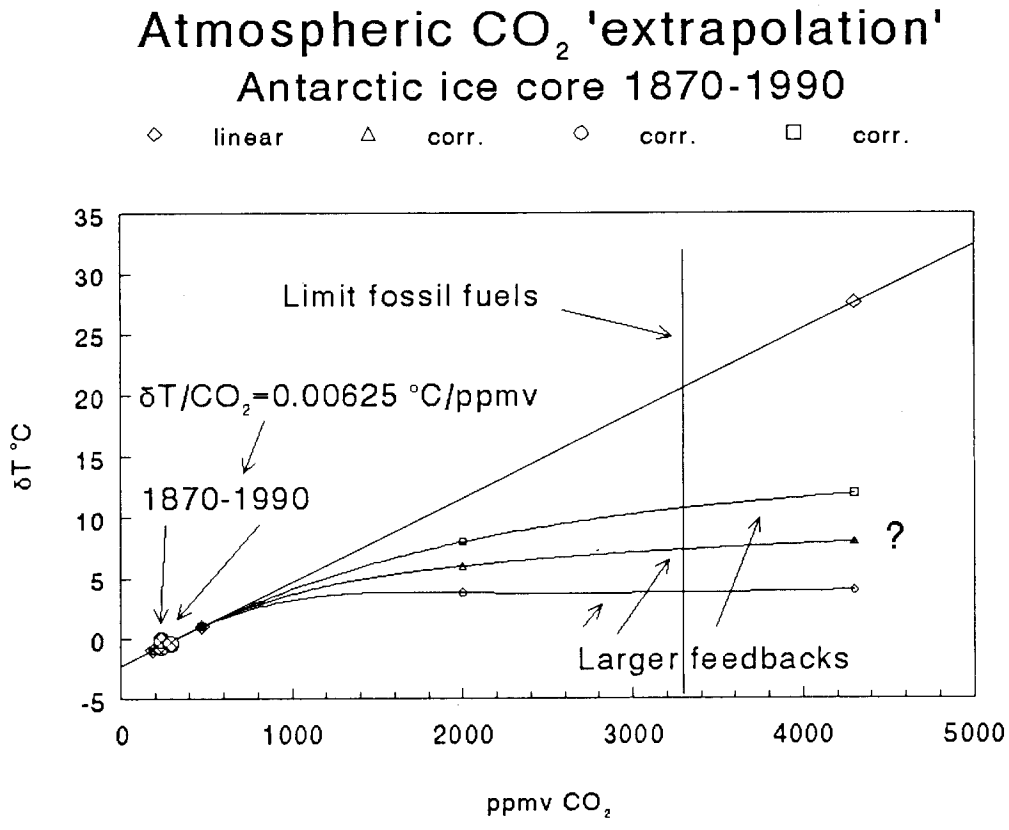

Fig. 3. Global atmospheric temperature extrapolation on the basis of an Arctic Ice core δT determination (references to be found in Duursma & Boison, 1994). The question is which feedback processes can change the extrapolated curve?

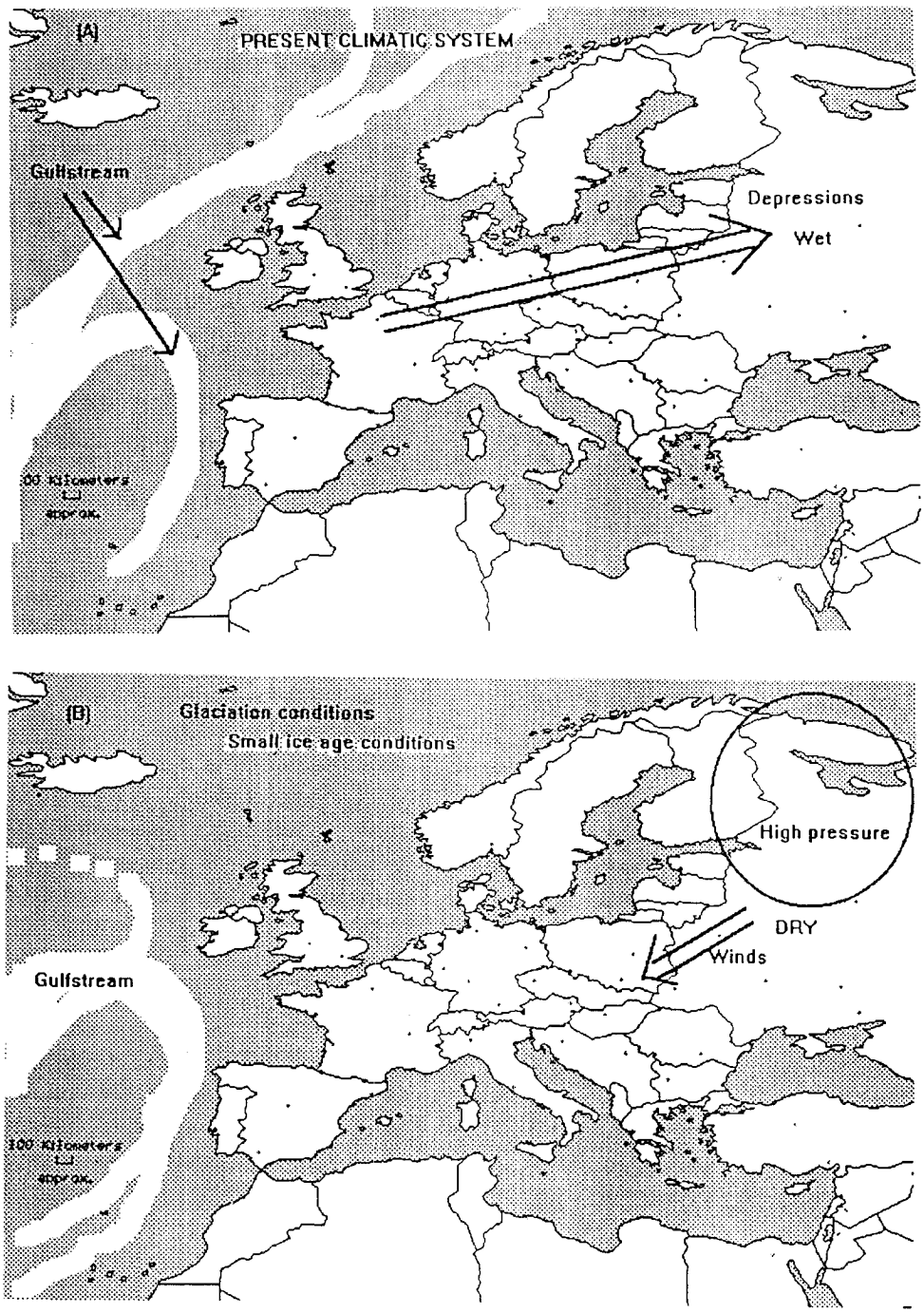

Fig. 4. Small ice ages are believed to be due to Gulfstream changes, which are triggered by a combination of various climatic conditions and ocean circulation patterns and positive feedbacks. Thus small atmospheric cooling can affect the present climatic system of Europe (A) to change into a system with a weakened Gulfstream pattern (B) (See Polonsky & Gorelits, these Proceedings, Session II-a). In case these small ice ages reappear, we will know that the tendency towards a new glacial age will proceed.

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SOCIETAL TRENDS AND THEIR IMPACT ON THE COASTAL ZONE AND ADJACENT SEAS

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ABSTRACT

Around the world, the coastal zone and adjacent seas are coming under increasing pressure associated with the societal trends of rising populations and increasing standards of living. Three consequences of these trends are considered: the development of coastal megacities; coastal and marine pollution; and the exploitation of coastal and marine resources. Many of the problems discussed seem almost insurmountable and science alone does not offer a solution. Nonetheless, it is important to have the best possible knowledge base in order to predict how the coasts and seas might change in the future in response to societal trends and to know how best to minimize adverse change. It is essential to strengthen communications between the sciences and also between managers, policy makers and others concerned with the consequences of coastal change and the unsustainable exploitation of the coastal zone and adjacent seas. A more holistic approach, coupled with a willingness to think laterally and examine new options that will ensure that the polluter (or despoiler) pays, may offer some solutions, provided these are pursued within a framework that recognizes sustainability, inter/intra-generational equality and the rights of all affected groups.

INTRODUCTION

The coastal zone, the interface between the land and the ocean, is in a constant state of change. The "natural" rate of change and the mode of that change varies with the wave and current regime, the climate, the biota and the nature of the hinterland. Profiles of high energy beaches flanking the North Sea may show marked variations from one day to the next, whereas low energy tropical coasts may show little or no change over many years. Conversely, a single tropical storm lasting a day can produce more physical change in a beach than might have occurred over the previous 50 or 100 years. On time scales ranging from thousands of years to many millions of years, factors such as eustatic sea-level change, plate tectonics and changes in ocean chemistry can impact profoundly on the coasts and seas. In the geologic record there is abundant evidence of worldwide marine transgression and regression related to eustasy. There is also evidence of widespread and at times global changes in the nature of coasts due to changes in the chemistry or biochemistry of coastal waters in response to changes in the world climate, variations in the world ocean or evolutionary change that enabled new genera to colonize the coastal zone. Many of these factors are, of course, related. The coastal zone and adjacent seas is a dynamic part of the earth's surface, characterized by inter-related changes, many of which are still imperfectly understood. Change has always been part of natural systems, and throughout the Earth's history the biota has coped with and indeed commonly contributed to that change.

Like other living forms, early man adapted to coastal change, migrating to new coastal areas in response to the movement of the strand line. But as technology advanced and coastal populations rose, man began to work against rather than with the forces of coastal change in order to secure coastal settlements from erosion, win new land areas for agriculture, or improve coastal trade routes. These activities became progressively more important, with significant coastal schemes in China and Europe 2,000 or more years ago. By the Middle Ages, the Dutch in particular had developed advanced coastal engineering schemes to reclaim and protect large parts of the Rhine

delta. But, despite this, the overall impact of human activity, whilst locally important, was globally insignificant. The Industrial Revolution and the attendant ability to undertake ever-greater coastal engineering schemes, together with the growth in population changed this, and the impact of human activity on the coastal zone became regional in scope and is now increasingly global (Hsu and Thiede, 1991). All of this has been given new impetus and a sharpened focus on sustainability through the Earth Summit (Agenda 21), the Convention on Biodiversity, the Framework Convention on Climate Change, and also to some extent through the entry into force of the United Nations Convention on the Law of the Sea.

This paper considers the current situation in the light of these recent initiatives, examines some societal trends and considers the likely impact of those trends on the coastal zone and adjacent seas. It also offers strategies that may help to ameliorate some of the impacts.

SOCIETAL TRENDS

Perhaps more than any other trend, it is the rise in world population that will most affect the coastal zone in the years ahead. The present world population stands at about 6 billion. This is likely to rise to 9 billion within 50 years and to in excess of 10 billion within 100 years (Fig. 1). More pessimistic projections double the world population within a much shorter time frame. Equally significant is that the majority of the population growth occurs in the developing regions of the world and is likely to be focused on the coastal zone in particular; this will be discussed in more detail later.

The other over-riding societal trend which has affected the coastal zone and will affect it ever more in the future is the rising aspiration of all people for greater material possessions and an enhanced standard of living. There are many ways that this can be expressed, but I have chosen to use the projections of world passenger car registrations (Fig. 2), though the number of televisions bought, the amount of electricity generated or the number of hamburgers eaten would equally well serve as indicators of changing life styles (though whether this represents a rising standard of living and enhanced quality of life is arguable). Again, the point is that growth projections for motor vehicles and most other consumer goods will continue to rise dramatically for the foreseeable future, with much of that growth occurring in the developing world. These two over-riding trends of population growth and increased standard of living are of course inter-related, with one reacting upon the other. Nowhere is this more apparent at the global level than in the rising levels of atmospheric CO_2 and other greenhouse gases. An increase in population alone would have produced enhanced levels of greenhouse gases. A stable world population but with increasing standards of living would have produced much the same effect. But the two, acting together, have had a very major impact indeed on levels of greenhouse gases, and given the trends illustrated in Figs. 1 and 2 the impact is likely to be even greater in the future, under a "business as usual" scenario.

Much attention has been given elsewhere to the greenhouse effect, global warming and rising eustatic sea-level rise and therefore I do not propose to consider that topic in detail here, though it obviously cannot be ignored when considering future trends. I propose instead to consider from a geoscience perspective the impact of increasing populations and rising standards of living by looking at three issues: the consequences of increasing coastal population, particularly in coastal megacities, the rising pollution of the coasts and oceans and the increasing use of coastal and marine resources. I do this against a background of the coastal zone and adjacent seas being seen as a critical issue in many parts of the world. For example, in the USGS report "Coasts in Crisis" (Williams et al, 1990), it is pointed out that the State of Louisiana alone is losing 100 km^2 of coastal wetlands each year and that some barrier islands are moving landwards at 7 metres a year. In recent years most developed countries have produced their own reports or conducted their own enquiries and without exception there is evidence of coasts everywhere subjected to a range of competing pressures. These are summarized in the "Coastal Zone Balance"

(Fig. 3): there are those who want to develop and despoil the coastal zone and those who want to conserve and preserve it. Many pollute the coastal zone whereas others work hard to clean it up. Some (commonly people with coastal property) feel that the present day shoreline is inviolate and must be defended at all costs whereas others feel that managed retreat is a more appropriate and cost-effective approach. Whilst the principle of "think globally act locally" is espoused by all, it is often the compartmental and local approach that is pursued at the cost of a holistic and more global approach. Underlying all of this are conflicts regarding public good or private good, public property or private property, and perhaps most fundamental of all is the question of cost. When the choice is between conserving a coastline and raising taxes to do it or leaving things "as is" and perhaps even lowering taxes, it is commonly the immediate cost-less option that prevails, whatever the long-term costs.

Given that the coastal zone and adjacent areas is so often a zone of competing interests, it is all the more important that there is a strategic framework for decision-making. This in turn requires the best possible knowledge infrastructure on which to base sensible decisions whether that knowledge is biological, sociological, geological or fiscal. Unfortunately that knowledge base is imperfect for most countries and non-existent for some. In the 1992 United Kingdom Report of the Environment Committee of the House of Commons, the statement is made that " . . . the coastal zone is in geoscience terms perhaps the most poorly understood and imperfectly documented part of Britain . . . (which) results in an inadequate knowledge base to support effective coastal zone protection and planning . . . . " This same statement could be made for many other countries.

Having pointed out these present-day conflicts and inadequacies let us now consider societal trends and the future consequences.

THE COASTAL POPULATION INCREASE AND ITS IMPACT

Inevitably, part of the overall increase in world population occurs in the coastal zone. However, the impact on the coastal zone is proportionately greater than on anywhere else. This arises in part because of an overall migration of people towards the coast. In other words, for a variety of reasons, people are choosing to live on the coast rather than elsewhere. Some of the movement to the coast is temporary, though even this is by no means insignificant. For example, the Mediterranean coastal zone, which has a permanent population of about 130 million, swells to 230 million for much of the summer. This in itself causes many problems because of the inadequate infrastructure to support the influx (see later), but it is the more permanent increase in population and its impact that I will consider here. The coastal population increase is demonstrable in many ways. For example, amongst the 20 largest cities in the world at the present day 14 are coastal cities. In the United States 50 per cent of the population lives within an hour's drive of the coast. The figure would be even higher for Western Europe. In Australia 86 per cent of the total population lives in the coastal zone. These, and many other statistics, can be used to show that mankind prefers to live on or near to the coast.

The future rise in the permanent coastal population will have the greatest effect in the developing countries. This impact will arise in several ways: there will be an ever-greater demand for space to live and work and to grow food. This will result in an increase in land reclamation or, in more advanced countries, perhaps the construction of large floating "islands". However, in many areas there will be large-scale destruction of coastal environments such as the clearing of coastal swamps . . . . This in turn will lead to a new suite of problems such as an increased rate of coastal erosion, a change in the flux of nutrients and the loss of coastal habitats. Already such problems are seen along densely populated coastal stretches of West Africa and South-East Asia, where initial attempts to obtain more usable coastal land by clearing mangroves has had the reverse effect, with loss of land through enhanced rates of erosion and acidification. The point here is that the coastal zone is a finite resource in terms of human time

scales; once destroyed it may take thousands of years to re-establish itself. There is likely to be broad-scale destruction of the coastal zone, particularly in the developing world, unless there is intervention by governments or international agencies. Any attempt to reverse the preferential movement of people towards the coasts is unlikely to succeed. In any case it could lead to other equally damaging forms of environmental impact on the coast (Milliman, 1992). Large dams such as the Aswan Dam on the Nile, built to help increase inland food production, generate power and control flooding have had the effect of dramatically decreasing freshwater flow, nutrient input and sediment supply. This in turn has meant that the delta no longer receives sediment, and the delta front has started to erode. Additionally, brackish conditions extend further up the river system leading to salinization. The net result of all this is that increased rate of landward food production through desert reclamation is countered by a decreased rate of production in the shoreward areas. Additionally, the decreased supply of nutrients from the Nile has led to a marked decrease in coastal fish stocks (Milliman et al, 1989). There are similar tales to tell for the Bengal Fan and the Niger delta (Haq, 1994). Therefore, movement of people to inland areas of itself is unlikely to offer a solution to the problems of the coastal zone and therefore a significant rise in the coastal population must be planned for.

Much of this growth is likely in and around coastal megacities. Already many of these cities exist and more will grow up in the developing world, particularly in South-East Asia. These megacities obviously produce major problems in terms of destruction of coastal environments and the influx of large quantities of sewage and other pollutants into the coastal zone (see later). To this must be added the physical destruction of the coastal zone itself through urbanization and the associated infrastructure. Therefore the question must be asked: is the coastal megacity itself sustainable? The answer to this is equivocable. Part of the uncertainty arises from the projected eustatic rises in sea level due to global warming with estimates (based on IPCC "business as usual" scenarios) ranging between 30 and 110 centimetres over the next century. At the lower end of this range most cities would probably be able to cope through a range of engineering measures, though the cost would be considerable. At the upper end of the range, a significant number of coastal cities and adjacent areas, particularly in developing countries, would find it very difficult indeed to cope, due to the engineering difficulties and the enormous cost.

In a recent report entitled "A Rising Tide of Concern", Tim Radford for "The Guardian" newspaper states that "The Chinese, with a little help from the World Bank, have been doing some sums about the impact of global warming. If nobody does anything about greenhouses gases, a new report says, then sea levels will rise by between 70 cm and a metre at Tianjin, 40-70 cm in Shanghai and 40-60 cm in the Pearl River delta. 'If coastal areas are not protected, a one-metre increase in sea level will flood regions lying below a four-metre contour line in China's coastal plains, when combined with tide and storm surges,' the report goes on. This would flood 92,000 km^2 and displace 76 million people. At least 14 cities in the Pearl delta, and 34 cities in east China, including Shanghai, would be affected. China gets 76 per cent of its energy from coal, and provides 10 per cent of global carbon dioxide emissions. Its mines, farm animals and paddy fields make a big contribution to methane as well." As Tim Radford observes, "It is in China's own interests to limit greenhouse gas emissions . . . ."

However, the impact of eustatic sea-level rise in many areas is reinforced by the effects of coastal subsidence. Many of the world's coasts are undergoing vertical movement: emergence dominates coasts near to some tectonic plate boundaries and where there is glacial rebound. However, most of the world's major coastal cities occur in areas of submergence, in other words areas where the impact of sea-level rise is reinforced. This preferential location of major cities in submergent areas is not fortuitous; it arises from the fact that these submergent coasts are where the major rivers systems and deltas are located. In other words, these are the areas where

there is abundant flat land for urban development or agriculture and suitable harbours in river mouths for trade and transportation.

Therefore relative sea-level rise is much more important than eustatic rise when considering the future sustainability of coastal megacities. In many cases this future impact is being exacerbated by the cities themselves (Haq, 1994) due to activities that result in even more subsidence (Emery and Aubrey, 1991). These include excessive groundwater withdrawal (for example Bangkok), exploitation of oil and gas (for example Wilmington, California) and the interruption of sediment input (for example the Nile delta region). In some cases the accelerated subsidence rates result from several of those factors acting in concert. For example, subsidence in New Orleans and other parts of the Mississippi delta results from various combinations of groundwater withdrawal, exploitation of oil and gas, solution mining of salt domes for sulphur and decreased input of fluvial sediments due to extensive engineering of the Mississippi. The sum of all of these effects, namely, eustatic rise of sea level due to global warming, "natural" subsidence due to neotectonics and compaction, and enhanced subsidence due to anthropogenic activities such as withdrawal of subsurface fluids and decreased sediment flux could potentially produce a relative rise in sea level of several metres over the next century in the vicinity of some coastal megacities. Given the current rate of growth, up to 2 billion people will live in coastal megacities within the next 50 years. By that time they will be contributing up to 20 per cent of all greenhouse gases and drawing ever more on the resources of the surrounding coastal environment. To put it in rather stark terms, unless carefully planned to minimize their environmental and resource impact, coastal megacities will, to a significant degree, be responsible for sowing the seeds of their own destruction! Is this inevitable as populations continue to rise or can some steps be taken to minimize the scale of the problem? Steps which should be taken now include

1. Accurate measurement of all the processes contributing to relative sea-level change on all coasts with large populations or where major population increases are likely to take place in the next 50 years;
2. Development of a better understanding of the geological, biological and biochemical processes and fluxes in present-day coastal megacities and adjacent areas;
3. determination, where possible, of "natural" rates of change and natural background levels of chemical, biochemical and biological materials, including pre-anthropogenic rates and levels;
4. improved recycling of materials in order to minimize impact on the coastal zone and on the use of coastal resources;
5. decreased withdrawal of subsurface fluids;
6. more comprehensive evaluation of the impact of activities in coastal catchment areas, particularly sediment and nutrient fluxes;
7. more complete costing of coastal activities including land reclamation and habitat, destruction.

Ultimately, we must seek to work with rather than against natural processes in the coastal zone adopting the precautionary principle where we do not know, and ensuring that where change is inevitable that the rate of change does not exceed the capacity of the coastal system to "absorb" that change. This sentiment is expressed eloquently by Clayton (1991) in speaking against the general tendency to "hard engineer" coasts rather than adopting his preferred solution of "soft engineering" where he states " . . . Indeed we could rediscover the value of a natural coast and so adopt a more realistic policy for managing the whole of the coastal zone, accepting above all that blind opposition to the waves will in the end destroy those features we value most . . . . "

POLLUTION OF THE COASTAL ZONE

Increasing pollution of the coastal zone is an integral part of the whole issue of development of the coastal zone and the increasing pressures to which it is being subjected. However, it is so all-pervasive and so significant that it requires separate consideration though it is not possible to consider the matter in any depth here. Pollution of the coasts and seas is constantly being brought to our attention these days in ways that grab the headlines. In the recent report "Coasts in Crisis"

(Williams et al, 1990) it is pointed out that one-third of the shellfish beds in the United States are closed or restricted because of pollution. In a graphic article in "New Scientist" (Anon, 1995) the impact of pollution in the Mediterranean is described. The Mediterranean coastal zone has a permanent population of about 130 million. This swells to 230 million for much of the summer and here immediately is one of the problems, namely that the infrastructure, including the sewage system, is unable to cope with this massive influx. Each year visitors and permanent residents together add more than 500 million tonnes of sewage (80 per cent of it untreated) to the coastal waters. They also contribute 120,000 tonnes of mineral oils, 60,000 tonnes of detergent, 100 tonnes of mercury, 3,800 tonnes of lead and 3,600 tonnes of phosphate. Along with these disturbing figures are equally disturbing but more emotive manifestations of the problem, with, for example, a report that several thousand dolphins died in the Mediterranean from a morbillo virus between 1990 and 1992 as a result of pollutants attacking their immune system. Oil spills are equally emotive "events", with dramatic pictures of birds or fish dying from the effects of the spill. The disposal of solid wastes in the coastal zone, including sewage sludge, represents a cheap but increasingly unacceptable way of disposal, though the pressure arising from the growth of megacities means that this is often seen as the only solution for the present. In many areas the coastal zone is under sustained attack from rather more insidious pollutants such as PCBs which may remain in the environment for hundreds if not thousands of years, whilst heavy metals may remain in the environment and available to the biota through informal activity for many thousands of years. Even the apparently more "benign" pollutants such as aluminium cans and plastic bottles can remain for a hundred years, having a major and adverse impact on the benthos throughout this time.

Whilst the source of some of the pollution lies in the coastal areas themselves, much of it is derived from the inland. For instance, high use of fertilizers in distant catchment areas may produce excess nutrients and problems of anoxia in the coastal zone. The fundamental problem is that humanity has seen the oceans as having a limitless capacity to accept/absorb all the pollutants that we wish to put into them (Emeis et al, 1991). This same presumption applied to the atmosphere with respect to CFCs, NO_x, SO_x, CO_2 and countless other gaseous materials, but we now know that the capacity of the atmosphere is finite if the greenhouse effect or the destruction of the ozone layer is to be minimized and the general quality of life maintained. This new understanding regarding "capacity" has resulted in protocols being developed to eliminate CFCs for example. The principle of the so-called carbon tax has also been developed whereby a levy would be charged on countries which discharged greater than the world per capita average for CO_2 emission. This would, in theory, give an obvious incentive to countries to minimize CO_2 emissions. Under the carbon tax scheme it is proposed that CO_2 credits could be bought and sold, potentially resulting in some transfer of funds from the developed countries (which have high rates of fossil fuel usage) to developing countries (with low rates of usage). It is in essence a global approach to the polluter-pays principle but is by no means a universally accepted approach, with a number of countries strongly opposed to it because of the increased energy costs that would result. Nonetheless, the concept is receiving increased attention and already in the United States SO_2 credits are being traded. Could the same principle be applied to coasts and seas and in turn to the world ocean? We know that the "carrying capacity" of the oceans, like the atmosphere, is finite, particularly if we are to minimize the impact on the marine biota. We also know that some countries, on a per capita basis, are far greater net contributors of PCBs, heavy metals, untreated sewage and tin cans to the sea than other countries. The London Dumping Convention prohibits the dumping of waste at sea and represents a step in the right direction. But there is little attention paid to land-derived material, which forms the bulk of the problem. Is it reasonable then to consider a marine pollution tax - a thalassic tax? This would be analogous to a carbon tax, meaning that those countries which have a higher than average per capita rate of marine pollution would either

decrease that rate or buy credits from low use countries. Clearly it would be difficult to implement for there is such a wide range of pollutants with an equally wide range of impacts extending from the benign to the highly toxic. Nonetheless, a start could be made with some of the more ubiquitous, long-lived and toxic pollutants such as PCBs, mercury or cadmium. Despite the potential problems of implementation, surely it is worth consideration?

COASTAL AND MARINE RESOURCES

Obviously living resources constitute a very important resource indeed of the coasts and seas. In many areas that living resource is under severe threat from over-exploitation and the impact of pollutants (see earlier). The coastal zone itself is a finite resource: once destroyed it may take thousands of years to re-establish itself. This has been considered earlier in the context of coastal megacities. The International Oceanographic Commission (IOC) Programme of Ocean Science in Relation to Non-Living Resources (OSNLR) has established a programme dealing with the Coastal Zone as A Resource (CZAR) in order to address some of these issues. Here, I want to deal briefly with another aspect of OSNLR; the exploitation of coastal and marine mineral resources.

Fossil fuels have been obtained offshore for many years, indeed offshore coal mining commenced more than 400 years ago and is still going on through undersea extensions of mine shafts sunk on land or shafts sunk from artificial islands (Earney, 1980). Perhaps in the future it will be possible to exploit coal energy by *in situ* gasification (Gudan et al, 1989), but for the foreseeable future, oil and gas will provide the overwhelming proportion of energy obtained offshore. This is not to discount the potential future importance of renewable energy sources (Vadus et al, 1992) such as tidal power, wave power and offshore wind power or ocean thermal power. All of these will make an increasing contribution though whether this contribution will ever offset the projected world annual growth in power demand is uncertain. Additionally, whilst such alternative energy sources have the advantage of being 'clean' compared, for example, to car emissions, they will impact significantly in other ways upon the coastal environment. Wave and tidal schemes in particular can involve major coastal engineering schemes which can have a major impact on sediment dynamics and coastal stability.

The offshore exploitation of oil and gas is a major and worldwide activity which is now a feature of every continental margin except Antarctica (Cook et al, 1991). Whilst the level of activity varies from time to time with the price of oil, overall there is no slackening in the level of exploration and exploitation. The area of activity varies with each new exploration success, the development of new pipelines, or changes in the fiscal or political regime. However, it is the development of new technology which has had the most profound impact, enabling exploitation to extend into progressively deeper waters. Twenty-five years ago, exploitation was limited to about 100 metres; today it extends to 1,000 metres with new techniques being developed that will extend the limit to the base of the continental slope and beyond. The other development which will undoubtedly extend the depth of exploitation is that a legal regime has now been established for deep sea mineral and energy exploitation through the entry into force in late 1994 of the United Nations Convention for the Law of the Sea.

The offshore oil and gas industry will continue to require a great deal of investment in engineering. For example the industry spent £25.8 billion on platforms, modules, pipelines and other offshore constitutions in the United Kingdom sector alone between 1980 and 1990. This has involved around 5,000 exploration wells, about 150 permanent platform installations and about 6,000 km of pipelines. Similar levels of activity are to be found in many other offshore areas. One of the important issues for the future is the abandonment of these various structures, for few oil and gas fields have a life of more than 25 years, and the clean- up of the sites is a matter of international concern. The International Maritime Organisation has issued guidelines for the removal of offshore structures but these are not mandatory and have been adopted to varying

degrees by coastal states. There is little doubt that the impact of exploitation of offshore energy sources is likely to increase in the future, whether that energy is obtained from fossil fuels or from alternative energy sources. It is also likely to come into sharper environmental focus as indicated by the recent controversy surrounding the proposal by Shell to dispose of a redundant North Sea production platform in the deep ocean, a proposal was subsequently reversed in response to strong pressure from the environmental lobby.

The potential of the oceans for disposal of CO_2 should not be forgotten. This can be done in deep cold ocean water but it can also be disposed of in large offshore anticlines from which the oil or gas has been removed or where it can be used in part to produce enhanced recovery through pressure drive. Both of these techniques are feasible but whether they can be done at reasonable cost and on an adequate scale to make a significant impact on the world CO_2 balance is questionable at this stage.

Compared to the offshore petroleum industry, the size of the offshore minerals industry is relatively small, but it is growing rapidly in many parts of the world (McKelvey, 1986; Teleki et al, 1987; Packer, 1988; Cook et al, 1991; Cook and Taylor, 1992). Dredging of placer deposits is taking place in a number of areas (tin in Thailand and Malaysia; gold in the Philippines and Alaska). Beach deposits of mineral sands (ilmenite, rutile, zircon, monazite) are mined in Australia, Malaysia, India, China, Sri Lanka, South Africa and the United States of America. Diamonds are worked from the coasts of southern Africa and offshore diamond exploration is underway off northwestern Australia. Diamonds are an excellent example of growth in usage, with society having what appears to be an almost insatiable appetite for this expensive commodity (Fig. 4). The picture is complicated by the controls on the market exerted by existing producers but nonetheless it does appear that growth in diamond production and sales will continue to rise steeply with, I suspect, an increasing proportion of the supply coming from offshore. Sand and gravel is perhaps the most important offshore mineral resource at the present time, with construction materials extracted from the offshore close to highly populated areas of Western Europe, the eastern United States and Asia. In 1990, the total amount of marine sand and gravel exploited by the United Kingdom from the North Sea was 13 million tonnes out of a total of 23 million tonnes of marine sand and gravel. The total amount of material dredged from the North Sea offshore aggregate operation is probably of the order of 40-50 million tonnes, most of it from depths of less than 30 metres. This amount is an order of magnitude more than the amount of material entering the North Sea from present day rivers but is probably very little compared to the amount of North Sea sediment moved in a winter storm (Cook et al, 1991). Perhaps a greater potential concern regarding the impact of sand and gravel extraction is its effect on the coastline and on the benthos. There are a variety of opinions on this issue, exemplified by two quotes from "The Times" newspaper. The first, from a report of 12 October 1994 states " . . . Dredging for sand and gravel could be adding to the damage of fish stocks in the North Sea, a government scientific report claims. Studies indicate that the seabed fails to recover its full marine life more than two years after dredging has ceased . . . . " The second report from "The Times" of 28 October 1994, in a letter from Ian Crombie of the British Marine Aggregate Producers' Association states " . . . In terms of the impact on fish stocks, it is important to appreciate that the area of seabed touched by extraction is minuscule - some 0.03 per cent of the North Sea annually when working at full current capacity. Research by the International Council for the Exploration of the Sea found that, in the worse scenario in the North Sea, extraction might reduce the numbers of fish available by 2000 tonnes, compared to a total fish biomass of 10 million tonnes . . . . " But whilst there are concerns regarding offshore aggregate extraction, it has to be recognized that modern societies are dependent on construction materials and that the environmental and social impact of onshore aggregate working can be far greater than that of offshore deposits. The population growth curve coupled with rising expectations regarding

material possessions means a major increase in the use of aggregate and it is likely that more, rather than less, of our construction materials will be derived from the coastal and nearshore zone in the future. Coastal quarries are an important new feature in some areas, for example Norway, but the debate on superquarries is also becoming a highly charged environmental issue. There is strong opposition to coastal quarries from environmentalists on the grounds of their impact on the landscape, noise, dust and pollution of the marine environment by ships discharging ballast, but again this has to be balanced against the difficulties of locating more environmentally acceptable sources.

Just as the demand for aggregate will rise inexorably with the rise in world population, so will the demand for phosphate. Phosphate is essential to life for it constitutes an integral part of DNA and ATP: without phosphate there can be no life. Much of the phosphate is used in phosphatic fertilizer and it has been a vital component of the so-called green revolution. Through this, world food production has been able to grow at a rate greater than world population growth. Over the past 40 years, phosphate rock production has grown by 500 per cent (Fig. 5) in response to demand. Most of this phosphate has been derived from onshore sedimentary phosphate (phosphorite) deposits. There are vast onshore deposits (Cook and Shergold, 1986; Northolt et al, 1989; Burnett and Riggs, 1990) and globally there is no shortage of phosphate. However, that phosphate is very unevenly distributed with some countries such as the United States and Morocco having vast deposits whilst others have no mineable deposits whatsoever (Cook, 1982). In the case of the rich northern countries the phosphate can be readily imported but this is not possible for many developing countries, which are of course the countries with the greatest requirement to increase food production in order to feed their rapidly rising population. Therefore it is inevitable that some of these developing countries will look for new, cheaper and closer sources, some of which will be located offshore in relatively shallow water, though the entry into force of UNCLOS will perhaps provide a basis for exploiting deeper deposits in the more distant future.

This is certainly the case for various types of deep water metalliferous deposits. These occur as nodules (manganese nodules or polymetallic nodules) on abyssal plain, seamounts and plateaux, as crusts, especially in active volcanic area and spreading axes or in the form of spectacular mounds and chimneys (Scott, 1987, 1991; Cronan, 1992; Cook, 1995). Deep sea manganese nodules in particular have been the subject of a great deal of speculation over many years because of their high nickel copper and cobalt contents. More than 20 years ago, Mero (1972) forecast that nodules would be in full scale production within 5 years. In 1980 Cameron et al. (1980) forecast production by the "early to mid-1990s". Yet despite this optimism, nodule production appears to be as far away as ever. Why is this so, given the massive increase in demand for manufactured products from rising populations? Part of the reason is the amount of substitution of metals by plastics that has taken place in recent years. A second reason is the success of the minerals exploration industry in finding new deposits. A further and related reason for the lack of any nodule production has been the significant drop in metal prices in real terms that has occurred over the last 30 years (Fig. 6). As long as this trend continues there is unlikely to be nodule production unless there are significant changes in demand. For example, the rise in the number of motor vehicles (Fig. 2) will be reflected in rising metal demand. One of those metals is platinum which is used increasingly in catalytic converters. But platinum is both expensive and in finely particulate form may constitute a health hazard. In 1976 NOAA noted that manganese nodules (probably due to the high surface area of fine grained manganese oxides, can absorb up to 200 per cent of their weight of SO_2 and suggested that they may find application in industrial power plants and in controlling motor vehicle emissions. If feasible, this could result in a major increase in manganese oxide use. There is a further factor which may also bring forward the use of all offshore mineral resources. This relates to the increasing unwillingness of people

(particularly in developed countries) to have mines or quarries anywhere near where they live. Marine mineral production may prove to impact significantly on the marine environment but the point is that any workings would be away from centres of population and for the most part would be out of sight. Therefore it may be that offshore production may be brought forward because it will be regarded by many as aesthetically more acceptable than offshore exploitation.

Whilst clearly it is dangerous to speculate on the future of offshore mineral production, present trends suggest that offshore aggregate production will increase though there will be questions regarding the environmental impact. Production of offshore placers will rise significantly perhaps with diamond production showing a major increase. Offshore phosphorite exploitation will probably commence in the next century perhaps as early as 2020 if the trends of population (and food) increase and raised environmental awareness are sustained. Deep sea nodules, crusts and chimneys are unlikely to be worked commercially in the near future and probably not before 2050. However, even this distant prospect will require consideration well before that time to ensure that all environmental issues are considered and comprehensive baseline studies undertaken so that any deep sea mining is conducted in an environmentally acceptable and ecologically sustainable manner.

DISCUSSIONS AND CONCLUSIONS

It is clear that societal trends and in particular the dual trends of the population increase and rising standards of living for that growing population will have a profound effect on the coasts and seas. The development of coastal megacities with all their consequences of increased pollution ranging from headline grabbing oil spills to the less visible, more insidious, and in many cases more lethal ongoing pollution by mercury, cadmium, PCBs, etcetera will be especially significant. Coupled with this is the increased pressure to exploit marine resources at levels that may or may not be ecologically sustainable. Whilst previously I have dealt separately with the topics of coastal population increase marine pollution and the use of coastal and marine resources, it is important to recognize that these issues are inter-related. Consequently many of the problems will only be solved by taking a holistic approach. This requires the breaking down of traditional barriers between the various sciences. In Lisbon in 1994 a large group of scientists from a great many countries together developed a "shared vision" which identified a number of broad scientific objectives for the marine scientific community. These objectives included:

- integrated management of the coasts and seas;
- the maintenance of biodiversity;
- sustainable harvesting and farming of living resources;
- exploitation of non-living resources in a cost-effective and environmentally acceptable manner;
- the more accurate assessment and production of marine hazards;
- building and strengthening the scientific capacity of less developed countries.

The 1994 Lisbon meeting also established a number of generic marine and coastal activities that will need to be undertaken in order to provide the knowledge base necessary to achieve the objective. These activities included:

- systematic baseline mapping, monitoring and analysis against which future change can be measured;
- the assessment of the economic and intrinsic value of resources;
- the development and application of appropriate new technologies necessary to measure and monitor a range of parameters relevant to the coasts and seas;
- evaluation of the capacity of coastal and marine systems to absorb change;
- documentation of the benefits derived from scientific programmes and through improving the knowledge base.

All of these scientific objectives and activities are relevant to the world's coasts and seas and all will need to be pursued to varying degrees in a multidisciplinary manner. We know a great deal about the world's coast and seas but there is still much to learn. The knowledge, skill and enthusiasm of the scientific community will be needed if the coastal zone and adjacent seas are

to be responsibly and sustainably used in the future.

But the problems will not be overcome by science alone though it will contribute to their resolution. What is needed is an approach that encompasses not just science but also sociological and managerial issues and needs. A number of these issues and the framework for bringing them together has been addressed by Cinin-Sain (1993). She sees "integration" as being paramount in the coastal zone. The integration can take many forms including:

- integration between the natural sciences, the social sciences and the policy makers-implementers;
- integration between sectors such as oil and gas developments, fisheries, sand and gravel extraction, tourism and port development and also with land-based activities such as agriculture;
- integration between the land and the ocean sides of the coastal zone;
- integration at all levels of government (national/regional/local).

The requisite degree of integration is not easy to achieve and Cinin-Sain, in an important address to the international conference in Lisbon in November 1994, suggested a number of incentives to facilitate co-operation between agencies and sectors including shared problems and shared professional (and scientific) values, a common wish to reduce uncertainties, financial incentives (the carrot!) or a legal requirement or mandate (the stick!) and a shared political advantage (whether perceived or real). All of this has to take place within the context of "sustainability" and related principles such as intra/inter-generational equity, appropriate environmental safeguards, and where knowledge is inadequate, the so-called precautionary principle should apply. Underlying this, it must be acknowledged, are economic issues.

But if free market principles are to be applied, if there is to be a presumption of the right to develop the coastal zone and adjacent seas, then there must be the correct balance between private profit and public wealth. There must be full consideration of the socio-economic values of all affected groups (particularly the rights of indigenous peoples) and the maintenance of the "natural" coastal and marine environments. If market forces are to prevail then this must be done in a long-term and comprehensive manner. If there is only short-term accounting (or no accounting at all) then the long term consequences can be devastating. The example was used earlier of mangrove forests (a cheap source of fuel) being destroyed, resulting in major (and expensive) coastal erosion problems. There must be proper natural resources accounting that takes into account the full cost of short term actions. Brundtland (1987) said the same thing but more eloquently in her often quoted statement "... Humanity has the ability to make developments sustainable - to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs ...."

IN CONCLUSION

1. We must accept that change is part of the natural system but clearly the type, magnitude and rate of change now affecting the coastal zone and adjacent seas is not "natural". We must carefully document those changes and develop a better understanding of the processes involved, for it is inevitable that the anthropogenic impact will increase. A better knowledge base may help to minimize that impact and in particular may help us to work with, rather than against nature.
2. Coastal issues will continue to rise up the political agenda in most countries because of development pressures; the development of coastal megacities will become particularly significant. The Earth Summit (Agenda 21) rightly emphasizes the importance of the sustainability of the coastal zone as a major issue.
3. A holistic approach must be taken to coastal and marine issues: The underpinning science must be multisectoral (natural science/social science/economics/policy/politics/etcetera). Along with this, as outlined by Cinin-Sain, there must be comprehensive communication, co-ordination, harmonization and integration at the local, regional, national and international level, including participation by all affected groups especially indigenous peoples.

4. A narrow short-term market driven approach underlies many coastal and marine problems. Conversely a broad scale long term market driven approach could provide many of the answers, but for it to succeed, it must incorporate such principles as intra and intergenerational equity, the precautionary principle and proper natural resources accounting. These, together with the polluter-pays principle, are used as the basis of the suggestion of a littoral or "thalassic" tax, which like a carbon tax takes a global view of the "polluter pays" principle. This will be difficult to implement but the problems of the coastal and marine environments require a new approach.

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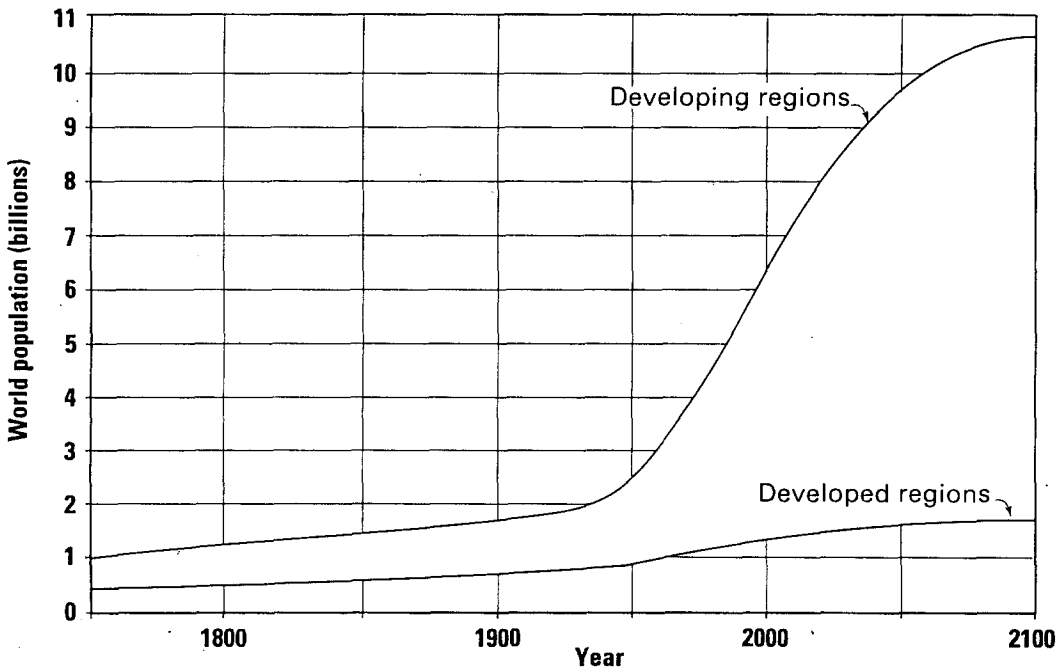
Fig. 1. World population increase 1750-2100 (source: The Economist).



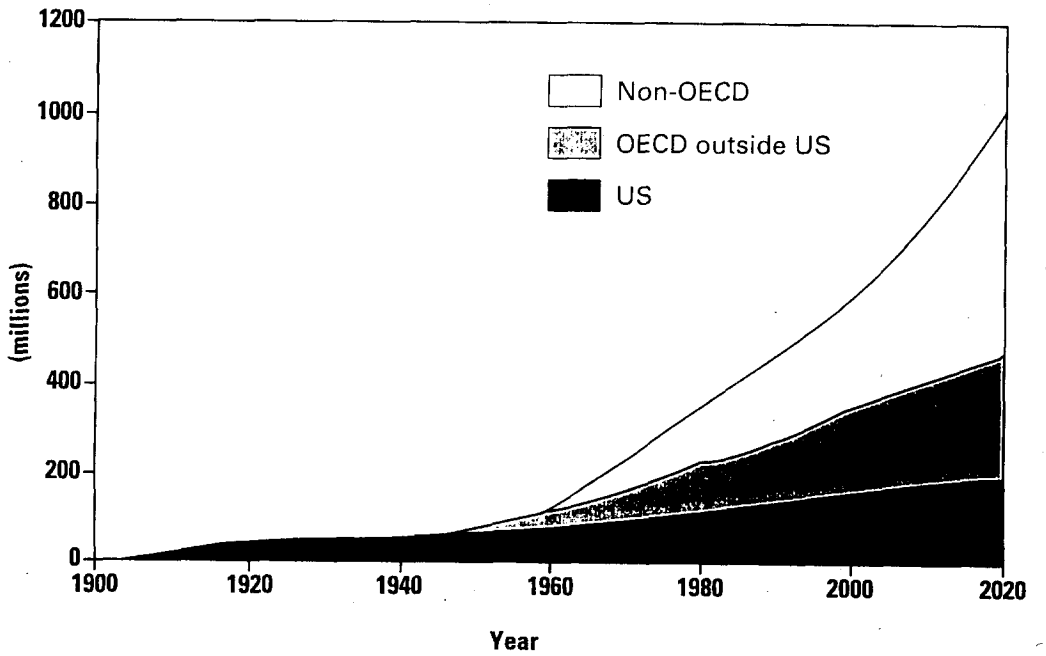
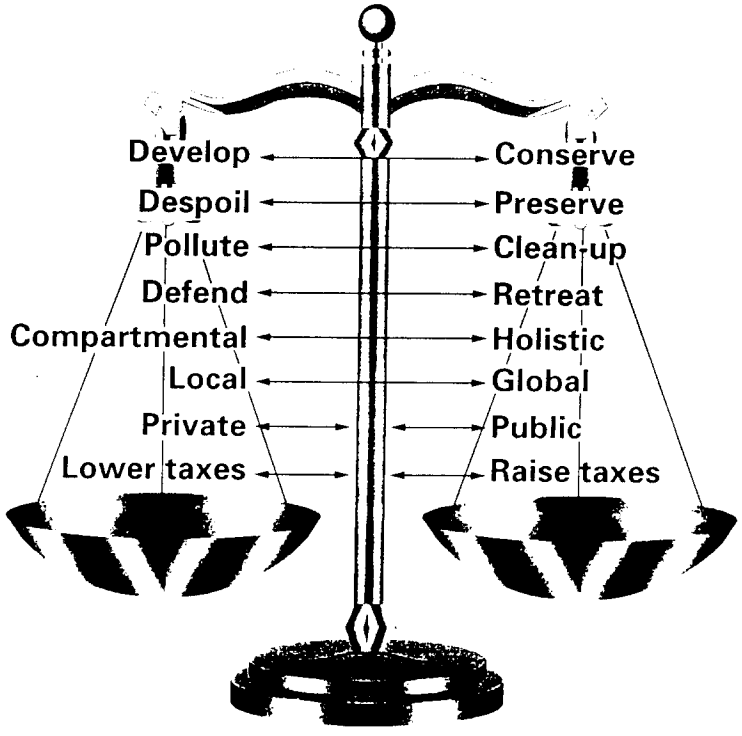


Fig. 2. World passenger car registrations (source: Petroleum Gazette 1994/2)

Fig. 3. The coastal zone balance.



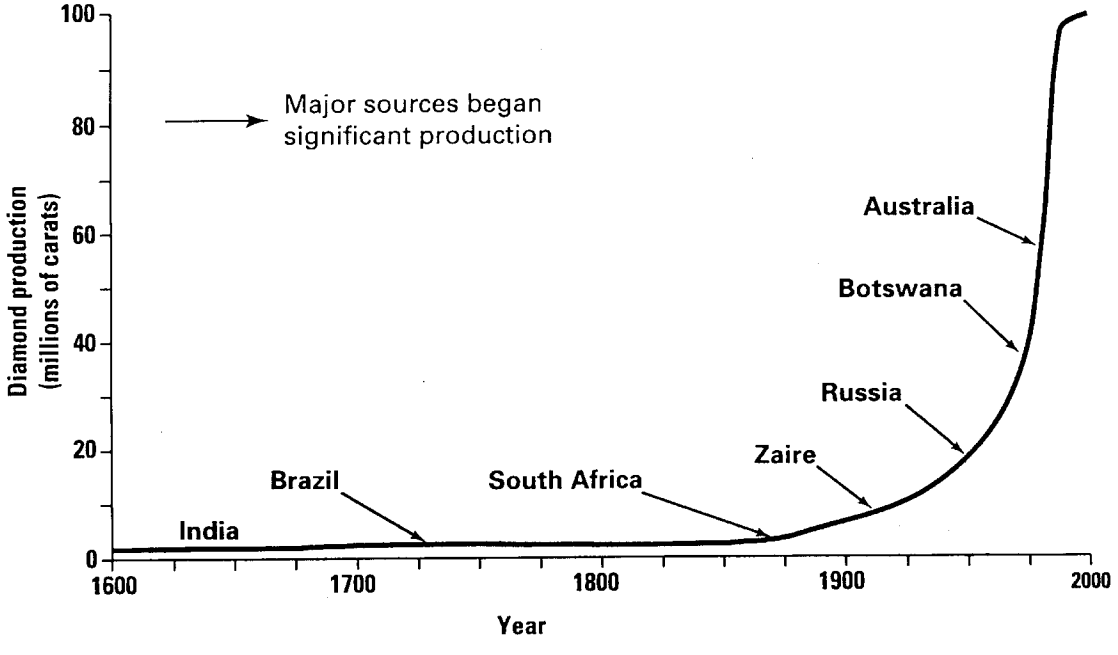
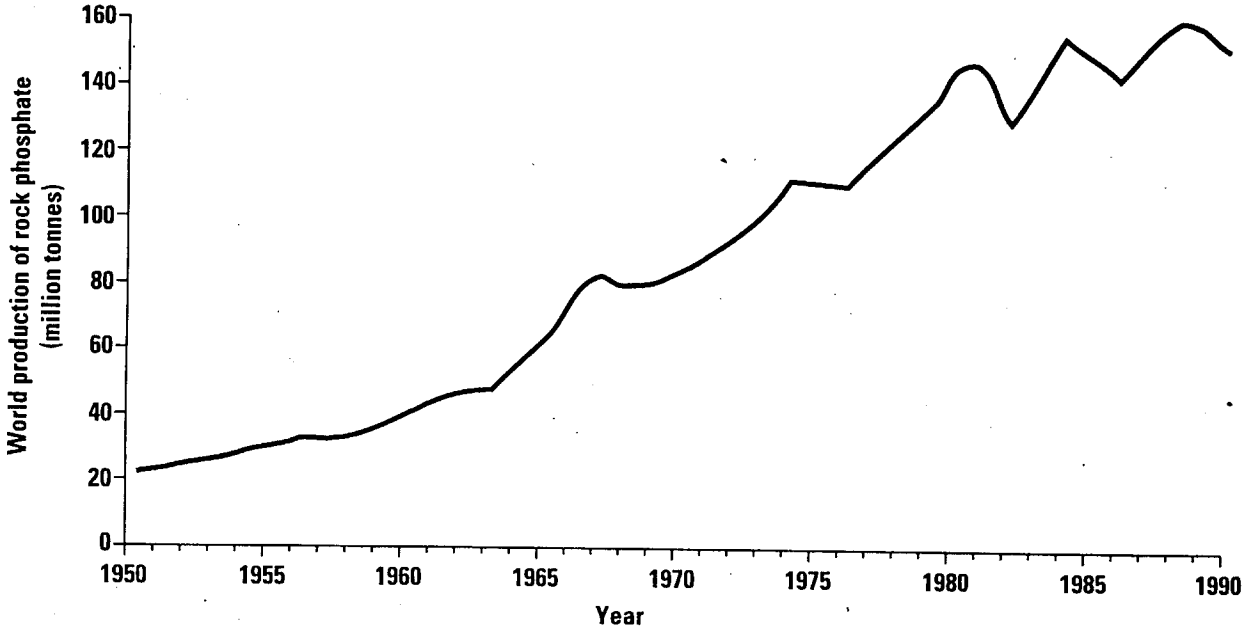


Fig. 4. World production of rough diamonds (gem and industrial) (source: Levinson et al. 1992).

Fig. 5. World production of phosphate rock, 1950-1990.



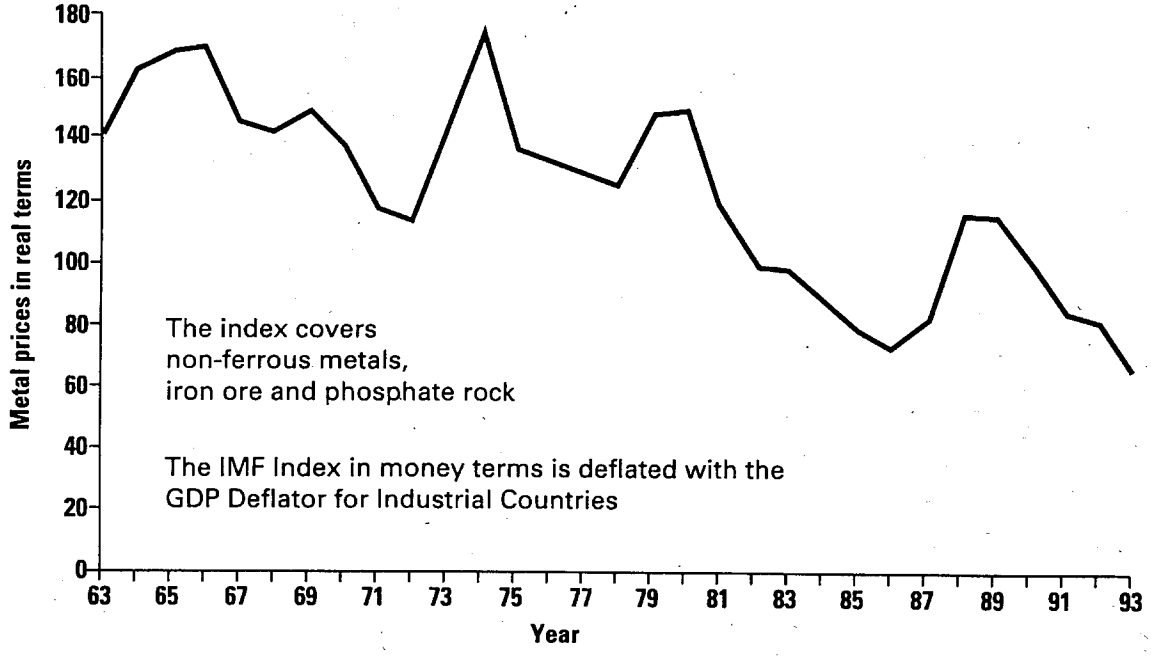


Fig. 6. Metal prices in real terms 1963-1993 (Index numbers 1990=100): The index covers non-ferrous metals, iron ore and phosphate rock (source: Ian-Strachan, 1994).

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ACTIVITÉS DU CONSEIL DE L'EUROPE CONCERNANT LA CONSERVATION DES ZÔNES CÔTIÈRES

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INTRODUCTION

Le Conseil de l'Europe se préoccupe depuis de nombreuses années des problèmes liés à la protection de l'environnement. Il constitue, tant de par son champ d'application géographique (33 Etats membres) que de par sa vocation (promouvoir la démocratie et rechercher des solutions aux grands problèmes de société), un forum de réflexion et d'action propice pour traiter de ces questions. Les textes et programmes d'action qu'il adopte et met en place contribuent à orienter les politiques nationales de ses Etats membres vers une meilleure prise en compte de l'environnement naturel.

Les actions entreprises tendent à assurer la protection de la nature, espaces et espèces, ainsi qu'à organiser les activités humaines de manière à ce qu'un "développement durable" intégrant la protection de l'environnement puisse se réaliser. Celles-ci relèvent pour l'essentiel de la coopération intergouvernementale sous l'autorité du Comité des ministres, organe de décision composé des ministres des Affaires étrangères. L'Assemblée parlementaire, composée de 472 membres et suppléants venant des Parlements des Etats membres, ainsi que le Congrès permanent des Pouvoirs Locaux et Régionaux de l'Europe (CPLRE) (auparavant Conférence permanente des Pouvoirs Locaux et Régionaux de l'Europe) qui rassemble des représentants des collectivités locales et régionales des Etats membres, jouent également un rôle décisif en ce qu'ils permettent de promouvoir des initiatives nouvelles et de sensibiliser leurs membres aux problèmes environnementaux.

ACTIVITES INTER-GOUVERNEMENTALES

Conservation des espaces naturels côtiers

1. La Convention de Berne du 19 septembre 1979 relative à la conservation de la vie sauvage et du milieu naturel de l'Europe a pour but d'assurer la prise en considération de la conservation de la vie sauvage et du milieu naturel dans les politiques nationales générales d'aménagement et de développement, ainsi que dans les mesures de lutte contre la pollution. Elle reconnaît dans son préambule que la flore et la faune sauvages constituent un patrimoine naturel d'une valeur esthétique, scientifique, culturelle, récréative, économique et intrinsèque, qu'il importe de préserver et de transmettre aux générations futures. Les Parties contractantes soulignent que celles-ci ont un "rôle essentiel" dans le maintien des équilibres biologiques, et considèrent que leur conservation devrait être prise en considération par les gouvernements dans leurs objectifs et programmes nationaux, et qu'une coopération internationale devrait s'instaurer pour préserver en particulier les espèces migratrices.

Véritable convention régionale de la biodiversité, la Convention compte à ce jour 31 Parties contractantes, dont 26 Etats membres du Conseil de l'Europe (Autriche, Belgique, Bulgarie, Chypre, Danemark, Estonie, Finlande, France, Allemagne, Grèce, Hongrie, Islande, Irlande, Italie, Liechtenstein, Luxembourg, Malte, Pays-Bas, Norvège, Portugal, Roumanie, Espagne, Suède, Suisse, Turquie et Grande-Bretagne), 4 Etats non membres (Burkina Faso, Moldova, Monaco et Sénégal), et la Communauté européenne. Le Comité des ministres du Conseil de l'Europe peut en effet, après consultation des Parties contractantes, inviter à adhérer à la Convention tout Etat non membre du Conseil de l'Europe. L'Albanie, la Belarus, la Lettonie, le Maroc, la Russie, la Tunisie et l'Ukraine notamment, ont ainsi déjà été invités à y adhérer, et d'autres Etats devraient l'être prochainement.

Le Programme d'activité de la Convention a développé diverses activités de recherche et d'expertise concernant les facteurs menaçant les espèces végétales et animales, ainsi que les milieux naturels côtiers. Un Séminaire sur la coopération en matière de conservation de la nature avec l'Afrique du Nord et du Nord-Ouest tenu à Dakar en juin 1993, a traité de la gestion de la faune commune et de la conservation des habitats, notamment des zones humides et habitats côtiers et marins. D'autres travaux concernent les zones humides et les bassins hydrographiques de type méditerranéen: un premier séminaire s'est tenu à Doñana en 1989 et un second à Ria Formosa en 1992, tous deux en liaison avec la Convention de Ramsar.

Composé des Parties contractantes et chargé de veiller à la mise en oeuvre de la Convention, le Comité permanent est parfois amené à adresser des recommandations spécifiques aux Parties. Certaines d'entre elles traitent de la conservation d'espèces côtières menacées:

- Recommandation N° 6 (1986) relative à la protection du phoque moine de la Méditerranée (*Monachus monachus*), du 4 décembre 1986;
- Recommandation N° 7 (1987) concernant la protection des tortues marines et de leur habitat, du 11 décembre 1987;
- Recommandation N° 8 (1987) concernant la protection des tortues marines à Dalyan et dans d'autres zones importantes de Turquie, du 11 décembre 1987;
- Recommandation N° 9 (1987) concernant la protection de *Caretta caretta* dans la baie d e Laganas, Zante (Grèce), du 11 décembre 1987;
- Recommandation N° 11 (1988) concernant la protection du phoque commun (*Phoca vitulina*) et de son habitat, du 9 décembre 1988;
- Recommandation N° 12 concernant la protection d'importantes plages de ponte pour les tortues en Turquie, du 9 décembre 1988;
- Recommandation N° 24 concernant la protection de certaines plages de Turquie d'une importance particulière pour les tortues marines, du 11 janvier 1991;

D'autres concernent l'espace côtier proprement dit:

- Recommandation N° 25 concernant la conservation des espaces naturels à l'extérieur des zones protégées proprement dites, du 6 décembre 1991 (VI, 1).

Il y a enfin lieu de noter que la Déclaration de Monaco sur le rôle de la Convention de Berne dans la mise en oeuvre des instruments internationaux mondiaux pour la conservation de la biodiversité, adoptée le 28 septembre 1994 à l'occasion d'un Symposium intergouvernemental, fait notamment état de la nécessité "d'identifier les processus et catégories d'activité ayant ou risquant d'avoir une influence défavorable sensible sur la conservation et l'utilisation durable de la diversité biologique et paysagère et de gérer ces processus pour éviter cette influence défavorable", ceci en accordant une attention prioritaire à certains secteurs, dont le développement côtier.

Le Conseil de l'Europe a par ailleurs institué deux réseaux de zones protégées qui comprennent plusieurs sites côtiers. Les autorités concernées doivent orienter leur gestion de manière à éviter toute intervention risquant de dégrader le milieu. Le Réseau européen de réserves biogénétiques créé par la Résolution (76) 17 du Comité des Ministres du 15 mars 1976, a pour objet de maintenir l'équilibre biologique et la conservation efficace d'un maximum d'exemplaires représentatifs de la flore, de la faune et des zones naturelles européennes. Il existe actuellement 286 réserves réparties dans 17 Etats. Plusieurs d'entre elles comportent une frange littorale. La Résolution (92) 20 a élargi le réseau aux Etats non membres du Conseil de l'Europe. Destiné à protéger les sites naturels les plus prestigieux de l'Europe de par leur valeur internationale et leurs qualités scientifiques, culturelles, esthétiques et/ou récréatives, le "Diplôme européen" a été créé en 1965 par la Résolution (65) 6 du Comité des ministres. Octroyé pour une période de cinq ans, renouvelable, il a jusqu'à présent été décerné à 41 sites répartis dans 15 Etats membres du Conseil de l'Europe. Plusieurs d'entre elles constituent des écosystèmes côtiers: réserve nationale de Camargue (France), réserve naturelle de Boschplaat (Pays-Bas), réserve

naturelle de Minsmere (Royaume-Uni), côte patrimoniale de Purbeck (Royaume-Uni), parc national de Doñana (Espagne), réserve naturelle de Scandola (France), zone panoramique de Fair Isle (Royaume-Uni), réserves naturelles de Bullerö et de Langviksskär (Suède), réserve naturelle de l'île de Monte-Cristo (Italie), réserve naturelle des Iles Selvagens (Portugal), parc naturel de la Maremma (Italie).

2. Le Centre de documentation et d'information sur l'environnement et la nature (NATUROPA) du Conseil de l'Europe, a organisé une série de colloques sur la protection des côtes méditerranéennes. Quatre réunions - tenues à Messine en 1988, à Izmir en 1989, à L'Escala en 1990, et à Bastia en 1991 - ont permis d'aborder les principaux aspects de la sauvegarde des côtes méditerranéennes par une étude et une présentation des différents instruments susceptibles d'assurer leur protection. Des Conclusions ont été adoptés pour chacune d'entre elles. Le Colloque de Messine s'est attaché à étudier la question de l'"achat des terres" comme moyen de protection. Les expériences du Conservatoire du littoral français et du National Trust britannique ont été analysées et présentées comme exemples possibles. Le Colloque d'Izmir a mis en relief l'importance des instruments de l'aménagement du territoire comme moyen de protection des côtes. Le développement en profondeur y a été mis en exergue. Le Colloque de L'Escala a permis d'étudier l'instrument "zone protégée". Le Colloque de Bastia enfin, a traité des parcs marins.
Le Centre NATUROPA a plus récemment organisé quatre Colloques paneuropéens sur le tourisme et environnement, dont l'un a traité de la protection des deltas (Bucarest et delta du Danube, Roumanie, septembre 1992). La Déclaration finale adoptée à cette occasion souligne l'importance qui doit être accordée à une politique intégrée d'aménagement du territoire.
Un Colloque international sur la protection des espaces côtiers de la mer Adriatique, réunissant de nombreux spécialistes des problèmes côtiers, a d'autre part été organisé en septembre 1994 en Albanie, à Tirana, en avant-garde de l'Année européenne pour la conservation de la nature 1995. Les Conclusions adoptées font état de la nécessité d'élaborer un instrument international contenant des principes et des engagements précis de gestion et de protection des côtes.

B. Organisation des activités humaines côtières

1. En ce qui concerne les activités humaines et tout particulièrement l'aménagement du territoire, trois textes adoptés par le Comité des ministres du Conseil de l'Europe en 1973, 1984 et 1985, sont essentiels pour les questions relatives à la conservation des côtes: la Résolution (73) 29 du 26 octobre 1973 relative à la protection des zones côtières, la Recommandation N° R (84) 2 du 25 janvier 1984 relative à la Charte européenne de l'aménagement du territoire, et la Recommandation N° R (85) 18 du 23 septembre 1985 relative aux politiques d'aménagement des régions maritimes. Ceux-ci définissent les principes généraux de planification et de gestion qui doivent guider l'aménagement des espaces côtiers de manière intégrée et en fonction d'objectifs à long terme. La nécessité de réglementer le dépôt sur les côtes ou le rejet en mer de tous les déchets ou substances nocives susceptibles de dégrader ou de polluer le milieu côtier, ainsi que celle d'instituer un contrôle régulier de la propreté des plages et de la qualité des eaux côtières le long du littoral sont mises en évidence.
Deux textes, fondamentaux pour les espaces côtiers, ont plus récemment été adoptés: la Recommandation N° R ENV (90) 1 du Comité des ministres aux Etats membres sur la Stratégie européenne de conservation, du 12 octobre 1990, et la Recommandation N° R (94) 7 relative à une politique générale de développement d'un tourisme durable et respectueux de l'environnement, adoptée par le Comité des ministres le 5 septembre 1994. Un projet de recommandation consacré à une politique de développement d'un tourisme durable dans les zones côtières est actuellement en préparation.

2. Le Comité des Ministres du Conseil de l'Europe a d'autre part été à l'origine de l'Accord EUR-OPA Risques majeurs - Accord

partiel ouvert en matière de prévention, de protection et d'organisation des secours contre les risques naturels et technologiques majeurs - en adoptant en mars 1987 la Résolution (87) 2. Son objectif principal est de dynamiser la coopération entre ses Etats membres, en faisant appel aux ressources et connaissances actuelles, afin d'assurer face aux risques majeurs (séismes, éruptions volcaniques, catastrophes industrielles...), une prévention, une protection et une organisation des secours plus efficaces. L'Accord est dit "ouvert" car tout Etat non membre du Conseil de l'Europe peut, après acceptation des Etats membres du Groupe de coopération institué, y adhérer.

Un réseau de douze centres européens spécialisés assurent des activités de recherche et de formation dans les domaines de la médecine des catastrophes, de la conservation du patrimoine culturel, de désastres technologiques, des risques géo- et morphodynamiques, de la géodynamique, des tremblements de terre, et de la contamination marine accidentelle. L'Accord a contribué à l'organisation d'une Conférence de la série "Clean seas" sur le thème de la surveillance comme outil au service des décideurs politiques. Un système d'alerte européen en cas de catastrophe est mis en place.

Le Centre européen de formation sur les désastres naturels situé à Ankara, le Centre européen pour la prévention et la prévision des tremblements de terre basé à Athènes, le Centre euro-méditerranéen sur la contamination marine accidentelle de La Valette, et l'Observatoire océanologique européen : prévisions des risques majeurs et régénération du milieu de Monaco en particulier, présentent un grand intérêt pour les espaces côtiers. L'Université de la Méditerranée, formée par un réseau d'une trentaine d'universités méditerranéennes, s'est joint à un projet de Formation européenne décentralisée sur les sciences du risque (Projet FORM-OSE : FORMation sciences du risque - Ouest (Europe) - Sud de la Méditerranée - Est (Europe)).

La Charte de Moscou sur l'Accord EUR-OPA Risques Majeurs comme plate-forme de coopération entre l'Europe de l'Est, le Sud de la Méditerranée et l'Europe de l'Ouest dans le domaine des risques naturels et technologiques majeurs, adoptée à Moscou le 2 octobre 1993, a pour but de mettre en place une organisation rapide et efficace des secours.

ACTIVITES INTERPARLEMENTAIRES ET INTERREGIONALES

Dans le domaine de la coopération interparlementaire et interrégionale, il y a lieu de mentionner qu'avec l'Assemblée parlementaire du Conseil de l'Europe, la/le CPLRE du Conseil de l'Europe développe depuis dix ans la coopération interrégionale en Méditerranée et traite à ces occasions des problèmes qui affectent les espaces côtiers. Trois Conférences des régions méditerranéennes ont ainsi jusqu'à présent été organisées: à Marseille en 1985, à Malaga en 1987, et à Taormina en 1993. La quatrième Conférence, qui se tiendra à Chypre (Nicosie et Limassol) du 20 au 22 septembre 1995, abordera la question du développement durable en tant que stratégie fondamentale pour faire face aux problèmes démographiques, migratoires et environnementaux. La cinquième Conférence sera ultérieurement organisée en France dans la région Languedoc-Roussillon.

La Conférence de Taormina notamment, a réuni 150 experts, parlementaires et mandataires des régions et collectivités locales venant de toute l'Europe et des pays du Sud de la Méditerranée. Les représentants des régions riveraines de la Méditerranée y ont adopté une Déclaration qui préconise la mise en place d'une politique de développement économique respectueuse des impératifs de la conservation des ressources naturelles dans une perspective à long terme. Une attention particulière devrait être accordée aux domaines suivants: gestion commune des ressources en eau; protection des rivages menacés par le tourisme, l'urbanisation, l'industrialisation, les transports et les activités militaires; protection des sols et lutte contre les pollutions, protection du patrimoine méditerranéen (patrimoine historique, culturel, paysages côtiers, zones protégées et parcs naturels).

L'Assemblée parlementaire du Conseil de l'Europe se penche également depuis plusieurs

années, sur certains aspects particuliers de l'environnement côtier. Elle a ainsi adopté d'assez nombreuses résolutions ou recommandations concernant par exemple la situation des forêts, la conservation et la gestion des ressources halieutiques, l'agriculture, ou encore la prévention et la protection contre les risques naturels.

La CPLRE a également développé des travaux concernant les espaces côtiers. Un Séminaire sur le tourisme et la politique intégrée de planification s'est tenu à Limassol en septembre 1989. La Déclaration adoptée à cette occasion fait valoir que le développement touristique au-delà d'un certain seuil, risque de détruire les biens - nature, patrimoine historique - qui sont les raisons même de l'attraction, de sorte que le coût de la restauration de l'environnement pourrait être supérieur aux revenus supplémentaires engendrés par le développement additionnel.

En ce qui concerne d'une manière générale la préservation des paysages, une Charte sur le paysage méditerranéen, élaborée dans le cadre de la CPLRE par les Régions de l'Andalousie, du Languedoc-Roussillon et de la Toscane, a par ailleurs été signée à Sienne le 1er juillet 1993 par les représentants de ces trois régions. Bien que non spécifiquement mentionnés, les paysages côtiers sont concernés.

Il semble que la connaissance des maux qui affectent les espaces côtiers soit, aussi bien que celle de leurs remèdes, chose désormais, sinon acquise, bien avancée. Il incombe dès lors aux gouvernements et aux responsables locaux, comme d'ailleurs aux "consommateurs" de ces espaces, de veiller à ce que l'utilisation qui en est faite ne conduise pas à la destruction de ce qui en fait l'attrait.

Espaces éminemment riches en espèces végétales et animales, particulièrement fascinants d'un point de vue esthétique, mais aussi particulièrement fragiles et menacés par des agressions de tout ordre, les côtes doivent faire l'objet d'une attention renforcée. Le Programme Action 21 adopté en juin 1992 à Rio de Janeiro, qui doit guider l'action de la Communauté internationale jusqu'au et pendant le siècle futur leur accorde une place spéciale dans son chapitre 17. Souhaitons que les principes d'action définis soient respectés. L'Année européenne pour la conservation de la nature (AECN) 1995, campagne paneuropéenne à laquelle plus de 40 pays participent et qui a tend a promouvoir la conservation de la nature non seulement dans, mais également en dehors des zones protégées, poursuit cet objectif.

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SOME ICES ACTIVITIES IN THE COASTAL ZONE ENVIRONMENTAL IMPACT ASSESSMENTS

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Key Words: Sand and Gravel Extraction; Mariculture, Integrated Coastal Zone Management, Codes of Practice; Environmental Impact Assessment

ABSTRACT

ICES activities encompass most marine science considerations of relevance to the provision of advice on the management of the marine environment and fisheries, especially in the North Atlantic area and adjacent seas. In recent decades an increased use of the coastal zone has resulted in the formation by ICES of Working Groups whose terms of reference have explicitly addressed the coastal environment. The activities of two of these groups, concerned with marine sand and gravel extraction and the environmental impact of mariculture, show our growing understanding of physical, chemical and biological processes in this area and, in particular, the need to manage the coastal environment in an integrated way. ICES is now in a position to provide clearer advice to its Member Countries and to regulatory commissions by means of Codes of Practice and other guidelines, which formulate the issues to be addressed to ensure the minimisation of the impact of anthropogenic activities in the coastal zone.

INTRODUCTION

The activities of the International Council for the Exploration of the Sea (ICES) encompass all aspects of those natural and anthropogenic factors that have an influence on the living resources of the sea. These activities consist, among others, of the evaluation of scientific statements made by expert Working Groups. These statements are then screened and reviewed by the ICES Scientific and Advisory Committees prior to information and advice being passed to ICES Member Countries and the various regulatory commissions (e.g., for fisheries and marine environmental protection). So far as issues related to the coastal zone are concerned, ICES has addressed various key issues over a number of years. Two of these issues, marine aggregate and sediment dredging and extraction, and the environmental impact of mariculture operations, have commanded specific attention.

Advice on marine aggregate dredging and extraction in ICES originates from the activities of its Working Group on the Effects of Extraction of Marine Sediments on Fisheries, which is overseen by the ICES Marine Environmental Quality Committee (MEQC), and the Advisory Committee on the Marine Environment (ACME). This Working Group has existed since the early days of the development of marine aggregate dredging which started to become a major industry in areas of the southern North Sea in the late 1960's. Although the 1968 ICES Symposium on the Biology of Early Stages and Recruitment Measurements of Herring was the first mention in ICES circles of the possible disturbance of herring spawning grounds by marine dredging operations, it was not until 1973 that this Working Group was established. Increased activities in the field of marine dredging subsequent to that time have meant that the Working Group has had and continues to have an ongoing series of important tasks. In 1974, ICES was informed of the results of full scale experimental dredging of approximately 1 million tonnes of gravel from an area along the French coast. Although it was clear that the

impact left by such operations were expected to remain for some time, the detailed effects on fishery interests could not be clearly predicted as this was an extremely complex issue which would require a series of multi-disciplinary studies to resolve.

Over the years the activities of this Working Group have provided a comprehensive picture of marine aggregate dredging, coastal engineering and related operations in the coastal environments of ICES Member Countries. It has addressed, inter alia, the effects of extraction activities on living resources in general and fish in particular. These include the nature of physical and chemical impacts on the seabed and the water column and the nature of biological impacts, especially consequences on sensitive species and communities. The Working Group has also addressed relevant management practices for aggregate extraction, including the development of laws and regulations, resource use planning activities, and monitoring activities.

In order to facilitate the implementation of the advice generated by this Working Group by the marine aggregate industry, a Code of Practice has been recently developed. This is known as the "Code of Practice for the Commercial Extraction of Marine Sediments (including minerals and aggregates)" and it endeavours to provide a set of guidelines to ensure the balanced and effective protection of the marine environment. In particular, it aims to ensure that commercially utilised fish, shellfish, and cephalopod stocks, and the fishing operations themselves, are not adversely affected by dredging activities.

The Code of Practice also calls for the preparation of an Environmental Impact Statement (EIS). This should be done by both the prospective contractor and the regulatory authority in order to form the basis for a balanced decision. In order to ensure that EISs are appropriately generated, the Working Group has now produced guidelines for the preparation of environmental impact assessments (EIA) of marine aggregate dredging. These guidelines will form the basis of subsequent technical considerations for marine environmental extraction. The basis of the guidelines is the recognition that the effects of marine aggregate extraction is both physical and biological. While the effects are often of a localised nature, assessments may also have to take into account the possibility that detrimental effects may occur far beyond the actual area of dredging. The guidelines also stress the need to evaluate the extent to which the proposed operations are likely to affect other interests of acknowledged importance to the area. Finally, in order to ensure a standardised application of these guidelines, the Working Group has now been charged with developing recommendations for the monitoring that is required to support these guidelines.

ICES believes that close adherence to all aspects of the Code of Practice will lead to the maintenance of a balance in favour of marine biota, particularly fisheries, when other possibly conflicting and adverse activities are being planned or executed. Fish and shellfish stocks, given a beneficial environment, are renewable resources with possibilities for long-term utilisation, whereas the extraction of marine sediments and minerals is comparatively short-lived. Marine aggregate and sediment extraction has the capability to produce a change that is not necessarily reversible.

The second area of ICES' concern in coastal management issues is the relatively new industry of mariculture. Presently ICES has a major scientific standing committee, the Mariculture Committee, and a number of Working Groups (including the Working Group on the Environmental Interactions of Mariculture) which examine mariculture activities. Any advice originating from these groups is peer reviewed by ACME before it is conveyed to ICES Member Countries or regulatory commissions.

Aquaculture has become of vital importance in many regions of the world, producing a prime food product in demand by consumers, as well as providing a potential source of socioeconomic benefits through employment and exports. In many regions, mariculture is identified as the only likely growth sector within fisheries. Aquaculture in marine and brackish waters (i.e., mariculture) has substantial potential for expansion, in both temperate as well as tropical regions. Progress in

mariculture development, however, will always be accompanied by a number of problems and constraints that arise with, or through the expansion of, the industry. As such, both the problems and constraints are essentially part of the environment and, consequently, consideration should be given to their wider environmental impact. The very presence of mariculture should help to discourage pollution from less environmentally friendly industries. Nevertheless, mariculture itself often produces its own pollution, albeit as a result of poor management. One of the public concerns frequently voiced with respect to finfish mariculture, and which is being addressed by ICES, is the use of therapeutants and the distribution and fate of these compounds in the coastal ecosystem.

Much of the work of the Working Group on the Environmental Interactions of Mariculture has related to the assessment of aquaculture impacts and interactions. It has designed and proposed monitoring schemes, the overall objective of which is defined to meet the biological requirements of the cultured organisms and, at the same time, achieve the environmental quality objectives within coastal waters set by regulatory authorities. In this way, the long-term use of the mariculture site should be assured by ensuring a close control on the accumulation of wastes.

Approaches to the monitoring and assessment of mariculture operations are now rapidly evolving, due largely to the incorporation of modelling activities within the monitoring and surveillance strategy. Such strategies are now being utilised by ICES Member Countries to assist them in the development of their own monitoring programmes.

The current paper provides an overview of:

the matters addressed by the Report of the Working Group on the Effects of Extraction of Marine Sediments on Fisheries, the Code of Practice for the Commercial Extraction of Marine Sediments, and the Guidelines for Environmental Impact Assessments of Marine Aggregates Dredging; and a brief history of the development of the Working Group on the Environmental Interactions of Mariculture and the key issues which it has addressed, especially those of relevance to integrated coastal area management.

EFFECTS OF EXTRACTION OF MARINE SEDIMENTS ON FISHERIES

Report of the ICES Working Group on the Effects of Extraction of Marine Sediments on Fisheries (ICES, 1992)

EXECUTIVE SUMMARY

Background

Aggregates are required principally for construction purposes, land reclamation, and beach replenishment schemes. As acceptable land-based sources are diminished, pressure is increasing in many ICES member countries to meet the demand with marine deposits. This in turn leads to greater potential for conflict between the marine aggregate extraction industry and other users of ocean space, in particular the fishing industry.

The ICES Working Group on the Effects of Extraction of Marine Sediments on Fisheries was convened in 1986 with the aim of increasing our knowledge and understanding of the impact of marine aggregate extraction activities on fisheries in particular, and the marine environment in general, as well as reviewing management practices adopted by member countries to control such activities. Members of the Working Group have met regularly to exchange information on these matters: the following report is a synthesis of the information compiled.

Objectives

The objectives are to review: marine aggregate extraction activities in the coastal and shelf environments of ICES Member Countries; the effects of extraction activities on living resources and fisheries; the management of aggregate extraction operations.

Progress .Thirty-three representatives from ten different ICES member countries contributed data to this report, or assisted in its preparation. All material was reviewed by members of the Working Group.

Marine Aggregate Extraction

The marine aggregate extraction industry is well established and growing in a number of ICES member countries, contributing up to 15% of some nations' demands for sand and gravel. While the report notes advantages accruing from marine aggregate extraction there are nonetheless a number of concerns relating to its negative implications for fishing, navigation, coastal protection, and benthic ecosystems.

The principal uses of marine aggregates (sand and gravel) are in construction projects, beach replenishment and land reclamation schemes, and the creation of artificial islands.

Physical and Chemical Impacts

Physical impacts of marine aggregate extraction arise from substrate removal and alteration of the bottom topography, creation in the water column of a turbidity plume, and sediment redeposition from this and from screening. The nature of these impacts varies according to the dredging method, the magnitude, and the location (Section 3.1). The physical impacts of trawling are similar in certain respects to those of dredging but in most areas affect a far greater proportion of the benthic environment (Section 3.5). Chemical impacts of extraction are considered to be minor owing to the low organic and clay mineral content of extracted material (Section 3.2).

Environmental Impacts

The biological impact of an extraction operation is largely dependent on the nature of the physical impacts and of the indigenous benthic communities and so is very much site specific (Section 3.3). Species considered to be potentially at risk as a result of marine aggregate extraction operations include sandeels, herring, and edible crab, as well as coregonid and other bottom-spawning fishes and maërl (Section 3.3). An approach to determining the scale of the effect on marine life and fisheries as a consequence of aggregate extraction is outlined. Rough calculations for the North Sea suggest that, unless spawning grounds are disturbed, effects on fish stocks are likely to be negligible overall although there may be areas of local significance (Section 3.4).

Beneficial interactions of marine aggregate extraction operations may occasionally arise, such as the concentration of fish stocks over dredged pits (Section 4.2.2).

Licensing

Most ICES member countries for which information is available have legislation and established review procedures for dealing with proposed aggregate extraction operations in the marine environment (Section 4.1.1). Scientific considerations to be taken into account when issuing all extraction licences should include potential effects upon shoreline stability, modelled where appropriate. The method of dredging, total quantity of aggregate to be extracted, and the extraction rate should all be stipulated in the extraction licence as a means of controlling the potential impact of the operation (Section 4.1.2). A "Code of Practice for the Extraction of Marine Minerals" is presented; it is designed to promote a good working relationship between the dredging industry and other ocean space users. Emphasis is placed on evaluating applications for prospecting and extraction in order to minimise the potential conflict between the dredging and fishing industries and to optimise the use of marine resources (Annex 1).

Resource Mapping

On the basis of available information, seabed sediment mapping is progressing well in most ICES member countries; resource mapping programmes have been initiated by some countries, but they generally lag behind those for seabed sediments (Section 4.2.1).

Monitoring

The use of electronic monitoring devices on board dredging vessels should be encouraged as beneficial to both the dredging company and the regulatory authority (Section 4.3.1). Physical and biological monitoring of extraction operations can be of great value in the protection of coastal and marine environments and fisheries resources (Sections 4.3.2 and 4.3.3).

CODE OF PRACTICE FOR THE COMMERCIAL EXTRACTION OF MARINE SEDIMENTS (INCLUDING MINERALS AND AGGREGATES)

1 INTRODUCTION

This code of practice is intended to promote sound management to ensure that the dredging industry operates in harmony with fisheries and other ocean space users. These guidelines are intended to provide a flexible framework that any country can adopt within its own regulatory system.

The following code of practice provides step-by-step advice on how marine dredging should be conducted in order to minimise conflicts with other users of the sea and optimise the use of marine resources. Specific consultation procedures with respect to fisheries are outlined in Appendix 1. Because of radical differences in approach by each country, this generalised code of practice is not intended to apply to navigational dredging. These recommendations relate primarily to prospecting and extraction of sedimentary materials, including sand and gravel, phosphorite, placer minerals, waste coal, and maδrl. The guidelines are intended to ensure that sufficient information is produced to enable an environmental impact assessment, covering the effects of the proposals on other interests including fisheries, to be carried out and an environmental impact statement to be produced as necessary.

2 PROSPECTING GUIDELINES

All potential conflicts between marine mining and other uses of the sea should be identified by the regulatory authority, along with relevant sea users and interest groups (government and non-government).Before the application for a prospecting licence is considered, the applicant should consult the groups identified in (1), above. It should be the responsibility of the regulatory authority to identify areas of particular sensitivity (e.g., herring spawning beds, marine conservation areas, archaeological sites, pipelines and cables) before any prospecting activity proceeds. The regulatory authority must ensure that appropriate prospecting techniques are adopted. The regulatory authority should ensure that an appropriate multilevel liaison network is established to permit timely decision-making at all stages of the exploration/development programme. Full details of the proposed prospecting programme should be submitted by the applicant to the regulatory authority for approval. There must be provision for a conflict-resolution procedure in which the regulatory authority, the applicant company, the fishery, and other interests participate. The exact procedure will depend on existing national practice.

Prospecting should cover the whole licensed area in order to provide a complete picture of the geological setting. All prospecting information compiled by industry should be submitted to the regulatory authority. Normal commercial confidentiality considerations should apply. Details of a prospecting licence will vary according to the requirements of the individual regulatory authority; however, it is recommended that the following elements be included:

- Identification of target commodities;
- Duration of prospecting licence;
- Specification of whether access to the prospecting area is exclusive or shared;
- Location of prospecting area (geographical coordinates);
- Types of prospecting techniques to be used (e.g., hydroacoustic methods, dredging, grab sampling, or coring);
- Details of the prospecting programme (e.g., timing and duration, vessel characteristics, geophysical line spacing, number and location of sample sites, volumes of material to be recovered, sample processing plans);
- Provision for notifying other marine users;

Liaison arrangements with other sea users and interest groups, as identified in Section 2.1.

An example of guidelines for consultation or liaison with fisheries interests is given in Appendix 1. Similar guidelines could be devised for other interest groups (e.g., conservation, navigation, military).

3 MINING GUIDELINES

Applicants for mining licences should submit outline proposals for informal discussions with the

regulatory authority. The regulatory authority should undertake consultations with authorities or agencies responsible for the following interests, as appropriate: a) Wildlife-conservation-environmental, b) Fisheries and mariculture,c) Defence, d) Energy, e) Navigation and harbours, f) Coastal protection, g) Engineering and construction works (e.g., cables and pipelines, sewer outfalls), h) Littoral areas (local planning authorities), i) Recreation/amenity interests, j) Waste disposal.

These consultations should include all relevant government and non-government organisations and interest groups likely to be affected by the proposal. The proposal should be published, indicating where relevant information can be obtained and providing an administrative address for all representations. All consultees should be informed of the outcome of the consultations and the decision of the regulatory authority. The regulatory authority should consider all representations received from consultees on the outlined proposals. Discussions and negotiations should take place as appropriate. A report should be prepared which sets out the proposals, the representations which have been received from those whose interests might be affected, and possible mitigating measures. This report should summarise the arguments for and against the proposal so that the merits of the proposal can be judged by the regulatory authority. In all cases, an environmental impact statement (EIS) should be prepared. If appropriate, the regulatory authority may also decide that an environmental impact assessment should be made in order to form the basis for a balanced decision. Details of a mining licence will vary according to the requirements of the individual regulatory authority; however, it is recommended that the following elements be included:

- The type of commodity to be mined;
- Period of the mining licence and provisions for premature termination of the licence;
- Specification of whether or not the permit for extraction is assignable, exclusive; or non-exclusive;
- Location (by coordinates) of the licensed area for extraction and any additional area for manoeuvring;
- Total quantities permitted for extraction/processing within the period of the licence. The point of measurement should be specified in the licence (for example, whether in the hopper or when landed). Extraction rates over specified time intervals could also be included, for example, an annual extraction limit rather than a total amount;
- The minimum water depth for extraction, stipulated where necessary, and a maximum permitted sediment depth of extraction, stipulated where appropriate;
- A requirement to leave behind a substrate of specified composition, where appropriate (in most cases, this will be similar to that which existed before extraction);
- The methods of dredging in detail;
- Specification of whether screening or other forms of processing may be carried out, and if so, where;
- Incorporation of an agreed and appropriate programme for monitoring the effects of extraction activities;
- Provision for access and on-board/on-site inspection by an appropriate authority to the dredger's log, company's records, etc., allowing surveillance to ensure that amounts stipulated by the licence are not exceeded, areas are not transgressed, and physical conditions are observed;
- Appropriate means of ensuring compliance (i.e., electronic monitoring devices), as requested by the regulatory authority;
- A minimal navigational standard on the dredging vessel, stipulated by the regulatory authority;
- Regular return of information on quantities extracted, supplied to the appropriate authority by the dredging company;
- Provision for seasonal or temporal restrictions, including the suspension of dredging where appropriate.

In addition to the Code of Practice, Guidelines for Fisheries Consultations (ICES, 1992) have been established to provide a framework for the information exchange required during consultations. Regulatory authorities should ensure that

all appropriate topics have been addressed in sufficient detail to enable them to make an informed decision about the license application and any conditions necessary to protect fisheries interests. It is anticipated that dredging information will be supplied by the mining company and fishery information will be supplied by the fishing authorities.

GUIDELINES FOR THE PREPARATION OF AN ENVIRONMENTAL IMPACT ASSESSMENT EVALUATING THE EFFECTS OF SEABED AGGREGATE EXTRACTION ON THE MARINE ENVIRONMENT (ICES, 1994c)

Introduction

This guidance describes the requirements of an Environmental Impact Assessment (EIA) such as required by the "Code of Practice for the Commercial Extraction of Marine Sediments (Including Minerals and Aggregates)". It forms the basis of the subsequent technical considerations for marine aggregate extraction.

The effects of marine aggregate extraction will be both physical and biological, as shown in a comprehensive literature review on the impacts on fisheries and the marine environment of sand and gravel extraction (ICES, 1992). However, the significance to the wider marine environment of such dredging-induced changes will clearly depend upon the size and location of the licensed areas.

An EIA should normally be prepared for each operation, but in cases where several extraction operations in the same area are proposed, a single impact assessment may be adequate.

A framework for the content of the EIA should be established by early consultation with interested parties, including the licensing authority, on all concerns, both regionally and within the proposed area of extraction.

Environmental Impact Assessment

Nature of the deposit and proposed method of extraction

The resource should be identified by geographical location and local and regional setting, and described in terms of:

- the bathymetry of the area;
- the distance from, and natural processes affecting, the nearest coastline;
- the geological history, including the source of the material, type of material, mean thickness of deposit, evenness of the deposit over the proposed extraction area, the nature of underlying deposits, sediment particle size, as well as the geological stability of the deposit;
- the natural mobility of the sediments.

The total quantity of material in the resource should be estimated along with proposed extraction rates and the expected life of the deposit. The method of dredging, including the effect of different suction equipment upon the seabed and the need for on-board processing, should be described.

Physical impact

The main physical impacts of marine aggregate extraction include possible changes in sediment topography and type through the removal of material, and suspension and resettlement of fine particles.

To assess the physical impact of aggregate extraction activities, information should be provided on:

- local hydrography, including tidal and residual water movements;
- wind and wave characteristics;
- average number of storm days per year;
- estimates of bedload transport;
- the occurrence of sand waves and topographic features;
- contamination of sediments and possible release of contaminants by dredging;
- natural suspended sediment loads under both tidal currents and wave action;
- transport and settlement of fine sediment suspended by the dredging activity and its impact on normal and maximum suspended sediment load;
- dispersion of an outwash plume resulting from hopper overflow or on-board processing and its impact on normal and maximum suspended sediment load;
- implications of extraction for coastal processes;

- implications for local water circulation resulting from removal or creation of (at least temporarily) topographical features on the seabed;
- regional, as well as local, effects of the above processes should be considered. When no data can be obtained, estimates may be acceptable.

Biological impact

The principal biological impacts of marine aggregate extraction may include the disturbance and removal of benthos and alteration of the substrate.

To assess the biological impact of aggregate extraction, the following information should be provided:

- a description of the benthic communities (e.g., species and abundance) within the proposed extraction area, including temporal and spatial variations;
- information on the fishery and shellfishery resources, including spawning areas with particular regard to benthic spawning fish, nursery areas, overwintering grounds for ovigerous crustaceans, and known routes of migration;
- predator/prey relationships between the benthos and demersal fish species;
- the recolonization time for the denuded sediments;
- areas of special scientific or biological interest in or adjacent to the proposed extraction area, such as adjacent sites designated under local or international regulations (e.g., sites designated under the Ramsar Convention, the World Heritage Convention or the UNEP "Man and the Biosphere" programme).

When no data can be obtained, estimates may be acceptable.

Interference with other legitimate uses of the sea

The assessment should consider the following in relation to the proposed programme for exploitation of the resource:

- areas of natural beauty or significant cultural or historical importance in or adjacent to the proposed extraction area;
- commercial fisheries in the area including seasonal fishing patterns, species caught, type of gear used, value of fish, and location and number of boats and fishermen involved;
- shipping lanes;
- military exclusion zones;
- engineering uses of the seabed (e.g., undersea cables and pipelines);
- adjacent areas of the sea designated in the present or past as sites for the disposal of dredged or other materials;
- adjacent current or proposed extraction areas;
- location of wrecks and war-graves in the area and general vicinity.

Evaluation of impact

In evaluating the overall impact, it will be necessary to identify and quantify the marine and coastal environmental consequences of the proposed activity and the basis of a monitoring plan. The EIA should evaluate the extent to which the proposed aggregate extraction operation is likely to affect other interests of acknowledged importance in the area. The environmental consequences of the aggregate extraction operation should be summarised as an impact hypothesis.

The impact hypothesis should include consideration of the steps that might be taken to mitigate the effects of extraction activities. These may include:

- the selection of dredging equipment and timing of dredging operations to limit impact upon benthic communities and spawning cycles;
- modification of dredging depth to limit changes to hydrodynamics and sediment transport and to allow future safe use of fishing gear;
- zoning the area to be licensed or scheduling extraction campaigns to protect sensitive fisheries or to respect access to traditional fisheries.

It is also necessary to demonstrate the need to exploit the resource in question through careful, comparative consideration of the local, regional and national need for the material in relation to the identified impacts of the proposal and the relative environmental and social costs of provision of material from other sources, both marine and terrestrial (ICES, 1992).

ENVIRONMENTAL INTERACTIONS OF MARICULTURE

Brief Historical Background

The issue of environmental impacts of mariculture was initially addressed in the ICES community by the establishment of an Ad Hoc Study Group on the Environmental Impacts of Mariculture in 1985. Since its formation, the group has been chaired over the last decade by Professor Harald Rosenthal (Germany). Early work involved the participation of experts nominated from 11 Member Countries. Initially the group worked by correspondence and first met in April 1987 to prepare a report. In its 1987 report the group identified a number of environmental issues of international importance which included:

- the effects of mariculture on microbial communities and on the possible spread of pathogens;
- possible changes in the populations of marine algae (phytoplankton and macroalgae);
- the influence of mariculture and its physical structures on sedimentation to the benthos;
- the use and the environmental effects of chemicals (including therapeutants/medicaments) in mariculture;
- the importance of site selection criteria in minimising environmental effects of mariculture operations;
- the state-of-the-art in developing predictive models of mariculture impacts.

In 1987 the Council upgraded the Study Group to a Working Group, a more enduring unit within the ICES hierarchy. At its 1988 meeting new terms of reference were addressed. In addition to the terms of reference previously mentioned, the Working Group was charged with producing guidelines which could be used in resource management and to compile a directory of chemicals, and their properties, currently used in mariculture, with a view to providing advice to Member Countries. [The review of chemicals in mariculture was vigorously pursued by the group and culminated in the publication of the report Chemicals in Mariculture (ICES, 1994b) in August 1994.]

In 1991, the Working Group became involved in a survey of monitoring and modelling programmes related to the assessment of the impact of mariculture, and in its 1991 report coastal zone management was introduced and defined as a "means of anticipating and thereby minimising potential ecological change associated with mariculture development". Several members of the ICES Working Group participated in the Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) meeting on "Environmental Impacts of Coastal Aquaculture" in January 1991. At the GESAMP meeting, the concept of an Environmental Impact Assessment (EIA) was presented (see Fig. 1).

In 1992, the Council renamed the group the Working Group on Environmental Interactions of Mariculture to reflect a broadened appreciation and study of mariculture with other human activities in coastal areas. New terms of reference turned the group's attention to:

- developing criteria for and a standard system of monitoring and reporting;

delineating the scope and nature of environmental interactions between mariculture and other uses of coastal marine resources;

- providing advice on approaches in such areas as improved site selection;

through advances in husbandry to minimise conflicts between mariculture and other coastal zone activities;

- reviewing and evaluating national monitoring programmes and preparing regular status reports on the impact of mariculture within ICES.

Since the establishment of ACME in 1992, a close working relationship has been established between the Working Group and the Advisory Committee, with ACME directing terms of reference relating to ICES' advisory functions. In 1993, the Council identified additional terms of reference with the Working Group being asked, inter alia, to:

- evaluate the potential environmental effects of new culture systems in ICES Member Countries;
- assemble and comment on the evidence for the interactions of complexed and/or particle-bound contaminants (e.g., antibiotics, antifoulants, biocides) from fish farms with marine flora and fauna and the significance of these interactions within marine ecosystems;

- prepare guidelines on the ecotoxicological information necessary to permit assessment of the relative environmental impacts of therapeutants.

Members of the Working Group also developed and coordinated a special Theme Session on "Mariculture and Coastal Zone Management (CZM)" at the 1994 ICES Annual Science Conference held in St. John's, Newfoundland, Canada. The session included a number of international contributions:

A case study of the Seto Inland Sea (Japan) showed how that country is addressing the relationship of mariculture and environmental change by monitoring and regulating nutrient concentrations that influence the appearance of toxic algal blooms (CM 1994/F:31).

A review of the coastal zone research in different Asian countries showed how a lack of coordinated communication among different government departments with responsibilities for aquaculture can cause developmental problems, particularly when specific mariculture legislation does not exist (CM 1994/F:27).

The Swedish model used for CZM showed how an integrated multilevel government approach was very efficient in resolving and preventing user group conflicts while defining future mariculture development (CM 1994/F:10).

The planning process for CZM encouraged the approach of integrating all levels of government and users of renewable resources; moving from a management policy based on a single land based activity to a multiple user-functioning ecosystem approach was advocated (CM 1994/F:28).

Norway is using modelling methods for CZM and is incorporating carrying capacity and environmental impact models to determine mariculture loading and the appropriate environmental monitoring required (CM 1994/F:26).

The Canadian Nova Scotia example showed how both direct community involvement and their perceptions must be included in a proactive manner to resolve CZM problems (CM 1994/F:23). The major discussion in the Theme Session revolved around the point that CZM is based on understanding the ecosystem carrying capacity of the mariculture site and the inter-relationships of all the coastal activities, including the regulatory framework of the different government managers. CZM is a basic cornerstone for the continued development of mariculture in response to the need for organised sustainable development.

Current Issues

A number of relevant issues that have been highlighted by the Working Group in 1994 are:

Potential environmental effects of new culture systems in ICES member countries. At its 1994 meeting the group discussed an optional scenario for salmon cultivation in Norway which was presented at the Trondheim Technical Conference on Aquaculture in 1993 (see Fig. 2). Cage farming is the most cost-effective grow-out system for salmon at present but alternative strategies (e.g., utilising a variety of combinations of land-based and water-based systems) are receiving increasing consideration by the industry as a move to overcoming environmental problems and to conform to regulatory measures.

New approaches to environmental assessment and monitoring of mariculture development. A new approach to environmental assessment and monitoring (MOM, developed by A. Stigebrangt, Sweden), which will be tried out in Norway in 1995, was presented at the 1994 meeting. The relationships among the four components of this approach (the model, the monitoring programme, the level of exploitation [i.e., fish production], and the level of surveillance) are illustrated in Fig. 3. The interaction among the four components of MOM (the fish module which simulates the actual effluent, the water quality module which simulates dissolved compounds and oxygen, the dispersion module which simulates the farm area, depth and current conditions, and the sediment module which simulates the accumulation and decay of the waste) are shown in Fig. 4.

The role of models in mariculture and recent relevant developments in modelling. In its 1994 report the group identified the main goals of modelling in the context of mariculture as the following:

providing information on environmental issues to regulatory agencies. (This is essential for effective

planning of development in the coastal zone where defining the holding capacity and/or carrying capacity are of great importance.);
modelling as a means to improve husbandry and optimise productivity, providing advice on site selection and management practices;
design of practical and appropriate monitoring strategies which allow assessment of regulatory thresholds and acceptable risk;
coastal zone management advice, including socioeconomic factors such as value of production, costs of input, employment implications and other macroeconomic issues related to the contribution of mariculture to regional scale economy and employment.

These goals raise more specific requirements for model development:

- the modelling approach and design should include an appropriate and flexible interface to be accessible to those making regulatory, monitoring and socioeconomic decisions;
- model output should include ecologically significant consequences as well as more easily quantifiable loading values;
- there is a need to define thresholds of environmental degradation;
- different types of models are required.

Integration of Mariculture into Coastal Zone Plans and Management Strategies

The Role of Mariculture in Integrated Coastal Zone Management (ICZM)

The mariculture industry is relatively new and its development has coincided with a substantial increase in environmental awareness. Unlike many other industries located in the coastal zone, mariculture relies heavily on natural aquatic resources for its existence, and it is characterised by the demand for a high quality environment. Mariculture development, because of its site specific selection requirements, is frequently forced into remote and disadvantaged regions with limited opportunities for development. However, a parallel increase has occurred in a number of other competing interests for coastal space. The mariculture industry operates in all environments (e.g., physical, social, economic), requires many inputs to be successful and also has multiple impacts on these environments, some positive and some negative. On the one hand, in the physical and biological environment, mariculture has been accused of visual, organic, chemical, and genetic pollution in addition to disease and parasite transfer to the native fish populations as well as being the cause of navigational hazards. On the other hand, mariculture offers employment and economic benefits from living marine resources, and the presence of these will help to discourage pollution from less environmentally friendly industries. The future role of mariculture in integrated coastal area management (ICAM) is to develop the industry with a full appreciation of the ecosystem - industry interdependencies and become a legitimate sub-system of the overall ecosystem. Mariculture techniques and planning and management must be developed with natural ecosystems and other coastal users in mind so that negative impacts can be reduced.

Pro-active Coastal Zone Planning and Management for Sustainable Mariculture

There is an urgent need to promote pro-active approaches for planning and managing mariculture as an integral part of the coastal zone management plans and investment strategies. Plans and management strategies must be based on sound scientific management principles for the protection of environmental processes which maintain the functional integrity of coastal ecosystems and sustain mariculture and other renewable resource dependent activities. Although the process of integrating mariculture in planning processes has started in a significant number of ICES countries, full realisation of coastal zone management practices can only be implemented by incremental steps as part of an overall strategic approach where different scenarios between communal management and private property rights obligations may co-exist depending on local and regional development priorities. Among other objectives, it is important to (a) promote institutional arrangements that foster integrated multi-sectoral planning of coastal resource utilisation and facilitate the transfer of new developments between scientists, industry, and regulatory bodies; (b) improve evaluation of the capacity of living coastal resource-systems to

sustain mariculture within a multiple-use management framework; and (c) initiate interdisciplinary research into the planning and management of mariculture by development of criteria to help evaluate the benefits and costs of mariculture, including the socioeconomic impact and corresponding cultural implications. Council Resolution 1994/2:24(d) charges the Working Group to study the interactions of mariculture with other users of the coastal resources and analyze the outcome of the proposed workshops and study groups in order to prepare guidelines for the management of mariculture within the larger context of a Coastal Zone Management Programme (CZMP).

Preparation of Guidelines

The Working Group is preparing guidelines for policy makers, planners, and managers responsible for formulating and implementing CZMP. These guidelines will, inter alia, address the following issues/subjects:

Inventory, mapping and development of Geographical Information Systems (GIS) for land and water resources in the coastal zone; Different users associated with the coastal zone conflicts;

Institutional infrastructure and legal system;

Integration and coordination of mariculture activities within the regulatory system adopted by the authorities responsible for the coastal zone; Planning of mariculture and other activities at the community level; Public education in mariculture at the community, regional, national and international levels; International cooperation for solving various issues;

International conventions and bodies.

Current Events

Some relevant ICES events taking place in 1995 are: A Workshop on Principles and Practical Measures for Interaction of Mariculture and Fisheries in Coastal Area Planning and Management to be held in Kiel (Germany), from 19-22 July 1995.

A Workshop on "Modelling Environmental Interactions in Mariculture" to be held in Dartmouth (Canada), from 6-8 September 1995.

A Theme Session on "Mariculture: Understanding Environmental Interactions" to be held at the ICES 1995 Annual Science Conference (21-29 September, Aalborg, Denmark).

RATIONALE FOR FURTHER WORK

The Rio Earth Summit resulted in a programme of action for sustainable development worldwide - the Rio Declaration from the United Nations Conference on Environment and Development (UNCED, 3-14 June 1992). Out of this emerged the Agenda 21 action programme, with Chapter 17 relating to protection of the oceans, all kinds of seas including enclosed and semi-enclosed seas, and coastal areas and the protection, rational use and development of the living resources.

The work and operations of the ICES Advisory Committees are described in Rule of Procedure 26: The Advisory Committees shall be responsible, on behalf of the Council, for providing scientific information and advice to intergovernmental bodies and Member Governments. The Advisory Committees may also provide scientific information and advice on such matters as the Council or the Committees may consider relevant.

The Advisory Committee on Fishery Management shall be responsible for scientific information and advice on living resources and their exploitation.

The Advisory Committee on the Marine Environment shall be responsible for scientific information and advice on the status of the marine environment (including marine pollution) and its consequences on living resources and related human activities.

The Advisory Committees of ICES are operating, by coordinating and directing the Council's many Study and Working Groups, within the spirit of the following programme areas identified in Chapter 17, viz.: Integrated management and sustainable development of coastal and marine areas, including exclusive economic zones; Sustainable use and conservation of marine living resources of the high seas; Sustainable use and conservation of marine resources under national jurisdiction; Addressing critical uncertainties for the management of the marine environment and

climate change; Strengthening international, including regional, cooperation and coordination. Because of the importance of ensuring sustainable development in the coastal areas by the rational utilisation of living marine resources, both through fisheries and mariculture, ICES Advisory Committees will continue to place firm emphasis on integrated coastal management.

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Fig. 1. Flowchart illustrating the Environmental Impact Assessment (EIA) process for coastal zone management as practised in New Zealand.

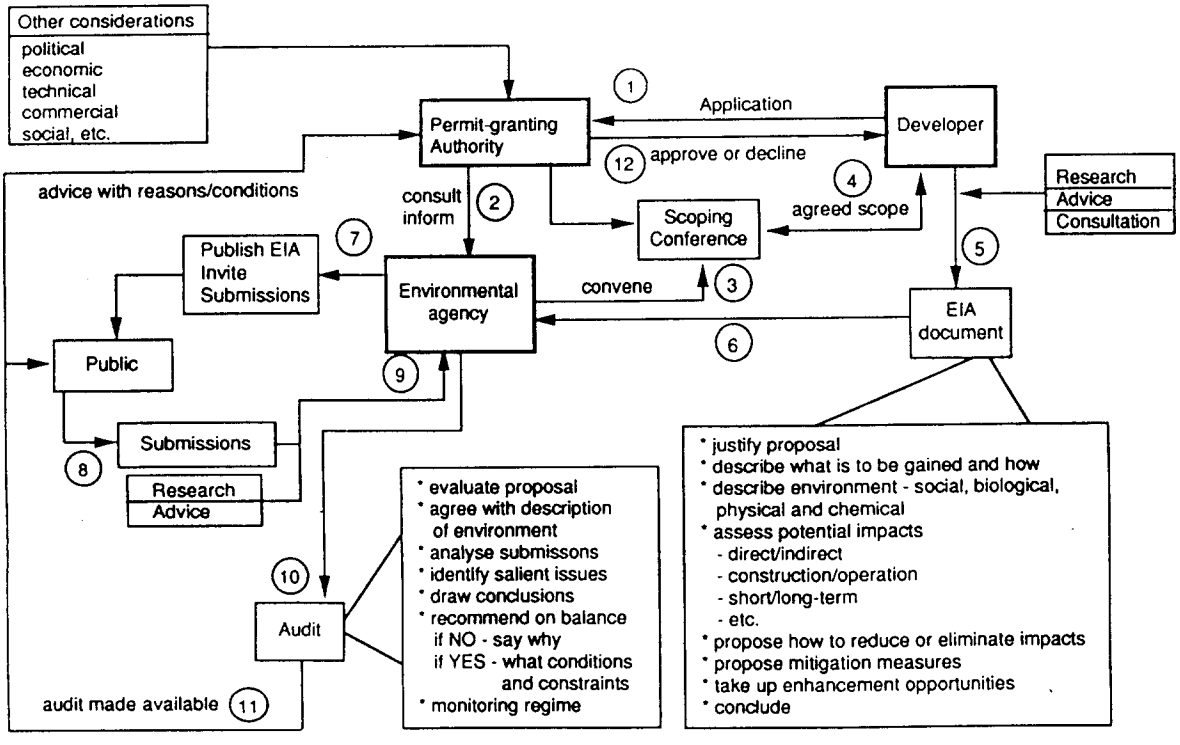


Fig. 2. Changing culture strategies in Norwegian salmon farming. Various combinations of freshwater and marine production scenarios are emerging that partially relieve the environmental load to marine coastal waters even if production increases further.

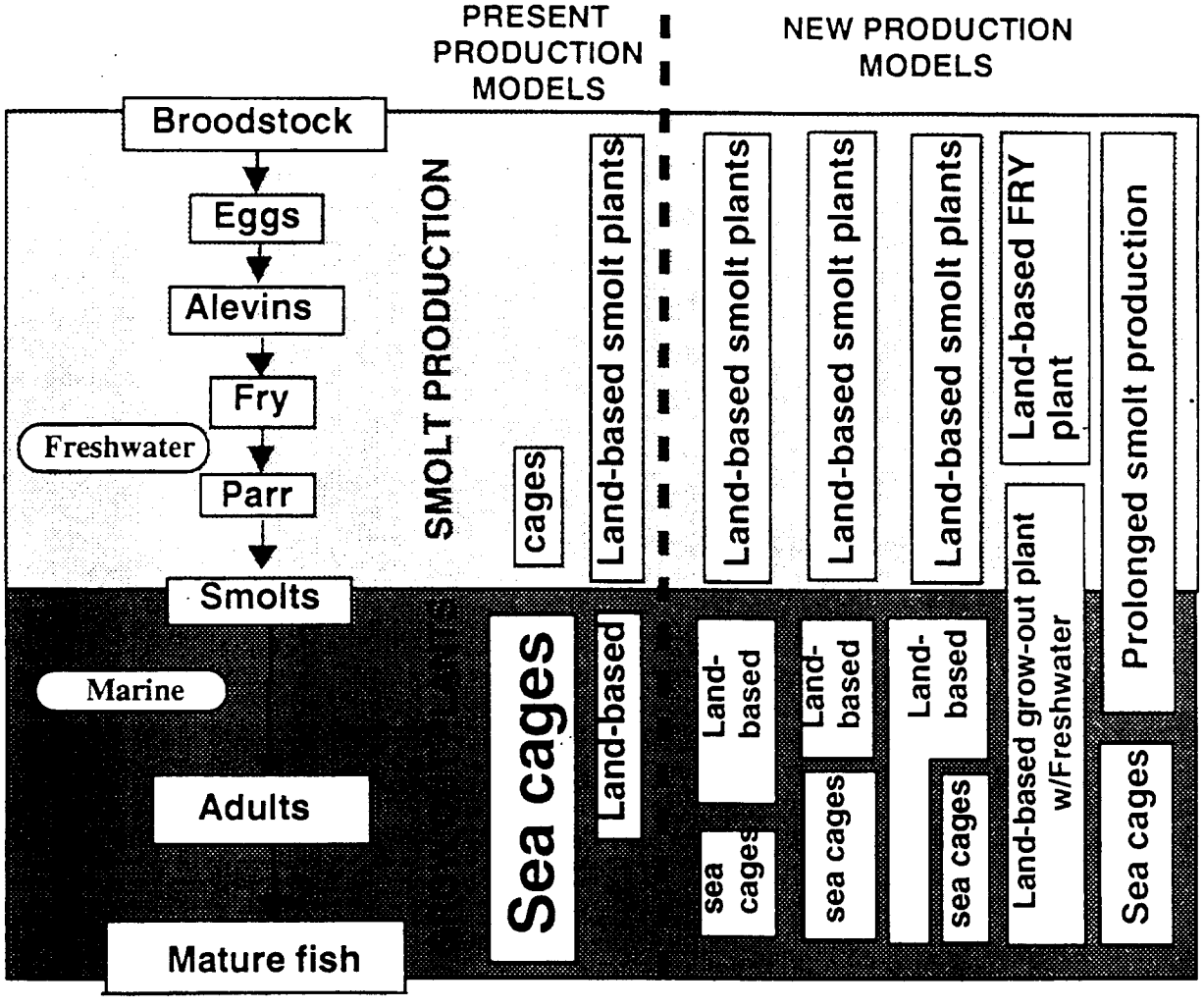


Fig. 3. Principle elements of the Norwegian MOM programme.

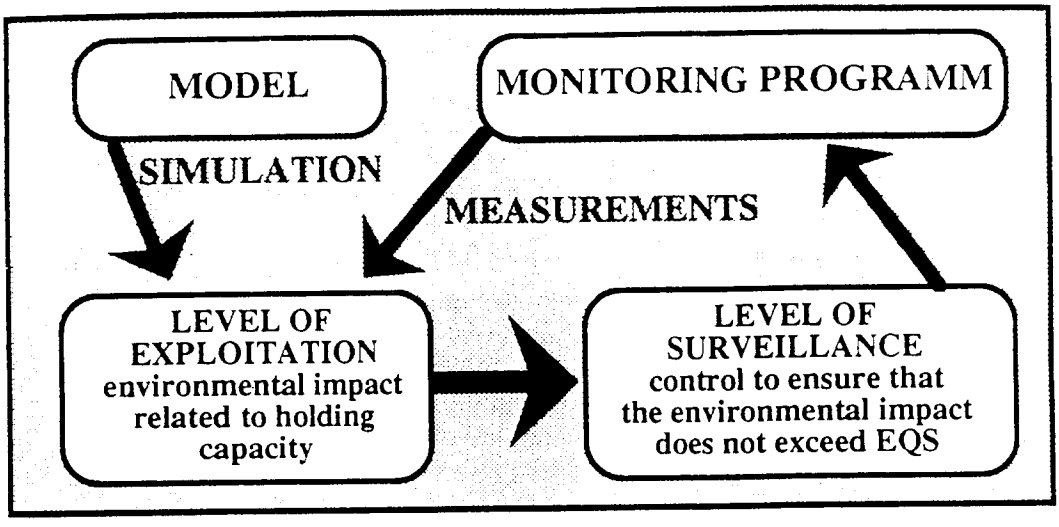
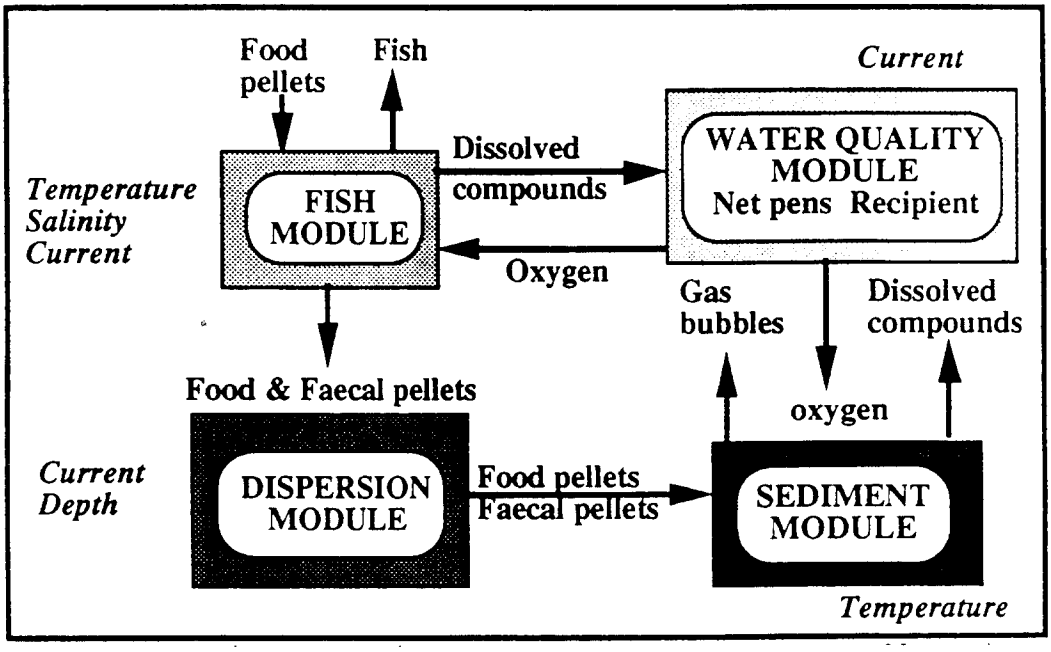


Fig. 4. Schematic representation of the essential sub-models of the Norwegian MOM programme for monitoring and modelling environmental impacts of mariculture for regulatory purposes.



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TECHNOLOGICAL DEVELOPMENT FOR THE EFFECTIVE UTILIZATION OF COASTAL SEA IN JAPAN

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ABSTRACT
The present situation and the views on future directives on environmental conservation and development of the coastal sea with respect to coastal change, such as topographical, environmental and economical changes in Japan, are discussed in this paper. The author believes that it is necessary to balance environmental conservation with sustainable development, in order to ensure a continuous economic development. As an example of this development, the Japan Marine Science and Technology Center (JAMSTEC) is introduced.

1. INTRODUCTION
Japan consists of 6,582 islands, and has a total shoreline of 33,889 km. About 60% of the population (120 million) live in the coastal zone. In order to protect the lives and property of those citizens who live in the coastal zone which suffers periodically from hazards caused by the ocean, to improve their quality of life and to improve their cultural environment, the Japanese government and local governments have made an effort to promote the development and construction of facilities for protection coastal land from storm surges, high waves and strong current of the ocean. Furthermore, fisheries, surface transport, marine sports and leisure have been improved by development of new technologies. However, in these days, other problems occur. These are the environmental problems caused by the "greenhouse effect", pollution or/and contamination, and "coastal change". Social problems due to changes in industrial activities in the coastal zone and those of fisheries are common. In order to realize a more wealthy society, we need to tackle these problems. In such a case, we need to develop new technologies.
In this paper, the author discusses the tendency of coastal development in Japan, and introduces several new technologies for improvement of the quality of the coastal seas, conducted by JAMSTEC through its R&D programme.

2. COASTAL DEVELOPMENT IN JAPAN
2.1 Categories of Coastal Development
Coastal development in Japan is classified in the following categories:
(1) Conservation of the coastline
In order to protect lives and property of people who live in coastal zone from big waves, tidal flooding, tsunamis and erosion, many kinds of constructions were developed along the coastline (Fig. 1). Already, more than 40% of the Japanese coast is covered with such artificial constructions through efforts by the national and local governments. These conservation works save lives and properties; however, it seems to obstruct the opportunities to enjoy the sea. Recently, several new types of coastal constructions, which promote leisure opportunities have been constructed.
(2) Development of new space in coastal seas
The ocean has a huge space and several kinds of natural resources. Japan, on the contrary, is densely populated, especially in coastal zone and has few resources. Consequently, we need to find effective methods for an efficient and significant utilization of the coastal sea. Particularly, we have to promote a more effective aquaculture and the construction of artificial land for habitation (Fig. 2), industries, airports, power plants, for convenient systems of transportation and traffic, and for the promotion of marine sports and amusement. From the point of view of construction of new land, we need to protect the erosion at the coast. However, sometimes, such development may destroy the natural coastal systems, such as wetland, tidal land, coral reefs,

algae-beds and coastal ecosystems. The author believes that each development should be a "sustainable development", which maintains a proper balance between nature and humankind. So, it is necessary to be careful about damage caused by development.

(3) Promotion of industries in coastal zone

The ocean has large quantity of living and mineral resources. Fishery is a very important industry for coastal zones, and it may become even more valuable in the near future with respect to the global population growth. The Japanese Government is eager to promote aquaculture, because it can sustain the population and economies in many fishing villages. The author believes that we must not lose or reduce our fishery and aquaculture "potentials", as is shown in Fig. 3. Consequently, we have to promote continuously every effort for development and study, and apply new technologies in coastal seas.

2.2 Present Situation of Coastal Development in Japan

In every category of coastal development, a large number of artificial constructions such as breakwaters, seawalls, block mounds, artificial islands, over-sea bridges and undersea tunnels have been constructed and this process will continue. A large amount of the state budget was also used for shore and sand beach protection from erosion and for the creation of new coastal areas. However, coastal changes occur increasingly at many places, in spite of the great efforts by national and local governments in the last 50 years. These coastal changes are not only caused by oceanic processes but also due to impacts from land. For example, the quantity of sand supply by Japanese rivers to beaches has been reduced, because many rivers have been more intensively used for water supply, agriculture, protective constructions for floods. In such cases, the beaches can not sustain their profiles.

The value of natural ecosystems has been reconsidered in these days. Marine ecosystems are indicative for the quality of the marine environment, which is affected by pollution and contamination, and by a change of sea level and water temperature. In the last years, many R&D projects on coastal environment and coastal ecosystem were conducted in Japan. However, it is very difficult to understand the mechanism of the change of ecosystem and to predict precisely its change in the future.

We, all scientists of multidisciplinary interest, every administrator of a related category and every involved company show cooperation for attaining an optimal quality of the coastal environment.

2.3 Future Direction

After the collapse of the Japanese economic prosperity, we had to change our mind. Before 1993, our economic benefit had the highest priority. But, in these years, the priority on environmental concern becomes increasingly in view. But due to the global population growth, the economics need to be activated as well. In such a situation, we need to determine the balance between development and environment in order to keep "sustainable development" for the next human generation.

Sometimes, we need to stop or even give up to continue to develop. Sometimes, we need to change original plans to introduce considerations on the environment. Sometimes, we introduce new tax systems or new laws in order to mitigate the development. And, sometimes, we need to try to discover new technologies to solve such difficult controversies. Including some countermeasures for coastal change, conservation of coastal ecosystems and promotion of fisheries and other coastal industries, new technologies should continuously be developed and utilized.

3. ACTIVITIES AT JAMSTEC3.1 R&D ON COASTAL ECOSYSTEM STUDIES

In order to establish a conservation policy on coastal environmental conservation, JAMSTEC began to promote R&D programmes on coastal ecosystems. As a first step, JAMSTEC concentrated its potential on coral reefs. The main argument was the very sensitivity of coral reefs with respect to environmental changes, especially coastal change, even when the reef productivity is high. The programme involved site survey, monitoring, development of a physical and

biological numerical model, jointly with R&D on new monitoring technologies. We hope that some results of these studies will contribute to establish effective countermeasures against the on-going coastal changes.

3.2 Development of a floating wave power device

JAMSTEC has developed a new type of a floating wave power device, as shown in Fig. 4. It can absorb wave power and convert this into electricity. On the other hand the sea area behind the device has calmed down, while it does not obstruct the exchange of seawater in the bay. This means that the device contributes not only electricity generation, but it creates space for aquaculture and conserves the coastal environment. From this year on, JAMSTEC will start to design and construct a prototype of 50 m length, and will carry out its test in 1998 and 1999.

3.3 R&D on new technologies for the promotion of aquaculture

Every local government of a coastal region is involved with R&D on coastal development, conservation and environment. However, they have usually little information on, and potential for, the development of new technologies. So, JAMSTEC has conducted since 1987 several kinds of R&D programmes on new technologies, which contributed to the increase of profits and improvement of the environment, and set up observation and monitoring studies as cooperative projects with the local governments, in particular for aquaculture.

These R&D projects up to 1994 are:

a) Transplanting technology of coral,
b) Artificial enclosures in the bay, using electrical screens,
c) Artificial sea floor for aquaculture in Abalone,
d) ROV, equipped with optical fibre cable systems for observation on deep sea bed,
e) Algae-bed renewal systems,
f) Effective utilization of deep sea technology,
g) R&D on refreshment of seawater in the bay using "mesocosms", and
h) Sea bed clearing system.

We hope some results of these R&D projects can be applied to other countries too.

4. CONCLUSIONS

The Japanese coast has been changed from ancient times up to now by geophysical phenomena such as "plate tectonics", change of sea level and erosion caused by natural phenomena and/or artificial activities. From the point of view of economics, culture and life, the coastal zone is a very valuable zone for mankind to live and work. Consequently, we, human beings have a duty to conserve and improve this zone for future generations. On the other hand, we need to improve the coastal zone safety and economic value. In such a case, we should make efforts not only to conserve and to protect it from "coastal change" but also activate industries and other economic activities in coastal zone in order to arrive at "a real sustainable development." In other words, we should balance the conservation and the development.

Fig. 1. A typical case of shore protection works against erosion, constructed by the Ministry of Construction in Japan. Many block mounds were constructed in front of a sand beach.

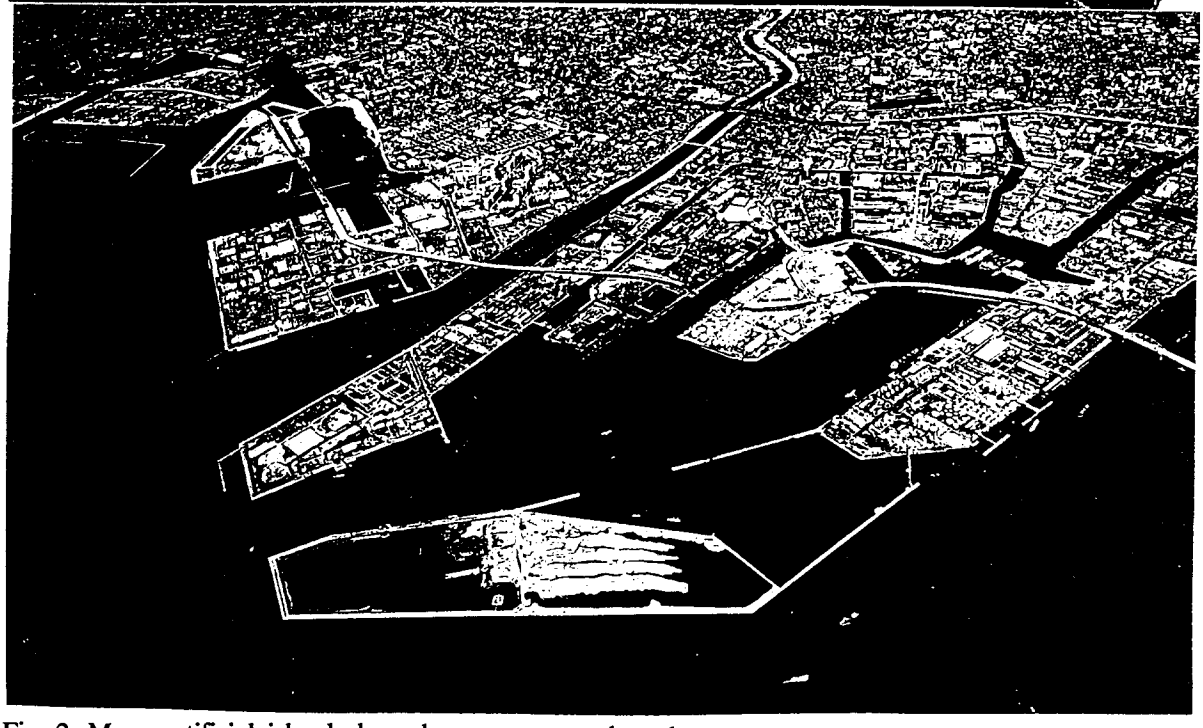

Fig. 2. Many artificial islands have been constructed at the water front of large cities in Japan. These islands are convenient for industries, however the cost of construction is high.

Fig. 3. Aquaculture is one of the most important industries in the coastal zones of Japan. Many new development projects and application of technologies have been conducted by Fisheries Agencies.

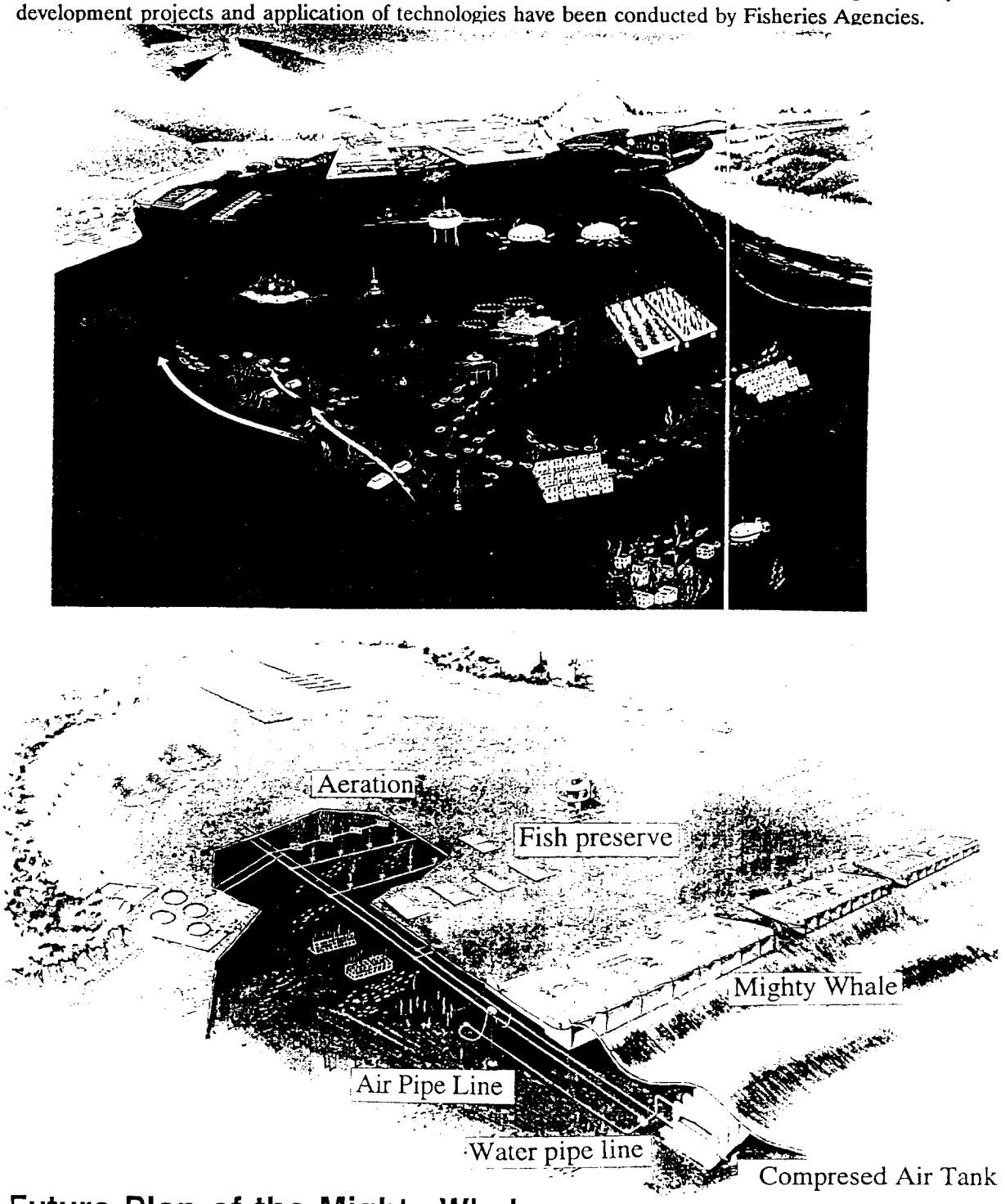

Fig. 4. "Mighty Whale" is a floating wave power device, which will be moored in front of the bay and will absorb wave power efficiently. A calm water area is thus created behind the device as a space for aquaculture. This is a project of Japan Marine Science and Technology Center (JAMSTEC).

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ON IMPROVEMENT OF HUMAN ENVIRONMENT IN HARBOUR WATERS AND RIVER ESTUARIES

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PART 1. ORGANIZATION OF AN ENVIRONMENTAL PATROL SERVICE

The Water Pollution Control Department frequently receives written and oral complaints from port authorities concerning regular discharges by ships of garbage, sewage, diesel oil as well as bilge water directly into the port waters during the night.

Objective of the project

Organization in ports of Environmental Services for pollution prevention actions by means of night patrols.

Description of the methods

Small craft, carrying out patrols during the night, are equipped with night vision devices. The most suitable craft for such equipment is the Surface Hydrography Apparatus (SHA), which is on the one hand light and manoeuvrable, like a boat, and on the other hand has a sheltered cabin set up with the help of transversal beams over floats of cylindrical or similar shape. The installed night vision equipment comprises a portable radar and a infrared generator. Radar signals in the millimetre range reflect oil slicks on the water surface as well as floating solid objects within a given area, which can be seen on the displays as spots. At the same time infrared generators make a planimetric registration of their distribution and of different temperatures within the area (This method is at the stage of development which has been interrupted by political events in Russia of the present time).

Prospects

Putting the above method into practice will give rise to its further development. In the long run it will increase the cultural level of ships' crews during port time and will improve the sanitary condition of port waters.

Patent

SHA is undergoing patent procedures (patent application N°. 5019924, priority of December 29, 1991). The craft is registered by the State Inspection for small craft in St. Petersburg (Russia) and is granted permission for sailing in offshore waters autonomously. The method itself has no patent.

Additional information

The radar used for this method is an ecologically clean small portable radar with millimetre range (wave length 8 mm), commonly used in modern armoured cars. Implementation of this method is also possible on surface stations.

PART 2. OFFSHORE WATER BOTTOM POLLUTION CLEAN-UP

There are semi-closed areas in modern sea ports where slack water zones are formed which contributes to concentrations of fine particle substances (as a rule, ooze). See Fig. 3. Environmental control surveys of offshore areas in the former USSR showed that 80 % of bacteriological and chemical pollution on the bottom of port waters is concentrated in ooze, which has a high absorption capacity. Such bottom polluted zones in port waters create a high ecologically unfavourable situation. During storms and floods they serve a source of a secondary pollution of adjacent water areas and shores as a results of bottom shifts. Moreover, the sludge, growing from season to season, alongside the piers and dikes under docks becomes a serious obstruction requiring dredging. In the course of the dredging operations, especially by means of suction dredge, zones of higher concentration of suspended particles are formed.

The technological cycle is completed by transport of dredged sediments to open dumping sites. During the dredging operations and discharge of dredged sediments at sea (in the form of volley discharge), oozy bottoms create a concentration of suspended particles 30 times higher than that of fine sand, which badly deteriorates the environment.

Objective of the project

A complex method of elimination of bottom pollution is being developed and partly tested by a group of Russian companies for reducing pollution in port waters. The scheme is the following: detecting of bottom ooze concentrations, clean-up of the area - processing of the ooze - and storage or utilization of the final product.

Description of the method

A large scale bathymetric and ground survey is effected simultaneously by means of SHAs, equipped with echo-sounders. The craft position is registered on the shore station throughout the survey by means of laser quantum distance-measuring theodolite of the second generation (KTD-2). On completion of the survey an operational chart is graphically made, showing depths and ground with indications of ooze concentrations. The data obtained by the graphical method is then converted by means of the navigation information system into an electronic chart and is shown on a display. (The information navigation system was developed by the Russian company "Morris" for shipboard use to the stage of working laboratory model). The navigation information system starts from a depicted location of ooze/sludge concentration and helps the navigator of the dredger (dredge master) to define the craft's position on the radar display, i.e. watch the movements of vessel. This method makes it possible to bring the vessel into operation with a high accuracy, thus reducing by several times zones of ground disturbance. On reaching the target area bottom ooze concentration clean up begins. The final clean-up is effected by means of a pneumatic ground scooper (suction tube type designed and developed in the "Lenmorniiproekt" by engineer A.N. Naumov to the stage of a pilot installation. Tests, carried out in the Asov Sea showed good results. (Other equipment can be used for ground intake). The intaken sludge is kept for sedimentation in a tank on the carrier vessel. The design of such a vessel has still to be developed. It is expected that such craft will be designed on the basis of the SHA. The intaken sludge pulp undergoes immediately thermal and mechanical treatment by means of a filter press and evaporation on board the carrier.

The treatment techniques are elaborated by the Russian company "Sredny Prospect Inc" in St. Petersburg on request of the Maritime Ecological Centre of Am. Makarov State Maritime Academy. The company does not use available industrial equipment for treatment of sludge as standard equipment is intended for a wide range of raw material, which reduces its efficiency. Individual combination of dewatering methods and equipment designed for a particular kind of sludge, reduces considerably the energy consumption. Besides, it is suggested to carry out bottom sludge treatment at temperatures below boiling point, which ensure an ecologically clean process.

At the present the operational scheme of sludge dewatering equipment has been developed in the laboratory. Its capacity is 1 m^3 of ready product per 24 hours. The raw material for the experiments was taken from the port of Klaipeda (Fig. 2; Lithuania). The experiments showed that the volume of the original pulp of 82% humidity after full treatment is reduced by a factor of 5 and the final product is a wet powdery substance which can be containerized for storage or utilized.

Prospects

If the final product of dewatered sludge does not contain excessive quantities of mercury or radionuclides, it can be used for brick production as an additive to clay. A successful experiment was carried out with sludge from the port of Klaipeda by the brick factory of the town of Priekule (Lithuania) in the late 1980s. The manufactured bricks, containing sludge powder, were lighter and stronger than ordinary bricks. The additional strength was obtained due to the

high content of calcium in bottom sludge. They were lighter because of a higher porosity as a result of burned away organic admixtures. The bricks underwent independent ecological control.

Patents

The pneumatic ground scooper is protected by a patent, together with the ground carrier. Certificate n°. 234240, application n°. 1149682/2974 of April 17, 1967 (USSR).

The treatment equipment is not protected as also of the navigation information system. A form of realization of this project may be set up by a transnational company in Europe for contribution to environment protection actions along the coastlines of the North Sea, the Baltic and the Mediterranean.

Fig. 1. Port of Klaipeda, the Baltic. Map of bottom sediments, July 22, 1992.

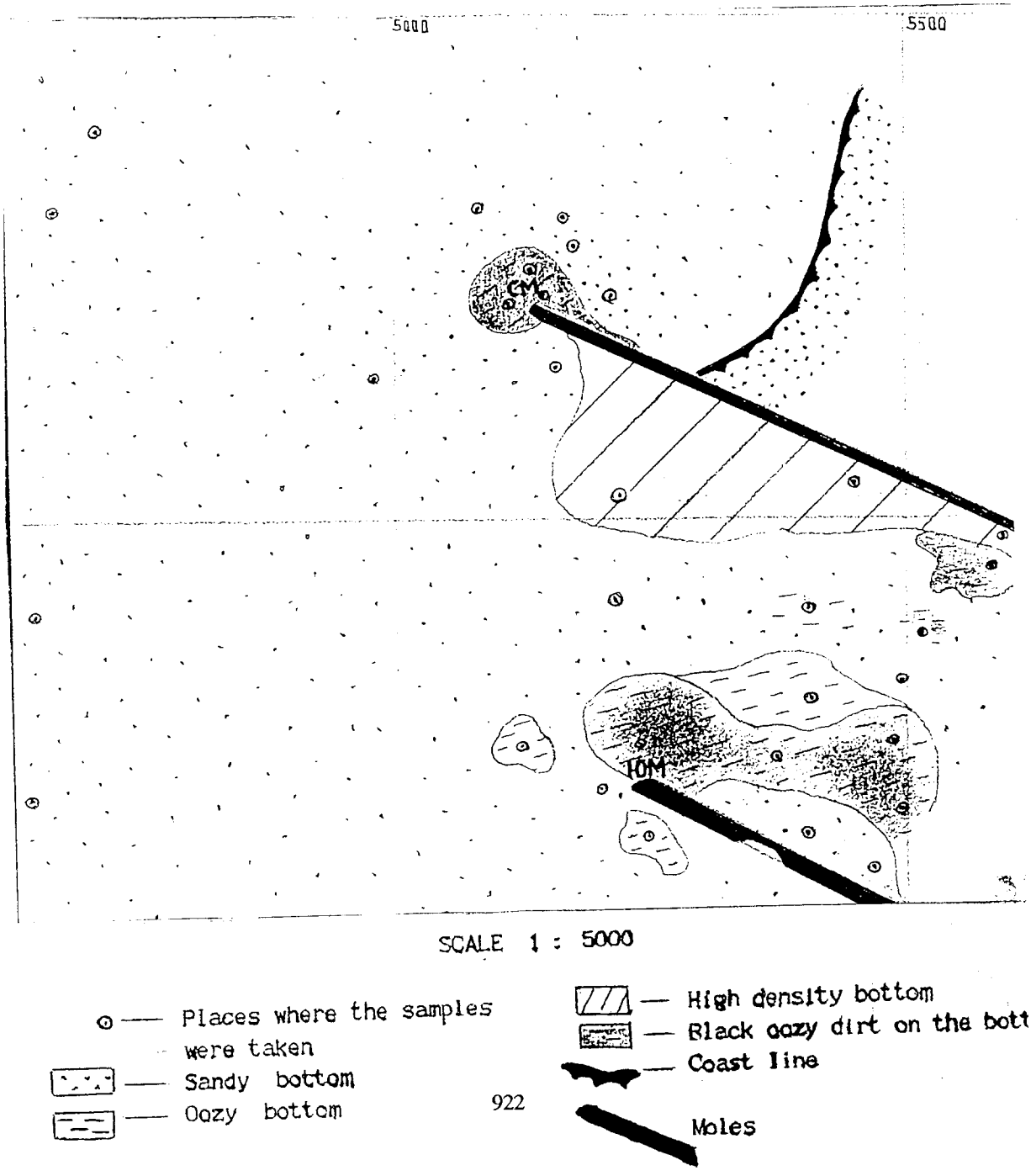

Table 1. Timetable and costs of projects.

Sub projects	Approximate costs of equipment (US$)	Men x days (wages in US$)
Surface craft building; Navigation Information System first step design; Dehydrate (low-capacity) system preparation;	18,000 50,000 3,000	9x300=2,700 9x300=2,700 12x300=3,600
Narrow-beam profilograph production; Second step of the Nav. Inf. System design; Dehydrate system's drawings completing; Craft's testing;	100,000 180,000 10,000 5,000	9x300=2,700 9x300=2,700 12x300=3,600 3x300= 900
Power station product; Dehydrate syst. product; Suction-tube choosing; Vehicle drawings prev. making;	20,000 25,000 2,000 2,000	9x300=2,700 8x300=2,400 6x300=1,800 12x300=3,600
Nav. Inf. System completed; Preparation of Self-propelled vehicle drawings; Bottom-scooper (tube) construction; Preparation of industrial conditioning system (dehydrate) drawings.	5,000 2,000 72,000 -	9x300=2,700 12x300=3,600 12x300=3,600 12x300=3,600
Tuning and starting of Nav. Inf. System; Construction of Self-propelled vehicle's blocks; Completing Bottom-scooper (tube); Completing Industrial Dehydrate system;	3,000 50,000 4,000 85,000	9x300=2,700 12x300=3,600 15x300=4,500 9x300=2,700
In situ testing of Nav. Inf. System; Production of Self-propelled vehicle; *In situ* testing of Bottom-scooper (tube); Completing Industrial Dehydrate system;	5,000 6,000 10,000 20,000	9x300=2,700 15x300=4,500 18x300=5,400 18x300=5,400
Completing production and techniques, and implementation of the water areas clean-up installation;	15,000	27x300=8,100
Installation's testing in natural conditions, adjusting of separate blocks; Control of cleaned-up areas;	20,000 10,000	27x300=8,100 27x300=8,100
	Complete costs:	US$ 831,200

Fig. 2. Sedimentary particles.

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LES APPORTS DE LA RECHERCHE POUR LA PROTECTION ET L'AMÉNAGEMENT DU LITTORAL

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LE LITTORAL

Né de la rencontre de la mer et de la terre, c'est un espace dont on dit qu'il est: convoité, fragile, sensible, vulnérable, beauté. A propos de son usage on évoque: l'occupation, la concurrence, la compatibilité, et le conflit. C'est un lieu de production, d'échange, de résidence, de détente, voire de tension.

Le littoral, frontière aux limites fluctuantes ne se laisse pas maîtriser au point de se définir par des catégories simples. Rendre compatibles les occupations, permettre des usages multiples nécessitent admettre, de comprendre et de gérer la complexité.

Un exemple illustre ce propos

Au Moyen Age les marais étaient considérés comme des lieux maudits ou les sorcières apparaissaient. Au cours des siècles, l'incompréhension à leur égard incitait à les détruire. C'est ainsi que nombre d'entre eux ont fait l'objet de bétonnage par méconnaissance de leur intérêt faunistique et floristique comme de leur fonction de rétention des eaux. Domestiqués au cours de ces dernières décennies, les marais de Charente maritime ont connu un développement de l'agriculture dont les rejets d'engrais et de pesticides nuisent à l'ostréiculture. La compatibilité entre ces deux activités est possible à condition de maîtriser la gestion des eaux.

La recherche vise à comprendre les mécanismes qui régissent le fonctionnement des écosystèmes côtiers.

Pour contribuer aux stratégies d'aménagement, il faut:

- acquérir des donnes sur l'état du littoral
- mettre au point des outils
- conduire des études régionales

Comprendre les mécanismes qui régissent le fonctionnement des écosystèmes côtiers

Les écosystèmes sont constitués de composantes géographiques physico-chimiques, biologiques et anthropiques. Il changent sous l'effet de processus naturels, de processus anthropiques et des interactions entre ces processus.

La variabilité des paramètres qui régissent le fonctionnement des écosystèmes littoraux est très grande:

- variation du niveau de la mer due aux marées, à la houle, au vent,
- variation des courants,
- variation des paramètres hydrologiques liée au climat, aux apports, aux saisons,
- diversité morphologique du littoral et donc des sédiments côtiers,
- variabilité biologique.

Les questions que se posent les chercheurs intéressent les aménageurs:

- Quels sont exactement les changements en zone littorale?
- Quelles sont les parts respectives de l'action de l'homme et des processus naturels dans ces changements?
- Quels sont parmi ces changements ceux qui présentent un risque pour l'homme?
- Peut-on prévoir les évolutions?
- Comment établir les bases scientifiques permettant de concevoir des approches techniques, réglementaires, voire politiques pour apporter des solutions à des problèmes d'aménagement du littoral?

Quelques exemples de programmes volontairement choisis dans le cadre de programmes nationaux qui associent l'IFREMER, les universités, l'INSU:

- Connaître l'impact à long terme des toxiques à l'état de traces sur le fonctionnement des écosystèmes littoraux à partir de la recherche de bio-indicateurs d'exposition.
- Etudier, à partir de sites ateliers, les mécanismes de dysfonctionnement des écosystèmes du fait des apports importants de nutrients dans le but de construire une théorie globale des mécanismes d'eutrophisation.
- Etudier le déterminisme d'apparition de micro-algues toxiques.

La compréhension des flux, des processus, des évolutions demande d'acquérir des données, de disposer d'outils.

Acquérir des données sur l'état du littoral

Il faut plusieurs années d'observation pour déterminer une évolution, pour mettre en évidence des tendances. C'est pourquoi, la constitution de bases de données constitue un atout stratégique pour comprendre et agir sur le littoral.

Le réseau national d'observation de la qualité du milieu marin conduit depuis 20 ans par l'IFREMER, pour le compte du Ministère de l'Environnement, permet de connaître les niveaux et tendances des paramètres physico-chimiques, nutrients, les teneurs en contaminants (métaux lourds, hydrocarbures, PCB, et pesticides). Deux autres réseaux (Rephy, Remi) surveillent la qualité des zones conchylicoles dans un but de protection de la consommation, d'acquisition des données sur les efflorescences phytoplanctoniques et sur la qualité bactériologique des eaux littorales.

Les données peuvent servir de révélateur de phénomènes atypiques, les recherches qu'elles induisent peuvent conduire à des prises de décision en matière de protection ou d'aménagement. C'est ainsi qu'ont été mise en évidence l'importance du cadmium en Gironde, intensifiés la source, les flux et processus et décidées les solutions qui s'imposaient.

D'autres domaines nécessitent l'acquisition de données notamment sur les ressources biologiques exploitées, la faune et la flore, la dynamique sédimentaire littorale.

Les progrès considérables en informatique, au niveau du traitement, de la conservation et de la diffusion des données permettront de disposer d'informations utilisables.

Les techniques d'acquisition des données évoluent vers l'automatisation de la mesure. Ceci est devenu possible par le développement de la technologie des capteurs et de la transmission des données par satellites. Le projet MAREL connu par MORS et l'IFREMER, vise à effectuer des mesures, à fréquence élevée, des paramètres physico-chimiques et météo, en surface et dans la colonne d'eau et ceci quelles que soient les conditions météorologiques. Le premier réseau suscite l'intérêt des régions de Haute et Basse Normandie, il sera développé en estuaire et baie de Seine pour suivre l'évolution de la qualité du milieu.

Pour l'avenir, la communauté scientifique est consciente de l'intérêt stratégique d'un développement de l'observation de l'océan et tout particulièrement du littoral. Le développement des moyens de calcul, des moyens techniques? notamment les moyens spatiaux facilitent cette évolution. C'est pourquoi est né le projet GOOS, système mondial d'observation de l'océan qui fédère des compétences en vue d'élaborer des programmes d'observation.

Mettre au point des outils

Pour améliorer la capacité à établir des diagnostics, pour mieux apprécier la validité des choix et prévoir leurs conséquences il faut développer des outils.

La modélisation

Une des questions centrales est de prévoir et de maîtriser l'évolution du littoral, de façon à pouvoir anticiper les effets et les risques éventuels.

La modélisation prend une place de plus en plus importante. Elle est nécessaire pour résoudre la question de la prévision. Le modèle est à la fois outil de représentation des connaissances, de dialogue interdisciplinaire, de test d'hypothèses. Les modèles numériques ont fait des progrès considérables depuis une dizaine d'années du fait

des progrès de l'analyse numérique et de l'informatique.
Les modèles de courantologie et de dispersion permettent de calculer les courants, les niveaux d'eau et les concentrations en substances dissoutes en tout point d'un domaine.
Quelques exemples concrets de l'apport de la modélisation illustrent notre propos. On a pu aussi pour les bactéries fécales montrer les temps de survie en fonction de la dilution, de la turbidité et de l'ensoleillement. C'est une approche utile, notamment pour choisir un site de rejet des eaux usées en fonction de ses capacités dispersives et du temps de résidence des masses d'eau. Les modèles de transport sédimentaire donnent une simulation du bouchon vaseux dans l'estuaire de la Loire. Les modèles de production primaire simulent les cycles de l'azote, du phosphore et de la silice et prennent pour partie les échanges avec le sédiment. Ils renseignent sur le paramètre à traiter pour diminuer l'eutrophisation. C'est ainsi qu'il a été mis en évidence, en Bretagne, que trois conditions simultanées sont nécessaires pour qu'il y ait prolifération d'ulves: un piégeage hydrodynamique des eaux côtières, un estran sableux à faible pente avait un apport d'azote significatif en fin de printemps.

Les systèmes d 'information géographique
La gestion intégrée du littoral se heurte aux frontières administratives, aux structurations par disciplines entre l'approche terre et mer ce qui rend difficile l'utilisation des informations requises.
Le SIG constitue un outil de gestion dynamique des usages du littoral. "C'est un ensemble de données repérées dans l'espace, structurées de façon à pouvoir en extraire commodément des synthèses utiles à la décision". Le SIG permet le stockage et l'accès rapide à des données géoréférencées hétérogènes, le traitement et la combinaison de données et la visualisation des résultats du traitement.
Il constitue une aide à la résolution de problèmes sur le littoral comme:
- la gestion cadastrale du domaine public maritime,
- la présélection de sites les mieux adaptés à une implantation,
- la définition d'un schéma d'aménagement de zone.
Regrouper les données, les synthétiser est le souci des collectivités territoriales, les projet d'observatoires en témoignent. Les grands organismes de recherche travaillent à la mise au point de cet outil (IFREMER, BRGM, CEMAGREF, IGN).

Conduire des études régionales
L'appréhension des problèmes à la bonne échelle est capitale. La proéminence des critères administratifs, des préoccupations de politique locale, pour la détermination de l'aire des schémas ne permet pas de traiter de façon satisfaisante les problèmes d'aménagement. Il convient de considérer les critères scientifiques (hydrodynamique, géomorphologique) et les caractéristiques économiques des zones à aménager. L'approche coordonnée des grands estuaires débouchant sur un programme d'aménagement décidée par le CIAT de Troyes du 20 Septembre 1994 constitue une bonne démarche à cet égard.
Mener une approche globale sur une zone, consistant à étudier les relations entre systèmes anthropiques d'une part et les autres composantes notamment géographiques, physico-chimiques, d'autre part puis les influences de celles-ci sur les systèmes vivants et anthrophiques, doit être encouragé.
Nous l'avons mis en oeuvre sur le bassin d'Arcachon. Lagune de 15 000 ha dont 11 000 découvrent à marée basse qui communique avec le Golfe de Gascogne par un système de passes en constante évolution. L'analyse s'appuie sur les connaissances scientifiques disponibles (données historiques) portant sur l'ensemble des domaines nécessaires à la compréhension du fonctionnement du système: hydrodynamique, morphodynamique, qualité des eaux, impact des activités sur le milieu évolution et développement de ces activités. Le document de synthèse, en cours de préparation constituera la base scientifique utile à l'élaboration du SMVM. Les données collectées permettront de réaliser un SIG du bassin

d'Arcachon. Cette étude est conduite par l'IFREMER et l'Université de Bordeaux, nous souhaitons qu'elle contribue à l'émergence de modes nouveaux de gestion du littoral.

CONCLUSIONS

Protéger et aménager le littoral doivent être poursuivis de paire.

Conserver des espaces libres en réponse à la forte poussée du béton est nécessaire mais, conserver à tous crains peut relever de la même incompréhension qu'agir à tout prix. Gérer le littoral c'est prendre en considération l'interaction entre les activités humaines et le milieu, c'est réunir les conditions pour ménager le littoral. Soyons capable de transmettre aux générations à venir la capacité de rêve qu'il inspire.

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PROPOSITION DE L'AMÉNAGEMENT DE LA RÉGION CÔTIÈRE DU NORTHUMBERLAND.[1]

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RESUME

Sur le littoral Est du Royaume-Uni, le Northumberland est le conté anglais qui se situe le plus au nord géographiquement. La côte du Northumberland qui s'étend sur 120 km de la rivière Tyne aux confins de l'Angleterre et de l'Ecosse en fait le conté le plus connu pour ses atouts naturels. Bien qu'elle soit réputée pour sa faune et sa flore naturelles, le paysage côtier est néanmoins soumis à de vastes influences. La proposition de management de la région côtière du Northumberland a été adoptée comme projet de parténariat afin d'explorer les solutions possibles ainsi que de reconnaître les atouts nécessaires pour la sauvegarde du littoral.

UN LITTORAL DÉLIMITÉ

Des falaises rocheuses à pic aux vastes étendues de sable que forment les baies, le littoral du Northumberland offre une grande variété de paysages. Une grande partie de ce littoral est sous la protection du patrimoine côtier pour sa beauté naturelle exceptionnelle. Elle bénéficie du statut de la protection de la nature sur le plan national et international. La presque totalité de la côte a reçu le titre national de conservation de la nature (Site of Special Scientific Interest, SSSI) en reconnaissance de l'importance de la population des oiseaux migrateurs. Les laisses et les îles le long de la côte sont des lieux protégés (Special Protection Area SPA et Ramsar Site Status); Un bassin de marée existe autours de Holy Island où près de 60.000 oiseaux sauvages hivernent. Les eaux côtières du Northumberland sont parmi les plus riches de la Grande-Bretagne pour la vie marine. La longue histoire de la colonisation humaine de ce littoral a légué un héritage important de sites historiques et de caractéristiques régionales. Cela comprend les plus grands châteaux forts de la région et les sites archéologiques funèbres exposés aux mouvements du sable. La haute qualité de nombreuses plages a été récompensée par cinq distinctions nationales (seaside award) en 1994.

LE LITTORAL ET SES CONTRAINTES

Le littoral du Northumberland doit faire face à des changements continuels, pour la plupart avec une côte aux reliefs changeants soumis à l'érosion rapide et très importante causée par le vent et la mer. La richesse de la vie marine, agricole, les ressources minérales de la côte et l'existence de ports naturels expliquent l'importante concentration de la population dans cette région du Northumberland. Les pratiques d'exploitation agricoles intensives autour des côtes et l'assainissement de terres marécageuses ont été la cause de pertes importantes de l'habitat. Bien que l'industrie poissonnière du littoral soit en déclin depuis le siècle dernier, quand l'importante pêche de hareng fonctionnait à partir des ports du Northumberland, il existe encore des conflits portant sur la protection du littoral.

La partie sud du littoral du Northumberland a été très exploitée pour sa richesse minérale. Cette exploitation a eu pour conséquences des terres dévastées et des plages polluées par les déchets houillers. Les exploitations de mines en profondeur ont été remplacées par l'exploitation minière à ciel ouvert et ont eu un impact sur le paysage et sur l'habitat de la côte.

Les visiteurs venus d'ailleurs apportent une source de revenu essentiel à beaucoup de communautés côtières mais ils imposent également une tension

[1] See also poster abstract of the same author.

considérable à l'intérieur de ces régions menacées. Les parcs de caravanes gâtent le paysage naturel sauvage. Les accès trop faciles de cet habitat menacé par les visiteurs provoquent des changements et l'érosion. Les sports maritimes en développement tels que le jet-ski et la plongée menacent ces régions autrefois paisibles.

UNE APPROCHE DE PARTENARIAT

Le management du littoral du Northumberland est sous l'égide du Conseil Régional (County Council), des Conseils de Districts (District Councils) et d'un grand nombres d'agences et d'organisations dont la Commission Nationale des Rivières (National River Authority), le Conseil National de la Protection de la Nature (English Nature), National Trust, le Patrimoine Anglais (English Heritage), le Ministère de l'Agriculture (Ministry of Agriculture, Fisheries and Food), l'Académie des Sciences pour la Protection des Oiseaux (the Royal Society for the Protection of Birds) et le Conseil pour la Faune et la Flore du Northumberland (the Northumberland Wild Life Trust).

Il était essentiel d'établir une infrastructure à l'intérieur de ces organismes pour qu'ils puissent travailler ensemble. Dans le Northumberland, un nouveau modèle de management a donc été établi. Une stratégie a été décidée pour tout le littoral du Northumberland dont l'objectif est de trouver des mesures pour la préservation et la beauté de l'environnement. La stratégie porte également sur la délimitation maritime pour permettre de faciliter le management de la zône côtière. Afin de mener à terme des politiques et de déterminer les actions prioritaires, un comité de restructuration concernant le littoral a été formé: il comprend des membres politiques du Conseil Régional (County Council), des cinq Autorités Locales (Local Authorities) et la Commission des Espaces Naturels (Countryside Commission). Une cellule de travail a été créée comprenant des fonctionnaires et des employés d'organisations spécialisés dans la protection du littoral afin de conseiller le comité et d'assurer la coordination entre les différents associés.

LE PROGRAMME D'ACTION

Grâce à l'aide financière du Conseil Régional du Northumberland, de la Commission des Espaces Naturels et des Conseils de Districts côtiers, une équipe a été mise en place avec comme objectif principal de coordonner et de mettre en oeuvre le programme de management.

Une recherche de grande envergure a été menée sur la côte du Northumberland afin de fournir des données de base pour le programme de management. En 1994, on a publié une étude et un programme archéologique concernant le littoral du Northumberland. Les différents points de la stratégie ont incontestablement aidé à établir un ordre de priorités concernant les travaux d'excavation pour la conservation et la sauvegarde de sites historiques ainsi que les caractéristiques régionales. Le programme mis en oeuvre a également été inspiré par la compétence dans le domaine de la recherche à l'Université de Newcastle upon Tyne. En effet, les chercheurs consacrent en ce moment une étude tout le long du littoral du Northumberland, et ceci fait parti du projet européen (BIOMAR) financé par l'Union Européenne. Une étude hydrographique du littoral est réalisée par des plongeurs, qui utilisent des techniques d'acoustique sur les sols ainsi que des prélèvements des sols afin de dresser une carte marine du littoral. Cette étude permettra d'obtenir une connaissance du sol marin, utile dans toute l'Europe.

Le programme a permis de mettre en oeuvre toute une variété de mesures concernant cette région du littoral. Ces mesures comprennent plusieurs plans qui vont permettent:

- de stabiliser l'érosion dans les régions de dunes qui sont soumises à l'affluence des visiteurs.
- d'améliorer les terrains de jeux.
- de protéger les sites historiques et les espaces naturels.
- de connaître les caractéristiques régionales.

Un programme d'actions précis et adéquat a été mis en place pour les endroits menacés du littoral. De tels plans ont permis aux communautés locales de participer et donc d'être impliqués dans le développement et la mise en place du programme d'action.

Des efforts considérables ont été menés afin d'assurer la participation de la communauté, grâce à l'envoi de bulletins d'informations réguliers.

Il faut néanmoins souligner que le programme de management du littoral du Northumberland n'en est qu'à son début. C'est une première approche aux problèmes du littoral du Northumberland. Ce programme décrit un processus d'apprentissage précieux pour le management du littoral.

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COASTAL CHANGE AT COASTAL ZONE CANADA'94

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ABSTRACT
From September 20-23, 1994, stakeholders in the coastal zone from around the world gathered in Halifax, Nova Scotia, Canada for the international conference *Coastal Zone Canada '94 (CZC '94)*. Over 700 people from 46 countries, representing the full spectrum of coastal zone interests, participated. In keeping with the conference theme, *"Cooperation in the Coastal Zone"*, the entire conference process -- from the make-up of the organizing committee to the representation in the conference sessions -- reflected a unique mix of disciplines, perspectives and experiences. Of particular interest to Coastal Change '95 is the way in which CZC '94 explored the local or community level application of coastal zone management. This paper reviews the conference in general terms and the coastal change thrusts in particular, the latter being considered under the following categories : physical change, biological change, anthropogenic change, climate change, management (institutional) change, and social change. It then outlines examples of issues relevant to coastal change that were developed during the conference and within the context of the central theme of cooperation. Because of the emphasis of the conference on community involvement, these issues focus largely on the human dimension.

1. INTRODUCTION

The Coastal Zone Canada '94 (CZC '94) conference grew from the conviction of a group of people in Canada representing government, the private sector, academia, non-government organizations and coastal communities, that the time was now right to hold a major broadly-based international coastal conference. While there are a growing number of conferences that address specific aspects of the coastal zone, including coastal zone management, it was considered that a forum for open dialogue among these diverse, yet necessarily intertwined, interest-groups on how to address the critical issues in the coastal zone was urgently required.

To this end, in 1991, the planning for CZC '94 began.

The goals of the conference were ambitious:

- to generate a cooperative dialogue among government officials, scientists and academics, industry leaders, aboriginal people and community representatives from around the world;
- to focus public, political, and intellectual attention on the need for new, cooperative approaches to managing coastal regions;
- to develop recommendations and guidelines for the advancement of integrated coastal zone management that answer this need; and
- to explore innovative approaches (social, scientific and technological) for dealing with the urgent problems that are being faced in coastal areas around the world.

With special emphasis on community-participation, CZC '94 was the first conference of its kind in Canada, and possibly in the world. With its theme *Cooperation in the Coastal Zone*, the diverse interests that comprise the coastal management regime came together to address the problems faced at local. national and international levels. At the core of most such issues is the challenge of reconciling environmental protection

and ecological sustainability with economic development. It was, therefore, appropriate that a key thrust of CZC '94 was the consideration by all stakeholders of the international obligations for coastal management that have arisen from the United Nations Conference on the Law of the Sea (1982); the 1992 'United Nations Conference on Environment and Development (UNCED), specifically 'Agenda 21'; the Organization for Economic Cooperation and Development (OECD); the Intergovernmental Panel on Climate Change (IPCC); and the Noordwijk Guidelines from the World Coast: Conference in 1993; among other international initiatives.

Perhaps the greatest issue to be confronted by the conference was that of breaking down the institutional, social and jurisdictional barriers to cooperation among those present and building new working relationships. The organizers wanted answers to questions such as the following: how can governments be encouraged to engage in partnership with industries and communities in coastal management; how can the confusing and often contradictory regulatory regimes which govern coastal development be simplified and made more effective ; and how can communities work with governments to build a sustainable future? The conference process was designed to facilitate the provision of such answers.

2. THE CONFERENCE PROCESS

CZC '94 was very much a working conference. The objective was to bring together, and draw upon the experience and perspective of, a broad range of players in the coastal zone in order to debate key issues shared by many coastal nations and to reach consensus on present and future needs and actions for effective planning and management of coastal and marine areas. Participants from diverse backgrounds and interests sat with representatives of groups and disciplines that they perhaps were not used to working with. Participants were advised to come prepared to work, and work they did!

The format of the conference was crafted to support the process of gaining insights that would contribute to cooperative coastal zone management as well as producing recommendations for action on critical coastal zone issues. A seven-person Conference Panel, supported by a Working Group, was in attendance throughout to facilitate this. The conference comprised the following main components:

- Sessions for the oral presentation of papers intended to diffuse scientific and technical knowledge and current practice for the improvement of planning, design, development and conservation actions to sustain our coasts and oceans (refer to Table 1). 226 papers were accepted for inclusion in these sessions and have been published in the Conference Proceedings (Wells and Ricketts, 1994).
- Display of some 50 poster papers, with authors present at specific periods; these papers also appear in the Conference Proceedings (Wells and Ricketts, 1994).
- Interactive workshops, varying in length from a few hours to a full day, and intended to enable in-depth consideration of specific coastal topics by experts, practitioners and others interested in the subject. In all some 23 workshops were held (refer to Table 2).
- Round table discussion sessions on key coastal zone issues in which participants from a cross-section of interest groups and disciplines discussed the topic from a variety of perspectives. Each round table was comprised of an inner circle of approximately 6 selected persons including a chair and a rapporteur. An outer circle of Conference attenders completed the round table. Following brief presentations by each of the inner circle, the topic was opened for debate by all round table participants. A total of 14 round table sessions was held (refer to Table 3).
- Pre- and post-conference events on a variety of topics including, in particular, two pre-conference workshops on integrated coastal management (primarily intended for persons from developing nations) and training and capacity building in integrated coastal management; a report on the latter has recently been published (Coastal Zone Canada Association, 1994).
- A trade show highlighting companies and agencies active in the coastal zone, including companies planning to diversify into this field. This involved 39 exhibitors with 43 exhibit booths.

Separate from the trade show was an area for smaller (static) displays of organizations, publishers, groups, etc., active in the coastal zone, e.g., Gulf of Maine Council on the Marine Environment. There were 20 such displays. For each paper session, workshop and round table, rapporteurs produced brief reports according to a standard format. These reports described the proceedings and results of the session on two levels:

a) Principles, issues and action proposals relevant to the overall thrusts of CZC '94;

b) the most important information and ideas relative to the specific subject of the session.

These reports were summarized and brought-forward to the Conference Panel for consideration and integration into a listing of conference results that was presented in very preliminary form at the final plenary session. Subsequent to the conference a team was struck, comprising several members of the Conference Working Group and several members of the Conference Organizing Committee, to further develop these results. As of the date of this conference (February, 1995), a final draft is under preparation to send to all conference participants for final review. Upon completion of this phase, it will be revised on the basis of the comments received. The material, in the form of a "Conference Summary and Statement" will be published as the sixth and final volume of the Conference Proceedings. This volume will be transmitted to various stakeholders, including governments and international agencies, for response and follow-up.

3. SCOPE OF THE CONFERENCE

As noted above under 2., the central theme of the conference was "Cooperation in the Coastal Zone". Within this broad theme, particular attention was paid to the areas of conflict resolution, sustainability, social equity, economic development and capacity building. While the round table sessions on the final day (refer to Table 3) addressed this theme in some detail, the foundation of the conference was built on the papers submitted for both oral presentation and poster display and which, together with the interactive workshops (refer to Table 2), were the centre of activity during the first part of the conference. The papers for oral presentation were delivered and debated in some 48 separate sessions that covered 39 subject fields (refer to Table 1). These sessions were designed to provide new knowledge and new ideas about coastal environments and the various attempts to manage them effectively, as well as proposing new approaches to integrated coastal zone management design and implementation.

4. COASTAL CHANGE COVERAGE

While coastal change per se was not an explicit thrust of the conference, a review of the program shows that several facets of this subject were covered. For the sake of convenience these are examined under six broad categories, i.e., physical change, biological change, anthropogenic change, climate change, management change, and social change.

4.1 Physical change

Most of the papers presented on this aspect of coastal change pertained to shoreline erosion. One such paper was a poster presentation by D.G.E. Liverman, D.L. Forbes and R.A. Roger on "Coastal monitoring on the Avalon Peninsula, Newfoundland" (Canada). This paper describes an ongoing program of monitoring that is providing estimates of mean coastal recession rates and a basis for relating variations in coastal response to the oceanographic, climatic, or geological factors that determine erosion rates. Several papers presented describe the methods and techniques of studying physical change, including one by D.L. DeWolfe and D.M. Willis on "Modelling shoreline evolution", which describes the development and application of a numerical model for the study of beach evolution.

Physical change was not addressed in depth in the interactive workshops or round table sessions. However, several of the former did address aspects of this category of change, including the workshop on "Elements of a coastal ocean program in support of UNCED objectives", where physical oceanography programs in support of the resolution of shoreline erosion and associated problems were considered. Among the round

table sessions, No. 3, "Managing land-based development along the shoreline", addressed shoreline-erosion protection.

4.2 Biological change

A paper on the proposed Global Ocean Observing System by M. Cole, W. Scherer and A. Tolkachev, "Global Ocean Observing System: providing information for coastal zone managers," focuses on the coastal zone module of this initiative. Reference is, however, made to the living marine resources module that will focus on monitoring species abundance and trends in the context of regime shifts, ecosystem changes and resource sustainability. Specific studies of biological change reported on at the conference included one by D.V. Subba Rao on "Potential for harmful marine algal blooms along the Atlantic coast of Nova Scotia (Canada): an Appraisal". This paper reports on a long-term phytoplankton sampling program that is identifying a wide diversity of these organisms including a suite of 25 potentially harmful algae.

As with physical change, biological change was not addressed in depth in the interactive workshops or round table sessions. Workshop No. 2, "The basic scientific requirements for coastal zone management", addressed both the resources and environmental data bases organized appropriately for coastal zones as well as indicators for gauging ecosystem health and the degree of success of the imposed management system. Among the round table sessions, No. 7, "Conservation and protection of coastal ecosystems" was relevant to this subject.

4.3 Anthropogenic change

Several papers were presented at CZC '94 on a variety of aspects of anthropogenic change. A paper by E. Saiu, J. McManus and R.W. Duck, "Impact of industrial growth and decline on coastal equilibrium, Eastern Scotland", addresses the impacts of the growth of the North Sea oil support industry and the decline in the traditional coal mining industry. Non-industrial anthropogenic pressures are addressed in a paper by N.R. Catto entitled "Anthropogenic pressures and the dunal coasts of Newfoundland" (Canada). Among the changing uses investigated are recreation (powered vehicles, horses and foot traffic), aggregate; extraction, sheep herding and rearing; and waste disposal.

Among the interactive workshops, No. 8, "Comparing harbour management approaches: Boston and Halifax - New Bedford and Sydney" addressed aspects of anthropogenic change. The Boston and Halifax example reviewed cases in waste water management and control, while the New Bedford and Sydney example reviewed cases in sediment contamination and the role of the public in environmental decision making. Relevant round table sessions included No. 3, "Managing land-based development along the shoreline", which addressed the impacts of human settlements, land-based sources of pollution and coastal development.

4.4 Climate change

"Impacts of climate change and sea-level rises on coastal resources futures and sustainable development : implications for coastal management in West and Central Africa" by O. Ojo was one of several papers presented on climate change in the coastal zone. The paper addresses both impacts and response measures. At the other geographic extreme was a paper by S.M. Solomon and D.L. Forbes on "Impacts of climate change on the on the Beaufort Sea coastal zone". This paper presents empirical results based on the data collected, as well as information on the development of process-based numerical models.

This aspect of change was directly addressed by one of the round table sessions, No. 13, "Assault from the sea." This session examined how communities, governments and scientists should prepare for and respond to climate change and the threat of sea-level rise, as well as to natural disasters.

4.5 Management (institutional) change

A paper presented by F.J. Vande Vusse describes a series of government and non-government projects over the past decade that have explored co-management of Philippine coastal resources. Entitled "Philippine experiences in coastal

resource co-management", the paper demonstrates that artisanal fishers responsible for much of the resource degradation can, when organized and provided with initial assistance, become effective resource managers. Several papers were presented at CZC '94 on the Canadian Atlantic Coastal Action Program (ACAP) initiative that espouses community based planning. One of these, "Atlantic Coastal Action Program - Cape Breton: coastal communities in action" describes the work of an ACAP committee that is developing an environmental management plan for the area surrounding the Sydney and Glace Bay Harbours in Nova Scotia.

Management change was a major thrust of both the interactive workshops and the round table sessions. It was also addressed in the plenary sessions by invited speakers. For example, in the opening address, the Honourable Brian Tobin, Minister of Fisheries and Oceans, stressed the importance of a cooperative approach to coastal zone management. The keynote speaker, Dr. Arthur May, President of Memorial University of Newfoundland, also addressed management change in his address. He proposed that in view of the common property nature of our fisheries, the east-coast fishery should be "given back to the people who do the fishing", noting analogies between the family farm and the family fishing enterprise. Another facet of the conference, the public meeting, also addressed management change. Dr. Evelyn Pinkerton, noted Canadian researcher and author, reviewed past experiences in community involvement in management of marine and coastal resources within Canada and the United States. Insights from these experiences were then explored in relation to Nova Scotian communities in the wake of the fishery crisis during an open discussion. Another part of the conference, the pre-conference workshop on "Integrated coastal management", addressed the importance of community participation and considered examples in the Philippines, Chile and Canada.

4.6 Social change

Social impacts as a result of the rapid expansion of coastal aquaculture operations were reported on in several papers. One such paper, "The legal context of industrial aquaculture: property rights, user conflicts and dispute resolution in three jurisdictions", by J.G. Phyne, traces the situation in Scotland, Ireland and Canada (Nova Scotia) since the early 1980's. Change as a result of marine natural disasters is another aspect of this category. This was addressed in a paper by A.K. Deb and K. Alam on the "Aftermath of cyclonic disaster on the socio-economics of coastal fishing community of Bangladesh : saga of sorrows and worst poverty scenario".

The workshop, "Making marine mammal management work: sustainability and social equity in the coastal zone", was one of many examples where this aspect of change was addressed at CZC '94. Through a series of case studies focusing on whales, polar bears, walrus', seals, etc., and involving participants from most Arctic nations, the workshop produced generic insights pertaining to sustainability and social equity in the management of marine mammals, and related these findings to problems surrounding marine management today. Among the round tables, No. 9, "Social change in the coastal zone", examined how communities can manage crises resulting from change, e.g., fisheries collapse, demographic changes and tourism development, while Round table No. 4, "Diversifying coastal economies", addressed the socio-economic aspects of this topic.

5. COASTAL CHANGE/COOPERATION ISSUES

Within the context of the conference theme, "Cooperation in the Coastal Zone", and the emphasis within this theme on community involvement in coastal zone management, it is not surprising that the majority of the issues raised were in this field. Improved cooperation, particularly when it involves community groups, mean change ! This section considers the coastal zone cooperation issues involving change that were raised at the conference. While various other coastal change issues were raised and debated at the conference, these tended to be more disparate in terms of their subject field and are not reviewed here. The key coastal zone/cooperation

issues are outlined below. There were eight such issues, and these are amplified with examples, points, etc. They reflect the relatively large attendance at the Conference by community representatives: from the east coast of Canada; from other coastal regions of Canada; from other developed nations; and from developing nations. Many of the latter are striving to manage the consequences of introduced cash economies and Western lifestyles and expectations on top of strongly traditional practices. This is occurring in conjunction with high rates of population growth, a high degree of dependence on foreign aid, and an over dependence on a relatively few sectors on which to base economic growth. Some of these factors, e.g., strongly traditional practices, high rates of population growth and an over dependence on a relatively few sectors, also apply to some developed countries including the east coast of Canada. It is not surprising, therefore, that there was a large degree of unanimity.

5.1 Community involvement in coastal zone management

Many developing countries, particularly small island states, generally exhibit a high level of community involvement in resource management across the coastal zone (Cornforth, 1994). In countries such as Canada, this has not been the case, but there is increasing interest and pressure to move in this direction. Among the points made at CZC 94 with respect the community involvement were:

- national and international guidelines should be translated to address community situations;
- management frameworks at the local level should be based on national/international guidelines, regional standards and local objectives;
- community history and values should be incorporated into coastal zone planning;
- community-based coastal zone management should be a priority for national, and international development agencies; and
- cross-cultural and intercommunity opportunities for information exchange should be developed.

And finally, a word of caution was raised with respect to community involvement, specifically that consultation with communities by governments, etc., does not always equal empowerment!

5.2 Sustainable development

This is a goal that requires active community participation and commitment. The topic is one that was raised many times and resulted in various recommended actions, including the following:

- the conference stressed the need for an ecosystems approach based on management units coincident with watershed boundaries; it also suggested that where jurisdictional reform is underway, consideration should be given to this course of action;
- sustainable development should include economic and social dimensions; and
- there is the need for education programs that provide consensus-building skills for persons involved in sustainable resource management, including policy formulation.

5.3 Co-management of resources

Co-management of resources, particularly fisheries, was a major point of discussion. The Conference recognized that co-management should be a principal objective of coastal zone management. Among the points made were the following:

- governments, etc., should work together to equip and build capacity among community stakeholders;
- the roles and responsibilities of all stakeholders must be identified;
- there must be inclusive programs for both public participation and conflict resolution;
- co-management requires both scientific information and traditional (local) knowledge;
- co-management must recognize equitable partnerships; and
- the issue of foreign ownership and domination of tourist industries in some countries requires partnerships between coastal nations and tourism operators, that are accountable to coastal communities.

5.4 Involvement of indigenous peoples in decision making

Various aboriginal groups were represented at the Conference. Among the points made with respect to this topic were the following:

- native concepts and beliefs should be incorporated into coastal zone conservation and protection;
- there is the need to take steps to build trust and mutual respect between indigenous and non-indigenous groups; and
- aboriginal spirituality should be incorporated as an aspect of sustainable development in the coastal zone.

The issue was raised, but not resolved, as to whether indigenous stakeholders should have special status in the coastal zone.

5.5 Poverty and the impacts of human population

Poverty issues in developing countries can act as a constraint in the meeting of environmental objectives in the coastal zone. Among the points raised on this topic were the following:

- population growth, inequality of wealth distribution and poverty are fundamental constraints to the conservation and protection of the coastal zone;
- governments and international development agencies must focus attention on the elimination of poverty;
- economists, social scientists and natural scientists must work together to poverty issues in the coastal zone and the impacts of human population;
- emphasis should be placed on education at all levels as a means of solving such problems; and
- there is the need to address public rights of access in coastal zone management policies and strategies.

5.6 Communities/scientists interaction

The Conference heard of some interesting initiatives involving collaboration between scientists and fishers, and discussed the broader subject at length. Among the points raised were the following:

- communities have much traditional, or community-based, knowledge that is not being considered by scientists and technologists;
- means of enhancing the incorporation of traditional (local) knowledge along with scientific information into scientific models needs to be developed;
- the limits of science and technology in addressing coastal issues should be conveyed to, and understood by, coastal community groups and other users;
- local communities cannot usually afford to pay for information, e.g., scientific data, collected by private industry; and
- there is the need to improve community perception of the benefits and risks of coastal developments, climate change, etc.

5.7 Compliance and enforcement

Enforcement of regulations, etc., is a crucial issue that must be as closely integrated into customary or currently operating practices and structures as much as possible. With this in mind, the following were among the recommendations made with respect to cooperative enforcement measures:

- there is the need to improve communication among fishers, governments and communities to promote compliance with regulations;
- advisory services and incentives should be provided in support of self regulation; and
- non-regulatory mechanisms for the control of coastal development, etc., should be developed that include conservation covenants, easements and tax incentives.

5.8 Diversifying coastal economies

An intimate relationship exists between economic development and environmental assets in the coastal zone. Economic diversification was the focus of one of the round table sessions that specifically addressed the issue of job creation for coastal zone inhabitants. It was organized in part as a response to socio-economic concerns arising from the collapse of the commercial groundfish fishery in eastern Canada and elsewhere. Conference participants made a number of recommendations on this issue, including the following:

- central governments should help establish self-sustaining funding mechanisms to enable community-based planning and decision making on this matter;
- there is a need to establish working relationships among government, fishers, community groups and the mineral industry in order to assess the economic attributes of the development of offshore mineral resources;
- resource potential options in the coastal zone should be identified by mapping and cataloguing uses, users and resources; and
- ecotourism should be designed in such a way that it is non-intrusive of the natural environment.

6. DISCUSSION

Coastal Zone Canada '94 was in the nature of an experiment. At the outset, the objective of the organizers was to host a conference that involved all key stakeholders including, most importantly, the people who live and work in the coastal zone. In this respect the conference was a success. Approximately 20% of the attenders were members of community organizations from Canada and other countries. Many of these persons interacted at length for the first time with established coastal zone practitioners -- managers, planners, scientists, academics, etc. And on the other hand, many long standing issues were exposed to this "new" group of people for the first time. Also, community groups from around the world found out that they faced very similar problems. As previously noted, CZC '94 did not specifically address coastal change as a major thrust but coastal change issues, particularly within the human dimension, were very evident.

One problem encountered by the organizers was in the translation of the deliberations into principles, issues and actions. A mechanism had been put into place to facilitate this, but in the event the output from the many (85) sessions was not captured to the degree of detail and clarity that had been hoped for. While this has resulted in delays it has not jeopardized the final outcome in the key area of cooperation. As of the date of Coastal Change '95 (February ~1995), the production of the sixth and final volume of Conference Proceedings, which will summarize the sessions and present the results of the conference in the form of a Conference Statement, is well underway and is expected to be published by mid year.

Specifically, the output arising from Coastal Zone Canada '94 will include a set of principles for cooperative action, key issues identified by the participants, and a series of concrete recommendations to be forwarded to appropriate agencies and institutions for action. The recommendations themselves range from calls for specific new initiatives, to suggestions for change of existing regulations or policies. They should provide an outline of coordinated action to which all stakeholders -- governments, agencies, communities, foundations, industries and other resource users -- can contribute.

Coastal Zone Canada '94 was only a step in a longer journey. In response to the sorry state of coastal environments around the world, many different initiatives have been taken by governments, agencies, and individuals including the 1992 United Nations Conference on Environment and Development, the World Coast Conference 1993, Coastal Zone Canada '94, and Coastal Change '95. These and other initiatives represent a momentum that, if harnessed, might lead to more effective management policies and practices for the future.

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Table 1: Paper presentation session topics

Aboriginal communities Aquaculture Atlantic Coastal Action Program (ACAP) Biological and chemical studies Climate change, sea-level rise and natural disasters
Coastal resource development - international Community-based management Conflict resolution and public access Cultural, economic and political considerations Data and information management
East Coast of North America Strategic Assessment Project (ECNASAP) Economics of coastal development - Northwest Atlantic Ecosystem health and rehabilitation Ecosystem protection and management Education and training
Engineering and technology Environmental quality Estuarine research Fish habitat Fisheries management
GIS mapping: applications and constraints Global experience in coastal management International development and cooperation Legal infrastructure Management and tourism in the coastal zone
Marine ecosystem health Marine parks and special areas Partnerships in coastal management Physical oceanography Policy issues and decision making
Pollution and sediments Pollution impact Public participation Remote sensing as a monitoring, classification and surveillance tool Scientific tools for coastal management
Shellfish and marine plants Shoreline and sediment studies Shoreline erosion and protection Wetlands

Table 2 : Workshops

No	Workshops
1	Asean-Canada cooperative program on marine science - Phase II
2	The basic scientific requirements for coastal zone management
3	Public and formal education in coastal zone management
4	Making marine mammal management work: sustainability and social equit in the coastal zone
5	Cooperation and dialogue between scientists and fishers in coastal communities
6	Obstacles and opportunities for the participation of coastal communities in fisheries management: the case of Newfoundland outports
7	The role of research in integrated coastal zone management
8	Comparing harbour management approaches: Boston and Halifax - New Bedford and Sydney
9	Integrated coastal food production
10	International obligations and legal principles
11	Application of information technology to monitoring and managing the coastal environment
12	Coastal community networks - lessons learned, future potential
13	Innovative technologies for coastal zone management
14	Coastal resource utilization: sand and gravel
15	Protecting natural areas in the coastal zone
16	Aboriginal rights and the management of coastal zone resources
17	Legal issues of the coastal zone
18	Managing shared resources: the Gulf of Maine
19	Remediation of environmental degradation in the coastal zone
20	Canadian Oceans Caucus sustainable fisheries project
21	Community based integrated coastal zone management: remediation of coastal environments and restoration of impaired beneficial uses
22	Socio-economic support to water related community initiatives; Environment Canada perspective
23	Elements of a coastal ocean science program in support of UNCED objectives

Table 3. Round table sessions.

No.	Round Table Sessions
1	Balancing resource use
2	Making co-management work
3	Managing land-based development along the shoreline
4	Diversifying coastal economies
5	Meeting our international commitments;
6	Mobilizing science and technology for coastal management
7	Conservation and protection of coastal ecosystems
8	International dialogue
9	Social change in the coastal zone
10	The great offshore
11	Rights of access
12	The politics of coastal zone management
13	Assault from the sea
14	Education training and capacity building for the coastal zone

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IMPACTS OF HARBOUR DREDGING ON THE COASTAL SHORELINE FEATURES AROUND COCHIN

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KEYWORDS: Coastal Zone Management, Dredging, Environmental, Effects, Littoral Transport, Wave Refraction, Shoreline, Coastal Processes

ABSTRACT

The study of coastal zones and its enviro-changes have generated great interest to oceanographers and earth scientists, especially in relation to large scale dredging activities which is a totally man made enterprise. This paper presents a series of topics on recent developmental activities and reflects on the plans for future programmes at Cochin harbour area. To illustrate, one such issue pertains to sedimentation of suspended solids within the harbour region, derived from terrestrial sources via river discharge (mainly during the monsoon season) and tidal inflow during flood from the seaward end as a silt- wedge, both having a large manifestation on nautical depth; the preventive measures include maintenance and capital dredging. The desilted sediment spoil is dumped at an offshore site, not far away from the harbour entrance. A typical circulation pattern in Cochin estuary and adjoining coastal regions rework the dumped spoil to move back into the barmouth region and outer harbour areas resulting in land development on either sides of the entrance. Not as a rule, but generally, land area develops more on the northern parts of Cochin coastal zone. These morphological changes do have great impact on future developmental activities; currently, changes in flow modification, sedimentation rates as well as wave induced circulation for this region are noticeable. This paper further attempts to bring out the impacts of harbour dredging on the coastal shoreline features and implores the scientific community to appreciate the drawbacks of unrestricted man made changes on natural, humble but dynamic coastal environments.

INTRODUCTION

Cochin harbour (9°58'N; 76°14'E) is situated along the west coast of India. There are three channels within this harbour, namely Approach channel, Ernakulam channel and Mattancherry channel. All channels are continuously dredged except during monsoon period. Sometimes purpose oriented dredging has been conducted. The approach channel of 9.5 km length, which is oriented along the east west direction allows the smooth entry/exit of the ships to/from the port. The presence of Willington Island bifurcates the approach channel into two which houses berths and jetties. The greater Cochin backwater system is part of the Vembanad lake which extends towards the south of Cochin parallel to the coast and terminates at the southern end of Alleppey. The presence of typical monsoon winds and related circulation system in the coastal region and within the estuary bring about highly dynamic shoreline changes. Near the coastal region current is southerly during the monsoon period and northerly in other seasons due to the influence of north east trades. Wave height is above 1-2.5 m during the monsoon season and results in rough weather condition at the mouth of Cochin estuary. This paper attempts to bring out the impacts of dredging and associated coastal processes on the shoreline changes around Cochin.

ENVIRONMENTAL SETTING

The meteorological and oceanographical conditions in three seasons; namely Monsoon

(June-September), Post-monsoon (October-January) and pre-monsoon (February-May) period set the estuarine circulation to varying patterns. During monsoon, heavy rains prevailing at the coastal regions lead to high discharge through the rivers connected to the backwater system marked with an increase in suspended solids content within estuary. During this period fresh water located above the high dense salt water shows stratification features leading to the formation of a salt-wedge estuary which prevails throughout the monsoon season. Predominant rough weather conditions generate longshore transport of material from the southern parts of the coastal region, enhances erosion and causes suspended sediments to flocculate at the approach channel. However during the post-monsoon period the entire system at the Cochin region alters with an increase in salinity longitudinally, which has been observed since Gopinathan and Qasim (1971). The post monsoon period shows sharp increase in salinity within the estuary to form a well mixed estuary when fresh water discharge is at its minimum.

Monsoon months, dominated by the heavy discharge of fresh water from Periyar and Muvattupuzha lead to the increase in the load of suspended material pumped into the estuary and the channels. Studies by Sundaresan (1991) indicated the suspended sediment concentration sharply to increase during these months and consequently reduce during nonmonsoon months. The input of increased sediment load on silting, decreased the depths in the channels; but during the pre- and post-monsoon period sediments entering from the sea eventually settle at the inner channels, both period necessitating maintenance dredging.

MARINE TRAFFIC OPERATIONS AT COCHIN HARBOUR

In order to facilitate smooth marine operations, the port is open to large vessels (35,000 dwt) which necessitates the deepening of the channels time to time due to sedimentation. The Cochin Port Trust (CPT) had completed the first part of the channel deepening programme by the middle of eighties and maintains the depth of inner channel around 12 m and the approach channel approximately at 12.8 m (Fig. 1). Recently, Cochin Port commenced a new project to further deepen the inner and outer channels to 13.0 and 13.8m respectively. The dredging activities in the harbour region causes changes in physical, chemical and biological parameters (Nair et al., 1988; Shibu et al., 1990; Rasheed et al., 1995); these aspects will have to be taken into account before the start of any large scale escavation processes. The huge quantity of material that may be removed would adversely affect the ecology of the region subsequent to continued (regular) dredging. At this time, it is too early to predict fully the flow pattern modification and associated changes during the event of such a development.

Associated with CPT dredging activities, a bund was constructed near Vaikom known as Thanneermukkon bund (1402 m length) to prevent salt water intrusion and allow only free passage of fresh water during monsoon period. The objective was to raise two time cropping per annum in the adjacent hinterland paddy fields. According to Balchand (1984 & 1994), the presence of the bund prevented the saline water intrusion but it paved the way for devastating ecological and socio-economic problems. The opening of the bund would increase the discharge of fresh water into the backwaters, leading to heavy siltation in the inner and outer channels.

The Cochin backwaters are constantly disturbed by land reclamation processes and the Government has put forward a plan to avoid further shrinking of backwaters; the message is canal development and improved navigation through isolated waterways to facilitate transport. This would however create new environmental problems (dredging, bank erosion etc.) and also require large sums of investment. First priority will be to find right dumping grounds, alternative to reclamation of land areas. Adequate requirements of the spoil location criteria have to be met in this context. Dumping site either may be at an offshore area or could be near the coastal regions but far away from the Cochin gut or preferably at the southern tip of the Willington Island.

The present practice of dumping at an offshore area has created new shoreline changes as observed from the development of the Vypeen region (Fig. 2 & 3 - discussed later). The sediment spoil which is dumped at the offshore sight has reasonable possibility to be transported to the coastal area under the influence of wave action and littoral currents. The continued reclamation at Vypeen area will cause to decelerate navigational prospects. This depositional features are not only observed on the northern part of the gut but also on the southern part of the gut where siltation has been observed time in and time out. The land development on both sides of the approach channel will now certainly influence the circulation pattern, as discussed later.

SHORELINE CHANGES THROUGH DECADES

The different stages of development of land is detailed on the basis of the shoreline features and depositional characteristics. The available oldest map of Cochin area is shown in the Fig. 1. This gives a pictorial representation of the area under investigation. Located on either sides of the Cochin gut are Vypeen and Fort Cochin land masses. Just east of the Fort Cochin area, Willington Island is located. Part of the Island was reclaimed by cutting the sand bar at the outer harbour and spoil disposed at the northern end of the Willington Island by using a dredger named after "Lord Willington" which was operational for cutting the sand bar at the bed of the sea for 8 long years under the leadership of Sir Robert Bristow (Sahai, 1986). In 1929, it was opened as a 5km long approach channel connecting the Cochin gut to the deep sea (Bristow, 1967). At that time, the channel depth was 9.0m and 137m wide marked by buoys on either sides. Bolgatty, Wallarpat Island and Ernakulam are also clearly visible in Fig. 1. To increase trade and commerce, in Cochin, two more channels were also dredged, namely Mattancherry channel and Ernakulam channel.

To further improve marine trade activities the CPT authorities regularly maintained the channel at a depth of about 9.0 m before 1950. Due to the continued and at times increased dredging activities and other related artificial exercises, the entire coastal region around Cochin underwent gradual changes in its geological and geographical characteristics. Fig. 1 reveals the pictorial representation of the inner and outer harbour during the year 1937. The figure clearly reveals that Fort Cochin area is far bigger than that of Vypeen area. But to the atypical circulation in the estuary, development of coastal currents, longshore sediment transport and development of mudbanks (Kurup, 1972) at the northern end of Cochin gut (Narakkal) plus river runoff altered the character of the shoreline. Among the above mentioned processes, the dredging activities and nearshore circulation were a significant factor in the development of land on the western part of the Vypeen land mass. The dredging activities augmented after 1950 was for trade and commerce to gain momentum. The next available and authentic data was for the year 1961 that will clearly indicate the variations of the coastal region adjacent to the Vypeen land. The newly formed area was less than 100 km^2. The profile connecting old Vypeen area and the profile of 1961 shoreline will give an idea on the area reclaimed. The deposition in that area was a result of atypical coastal currents and wave pattern. The disposed sediment on the northern parts did definitely find its way back to the Vypeen coastal area evidenced by textural studies. Further land development is evidenced in Fig. 2. These developments indicate that the depositional character shifted more towards the north and created a canal within the two newly formed land bodies. As seasons progressed, the depositional features also changed accordingly. The next stage of development can be observed from the profile of 1967 to 1977 (Fig. 2). During this period the development of land was more pronounced at the southern end. There was a seasonal formation of sand bar observed near Fort Cochin in 1977.

Land development after 1977 indicated in Fig. 3 shows the deposition to continue at Vypeen area of well sorted fine sand material. This material found in conjunction with clayish and silty characteristics is typical for this region. The wind activity, development of waves and associated

currents will bring the sediment in suspension and transport the same to the coastal area. During the tenure of a 10 year period from 1977 to 1987 the deposition was not much prominent. Any extension of land took place only on the south west part of the Vypeen area. During this decades the dredged spoil was dumped on the southern part of the approach channel by discontinuing the original dumping ground on the northern parts. This may have significant influence on the shoreline changes at Vypeen.

Since the middle of eighties, the observation indicated that rapid accumulation of sediments occurred on the western part of Vypeen to date (January 1995). The rapid change of the coast may be due to the increased dredging activities at the inner and outer channels and use of dumping grounds both north and south the approach channel.

FUTURE OUTLOOK

Cochin harbour is currently the fastest developing harbour of India; recently a container terminal has been constructed at the eighth and ninth berth of the Ernakulam channel. This will provide adequate facilities to transfer the bulk cargo within a short time. The use of gantry cranes, the second in the world to be operational, will serve the port and country in a better way. These are all fully computerized too. The above changes are part of the developmental activities, which would enhance the industrial and commercial aspects, especially the imports and exports sectors. A super container berth is also planned on the northern part of the Island (Wallarpat region). Then above mentioned developmental activities would however lead to a greater stress on the environment & ecology. The present ongoing activities of reclamation of land at the southern part of the estuary and construction of a marine park, in addition to recently proposed construction of bridges from Ernakulam to Bolgatty, further extended to the Vypeen land will invariably lead to increase in dredging activities and lead to more environmental issues.

The proposed dumping ground is slightly more than 3km from the north of the fairway buoy, located at the end of the approach channel. A few studies (Gole & Tarapore, 1966 & Anto et al., 1977) had showed that the material dumped 850 m on either side of the approach channel found it way back into the channel; however, a site selection study in 1968 showed that if the material was to be dumped 2 km north of the channel it will not find its way into the channel but move towards the Vypeen coastal area (CWPRS, 1969). At present the dredged material is dumped 3 km away from the north and south of the approach channel, measured from the fairway buoy.

The dumping site on either sides have created more interesting environmental developments. The waves, currents and littoral transport, and formation of mudbanks along the west coast of the Kerala are attributed to bring about the recent changes of in shoreline along the outer harbour regions of the Cochin gut, especially on the northern parts. Wave refraction of this area is conducive to the above observed changes. A mud bank formation on the Narakkal coast induces the acceleration of accretion at the Vypeen beach. It is likely that further deposition on the Vypeen side of Cochin gut would eventually prevent present navigation in the approach channel. In order to escape from these adverse effects, engineers have now to look afresh at the coastal processes and design adequate measures to circumvent the problems. The impact of harbour dredging is thus very visibly exemplified as shoreline changes at Cochin.

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Fig. 1. Map of Cochin Harbour in 1937.

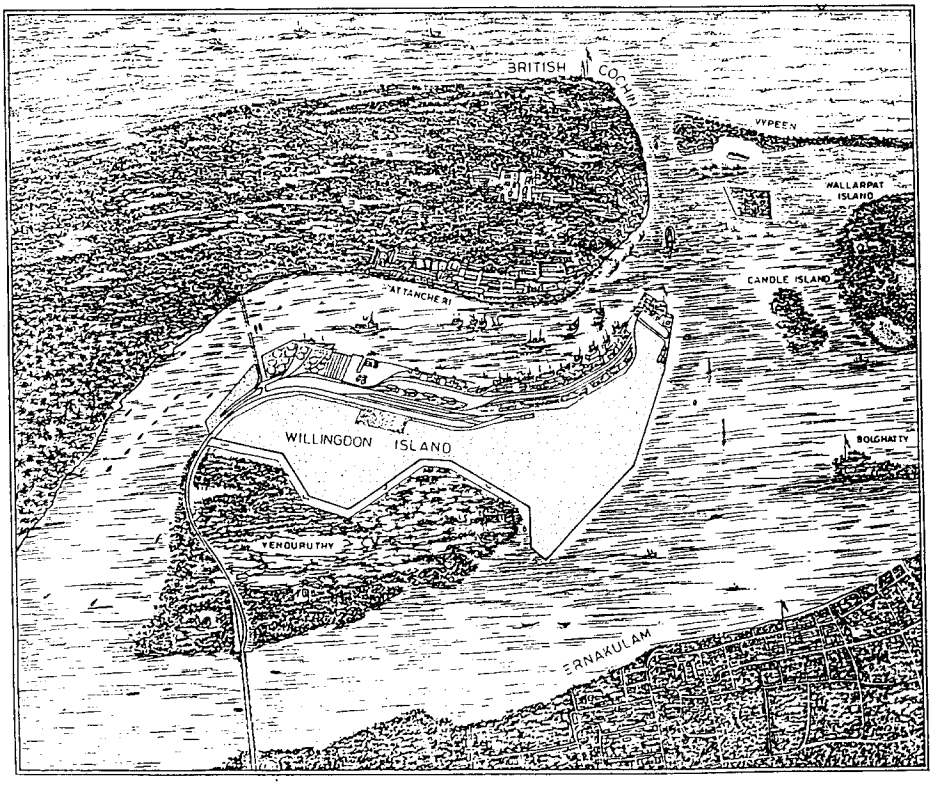


Fig. 2. Map of Cochin Harbour and adjoining coast during 1961, 1967 and 1977.

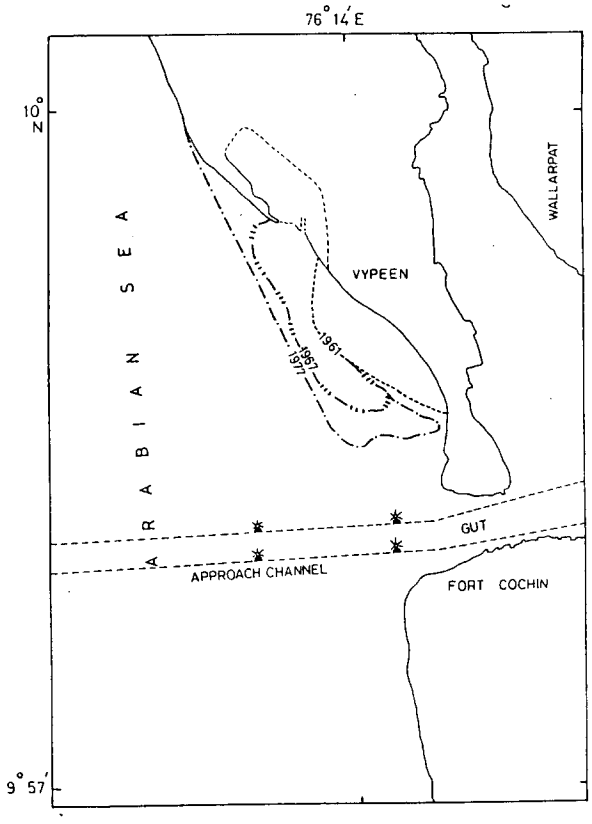
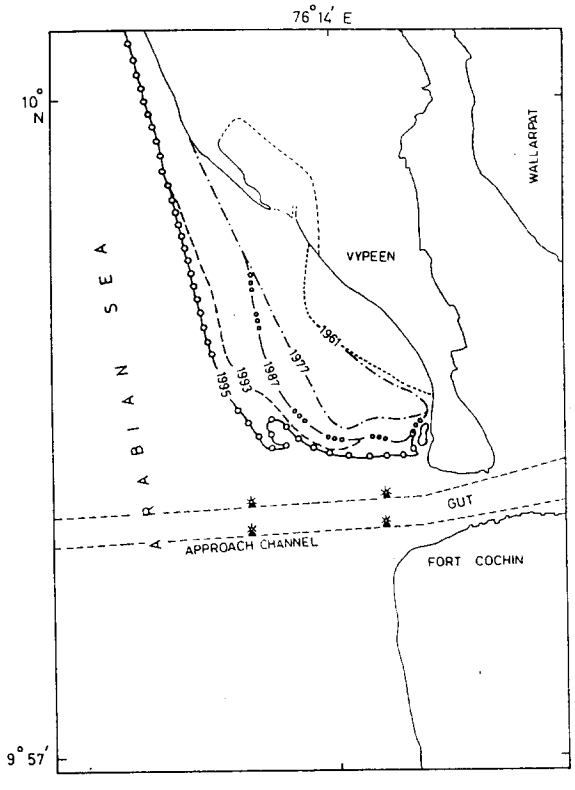


Fig. 3. Map of Cochin Harbour and adjoining coast during 1961, 1977, 1987, 1993 and 1995.



POSTER SESSION

Proc. Int. Conf. 'Coastal Change 95' Bordomer-IOC, Bordeaux, 1995.

LES PLAGES DE L'ÎLE DE SANTA CATARINA (BRÉSIL): UN SYSTÈME SÉDIMENTAIRE ÉVOLUTIF ET PRÉCAIRE.

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La façade océanique de l'île de Santa Catarina se caractérise par une alternance de caps rocheux granitiques et de plages (beach cells) de forme et de taille diverses, façonnées par des houles dominantes de N.E. et de S.-S.E.
Des ensembles de dunes côtières sont localement développes à partir de ces plages dans des "couloirs de vents" entre les principaux reliefs; ils participent localement a un flux terrestre de dérive littorale et constituent une réserve de matériaux sableux, qui est complémentaire de celle qui est située sur le proche plateau continental.
La récente urbanisation du littoral en bordure de ces plages a fort attrait touristique, révèle leur caractère evolutif et surtout leur tendance à l'erosion. L'étude de l'évolution du trait de côte (comparaison des photographies aériennes de 1938, 1991 et 1994, et un suivi régulier de profils de plages, depuis plus de 3 ans) montre des évolutions différentes pour 3 types de plages:

- Plages en forme de "demi-coeur" (half-heart shapped beaches):
Ces longues (3 à 5 km) plages exposées aux houles océaniques, de forme hyperbolique, montrent de fortes érosions (0,5 à 0,95 m/an) en particulier à leur extrémité sud, qui est la plus courbe et la plus abritée des vents du Sud.
- Petites plages en arc de cercle (pocket beaches):
Un suivi morphologique régulier de ces petites plages (1 km environ), bien délimitées par des caps granitiques, montre que leur budget sédimentaire est actuellement équilibre.
- Plages des flèches littorales en accrétion rapide:
Elles se caractérisent par une grande mobilité des sables et donc une grande sensibilité aux interventions humaines.

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ORIGIN AND DEVELOPMENT OF THE LARGE ACCUMULATIVE FORMS ON THE SEA COASTS (THE BALTIC AND THE CASPIAN SEAS OF RUSSIA)

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The relief of the coastal zone at the south of the Baltic sea was formed under the influence of the Littorina transgression, which started about 8000-7500 yr B.P. After the Ancylus lake regression, the Vistula river and the Neman river had deltas north of their modern positions at an elevation of 35-40 m below the present sea level.

There were two vast delta plains at the southern parts of the modern Gdansky and Kurshsky gulfs at the beginning of the Holocene. The sea level rise at the beginning of the Littorina transgression initiated the abrasion processes and the smoothness of the marine border of the river deltas due to the wave activity.

The rate of the Littorina transgression at the beginning was rather fast (1-2 cm/yr). Then the rate of the transgression decreased and the sea-level rise was accompanied by the formation of numerous islands, so called marine bars in the river mouths. The formation of the bars was initiated by the appearance of the accumulative banks over the water surface on the border of the avandelta. We suppose that such bars in the avandeltas of the largest rivers were the "first step" to the appearance of the large accumulative forms, not only in this region where the Vistula and the Kurshsky spits exist, but on the coasts all over the world.

The most favourable conditions for the bar formation were between 6500-5500 yr B.P., when the rate of the transgression decreased. It is necessary to note that these bars increased in height simultaneously with their displacement towards the land. The further sea level fluctuations and aeolian activity led to the growth of both width and height of these forms. The sea level oscillations promoted the expansion of the island areas and their interconnection into the large extensive forms. Due to the aeolian processes, the sand material moved from the coastal zone and created huge dune massifs. Now these dunes are moving landward, to the land borders of the spits.

The level of the Baltic sea at the end of the Littorina transgression, i.e. Limnea transgression (ca. 2500 yr B.P.) was higher than its present position by not more then 0.5-1 m, so the water of the sea penetrated into the delta plains. As a result, the Vistula and the Kurshsky gulfs appeared. Results from drilling suggest that these gulfs were always parts of the flooded delta plains but never an open sea.

The analysis of ancient cartographical maps gave evidence that the Vistula spit occurred as several sandy islands for a long time, and that they were only united in the single accumulative form ca. 800-1000 yr ago. Now the rise of the sea level is leading to the abrasion of both the marine and land borders of the spits.

The study of large accumulative forms of the Caspian sea, which developed in the river mouths under the sea level fluctuations during Holocene, revealed that they were formed in the same way as those of the Baltic sea. These accumulative forms are, in their first stage of development, represented by the small islands, i.e. marine bars on the marine border of the Terek, the Volga and the Ural deltas. The sea level at the beginning of the Novocaspian transgression (Holocene) was lower by 30-40 m in comparison with the contemporary one.

The sea-level rise in the Holocene was not constant, there were some regressions and transgressions. These oscillations led to the growth of the wider and higher shore bars. Moreover, the shore bars moved landward due to the sea-level rise. This process promoted the moving of accumulative forms to the delta plains. Under certain conditions, when the rise of the sea was too fast, the shore bars and the islands had no possibility to overbuild, following the sea-level rise. So most of them were flooded.

There are many single accumulative forms on the coasts of the Caspian sea, which have not developed in the river mouths. The study of their genesis revealed their attachment to abrasion surfaces, drawn up during the previous stages of the high sea-level position. They are the Karabugas, the Krasnovodsky and the Cheleken spits, the bars on the Buzachi peninsula and others. Such huge shore bars can appear only if the slopes of the coastal plains are less steep than the submarine ones. The sea-level rise led to the remaking of the border of the coastal plains and this promoted the appearance of shore bars. All these bars developed on the coasts but not on the submarine slopes, i.e. they had never been the submarine bars.

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ON THE FREQUENCY OF EXCEPTIONAL WATER LEVEL EVENTS AT THE GERMAN BALTIC COAST

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INTRODUCTION

Coastal zones show a particularly sensitive response on variations of atmospheric circulation since it is boundary zone between ocean, atmosphere and land. The wind field directly influences the water level, strength and direction of sea state as well as the current conditions in the surf zone. These processes determine the accumulation and abrasion of the coast. Thus the coast-dynamic processes are coupled with the atmospheric parameters and its variations. This paper focuses on extreme water level variations at the German Baltic Coast caused by strong wind fields.

Storm surges are extraordinary wind driven rises of the water level at the coast. KOLP (1957) has interpreted such events as disturbances, which are secondary superimposed the slowly running coast building processes. Indeed they can exceed the annual mean shore decline by many times. For the extent of devastation the duration of the extreme event and not only the water level height itself is important. A water level of about 80 cm above Normal(approximately the mean sea level) is supposed to be favourable for a severe shore decline. On cliffs the impact of storm surges seems to be more serious than on flat shores, especially since the devastation is irreversible. According to STERR (1989) the share of storm surges in the total balance of cliff-decline is important or even dominating. The rate of decline at Krusendorff-Cliffin Schleswig-Holstein was about 66 cm/year from 1957 to 1987. In the total rate three storm surges (1957, 1978/79 and 1987) have a share of more than 40%.

Extreme low water level events seem to have a less impact on the coast than storm surges, however the German Baltic Coast is more concerned by extreme low water level events. Besides the knowledge about low water level events is very important for marine navigation.

DEFINITION AND CAUSE OF EXTREME WATER LEVEL EVENTS

If the water level increases at the gauges of the German Baltic Coast at least up to 100 cm above. Normal, then we have a so-called storm surge or wind flood. We subdivided these exceptional water level events into three storm surge classes:

100-124 cm above Normal = Light
125-149 cm above Normal = Medium
≥150 cm above Normal = Heavy

The storm surges at the southwestern Baltic Coast are caused by deep cyclones, which are moving over the Baltic proper. The wind fields, related to these cyclones, with wind directions of about NE cause a considerable water build-up at the coast of the southern Baltic. There are two main classes of cyclone tracks (according to KOHLMETZ, 1964), which are relevant for the occurrence of such exceptional water level events:

I. Cyclones, approaching from NW or W to the Baltic, move over the Baltic proper or south of it respectively.

II. Cyclones, approaching from South: This is the track Vb according to VAN BEBBER.

If the water level falls to under 400 cm above Gauge Zero (what is 100 cm below Normal), this is an extreme low water level event. We subdivided these ones into three low water-level classes:

376-400 cm above G.Z. = Light
351-375 cm above G.Z. = Medium
≤350 cm above G.Z. = Heavy

Extreme low water level events are caused by cyclones moving over South or Central Scandinavia. Strong southwestern winds over the Baltic lead to an exceptional fall of the water level at the gauges of the German coast. Three main cyclone tracks can be divided (MEWES, 1987):

I. Cyclones, which develop in the western North Atlantic and move over the North Sea and Scandinavia.

II. Cyclones, which develop south or southeast of Iceland and move on strong bent tracks in a north-eastward direction.

III. Cyclones, which develop in the area around Iceland, move to the Norwegian Sea or to the Scandinavian Coast, however the cyclone centre does not cross the Baltic region. Variations in the occurrence of extreme water level events correspond with those of the tracks of northern hemisphere extra tropical storm cyclones.

12 gauges along the German Baltic Coast were chosen for the investigation of storm surges and 8 for the extreme low water level events respectively. It has to be noticed, that the values are corrected to a standardized reference system.

RESULTS

In the last decades a significant increase of the number of storm surges at all investigated gauges has been noticed. Above all the light and medium ones are concerned by an increase. The absolute monthly maximum is found in December and January. The date of the maximum has shifted in this century from December to November (Fig. 1).

The number of extreme low water level events has significantly increased at the Baltic Coast of Schleswig-Holstein, however at the coast of Mecklenburg it has decreased significantly (Fig. 2). Most of all low water level events occur in November and January, in December a relative minimum can be found at some gauges. An analysis of the annual cycle in several 30-year-periods shows no significant differences. The gauges at the inner coast are more affected by extreme low water level events as well as by storm surges.

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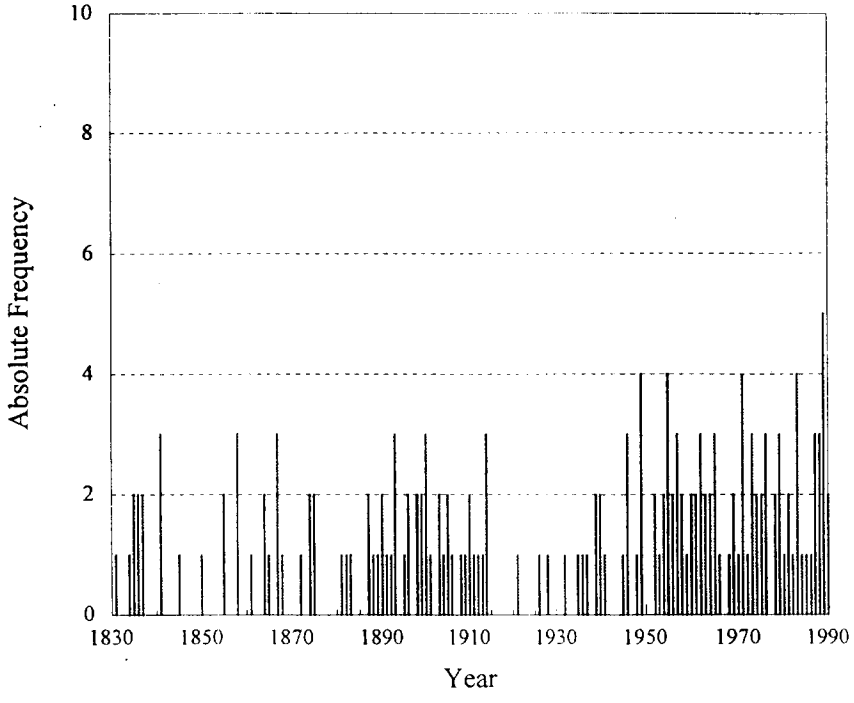
Fig. 1. Yearly frequency of storm surges at the gauge of Travemünde between 1831 and 1990. Significant increase: + 1.0/100 yr.



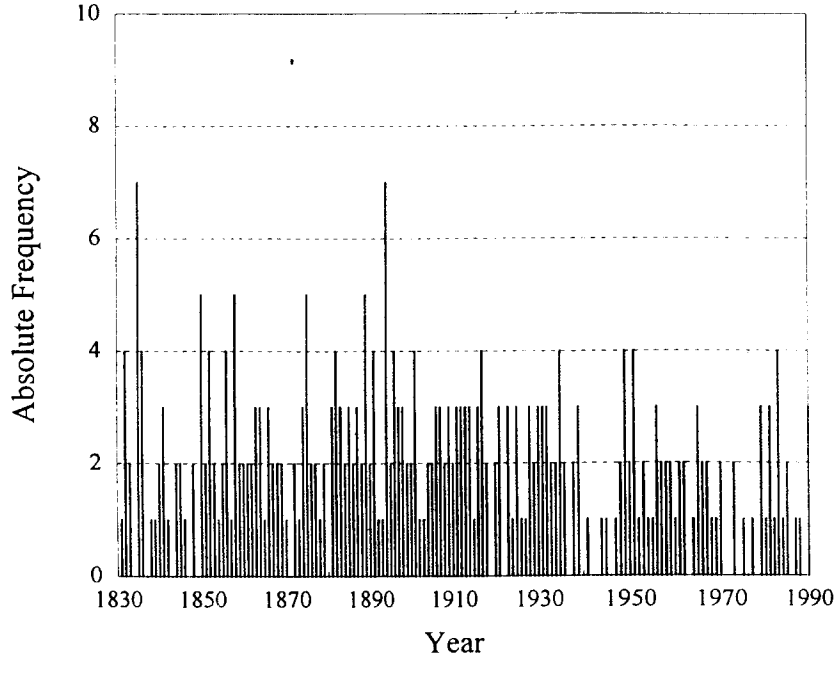


Fig. 2. Yearly frequency of extreme low water level events at the gauge of Travemünde between 1831 and 1990. Significant decrease: -1.4/100 yr.

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THE IMPORTANCE OF THE LONG-TERM PERSPECTIVE IN COASTAL MANAGEMENT ISSUES.

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Public appreciation of the rate of coastal change is often coloured by the sudden, dramatic changes which occur as the result of short-lived, episodic and extreme events caused by storms, floods or landslips. Such events lasting hours or days may even be responsible for the major part of the total coastal recession, accretion, longshore transport, and sediment inputs to the system. Consequently, attempts to determine average or long-term estimates of rates of change which involve relatively short-term monitoring may miss, or be incapable of making measurements during such violent events. Short-term monitoring may also be unable to determine the natural variability of the system or to discriminate natural changes from those which result from human interference. Some processes occur too slowly and over time scales which are too long to be measured by monitoring programmes.

A better approach to the determination of long-term rates of change is to integrate short-term results with results obtained from the examination of the sedimentary record to give a long-term perspective over time scales of decades, centuries or millennia.

To this end the Land-Ocean Evolution Perspective Study (LOEPS), a part of the NERC Land-Ocean Interaction Study (LOIS) is examining the evolution of the English east coast between Berwick-upon-Tweed in the north to Great Yarmouth in the south. This stretch of coastline is over 650 km long and includes a great diversity of coastal forms and a wide range of coastal management problems. It includes the heavily polluted Humber Estuary and some of the most rapidly receding cliffs in the United Kingdom. LOIS aims to quantify the exchange, transformation and storage of materials at the land-ocean boundary, and to determine how these parameters vary in space and time. LOEPS aims to place these parameters into a longer timeframe to enable models and predictions of coastal change to be refined. LOEPS is studying sedimentary sequences from the upland catchments, coastal lowlands, intertidal and offshore regions. Intensive study of cores is being integrated with seismic and geomorphological data to produce a 3-D framework for coastal evolution spanning the Holocene period.

Five major themes within the LOEPS programme illustrate the importance to coastal management of taking a longer-term perspective to provide a context for short-term monitoring studies.

1) Sea Level Rise

Postulated future sea level rise has important implications for the construction of flood defences in low-lying areas. Modern tide gauge records show mean sea level changes over the last century or so. This time scale is inadequate to measure long-term trends. A longer record is available within the Holocene sedimentary record composed of terrestrial, brackish and marine sediments. Past sea levels can be determined by reference to the transitions between terrestrial and marine sedimentation, although careful account needs to be taken of the changing tidal regime which is linked to changes in coastal configuration and nearshore bathymetry.

At a given point relative sea level depends on 3 factors;

- Eustatic (global) sea level
- Vertical land movements (crustal subsidence-uplift, sediment consolidation)
- Local sediment supply

Along the English east coast removal of ice loading after the last glaciation 18000 years ago has resulted in relative uplift of the land to the north and subsidence to the south. The LOEPS project is studying these differential earth movements by examining sea level indicators in the sedimentary sequence both along the coast and offshore.

2) Climate History

Changes in climate can have profound effects on the coastal zone. Global warming will result in a rise in sea level through melting of polar ice and thermal expansion of the oceans. Changes in prevailing wind directions and the frequency of storms may have a strong influence on coastal erosion and deposition.

In the UK reliable meteorological records exist only since the 18th century and are insufficient to indicate long-term trends. Evidence of climate change can be found in the geological and historical record. For example, an increase in the incidence of storms during the 13th century appears to correlate with large-scale changes in coastal geomorphology at several locations along the English east coast.

3) Coastal Geomorphology

Dramatic changes in coastal geomorphology have occurred in the past as a result of natural processes. The low-lying coasts of north-west Europe have been defended by Man against the forces of nature, in some places since Roman times. Analysis of the geological, archaeological and historical records can reveal evidence of the natural response of the coast before human interference. The effects due to man can therefore be isolated in studies of coastal change and predictions can be refined.

Around 1000 years ago the estuary of the River Yare opened directly to the sea and was navigated by vessels travelling to the Roman port of Burgh Castle. The rapid growth of a spit across the estuary mouth blocked the estuary and diverted the river several kilometres to the south. The most rapid stage of spit growth occurred during the 13th century and appears to have coincided with an increase in storminess in the North Sea. Similar examples of rapid coastal change during Medieval times occur elsewhere along the English east coast.

4) Coastal Recession

Long-term rates of coastal erosion have traditionally been estimated by analysis of historic records. In the UK the first reliable large-scale maps were produced towards the end of the 19th century. Older maps and records are not sufficiently reliable for measurement of coastal recession rates. Sediments derived from coastal erosion may be deposited in coastal accumulations such as spits or barriers, or in offshore sediment sinks. Analysis of the lithologies and stratigraphic sequences in these accumulations may reveal changes in the rate or locus of coastal erosion.

The cliffs of Holderness form part of one of the most rapidly receding stretches of coastline in the UK and represent one of the largest sources of sediment within the LOEPS study area. The potential destinations of the eroded sediment are being studied by the LOEPS project. These may include the tidal flats of the Humber and the Wash and offshore sediment sinks within bathymetric depressions in the North Sea. Analysis of cores from these sedimentary environments may reveal changes in the rate of sediment supply which may be directly related to rates of coastal recession.

5) Human Impacts

For centuries the coastal zone has supported a large proportion of the world's human population. In this time Man has had a considerable impact on this environment. In low-lying areas land reclamation and sea defences have strongly influenced the natural physical processes which drive coastal change. In recent years domestic and industrial waste products entering the coastal zone have increased in volume. Monitoring of river and estuary waters cannot distinguish anthropogenic inputs of certain elements from the natural background levels characteristic of the catchment. Analysis of pre-industrial sediments in stratigraphically dated sediment cores from the river floodplain or estuarine tidal flats can allow this natural background to be measured and important changes in the history of the river or estuary to be identified. In some estuaries erosion of older tidal flat deposits may release pollutants back into the system even though discharges of the pollutant have ceased.

In the Humber estuary analysis of intertidal mud flat sediments reveal high levels of arsenic.

The source of this contaminant commenced discharge into the estuary in 1937. Identification of the point at which enrichment occurs in sediment cores allows sedimentation rates to be calculated and can be used as a stratigraphic marker over a wide area within the estuary.

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EFFETS À ATTENDRE D'UNE ÉLÉVATION DU NIVEAU MARIN SUR L'ÉVOLUTION DES "CÔTES BASSES" DU LITTORAL NORMANO-PICARD.

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INTRODUCTION

Le littoral normano-picard est pour l'essentiel constitué de hautes falaises crayeuses, localement entaillées par de profondes vallées perpendiculaires au rivage et dont le plancher est à une altitude sensiblement inférieure à celle du niveau des plus hautes mers de vives-eaux. C'est pourtant dans ces zones à haut risque potentiel de submersion que les hommes et leurs activités se sont implantés préférentiellement.

La conjonction de tempêtes et de forts coefficients de marée peut conduire à la submersion, voire la destruction de cordons de galets protégeant les villes côtières comme Etretat, Fécamp, Pourville, Criel, Cayeux. Ces évènements paroxysmaux sont à l'origine de surcotes et d'inondations par la mer qui menacent l'homme et ses activités. Ces phénomènes sont d'autant plus préoccupants, qu'ils semblent prendre des proportions et une fréquence croissante.

Ce travail tente de faire la part des actions de l'homme et des forçages climato-océanographiques récents dans la dynamique de ce littoral.

CONSÉQUENCES DES ACTIONS ANTHROPIQUES SUR LA DYNAMIQUE LITTORALE

A l'état naturel, les cordons de galets transitaient au pied des falaises d'Antifer jusqu'au port du Hourdel sous l'action des houles dominantes (transit WSW-ENE).

Depuis le début du siècle, les ouvrages portuaires ont sectionné ce vaste système hydrosédimentaire en petites unités indépendantes. Les actions anthropiques (rupture du transit des galets et extractions), ont modifié le volume, la répartition et le cheminement des cordons de galets, contribuant à l'intensification du phénomène d'inondation par la mer.

Notre recherche montre qu'il est réducteur de penser que les submersions de tempêtes sont le résultat de la seule conjonction d'un coefficient de marée important et d'un fort coup de vent. A partir de l'étude de ces phénomènes paroxysmaux passés, il apparaît nettement que la forme et le volume du cordon de galets devant les plages conditionnent également l'apparition et l'ampleur de l'inondation.

PARAMÈTRES MÉTÉO-OCÉANOGRAPHIQUES INTERVENANT SUR L'INTENSITÉ ET LA FRÉQUENCE DES SUBMERSIONS DE TEMPÊTE

La perturbation du budget sédimentaire de notre système littoral apparaît fondamentale pour expliquer la multiplication des inondations par la mer de certaines villes côtières depuis ces vingt dernières années.

Afin de préciser les causes de cette récurrence, nous tentons de vérifier l' existence d'une éventuelle élévation du niveau marin, d'une évolution de la fréquence et/ou des caractéristiques des tempêtes.

Ce travail, effectué à partir de l'analyse de séries chronologiques d'observations météorologiques et marégraphiques sur la période historique récente (1950-1993), s'efforce de préciser les conséquences, sur notre littoral, de l'évolution passée des tempêtes, des niveaux de pleine mer et des surcotes.

EFFETS À ATTENDRE D'UNE ÉLÉVATION DU NIVEAU MARIN SUR LE LITTORAL NORMANO-PICARD

A partir de l'analyse synoptique des tempêtes ayant engendré des inondations, nous proposons un scénario minimum de submersion, basé non pas sur un évènement exceptionnel de période de retour trop longue, mais sur la seule combinaison des marées astronomiques et de la

houle annuelle maximale de cette section côtière. En ajustant ce scénario aux perspectives futures d'élévation du niveau marin proposé par l'Intergovernmental Panel on Climate Change 1992, nous avons tenté de définir le devenir des zones actuelles à haut risque potentiel de submersion.

Dans le cas d'une politique d'aménagement attentiste, l'élévation du niveau marin ainsi que la modification des paramètres hydrodynamiques associés, provoqueront des submersions plus fréquentes et plus intenses, pouvant être délimitées par une bonne connaissance de la topographie des zones basses inondables.

Par ailleurs, l'adaptation du profil d'équilibre des plages, consécutive aux variations du niveau de la mer, ne peut être sur notre côte, déterminée sur les bases du principe de Bruun. L'étude morphodynamique des cordons de galets situés devant les villes côtières, fait apparaître que ces derniers se trouvent dans l'impossibilité de s'adapter aux nouvelles conditions hydrodynamiques, sans engendrer de nombreux désagréments aux ouvrages de défense et aux riverains.

Afin de contribuer à la réflexion sur les conséquences à attendre d'une élévation du niveau marin sur les réactions adaptatives naturelles du système littoral, nous proposons un schéma d'évolution des cordons de galets anthropisés de la côte normano-picarde.

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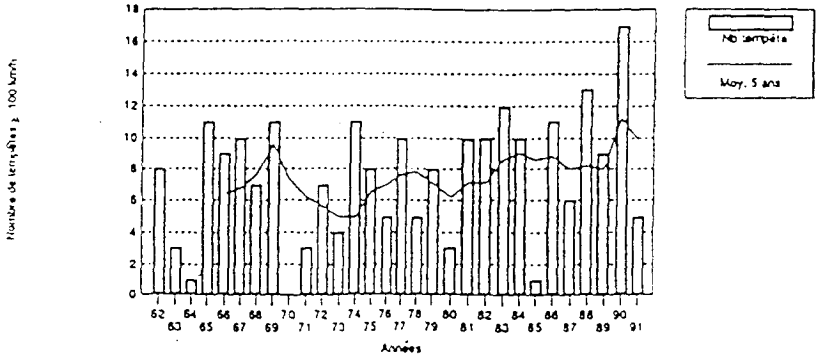
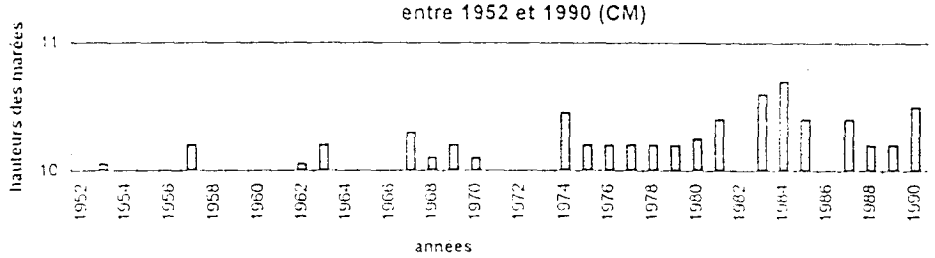
Illustrations:

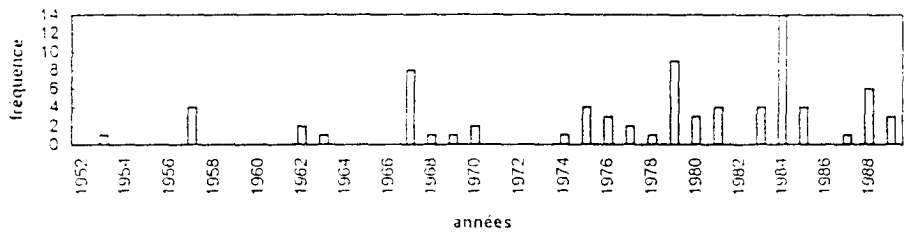


Graph. 6 Fréquence annuelle des tempêtes ≥ à 100 km/h. entre 1962 et 1991
Storm yearly frequency ≥ 100 km/h. from 1962 to 1991

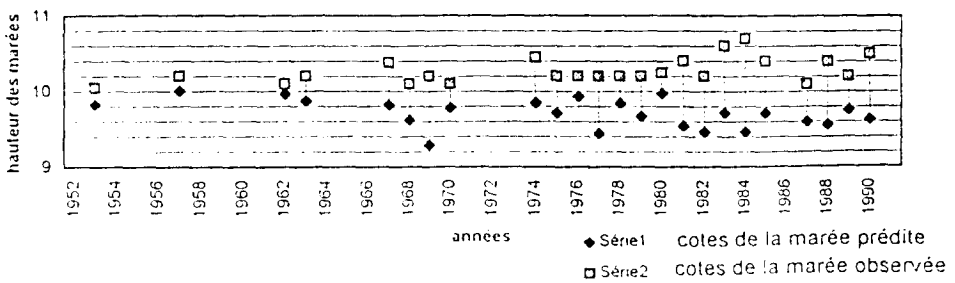
Graph. 2 : hauteur des marées à Dieppe dépassant la cote de 10m. entre 1952 et 1990 (CM)



Graph. 3 : fréquence annuelle des marées dépassant la cote des 10m. à Dieppe entre 1952 et 1989 (CM).

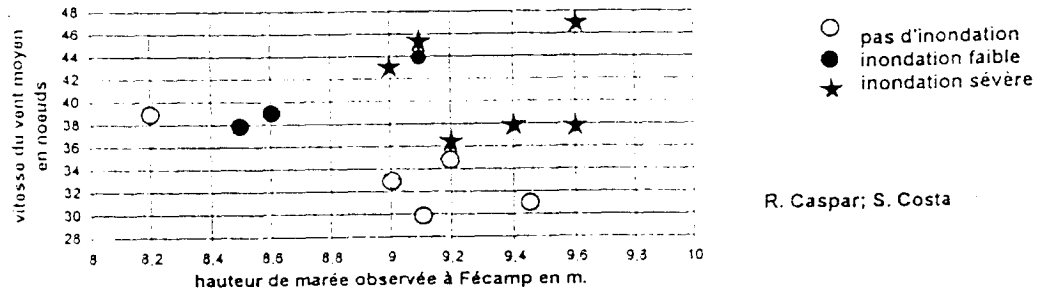


Graph. 4 : comparaison des hauteurs de marées prédites et observées supérieures à la cote 10m.(CM) à Dieppe entre 1952 et 1990



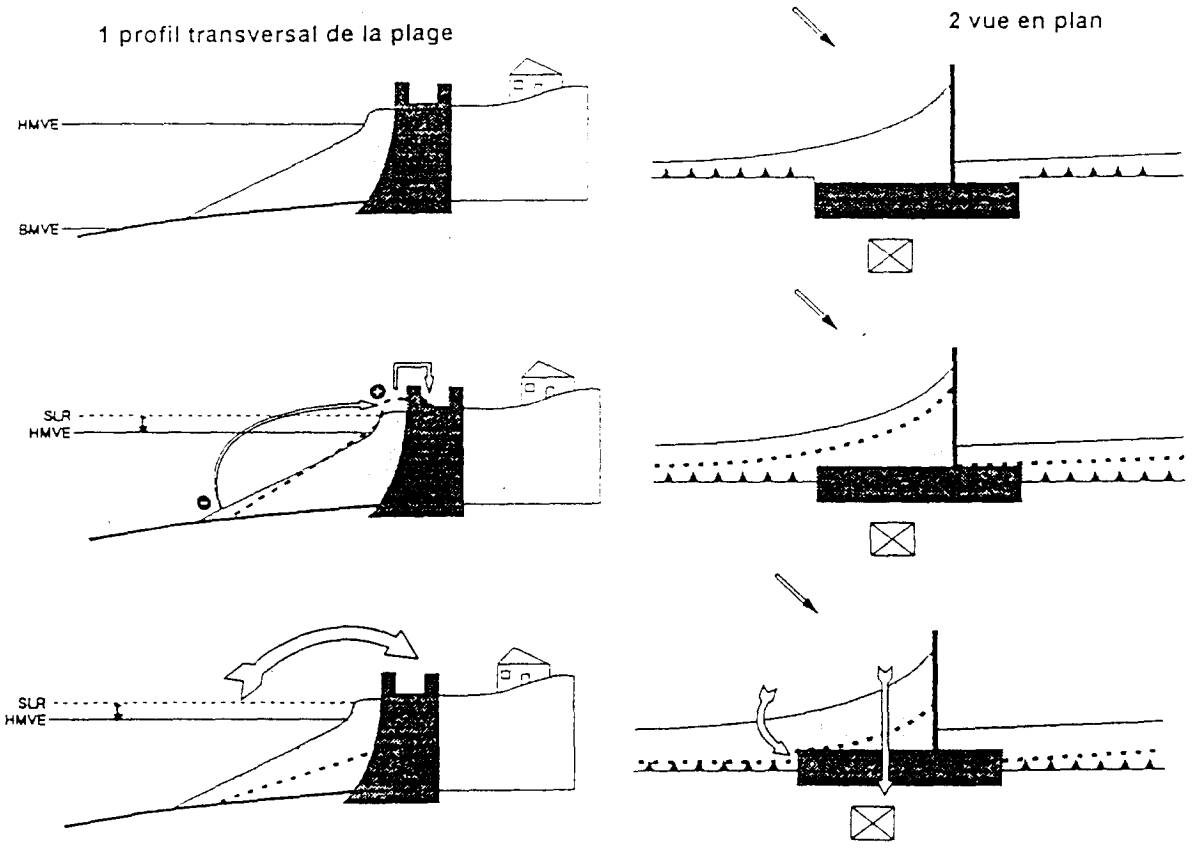
Illustrations cont.:

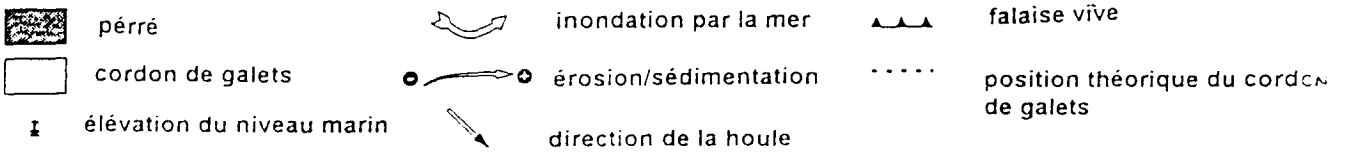
graph. 1 conditions météo-océanogaphiques menant à l'inondation de Fécamp entre 1977 et 1993



R. Caspar; S. Costa

Evolution théorique du cordon de galets des plages normano-picardes face à l'élévation du niveau marin





1a et 2a situation actuelle

1b et 2b situation dans le cas d'une conservation du stock sédimentaire

1c et 2c situation dans le cas d'un démaigrissement du stock sédimentaire

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RAPID RATES OF CHANGE ON A LOW-ENERGY COAST: EXAMPLES FROM PRISTINE AND DEVELOPED AREAS, FLORIDA, USA

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Coastal morphodynamics are controlled directly or indirectly by tidal and wave processes. It is typically considered that large tidal ranges and energetic wave climates cause rapid modification of the coast by mobilizing large amounts of sediment and moving it at a rapid rate; a rather straightforward process-response relationship. What is not so well known is that rapid changes in coastal morphology also take place along low-energy coasts; those well into the microtidal range and with low wave climates. A key factor is the relative interaction between tidal- and wave-generated processes (Hayes, 1979). A well-known diagram that plots tidal range against wave height shows how these processes relate to the general morphology of the coast (Figure 1). Various fields in this diagram converge near the origin.

The Gulf Coast of Florida includes an extensive barrier-inlet system of 30 islands and a like number of inlets. Overall littoral drift is to the south at rates of less than 50,000 m^3/yr. There are numerous local cells where reversals in drift direction occur. This coast is characterized by spring tidal ranges below 1.0 m and mean annual wave heights of 0.25-0.30 m. A glance at Fig. 1 shows that these parameters place this coast in a position near the origin where only a small shift in either wave or tidal values will result in a marked response in coastal morphology. These shifts in the level of either tide or wave parameters can take place both naturally or anthropogenically. The Florida Gulf Coast is an excellent place where these types of change have taken place on both natural and highly developed sections of the coast. This paper will provide examples of the spectrum of rapid coastal changes that have taken place along this low, mixed-energy barrier-inlet system.

Longshore accretion and progradation of barrier islands has been common locally (Davis, 1989). These phenomena are limited because of local problems of sediment availability. Where sediment is abundant, there have been very rapid changes to barriers. Anclote Key on the north end of the system is a wave-dominated barrier. After the die-off of the nearshore sea grass community in the late 1950's, there was a rapid shoreward and longshore movement of sediment that extended the island nearly 2 km in a decade (Hine et al., 1987). Additional sediment is being added to the shore area of the barrier which is beginning to take on the typical drumstick morphology.

Extensive shallow shoals adjacent to Cayo Costa Island have influenced wave refraction and thereby have caused major changes in accretional features on the barrier in the form of small cuspate forelands. Multiple sets have come and gone over the past few decades.

Construction of fill causeways have altered tidal prisms and thereby caused major changes in inlet behavior. Dunedin Pass was 500 m wide and 4 m deep in the early 1900's. It is now closed. The deterioration of the inlet can be directly linked to causeways constructed in 1922 and 1964 (Lynch-Blosse and Davis, 1977). The final step in the process was a result of the nearby passage of a hurricane in 1985. The hurricane removed the small ebb tidal delta that protected the mouth of the inlet and permitted longshore sediment transport to quickly close the inlet completely.

Dredging of the Intracoastal Waterway in 1964 diverted considerable tidal prism from Midnight Pass. In less than 20 years the inlet went from a pre-dredging prism of 7.9×10^6 m^3 to one of 1.5×10^5 m^3 in 1982. The cross-sectional area decreased from 550 m^3 to only 20 m^3 just before closure Davis et al., 1987).

Natural and anthropogenic changes to the coast can alter wave energy and tidal prism; tidal range on the open coast remains the same. These changes in energy have produced major, rapid changes in coastal morphology on the scale of years and decades. Such rapid changes are very difficult to predict thereby making long-term coastal management nearly impossible.

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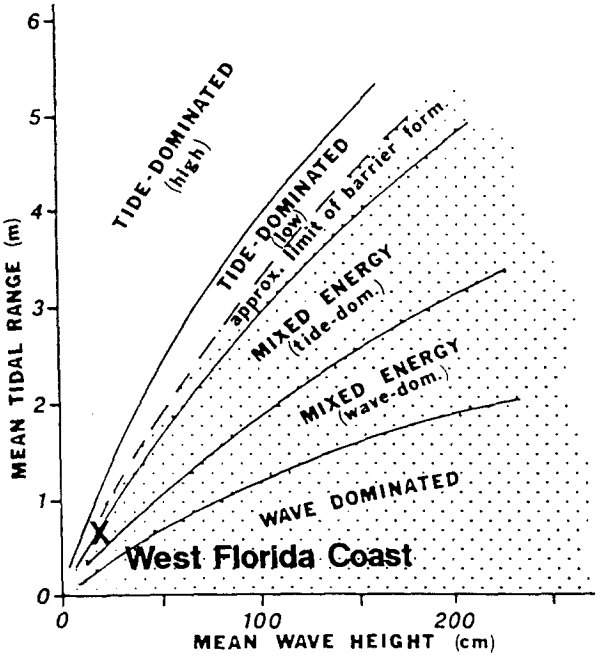

Fig. 1 - Diagram showing how tidal range and mean annual wave height influence coastal morphology. (after Davis and Hayes, 1984)

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RECENT FORMATION OF BARRIER ISLANDS, FLORIDA GULF COAST, U.S.A.

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Barrier islands are one of the most prized of all coastal environmental systems because they provide protection for the adjacent developed upland and because they provide a wide range of habitats for plants and animals. They are also a prime location for a wide range of recreational activities. Although our knowledge of the morphodynamics of modern barriers is extensive we have relatively little direct data on how these systems come to be. Multiple new barrier islands have emerged along the Florida Gulf Coast during the past few decades. Their recent origin has provided excellent opportunity for monitoring the development of these complex coastal systems.

Three elongate and wave-dominated barrier islands have formed on the central Florida coast beginning in 1961 (Crowe and Davis, 1985), 1969 and 1977 (Gibbs and Davis, 1991). Each has been monitored closely since its beginning through aerial photographs, field surveys and vibracoring. Each of these barriers has increased in area and elevation since first becoming supratidal and although there have been severe storms including hurricanes, they have persisted. They range from 3 to 5 km in length and up to 1.5 m above mean sea level. Each of the barriers includes beach, dune, washover fans, tidal flats and wetlands. Two have had tidal inlets during their short existence. This coastal region is microtidal with a mean range of only 0.7 m, a mean annual wave height of 0.25 m, and a mean wave period of 3-4 s. It is strongly influenced by the passage of cold fronts which approach from the northwest during the winter. These energetic weather systems may generate wave heights of 1.0-1.3 m. The coast is also subjected to infrequent influence of hurricanes; the most recent to pass directly over this area was in 1960.

This low-energy, low-gradient coast coupled with locally abundant sediment provides an ideal setting for the development of barrier islands through emergence as first proposed by De Beaumont (1845). The small waves transport sediment landward across the shallow, gently sloping shoreface producing sand bars over which the waves break. Continuation of this scenario eventually produces intertidal sand bodies which become supratidal with time. Opportunistic vegetation helps to stabilize the backbeach and dunes develop rapidly. Within less than a decade of becoming supratidal the islands develop mature vegetation, dunes and local washover fans. Although a severe hurricane could cause major modification to or possibly, destruction of the islands, they have withstood nearby passage of multiple hurricanes and numerous severe storms. Washover and breaching has occurred but the islands persist.

Such development of new barrier islands provides both opportunities and challenges for coastal management. The availability of new protection for the coast which includes a variety of habitats is always a welcome addition to the coast. Two of the islands in question are isolated from the mainland and are fairly remote. They have become very important rookeries for a wide variety of sea birds. They are also a prime location for recreation by people with small boats who wish to escape the crowded nearby Florida beaches. At the same time, there may be some problems associated with the new barriers. As an example, one of the three has become attached to a major recreational beach on a larger barrier island. The development of the new barrier has necessitated modification of the recreational facility, caused some management problems because of the difficulty of monitoring a remote area, and has resulted in a decrease in water quality in the lagoon separating the new barrier from the previous open shoreline.

In summary, the development of new barriers islands can take place rapidly, even on a low-energy coast. The rapid development of new environments provides for a variety of desirable coastal habitats. In some cases there can be management problems associated with the new barriers. Legal questions can also arise concerning jurisdictional designations. Although the new barriers create some additional problems, they are a significant asset to the coast and are welcomed by all.

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LA GESTION DE LA BANDE CÔTIÈRE

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Le littoral, territoire constitue d'une double frange marine et terrestre est une zone d'interface aux multiples conflits qui trouvent leur origine dans les fortes préoccupations économiques et environnementales existantes. Ce territoire évolue dans un contexte très segmente et compartimente nécessitant une harmonisation des actions de gestion et de planification. Il en résulte un besoin d'approche globale par la formalisation d'unités territoriales cohérentes qui favoriseront la gestion intégrée du milieu littoral.

C'est ainsi qu'a été conçue, en parténariat avec l'Agence de l'Eau Rhône Méditerranée Corse, une méthodologie de qualification du milieu littoral fondée sur une zonation géographique et une analyse multicritères pour répondre à la problématique du suivi de la qualité des eaux de la bande cotiere. Après classement des zones et établissement d'une typologie littorale, les risques environnementaux sont analyses pour conduire à la formulation de recommandations en termes d'objectifs et de stratégie de surveillance ou d'intervention.

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TRANSPORT PATHS OF DUMPED DREDGED MATERIAL IN THE SOUTHERN BIGHT OF THE NORTH SEA

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About 20,000,000 tons of dry solids are dredged annually in the coastal harbours and access channels along the Belgian North Sea coast. Authorities and consultants put considerable effort into the research of the behaviour of dumped material since 1984. This research has specially focused on the study of the dispersion and recycling of fine grained material. It is quite important with regards to the optimisation of dredging activities and the assessment of their ecological impact.

Various research techniques were used to evaluate the processes involved. Radioactive tracers are used to measure the dumping processes. This made it possible to trace the dispersion of the dumped sand and mud fraction during dumping and within 2 days following the dumping. Vibrocoring on the dumping sites revealed the dominance of the coarsest sand fraction. Differential mapping and volumetric calculations enabled the computation of the total sediment balance, confirming these observations. They stress the separation of the sand fraction, which remains mainly on the dumping site, and the mud fraction, which is recycled by wave and current action and by density flows.

The migrations and recycling of these dump losses were measured using long-life radioactive recycling tracers. After injection, the tracers were readily detected in all of the coastal harbours and waterways along the Belgian North Sea coast, evidencing the previously underestimated exchange with the North Sea (Fig. 1).

Finally, the residual sediment transport paths were determined by applying statistical calculation methods on grain-size data. Krigeing techniques enabled a 2-dimensional approach and allowed the analysis of irregularly spaced samples. The concurrent results of the analysis of two large databases illustrate the strength of this technique. The spatial variations of the different fractions complement the interpretation of the results of this sediment trend analysis. The derived sediment transport paths were then compared with the results of the tracer experiments.

The outcome of these different analysis techniques revealed a zone where transport towards the coast prevails. This zone extends seawards to about 5 km to the west and 20 km to the east of the Belgian Continental Shelf (Fig. 2). Within this zone, a high probability of recycling dominates. Displaced fine sediments will always tend to move to an area where they are in dynamic equilibrium. The in situ measurements and statistically derived sediment transport paths are indicative of a hydraulical trapping of fine sediments, of the interaction between the loosely compacted upper sediment layer and the suspension layer, and of a partial recirculation to the dredging areas.

The tracer experiments are also used to calibrate and validate sedimentological dispersion models currently under development.

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Fig. 1. Tracer dispersion map, 4 days after injection. Scale 1/400,000.

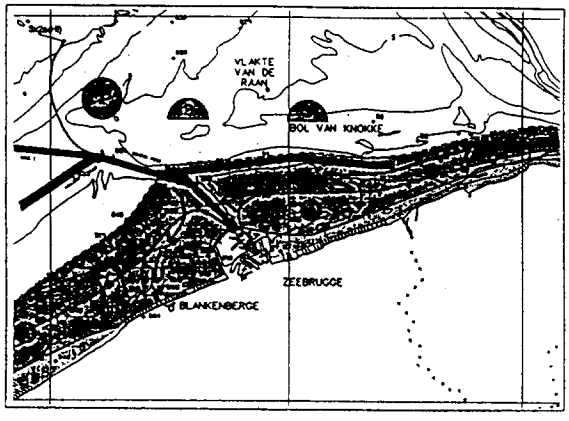
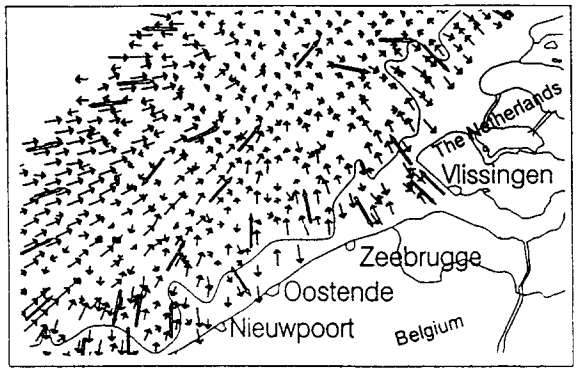


Fig. 2. Residual sediment transport derived with sediment trend analysis. Arrows indicate direction of transport. Scale 1/1,000,000.



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THE ROMANIAN COAST - MARINE ENVIRONMENTAL DEGRADATION

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GENERALITIES

The Romanian Black Sea coastline, which extends over about 250 km, consists of several geomorphologic areas, grouped in two great zones: the delta of the Danube, consisting of alluvial sediments with extensive lowlands, marshes and lagoons, a great part are about 0.5-0.8 m above sea level and a higher zone that consists mainly of cliffs interrupted by short beaches from place to place. In addition, the two zones are different in development and in their distance from terrigenous influence, industry, tourism, or harbour activities. Due to these influences, the marine environments are disturbed. The main negative influences are described here.

COASTAL EROSION

The shoreline of the Danube Delta from Sulina to Vadu retreated up to 340 m in the last three decades, with an average of 200 m. Table 1 includes values for specific coastal segments. Depending on the intensity of erosion-accumulation, the average rate of the beach surface changes are distributed along shore, as follows:

- 60% between 0.90-1.2 ha/yr/km (erosion);
- 25% between 0.03-0.5 ha/yr/km (erosion);
- 15% between 0.06-0.6 ha/yr/km (accumulation).

From Vadu to Vama Veche, where the high shores prevail, the breakdown of the high shore has taken place discontinuously. The evolution of cliffs is more rapid in the sectors formed of loess and slower when the sea attacks the Sarmatian limestone; in both cases, abrasion is frequently accompanied by rain-wash, piping, solution and collapse. There are some little beaches in this area. These are used especially for recreation and tourism. Their evolution has a particular feature, depending on the position between the sections with a high shore which continues into the sea by submarine promontories.

Touristic facilities are sources of a high pollution level. Sand extraction is not licensed, except for the entrance channel to the Sulina branch and for the harbours (Midia, Constanta, Mangalia). However, some companies extract sand from beach for different applications. These negative aspects are increased by the load of contaminants of fluvial origin. In addition, sand supply from the river decreases permanently (Bondar et al., 1992).

BIOLOGIC CHANGES AND DECLINING BIODIVERSITY

Considering the bibliography and the analyses of the present state of the marine ecosystems, Gomoiu (1985) mentions the following changes:

- increase in nutrient concentrations;
- increase in phytoplankton concentrations and the appearance of red-tides, which become chronic and at a higher level every year;
- increase in dissolved and particulate organic matter concentrations, both in sea water and sediment;
- the appearance of hypoxic and anoxic conditions;
- a decrease in the number of zooplanktonic species, with a parallel increase in the density of dominant forms;
- disappearance or decrease in the population of *Zostera*, brown algae and red algae and development of some species of green algae;
- mass deaths of some benthic organisms and modification in the qualitative and quantitative structure of the bottom community;
- modification in the structure of fish and mammal populations.

An important reduction of biota, affecting both the qualitative and quantitative state of the benthic and plankton phyto- and zoo-communities, has resulted (Petran, 1982):

- The Macrophytobenthos has shown a gradual, but continuous decline. Since 1935 up to 1981 the number of macrophyte species decreased from 154 to 69.
- The Zoobenthic communities marked a reduction of species number by 50-60% in comparison with the year 1960.
- The Phytoplanktonic communities: an increase in the amplitude and frequency of algal blooms. It emphasizes the outstanding increase of the proportion of non-diatoms (7.7% in the 1960s to 61.7% in the 1980s) and the decrease of the fraction of diatoms (92.3 % to only 38.7 % for the same period). Bodeanu (1989) mentions that more than 20 monospecific algal blooms have occurred in the Romanian coastal waters between 1983 and 1988. Out of the 8 species responsible for these phenomena, 5 species achieved the greatest blooms ever known at the Romanian littoral.
- The Zooplanktonic communities showed a diminution of the species diversity in the shore areas and in the superficial biotope.
- Ychtiofauna showed major and irreversible changes. Until the 1960s, 26 commercially fish species were caught. This number declined to only 5 main species. There is a drastic catch decrease during the last years, from an annual catch of about 14,000 tons until 1989, to 6,200 tons in 1990 and 3,900 tons in 1993.

INDUSTRY AND LOCALITIES

In the marine Delta area, only three localities of importance can be considered, which are the small town Sulina and the villages Chilia and Sf. George. In the rest of the area the presence of the human habitat is restricted to only some fishermens houses, only used during the fishing season. An exception could be Portita point, where some other activities develop: a camping point, and a meteorological station.

More numerous are the localities in the southern area. The main towns Constanta and Mangalia and some villages are situated here, while touristic sea-resorts (Mamaia, Eforie North and Eforie South, Costinesti, Mangalia North), and a series of small sea resorts are present, such as Aurora, Olimp, Neptun, Jupiter, Venus, Saturn).

Concerning the economic and industrial activities, the northern region has primarily fishing and agricultural (in inner zone) activities and some reed harvesting too. In the southern area are developing important industries (Midia, petrochemical plant, Navodari, fertilizer plant, etc.), harbour activities (Midia, Constanta, Mangalia), production of goods and services. All these activities have a certain impact on the coastal environment by the discharge of waste waters into a sea with an increasing pollution level.

MARINE POLLUTION

Marine pollution derives from widely dispersed sources, both on land and sea. Land-based pollution is generated by urban and rural land use. River systems, mainly the Danube, carry important quantities of chemical compounds to the coast.

Discharge of sewage, processed wastes and street drainage from urban and industrial centres are of particular concern. An overabundance of nutrients from sewage, fertilizers, processed organic wastes and other sources, lead to eutrophication. Agricultural activities also give rise to pollution of coastal systems. Marine-based activities, such as oil extraction and shipping are other sources that increase sea pollution.

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Table 1. Erosion and accretion of shores.

Shore segments	Erosion (ha)	Accumulation (ha)	Retreat of shoreline (m)
Sulina-Sf. George	737	75	>300
Ciotica-Perisor	680	1	350
Perisor-Periteasca	9	55	200
Periteasca-North Chituc	333	0	180
North Chituc-Vadu	437	37	alternate

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ÉTUDE DES FACTEURS DE SÉDIMENTATION DU LAC D'HOSSEGOR

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Dans le S-W de la France, sur la côte landaise, le Lac d'Hossegor présente la spécificité d'être un lac marin, contrairement aux nombreux lacs d'eau douce qui bordent ce littoral. En égard à cette morphologie particulière, sa communication avec l'océan est plus limitée que pour d'autres structures qui échancrent la côte landaise, comme plus au nord, le Bassin d'Arcachon. Des processus d'envasement liés à des facteurs dynamiques tendent à s'y manifester. En raison de la morphologie originale de ce plan d'eau et de sa périphérie immédiate, il constitue une station balnéaire estivale très recherchée, pour laquelle se justifient les efforts visant à en contrôler l'envasement. Il communique avec la mer par un chenal, le Boucarot qui reçoit deux ruisseaux le Boudigau et le Bouret, dont la confluence constitue le port de plaisance et de pêche. Près de 20 % de ces < < eaux douces > > entrent dans le lac par le jeu des marées.

Ces ruisseaux drainent:

- un contexte agricole (maïsicole) responsable d'apports de NO_3 et de MES (matière en suspension).
- des lieux humides constitués en grande partie par le marais d'Orx qui représente un des plus vastes sites européens de stationnement de la faune avicole, sur le trajet des grandes migrations saisonnières.

Ce contexte marécageux fournit aussi COP (carbon organique particulaire), COD (carbon organique dissous) et MES. Ces eaux peuvent également être affectées par des effluents industriels (conserveries) et portuaires, riches en COP et en COD.

Un modèle, établi à partir du bilan général des flux, reposant sur un nombre suffisant de mesures effectuées sur deux saisons pour obtenir une estimation représentative d'une année moyenne (ni sèche, ni humide), permet de comprendre le schéma de sedimentation, donc de l'envasement du lac. Les matières en suspension, et particulièrement la composante organique (4 % d'origine océanique et 48 % d'origine terrigène) apparaissent comme l'une des causes principales de l'envasement du lac. L'effet peut être direct, puisque le dépôt de ces matières riches en carbone entraîne une sedimentation moyenne de l'ordre de 0,13 cm/an (1000 m^3 environ).

De manière indirecte, la sedimentation freine le renouvellement des eaux, accélérant ainsi le dépôt de particules. Autre effet induit, la présence de matières organiques, favorise l'eutrophisation du système en entraînant un développement algal notable, surtout à base d'ulves qui prolifèrent intensément, surtout dans la partie nord du lac. Cet environnement peut également se comporter comme un milieu producteur de carbone organique dissous.

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MANAGEMENT AND SUSTAINABLE DEVELOPMENT OF THE MEDITERRANEAN COASTAL ZONE OF EGYPT

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The Mediterranean coastline of Egypt extends over about 950 km. The coastal area experienced potential activities in fields related to marine resources. Tremendous environmental pressures have been exerted because of expansion of urbanization centres, summer resorts, industrialization, harbours, an oil pipeline terminal, agricultural and land reclamation, five coastal productive lagoons, oil and gas fields, among many other activities. The estimated population which occupies the Mediterranean coastal area in Egypt is about 5 millions.
Forty percent of Egypt's industry surrounds Alexandria (second largest city in Egypt). These are mostly chemical and petrochemical, refineries, textiles, food processing, steel and iron, cement, paper, etc.

The major problems in the Mediterranean coastal area of Egypt are:
- overdevelopment of the coastal zone;
- pollution (anthropogenic, industrial and agricultural), coastal erosion and
- the likely impact of sea level rise on the Nile delta.

National efforts in developing CZM Program

The serious environmental coastal situation calls for immediate action in order to achieve sustainable development. The authorities in Egypt being aware of the situation have initiated, through the Egyptian Environmental Affairs Agency (EEAA), a National Coastal Zone Management (CZM) Committee, which at present is developing an integrating CZM program.

The Environmental Law and International Initiatives

The Environmental Law No 4/1994 has included the following sections for the protection of the coastal area aiming at efficient management and sustainable development of the coastal zone:

- EIA
- Land-based sources and shore protection
- Protection and Conservation of the coastal area
- Administrative and legal procedures

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WETLAND GRAZERS AND COASTAL WETLAND LOSS

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ABSTRACT

We are accustomed to thinking of factors such as wave dynamics, global sea level rise, and human development as the types of factors that shape landscapes in the coastal zone. However, biotic factors may play pivotal roles in certain threatened wetlands. In the coastal wetlands of Louisiana, USA, grazing effects appear to play a significant role in marsh health and sustainability. This region constitutes one of the most threatened wetland ecosystems in the world and over the last 20 years has sustained an average wetland loss rate of 56 km^2yr^{-1} (NBS, 1994). The ultimate causes of loss have been attributed to various layers of factors. Prominent in these factors are; geologic stage of deltaic lobe development, wetland process alteration through anthropogenic landscape features such as canals and dike construction, and altered sedimentation and hydrologic regimes (Gagliano et al., 1981, Templet and Meyer-Arendt, 1988). Only recently has the role of grazing animals been recognized as an ecosystematic factor contributing to wetland loss. In 1937 nutria (*Myocastor coypus*, Molina) were introduced to the Louisiana coastal marshes from South America. This large aquatic rodent may reach 8 kg and because of its semi-social behavior, may attain densities as high as 10 per ha. Nutria are very wasteful feeders and often resort to foraging on below-ground plant parts, causing considerable disruption to wetlands and prompting the conversion of emergent marshes to open water lakes and bays (Linscombe et al., 1981).

To measure the grazing effects on coastal wetlands we conducted a 4-year controlled study of grazing effects on wetland plants by comparing areas protected from nutria grazing with areas to which nutria had free access. Differences in the aboveground biomass produced, plant stature, longevity, and continuity of root mats were obvious and statistically significant ($p < 0.05$). For certain, important forage species (e.g. *Scirpus americanus*) we found almost an order of magnitude more vegetation on the protected plots. We concluded that the continuous and systematic removal of vegetation biomass by grazers reduces

the organic input into these highly organic marsh soils, leading to reduced soil strength and greater wetland loss rates.

Historically, the trapping of nutria for their dense, valuable fur has lowered their numbers and reduced the effects of overgrazing. However, changes in fashion have lowered the demand for furs and trapping efforts have diminished. One of the primary motivating factors in the reduced demand for fur apparel has been an increase in public sentiment against the trapping and death of wild animals. In the case of exotic grazers in fragile wetlands, it is paradoxical that anti-fur sentiments may inadvertently contribute to the loss of valuable coastal ecosystems.

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COASTAL LANDSCAPES AS GUIDELINIES FOR COASTAL MANAGEMENT

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ABSTRACT

Coastal management and coastal protection would be successful if they were based on understanding of natural laws and processes of coastal landscapes. This is the reason why comprehensive study of processes of formation of coastal landscapes, their structure, dynamics, and functioning is required. The landscape is a natural system of homogenous genesis, with close vertical links between its components and with lateral links with included landscape-elementary natural-territorial complexes (habitats). Each patch has the same type of geological basis, ground water, soil, vegetation and micro-climate. The interaction between these vertical components is stronger than between those of the horizontal processes in the patch. Due to the relief morphology and redistribution of substances between elementary patches, they are divided by Polynov (1952) into autonomous ones (patches of watersheds with deep ground water where the substances arrive through the atmosphere), super-aqueous ones (above water, with close to surface ground water and accumulation of substances coming from autonomous patches) and sub-aqueous ones (under water, with import of substances with sediment and water flow).

The landscape usually is subjected to several transitional flows such as rivers, aeolian transport of sediments, migration flows through animals and transit of air masses, which play a specific role in the formation and functioning of the landscape.

Thus, fresh river flows bring into the sea biogenic elements feeding plankton, and sediments feeding longshore drift with load and consequently beach and other coastal forms. But river flows bring also a number of pollutants into the coastal waters. Aeolian transport of sediments is of great importance, because it moves sand from the land into the sea and along the shoreline, thus participating in the nourishment of the beaches. In South Africa we saw headland-bypass dunefields defined by Tinley (1985) as transgressive corridors of transverse dunes which cross low-relief headlands, transporting sand from an upwind sandy beach into the downwind bay. Over the past 50 years most of these active dunes have been stabilized without due cognisance of the role that the dunes play in the coastal sediment transport system, resulting in beach erosion in down-transport areas (Dunes '94. Abstract and mid-conference tour guide; McLachlan et al., in press). Bird populations on the rocky slopes of the Barents Sea cause increasing phosphate content in the coastal water with concentrations 400 times higher than normal (Matishov, 1990). The structure and functioning of the coastal landscape is more complicated, because it is created at the boundary of two environments: rather stable land and dynamic water (sea). The main factors, determining the structure of coastal landscapes, are sea-level fluctuations of different periods, short-term fluctuations (waves, tides, wind-induced surges, seasonal and others), long-term fluctuations occurring during centuries and climatic conditions. By definition all relief features in coastal zone are created by wave activity in the zone of land/sea interaction. A peculiarity of the landscape of coastal zones is the fact that, after its creation, still undergoes changes due to sea-level fluctuations, determined by dynamics and the functioning of the patches. The influence of the sea on the coastal patches depends on the amplitude of these fluctuations and the shore declivity. For example, in the North Caspian Sea, wind-induced surges can cover a territory up to 50 km inland due to the small declivity of the coastal zone. On the coast of the Barents Sea, the narrow fjords have the tidal range up to 7.5 m. The energy of these different types of fluctuations determines the range of elevation and scale of the morphological shore elements. This defines the size of autonomous, super-aqueous and subaqueous patches in the coastal landscape.

Climatic conditions determine the type of vegetation of coastal landscapes in different geographical zones. For example, in low latitudes, and in the absence of frost, mangroves spread over the low-lying coasts, while in higher latitudes marshes do the same. But coasts without mangroves differ due to regional climatic conditions. They determine the differentiation of patches of the same geochemical type: autonomous patches in humid climate would differ from automorphic patches in arid climate. On the top of the coastal dunes in humid climates, such as at the North Adriatic coast or at the west coast of the South Caspian Sea, mesophytic vegetation is found: shrubs *Rubus* sp., while in the arid subtropical climate on the east coast of the South Caspian Sea the psammophytic plants are found, such as *Nitraria schoberi, N. komarovii, Ammodendron konollyi* and others. The influence of climatic conditions is highest on the autonomous patches and lowest on subaqueous patches where groundwater influences are dominant. The impact of the climate on the super-aqueous patches is indirect and manifests itself through groundwater mineralization, which is higher in arid climates than in humid. The vegetation of marshes of the North Adriatic coast consists of *Juncus inflexus, J. maritima, Limonium vulgare* (salt content in silty-loam soil is 2.53-2.18%, ground water mineralization is 43.4 g/l) and in some parts of lagoon marsh having higher salt content in grounds (3.7%) with *Salicornia fruticosa*. On the coast of the North Caspian Sea the vegetation of marsh zone consists of *Limonium gmelini, Puccinellia distans, Halocnemum strobilaceum* (on the soils with medium and high salt content up to 2%), *Halocnemum strobilaceum* and *Salicornia europaea* on the soils with 4.5-5% of salt content. It is very important to make an accurate assessment of all factors, links and processes, acting in the coastal landscape and to understand their role in this complicated system. This will help to

understand degree of stability (ability of natural system to resist external impact and to return to the initial state) of coastal natural systems and to make decisions about types of land use in the coastal zone. The degree of stability determines how much effort should be invested to rehabilitate or to protect a coastal landscape.

All anthropogenous activities in the coastal zone can be described as utilization (to get profits for man) and reclamation (to get profits for nature). Utilization can be divided into 4 main types:

1. withdrawal of resources
2. partial utilization of resources
3. transformation of quality of resources
4. allocation of technogenous objects

Discussing these 4 types of anthropogenous activity we must take into consideration the kind of resources:

- nonrenewable or renewable ones,
- limits of withdrawal, utilization and
- transformation of quality, value of landscape where the technogenous object are to be allocated.

In each case of human activities, the manager should consider manipulated resources as a landscape component (rocks and grounds, water, plants or animals) or as a flow of substances (sediments or water or chemical elements). The impact on the resources by human activity should be foreseen. For example, the construction of a river reservoir results in the reduction of its sediment flow (partial utilization of the resources) and alters the balance of sediments in the coastal zone and transforms the coastal morphology. Utilization of beaches and dunes for recreation can cause a destruction of plant cover and deflation of sand and retreat of the dunes. Reclamation of landscapes of the coastal zone means activities aimed at improvement of these natural systems, deteriorate by anthropogenous factors.

There are two ways of reclamation: a passive and an active one. The first one uses and follows natural laws of this territory in order to improve or protect coastal landscapes. This is the case when small disturbances occur as a result of recreation activity or house building, when indigenous plant species are used to stabilize dunes or to prevent erosion. But in many cases this is not enough and engineering defensive constructions should be built to prevent coastal erosion or new plant species should be introduced to stop deflation and migration of coastal dunes. Following natural laws of coastal systems, the manager can expect very little unforeseen impact on the environment, but in the second case - active reclamation - the probability of such impact is higher. For example, the construction of groins can stop erosion in one place but will stimulate erosion in the nearby location due to the interruption of longshore sediment flow. Introduction of new plant species can successfully stabilize dunes, but it can lead to the disappearance of indigenous species, which reduces the biodiversity of the coastal region. Sometimes these new species spread inland, occupying large territories.

Landscapes of coastal dunes and their structure are discussed for the regions of the North Adriatic Sea with subcontinental climate and mesoenergy sea fluctuations, where vast drainage of the coastal lands was carried out.

For the East Caspian Sea with arid climate and large amplitude of long-term sea-level fluctuations; for the East South African coast with mesoenergy of sea-level fluctuations and high wind energy and with rich experience of coastal protection (introduction of new species and beach constructions).

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REALIDADES, DESAFAOS Y AMBICIONES DEL DESARROLLO DE LA ACUICULTURA

Realities, challanges and ambitions of the development of aquaculture

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El marco de funcionamiento de la actividad de la acuicultura[1]
The framework of the functioning of aquculture activities
La realidad de la acuicultura en España
The reality of aquaculture in Spain
Perspectivas para la década de los 90
Perspectives for the decenium of the 1990's

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ÉVOLUTION HOLOCÈNE DU DELTA DU TUBARAO DANS LE SYSTÈME LAGUNAIRE SANTO ANTONIO-IMARUI-MIRIM, ÉTAT DE SANTA CATARINA (BRÉSIL)

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Le Rio Tubarao débouche dans un vaste systeme lagunaire ou il a construit un delta interne de type "patte d'oiseau". La reconstitution paléogéographique des étapes de construction de ce delta est fondée sur la position altimétrique relative des terrasses fluvio-deltaïques et sur l'organisation hiérarchique des chenaux distributaires. Elle conduit à distinguer quatre ensembles de lobes dont les altitudes relatives sont conformes aux variations du niveau marin survenues au cours de l'Holocene dans cette région côtière du Brésil depuis que la transgression "Flandrienne" y a atteint son niveau maximum (+4 à +5 m au dessus du niveau actuel il y à 5 100 ans).

Actuellement, le niveau de la mer et de la lagune sont réputés stables (depuis 1 000 ans), et le delta continue sa progradation dans la lagune vers le N., à partir de 3 distributaires qui sont affectés d'une méandrification croissante.

La connaissance de cette évolution du delta, commandée par les variations du niveau de la mer et de la lagune, et la considération des flux d'eau et de sédiments qui dépendent des facteurs climatiques, et depuis peu, anthropiques, rendent possible l'élaboration d'une prévision des changements qui pourront affecter le fonction-

[1] From this paper in Spanish, only the section titles are given. For obtaining further information the reader is advised to contact the author.

nement de ce systeme, soit pour des causes naturelles, comme par exemple la remontée du niveau de la mer constatée dans des régions voisines (Tomazelli, 1994), soit par suite de la construction d'ouvrages modifiant l'un ou l'autre des facteurs qui dirigent la construction de ce systeme fluvio-deltaïque complexe.

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A METHOD TO COUNTERACT EROSION

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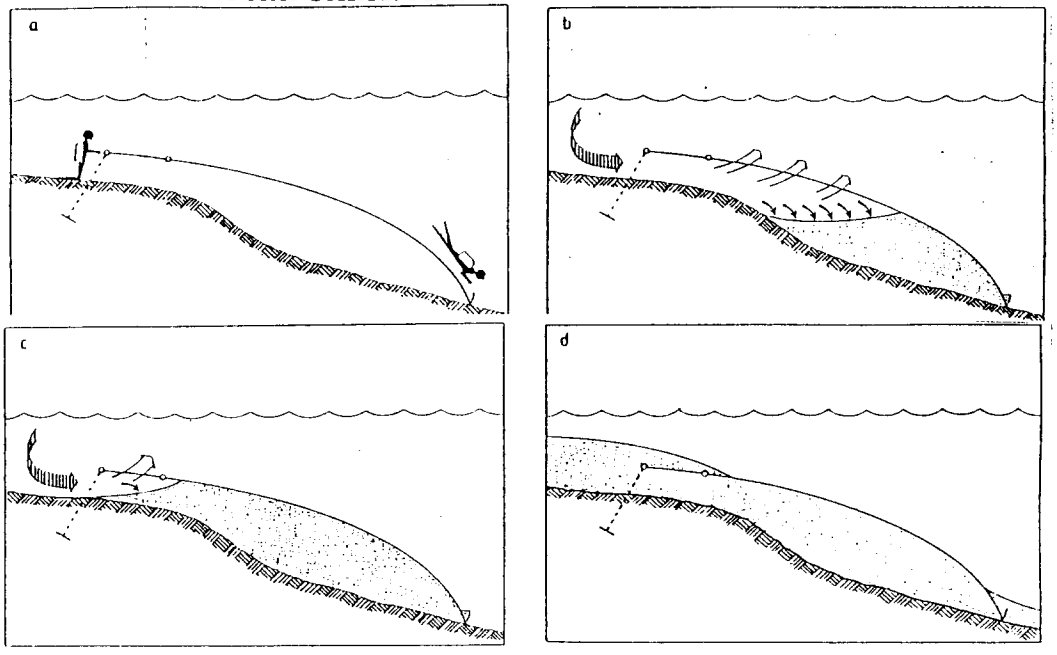
A method, abbreviated as Berosin, is developed to solve problems of erosion caused by: Sea level rise, wave action and meandering rivers and too shallow shipping lanes.
The method is based on the application of a textile product with a weight of 220 g/m^2, which has been tested since 1977. It is demonstrated that the application (Fig. 1) will not only stop erosion, but can regenerate eroded beaches and river banks through effective and fast sedimentation.

The goal is to catch sand and silt in coastal areas where rebuilding is needed most, making use of the natural processes of wave-action and currents. The advantage of this method is that no dredging, no stone dumping, no repeated beach nourishment, no groynes and no expensive floating equipment will be needed. Thus beaches can be built again with use of nature at a very competitive price.

Fig. 1. Application of the Berosin textile for accretion of sand on a beach, with the result: a well protected coastline. (a) With the help of 2 aqualung divers the textile is placed in the desired underwater position. (b) The river or sea drops its sand continuously under, on top of and even around the textile in substantial quantities (see arrow). (c) The coastline and riverbank are substantially rebuilt. (d) Huge quantities of sand are deposited by nature itself. Within 3-30 days a solid sedimentation under, on top of and around the light textile has taken place (see next page).



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SEDIMENT TRANSPORT, SEA LEVEL RISE AND SHORELINE MANAGEMENT: ADVISING DECISION MAKERS ON THE SOUTH COAST OF ENGLAND

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ABSTRACT

Statutory authorities on the south coast of England, responsible for coast protection and sea defences, cooperated in 1986 to form a Coastal Group called SCOPAC. Its aim is to coordinate action and avoid damaging effects of engineering works.

Beach depletion was the main problem facing the authorities so SCOPAC commissioned research on sediment transport with the particular aim of identifying major sources of sediments, major pathways of transport and the major littoral cells. Initially, a bibliographic database was compiled containing much unpublished literature as well as conventional publications.

The 3000 items in the database provided the basis for analysis of present understanding of the sediment transport systems on the south coast, from which maps of each local area showing all inputs, transfers and exchanges of sediment were constructed.

From this very detailed analysis, nine major cells of littoral sediment circulation were identified. The maps and accompanying report are now used by the authorities to help assess impacts of works and to plan strategic and coordinated action.

The study also identified research gaps and was highly cost effective. A second issue on which SCOPAC sought guidance was sea level rise and climatic change, the possible impacts arising from those and the alternative policy actions which are available. IPCC figures of estimates of sea level rise were combined with data on subsidence rates in southern England to provide a regional scenario of relative rise to 2050.

Physical impacts of the rise on different types of coast were assessed and factors influencing response were identified.

Strategies of retreat, accommodation and protection were evaluated in physical, ecological and socio-economic terms and applicability indicated.

The opportunities for strategic planning at present and the potential role of the various statutory authorities were demonstrated.

All this work has involved the transmission of scientific results to the decision makers in the local authorities and has increased awareness of the spatial and temporal contexts of problems and possible short and long term strategies for solution.

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ÉVOLUTION HOLOCÈNE DE LA PLAINE COTIÈRE DE L'ÉTAT DE SANTA CATARINA (BRÉSIL); CARACTÉRISATION MORPHOLOGIQUE ET SÉDIMENTOLOGIQUE DE LA PROGRADATION DES CORDONS LITTORAUX

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La plaine côtière de l'Etat de Santa Catarina (Brésil) est constituée par des dépôts de plages, dunes, flèches littorales, qui s'organisent sur un réseau de reliefs granitiques formant les îles, les caps ou péninsules qui jalonnent les 561 km de côte de cet Etat (Martin et al., 1988).

Dans certains secteurs où d'importants stocks de sables ont été mobilisés par la mer au cours de l'Holocene, des plaines côtières se sont constituées par progradation de flèches ou de faisceaux de cordons de plages dont l'agencement traduit les divers épisodes trans-régressifs qui ont succédé au maximum de la transgression holocène (5100 ans A.P.), et décrits par Martin et Suguiu (1986), puis par Gré et al. (1993).

Les crêtes de plages (beach-ridges, selon la définition de Strapor et al. (1988) sont bien repérées en photographies aériennes et sur le terrain. Leur étude sédimentologique montre les trois types de cordons sableux ou coquilliers définis par Tanner (1992): Des "*swash-ridges*" et "*storm-surge-ridges*" reliés aux mécanismes marins de construction des plages, et des "*dune-ridges*" résultant de phénomènes éoliens.

En certains points du littoral, où les reliefs granitiques déterminent des "corridors de vents", ces faisceaux de cordons littoraux sont recouverts par des systèmes dunaires, issus des plages exposées aux vents dominants du Nord-Est ou du Sud. Ces vents génèrent soit des cortèges de petites dunes barkhanoïdes plus ou moins isolées, soit des massifs de dunes de plusieurs dizaines de mètres d'épaisseur.

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MORPHOSTRATIGRAPHIC APPROACH TO ASSESSMENT OF VULNERABILITY OF COASTAL ENVIRONMENTS TO MARINE EROSION, A KENYAN CASE STUDY

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The passive Kenya continental margin rises from sea level through three distinct physiographic provinces, the coastal plain at 0-90 m OD, the foot plateau at between 90 and 150 m OD and the Nyika between 150 m and 600 m. The coastal plain constitutes the coastal zone proper and increases in width from a few km in southern Kenya to over 40 km in the Sabaki - Tana delta area. The same physiography is observed in the continental shelf.

In Pleistocene to recent times, fluctuations in sea level, proliferation of extensive reefal systems and river sediment influx dominated the evolution of the modern coastal configuration. Due to its recent history, apart from the carbonate platforms, the near surface geology comprises of sands, silts or clays deposited in nearshore or terrestrial environments. Depending on the geologic setting, these units overlie poor or well cemented sandstone or limestone terraces that occur at different levels, relative to mean sea level.

The oastal erosion inventory indicates a close relationship between the geologic setting, the evolution style and the occurrence of erosion. If the sea level continues to rise, it is anticipated that the present erosion phase will intensify in vulnerable environments. For any given variation in the relative sea level, or the depositional process, the response of the shorelines will depend on their character, especially the morphostratigraphy. This study identifies and delineates areas vulnerable to coastal erosion on the basis of their morphostratigraphy, the evolution style and the geologic setting.

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TYPICAL EXAMPLES OF BEACH EROSION AND COUNTERMEASURES IN JAPAN

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KEY WORDS: Beach erosion control, detached breakwater, reef, headlands, coastal environment

Japan is an arc-shaped chain of islands located in the north-western, monsoon region of the Pacific Ocean. Compared to other places in the world, it has suffered from a lot of tidal waves, or tsunamis, in addition to being very susceptible to the harsh effects of waves and storm surges and being situated in the circum-Pacific earthquake region.

Japan has suffered from serious beach erosion for several decades. Due to the increasing erosion, the environmental condition of Japanese coast has worsened considerably. A few examples are given of typical beach erosion and countermeasures, which we developed and applied against erosion.

Kaike beach is located in the mid-west part of the Japan Sea coast, adjavent to Kaike hot spring and Yonago city. It is considered that Kaike beach had been formed of the sediment discharged from the Hino River, whose basin is known for its iron production and iron sand. The shoreline progressed from 1868 by 180 m over 30 years. However, as the iron production declined around 1920, due to modernization, the beach began to suffer from erosion. The first jetties were constructed in 1947. In a few years it became obvious that this project was unsuccessful. As a next step, a seawall was made. However, erosion could again not be stopped. Finally, detached breakwaters were introduced from 1971, tombolo's formed behind the detached breakwaters and beach erosion was stopped (Photo 1).

Niigata is located in the central part of the Japan Sea coast. The Niigata Plain is one of the largest alluvial lowlands in Japan and has several sand dune ridges. The Shinano River, which is the longest river in Japan, and the Agano River run into the sea at Niigata city. It is said that the Niigata coast has been eroded since the 1890s. A meteorological station was constructed 100 m landward from the shoreline in 1928, but it collapsed in the water in 1949. The major causes of the beach erosion have been thought to be the construction of the breakwater of Niigata harbor, river discharge to the Okouzu flood channel and ground subsidence due to extraction of underground water for obtaining natural gas.

As a countermeasure, the seawall was constructed first. The beach could not be restored enough untill the detached breakwaters were introduced. Instead of detached breakwaters, however, a "Reef" method has recently been applied because Niigata city, the major city along the Japan Sea, is famous for its sunset scenery. Fig. 1 illustrates the functions of the "Reef".

Kashima-nada coast is located on the central Pacific Ocean coast and has one of the longest sandy beaches of Japan. The coast has been eroded due to the influence of the breakwaters of Oarai port and Kashima port. Since this coast is very long and the shoreline changes alternately according to wave directions, newly developed "Headlands" were applied. This countermeasure is to divide a long beach into small pocket beaches, for example 1 km long, by headlands. It aims to confine the littoral sand drift as much as possible in a pocket beach, in order to control erosion. Fig. 2 illustrates the concept and functioning of the Headlands.

Today, detached breakwaters, reefs and headlands become major works for cowntermeasures against beach erosion in Japan. By using these facilities, we have been able to prevent local beaches from erosion.

But it still remains to be investigated how we have to cope with the increasing erosion without spoiling the various environmental preciousness, especially for the long sandy beaches.

Fig. 1. Functioning of the "reefs".

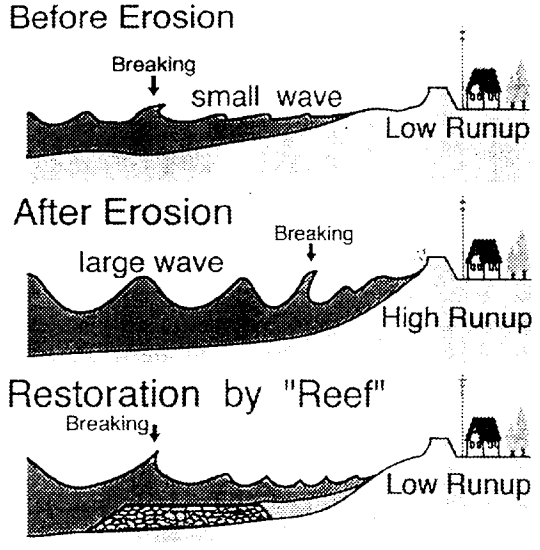

Fig. 2. Concept of headlands.

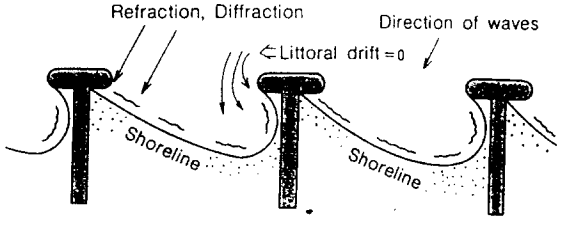

Photo 1. Detached breakwater and tombolo in Kaike coast.

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PROTECTION OF GEORGIAN BLACK SEA COAST WITH ARTIFICIAL BEACHES[1]

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The eastern part of the Black Sea coast, belonging to Georgia (313 km), is partly accumulative (62.3%) and partly abrasional-accumulative (37.7%). The beaches are pebble-sandy (80%) and sandy (20%). The coast is characterized by steep pebble beaches, large sediment flows of 200m/day with a capacity of more than 10^5 m^3 over a length of tens of km.

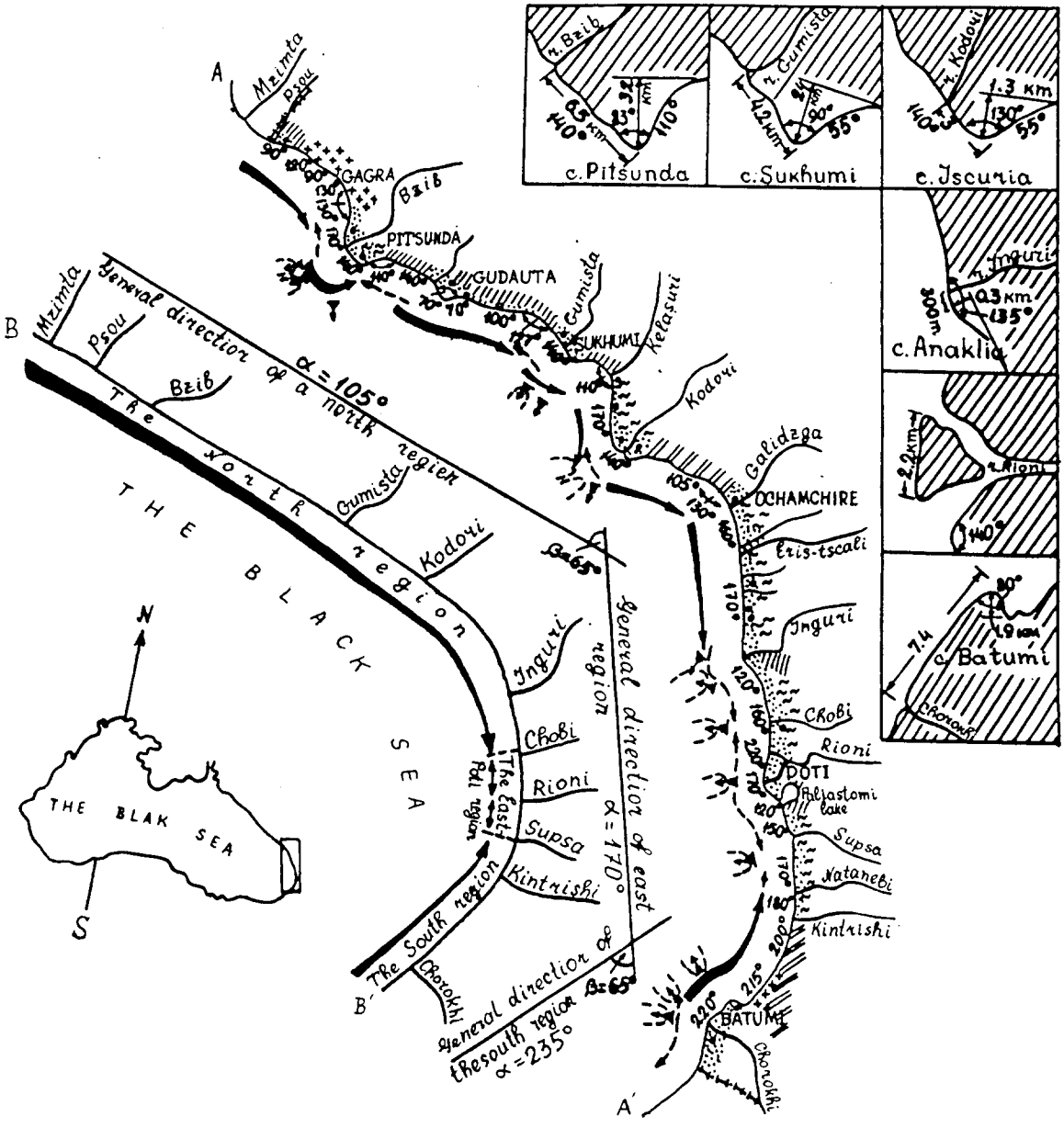
Due to the strategy of coastal protection with protective structures for railways and towns between 1961 and 1981, at the expense of 145 million roubles, coastal erosion had increased elsewhere.

The Georgian Association of Seacoast Protection was created in 1981 in order to integrate scientific research, analysis of empirical data and carrying out studies on coastal morphology. It developed a new method and strategy for the restoration and protection of the sea coast of Georgia (Fig. 1). It is not based on the "fortification" of sections of the coast, but supports the balanced budget of beach-forming material for each morphodynamic dynamic subsystem or cell. In that case the energy of waves is spent solely for transport of sediment in a beach creative way instead of being destructive. The scientific strategy is based on the concept of discontinuous lithodynamic cells which determine the boundaries of morphodynamical regions.

In essence the methods imply the restoration of the controlling processes of closed beach systems by cutting down loss of sediment by regulation and increase alongshore sediment drift, enhancing the processes of self-regulation of the sediment budget. During a 20 years programme erosion was reduced, where the incoming sediment load from rivers was increased. As a result the eroding coastline of in total 200 km was reduced by 80 km between 1982 and 1991, for which 93.2 million roubles were spent, A natural landscape was created in place of concrete constructions and 110 ha of beaches was restored.

[1] For the full paper, the reader is advised to write to Mrs. S. Jaoshvili directly or through: Georges Djaochvili, 5, rue Vulpian, 75013 Paris, France. See also the paper in Session II-c of Jaoshvili.

Fig. 1. Schematic map of morpho- and lithodynamic coastal zones of the Black Sea in Georgia. A-A' : Present coastline; B-B' : Coastline 5-6 thousand yr ago, when the sea-level rise slowed down; —> Longshore sediment drifts, their direction and relative actual capacity; — —> The direction of migration and transport of small-sized material; ↑ Partial loss of materials at large depths; ∩ Canyon heads and steep falls; + + + Cliff rocks with erosional relief; // // Semi-cliff rocks (conglomerates, marl, schists) with erosional relief; /////Connected rocks (clay from sea and lagoons) with plain relief; •.•.• Friable deposits (pebbles, gravel, terraces, dunes and beach sand); ~~~ Specific deposits (marshes, lake).



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LE LITTORAL À MANGROVE D'ALCÂNTARA (MARANHÃO, BRÉSIL) ÉVOLUTION ET CONSÉQUENCES RELATIVES À SA GESTION

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Autour d'Alcântara, sur le littoral de la baie de São Marcos, a été mis en évidence un phénomène original de probable recolonisation de la mangrove sur les tannes (appelés localement *apicums*), surfaces nues ou herbeuses développées originellement au dépens de la mangrove.

En l'état de nos connaissances, nous retiendrons les deux hypothèses les plus vraisemblables:

1) un renforcement de la pluviométrie entraînant une diminution en durée ou en intensité de la saison sèche lors des dernières décennies;

2) une légère élévation actuelle du niveau marin.

Parmi les raisons qui militent en faveur d'une conservation intégrale d'importants secteurs de littoral, la préservation d'"enregistreurs" de l'évolution de l'environnement paraît fondamentale.

En effet, la mangrove en enregistrant des variations infimes du climat ou du niveau marin, nous indique certaines tendances actuelles non seulement dans ce cas précis mais partout où son développement naturel n'est pas perturbé par l'homme.

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ÉVOLUTION MORPHOLOGIQUE RÉCENTE DU BASSIN D'ARCACHON

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Le Bassin d'Arcachon est le siège des processus d'érosion et de sédimentation, qui, au cours des temps, ont modelé les bancs sablo-vaseux internes et ont créé une succession d'axes hydrauliques qui sont les circuits privilégiés des échanges entre la lagune et l'océan. C'est autour de l'Ile, située au centre de la baie, que s'organisent les axes hydrauliques actuels.

Si l'on considère l'évolution de la partie profonde des chenaux au cours des 160 dernières années, on constate qu'elle s'est déroulée ainsi: le principal chenal nord-est, sud-ouest (Piquey), dominant jusqu'en 1826, a été relayé par un

autre chenal orienté est-ouest (Teychan) dès 1865. Depuis 1936, la création d'un nouveau chenal (Mapouchet) entraînant une très forte érosion des bancs sablo-argileux du sud-est de l'Ile, est à l'origine de la formation d'un nouvel axe hydraulique orienté nord-nord est - sud-sud ouest.

Erosion et sédimentation s'équilibrent avec cependant une tendance érosive globale : -14,5 $x10^6$ m^3, entre 1865 et 1993, que l'on constate surtout beaucoup plus active dans les chenaux à puissance hydraulique élevée. La sédimentation sur les bancs émergeables reste relativement faible, sauf sur ceux de la partie nord-est du Bassin. Quant aux chenaux secondaires, le changement des axes d'écoulement les vouent à un comblement inéluctable.

Selon l'orientation de l'axe hydraulique principal vis à vis des passes d'entrée, l'effet des courants de jusant du Bassin peut être plus ou moins bénéfique. Alors que les mouvements morpho-sédimentaires internes suivent un schéma évolutif régulier, lent et profond, les passes d'entrée ont une évolution cyclique rapide. La stabilité de ces derniers dépend de la conservation du volume oscillant interne, de l'orientation de l'axe hydraulique et de l'intensité du transit littoral. Il se dessine actuellement une auto-régulation hydraulique de la lagune qui concilierait pour longtemps les trois facteurs d'évolution précédents.

RECENT MORPHO-SEDIMENTOLOGY EVOLUTION OF THE ARCACHON BAY

The Arcachon bay is the centre of an erosion sedimentation system that induced at least, since the 18th century a succession of different hydraulic axises. The rapid erosion of a tidal flat of the centre of the lagoon (from 1936) built a new central axis and improved the circulation of water masses, that more and more directly runs toward the entrances. Strong deposits of fine sediments and organic matter take place in the sheltered channels of low energy ; channels which were the early main hydraulic axis, or in relation with them. Fine sediments may also settle on the tidal muddy banks of the north eastern part of the bay. Globally, erosion predominate over sedimentation (-14,5 $x10^6$ m^3, from 1865 to 1993). It take place on converging channels of strong tidal action, that create the unification and the stabilisation of a central and straightaway axis toward the northern entrance.

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COASTAL MANAGEMENT IN RUSSIA: PROBLEMS AND PROSPECTS

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The centralized administrative system of economic management, that has existed in the country until recently, had no objective need for scientific managerial advice, regarding the use of the marine environment. The economic problems of ocean resource development were dealt with in the former USSR by the Institute of Economic and International Problems of Ocean Development (Far Eastern Branch of the USSR Academy of Sciences), established in Vladivostok in the mid-1980s, which was taken over several years ago by the new authorities of the Far Eastern Branch of the Academy of Sciences. Beginning from the middle 1970s, those problems were studied by the Odessa Division of the Institute of Economics of the Academy of Sciences in the Ukraine , now a different state, as well as by several small divisions or individual experts of a number of other research establishments.

Meanwhile the problems of coastal management are becoming ever more acute during the transitional period of the Russian Federation to a free market economy. A scientifically based expansion of rational and sustainable use of the marine environment is becoming one of the most important aspects of successful economic development of the country. The scale of such an expansion, however, should be determined by the optimum ability of the marine environment to tolerate the man-induced effects, as based on the principle of sustainable development declared by the world community, rather than by maximizing the development of individual industries. The process of economic development of the marine environment has an objective character, and is progressive in its nature. That is why one has to have a balanced mechanism and a scientifically based methodology of choosing the optimum solutions. Such solutions are themselves based on an integrated approach to the use of the marine environment with due regard to various factors, circumstances and conditions that have varying vectors, significance, scale and pattern of impact, as well as spatial and temporal variability.

This puts on the agenda the problem of organizing and developing the activity of coastal management in Russia. Some efforts in this field are being planned for the Russian Black Sea coast under the aegis of the Ministry of Protection of the Environment and Natural Resources of the Russian Federation, in the framework of International Program for Environmental Management and Protection of the Black Sea. The new project "Coastal management" is being developed now within the framework of the Russian National Research Programme "Comprehensive Investigations of the Oceans and Seas, Arctic and Antarctic" implemented by the Ministry of Science and Technology Policy of the Russian Federation. Among the main aims of the new project are:

- general study of the situation in the field of the use of the marine environment in Russia;
- activity, aimed to have recognized by the ruling circles and broad public of the necessity and importance of coastal-zone management (CZM);
- identification of responsible national agencies, institutions and groups of experts in each region;
- promotion of the development of national and regional coastal legislation, including such basic points as clarification of ownership versus right-to-use, definition of leading agency responsibilities, and establishment of minimum standards;
- study of international experience on both national program scale and regional scale for concrete cases;

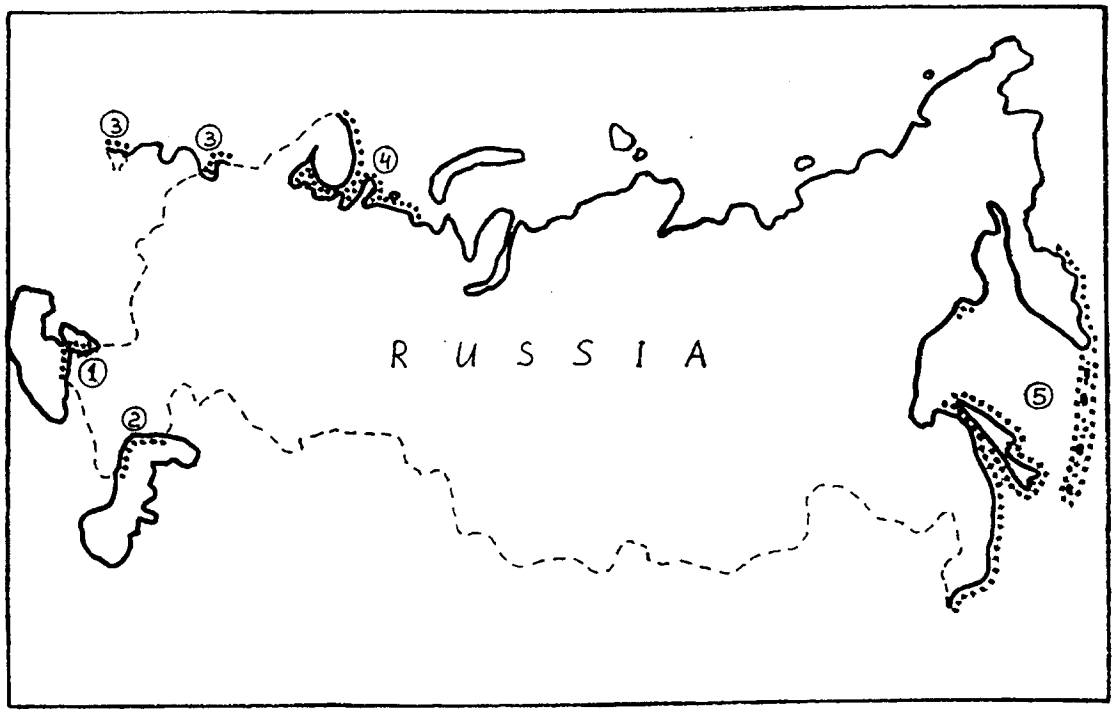
- formation of a group of international experts, whose help might be asked for the development of programs and obtaining of international funding;
- organization of appropriate research at marine scientific institutions;
- training of personnel; and
- development of coastal management programs for concrete regions of Russia: Black Sea, Baltic Sea (Leningrad and Kaliningrad regions), Barents and White Seas, Caspian Sea, region of the Far Eastern Seas (Fig. 1).

We hope that our cooperation with foreign institutes and programs in the field of CZM will contribute significantly in the realization of these objectives.

We find it expedient to establish a special Centre under the aegis of the Ministry of Science and Technology Policy that would deal with problems of coastal management. It would coordinate scientific research in the area with the development of concrete practical projects and the advice given by leading national and foreign experts, invited on contractual basis.

It would seem reasonable that a part of the funding, provided to Russia as technical aid by international institutions such as the World Bank, International Monetary Fund, and others for reforming the economic system, is used for development of coastal management.

Fig. 1: The combined length of the Russia's sea coast is over 50,000 km (without the islands). 1 - Black and Azov Seas, 2 - Caspian Sea, 3 - Baltic Sea (Leningrad and Kaliningrad regions), 4 - Barents and White Seas, 5 - region of the Far Eastern Seas



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THE NORTHUMBERLAND COAST MANAGEMENT INITIATIVE

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On the eastern seaboard of United Kingdom, Northumberland is the most northerly English county. The Northumberland Coast, which extends 120 km from the mouth of the River Tyne, to the English/Scottish border is the county's most famous natural asset.

Although well known for its unspoilt character, the coast is nevertheless subject to wide-ranging pressures. The Northumberland Coast Management Initiative was established as a unique partnership to explore ways in which such pressures could be addressed and the special qualities of this coastline conserved for the future.

A Special Coastline

From high rock cliffs to sweeping sand bays the Northumberland coast displays great landscape variety. Large parts of the coastline have received the national designations of Area of Outstanding Natural Beauty and Heritage Coast. The coast also enjoys national and international status for nature conservation. Virtually the entire Northumberland shoreline has received the national nature conservation designation of Site of Special Scientific Interest (SSSI) in recognition of its importance for migratory bird populations. The mud flats and islands along the coast hold Special Protection Area (SPA) and Ramsar site status with the tidal area around Holy Island alone accommodating a wintering population of 60,000 wild birds. The inshore waters of north Northumberland coast are among the richest in the United Kingdom for marine life. The long history of human settlement on the coast has left a rich legacy of historical sites and features. These range from major defensive castles to ancient burial sites exposed within the shifting sand dunes. The high environmental quality of many of the Northumberland beaches and bathing waters has been recognised by the receipt of five national Seaside Awards in 1994.

A Coastline Under Pressure

The Northumberland coast experiences continuing forces for change. Predominantly a soft coastline, it is subject to substantial and rapid erosion from wind and sea. The presence of rich marine, agricultural and mineral resources of the coast and the existence of natural harbours result in the coast being the most densely settled area of Northumberland. Intensive farming practices within the coastal fringe and the reclaiming of wetlands causes the loss of important coast habitats. Although the coastal fishing industry has substantially declined from the last century, when major herring fleets operated from Northumberland's ports, conflict with conservation interests still exist.

The southern part of the Northumberland coast has been widely exploited for its mineral wealth. The legacy of this exploitation was despoiled land and beaches polluted by colliery waste. Deep coal mining has now been replaced by open cast extraction which has also impacted upon the landscape and habitats of the coast.

Visitors provide an essential source of income to many coastal communities but also impose considerable pressure within sensitive areas. Caravan parks intrude within some otherwise unspoilt coastal landscapes. Unmanaged visitor access within sensitive habitats results in habitat change and erosion. Recreational activities at sea, include growing sports such as jet skiing and diving have introduced pressure into previously undisturbed areas.

[1] See also Accompanying Session.

A Partnership Approach

Management of the Northumberland coastline is the responsibility of the County Council, five District Councils and a wide range of agencies and organisations including the National Rivers Authority; English Nature; National Trust; English Heritage; Ministry of Agriculture, Fisheries and Food; the Royal Society for the Protection of Birds and the Northumberland Wildlife Trust. It was essential that a framework was established within which these management bodies could all work together. In Northumberland, therefore, a new management model has been initiated. A Management Plan has been prepared for the entire Northumberland Coast, which seeks to initiate measures for both conservation and enhancement. The plan also adopted an offshore boundary to facilitate comprehensive Coastal Zone Management. To steer plan policies and determine action priorities, a Coastal Advisory Committee comprising political members from the County Council, the five local authorities and the Countryside Commission has been formed. Advising the work of the Committee and ensuring on the ground co-ordination between all management partners, a working group has also been created comprising officers from the authorities and organisations with significant interest in the county coastline.

Implementing Action

With funding support from Northumberland County Council, the Countryside Commission and the coastal District Councils, a coast team has been established with the task of co-ordinating and implementing management action.

Extensive research has been initiated within the Northumberland coast to provide an informed base's for management. In 1994 the Initiative published a survey and strategy of coastal archaeology within the Northumberland Coast. The recommendations of the strategy have been invaluable in establishing priorities for the conservation and rescue excavation of coastal sites and features. The Initiative has also drawn on the research expertise of Newcastle University who are undertaking survey work along the Northumberland coast as part of the European Union-funded BIOMAR project. Inshore waters have been systematically surveyed by divers using acoustic ground discrimination and remote sampling techniques to provide comprehensive maps of the seafloor communities. Knowledge gained through this survey work will inform marine management throughout Europe.

The Initiative has implemented a wide variety of management measures throughout the coastal area. These include schemes to stabilise erosion within dune lands which are subject to high visitor pressure, works to improve recreational access, initiatives to conserve sites of high historic and nature conservation value, and interpretation of special areas and features. In areas of the coast which are subject to acute management pressures, specific local action plans are being formulated. Such plans permit local communities to have input and involvement in the development and implementation of management proposals. Considerable efforts are being made to ensure community involvement through public meetings and regular newsletters.

Within the United Kingdom Coastal Zone Management is at an early stage of development. The Northumberland Coastal management initiative represents the first approach to addressing coast management issues on a co-ordinated basis within an entire county coastline. The Initiative provides a valuable learning process in Coastal Management.

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WATER MANAGEMENT FOR CONSERVATION OF BIODIVERSITY IN THE DESERTIFIED DELTA PLAINS OF THE ARAL SEA BASIN

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The Aral sea is situated in the centre of Turan desert area in Central Asia. Its water balance depends on the Amudarya and Syrdarya rivers inflow. Historically, the Aral sea region has been desertified on several occasions. The recent desertification is a human-induced phenomenon, due to an overuse of river water in the middle and upper regions of the Amudarya and Syrdarya rivers for the needs of developing irrigation. This has led to a lack of available water resources in the deltas.

The biodiversity in the delta plains depends on the processes in the delta plains. Most of deltaic processes have a physical character and, as a rule, have always taken place as a result of the surface-forming processes. The main ones are the drying and salinisation of land, combined with the hypsometry lift-up of the territory and river branch changes. This led to increasing ecological diversity of the delta plains environment, due to a greater diversity in soils' humidity and salinity, i.e.: from very humid to semi-desert soils and from fresh to saline ones and solonchaks (Table 1.). This diversity is supported by periodic or sporadic floods and meandering of river beds and water channels, which lead to periodical renewal of landscape evolution and provide for a continually shifting pattern in the dynamic equilibrium of the territory. These processes are the cause of a plant community succession, which changes by way of xerophytization, halophytization and psammophytisation. These successional communities of the delta plains comprise a biological richness and diversity of flora, plant communities and types of spatial structures, such as plant ecotone systems. So we could say: "The biodiversity in the delta plains is due to the cycles of environmental changes of the deltaic processes".

However, nowadays, these cyclic processes on the Amudarya and Syrdarya delta plains are interrupted due to major desertification. The main deltaic processes of alluviation and flooding are absent. The result of reduced moisture is that the dynamic equilibrium is disrupted so that aridity is increased, which leads to desertification of the whole territory of the Amudarya and Syrdarya river deltas. The ecological niches of the beginning of the cycles - overmoistening and non-saline soils - are completely absent. It is the cause of decrease of the biological diversity of these delta plains.

The decrease of the input of the river water in the Aral sea and in the river deltas reached it critical situation in 1960, when the main reservoirs were built and the irrigated area in the Aral Sea basin reached $5x10^6$ ha. Since this time the Aral Sea level has dropped from the absolute elevation of 53 meters to 29 meters in 1994. The Aral Sea was divided by an artificial dam (man-made) into two lakes - Big Sea (south, Uzbek's part) and Little Sea (north, Kazakh's part) in 1992. The Amudarya river now goes to the Big Sea and the Syrdarya river to Little Sea.

The average water inflow in the Amudarya delta in 1932-1960 was 47.3 km^3/yr. The open water surface area was 980 km^2. The area of permanently flooded reeds reached 3456 km^2 and seasonally flooded ones, 4186 km^2. The abrupt ecological changes began to be manifest by the spring of 1974, when the first facilities of the Tachiatash hydraulic structure came into operation. The water flow into the delta declined in 1975 -1980 to 15.0 km^3/yr. The mineral content of the Amudarya river water increased from 0.3-0.7 g/l to 1-1.4 g/l and in the channels, up to 2-4.4 g/l. More importantly, summer floods ceased completely. In some years (e.g. in 1980) the river flow was zero during the growing season. As a

result, the ground water table dropped from 1-2 m to 3-5 (10) m; the area of the delta lakes decreased to 214 km^2. The natural river net changed into a system of irrigation canals and the return of irrigated water began to play an increasing role in the quality of the aquatic ecosystems and wetlands.

In the Syrdarya delta the ecological situation is very similar. The 600 ha of bog and meadow-bog soils, forming a strip 25-100 m wide along the river-bed, have undergone excessive drainage and degradation. Around 13 to 27 tons/ha of organic matter was lost from the meadow soils; in bog soils, the loss was around 30 to 35 tons/ha. The area of reed growths decreased from 170 000 to 20 000 ha. The level of ground water has lowered and its mineral content has increased.

The purpose of our investigations was to study and describe the biological diversity and its ecological basis, and to recommend the way to conserve it.

The measures, we recommend, may be ordered in 5 groups (Fig. 1):

(a) Measures to protect and to improve the conditions of ecosystems, without changes in the hydrological regime;

(b) Measures aimed at preserving existing hydrological regimes;

(c) Measures to modify the water supply and water quality;

(d) Measures to restore lacustrine, wetlands and terrestrial ecosystems;

(e) Measures to study and monitor results of all (a-d) measures.

ACKNOWLEDGEMENTS

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Table 1. Main types of ecological ranges on the lake shores.

N type	Lake characteristics	Aquatic vegetation	Seres of coastal ecoton ecosystems	Birds	Economic use
1	Permanently flowing transparent water, Depth-up 6-8 m Transparency-up to 4-5 m	High degree of overgroving with *Potamogeton sp.* *Chara sp.*	Hydrosere Typha sp. --> Phragmites australis	*Netta rufina* *Aythya nyroca* *Phalacrocorax carbo* *Pelecanus crispus*	Fishery Hunting Grazing Haymowing
2	Permanently flowing turbid water Depth-up 2-4 m Transparency-up to 0.2-0.4 m	Almost total abscence of submerged aquatic plants, area of the *Phragmites australisd*	Hydrosere Typha sp. --> Phragmites australis Vast massifs of half-submerged reedplantations	*Larus argentatus* *Egretta garzetta* *Ardea cinerea* *Anatinae*	Fishery Grazing Haymowing
3	Floodplain lakes: a)permanently connected with main delta branches by fals channels; b) lakes fed by groundwaters during the low-flow period	Rich and diverse submerged plants: *Potamigeton sp.*, *Chara sp.*	Xerosere Phragmites australis--> grass meadows--> bushs--> takyr	*Anas clypeata* *Anas platyrhynchos* *Netta rufina* *Sterna hirundo* *Charadiiformes*	Haymowing Grazing
4	a) Lake systems becoming flowing during floods. During dry periods water goes away. b) Sertain floodplain lakes, copletely or appreciably drying in the low-flow period. Depth 1-2 m, in dry period - 1 m	Diversified aquatic plants dying during dry season *Potamogeton cristatum*, *Charas sp.*	Halosere weakly developed reed --> Halostachys caspica --> solonchaks	*Hymanthopus hymanthopus* *Charadrius alexandrinus* *Charadrius dubius*	Grazing
5	Salinized lakes with groundwater feeding; Depth 1-3 m	Vegetation depends on salinity, *Zannichelia sp.*	Halosere *Salicornia herbacea*, --> *Tripolium aster* *Salsolas sp.*, *Suaedas sp.*--> solonchaks	*Tardona tardona* *Hymanthopus hymanthopus* *Charadrius alexandrinus*	
6	Floodland lakes with stable water feeding all the year	Diversified, but not reach submerged vegetation	Xerosere Reed --> grass meadows--> tugai forests and bushes	*Phasanius colchicus* *Anatinae* *Ardea*	Haymowing Grazing Hunting

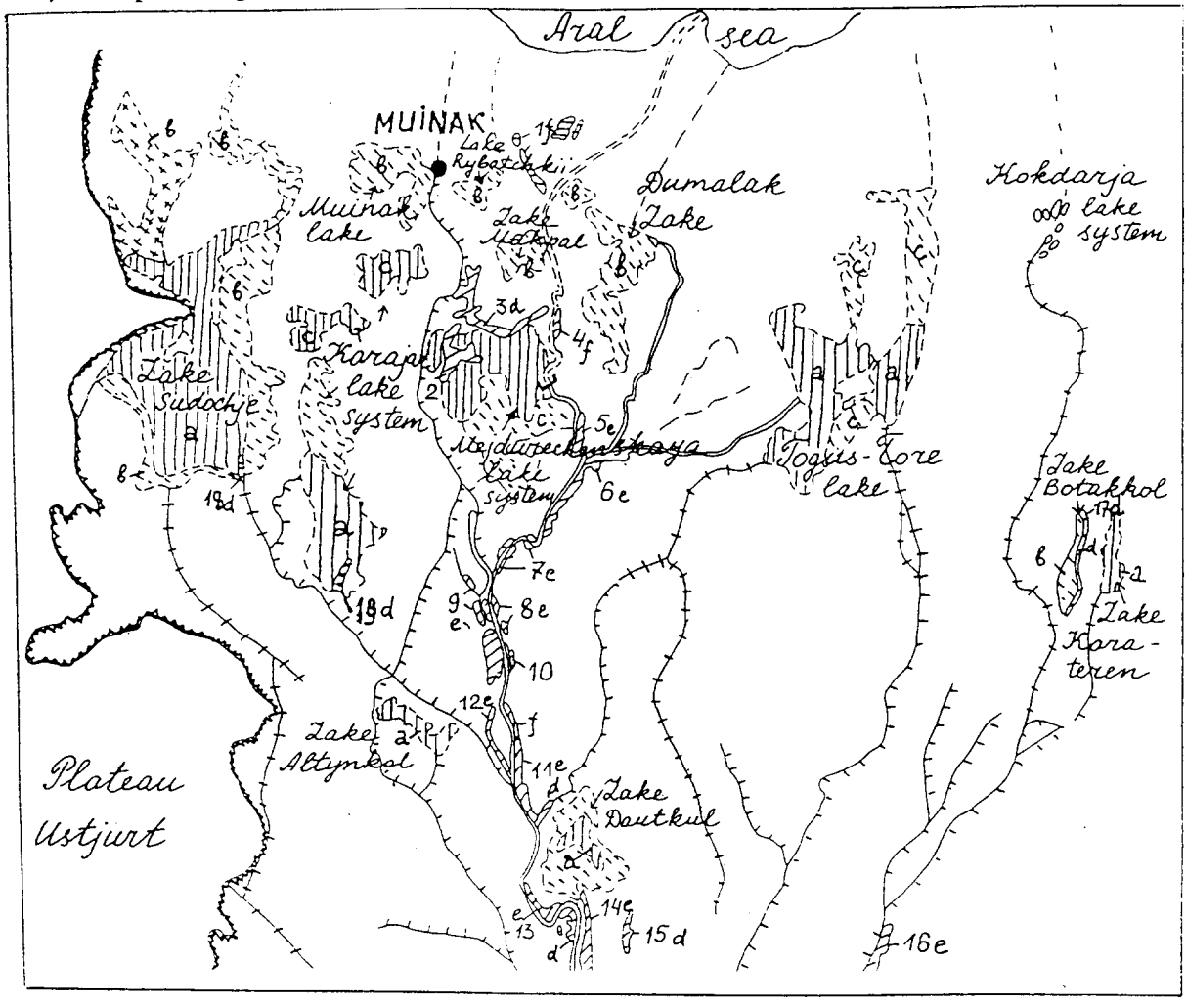
Fig. 1. Contemporary hydrographic scheme of the Amudarya river delta and recommended measures for water management.

A. 1 - Main river body of Amudarya; 2 - river branches used as channels; 3 - drainage channels; 4 - borders of plateau Ustjurt

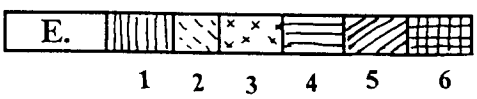
B. Tugai forests: 1 - Muinak, 2 - Shege, 3 - Zakirkol, 4 - Zair, 5 - Voroshilov, 6 - Kazakhdarya, 7 - Aspantaj, 8 - Bozatau, 9 Kyzyldjar, 10 - Dzerjinskii, 11 - Erkindarja, 12 - Akbashly, 13 Dautkul, 14 - Sovkhoz "Russia", 15 - Chortambaj, 16 - Nurumtubek, 17 - Botakkol, 18 - Raushan, 19 - Kungrad

C. Lake ecosystems watering: a - permanently all the year, b - periodically for a long time, c - periodically for a short time; D. Situation in the tugais: d - good conserving, e - desertified, f - degraded

E. Recommended water regime: For the lakes: 1 - conserve modern water regime, 2 - stable watering, 3 - stop watering; For the tugai forests: 4 - conserve modern regime, 5 - flooding in autumn or in spring time, 6 - stop flooding.



A. 1. 2. 3. 4. B. 1 - 16; C. a,b,c; D. d, e, f



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THE ICHTHYOFAUNA OF THE RIA DE AVEIRO, PORTUGAL; BRIEF CONSIDERATIONS ON ITS EVOLUTION IN THE LAST 75 YEARS

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The Ria de Aveiro, on the west coast of Portugal, is typically an estuarine coastal lagoon system (43 km²), which has both marine and fluvial influences. The morphology of the Ria de Aveiro has been shaped only recently. The lagoon began its geological formation in the 10th century, and in 1808 the connection with the sea (470 m long) was first stabilized by man (Cunha, 1930).

The substantial development of industries and population in the watershed, with only minor effluent treatment, coupled with the intense activities of the industrial and fishing ports, are the principal sources of organic, chemical and microbial pollution (Hall, 1980a and b; Lima, 1986; Lucas et al., 1986; Anon., 1990).

The Ria de Aveiro is an area of important economic development based on fisheries, industry, agriculture, seafaring and tourism. Fishery statistics are not available for the last forty years, however, there is very intense artisanal catchery made by more than three hundred boats throughout the year.

Because of the excellent environmental conditions of the Ria de Aveiro, it is colonized by a high number of fish species (more than fifty species) (Rebelo, 1992). As a consequence of the lagoonal geographic position, the great part of these species have general occurrence in Atlantic and Mediterranean systems.

Fishes colonize the Ria de Aveiro for different purposes: as a permanent abode throughout the life-cycle for sedentary species; by chance, following their prey or drifted by currents, for occasional fresh water and occasional marine species; as a nursery for marine lagoonal dependent species; and as a travel route for anadromous and catadromous species.

In an analysis of the ichthyofauna evolution since the first decade of the present century (Tab.1), the species richness shows no considerable change. In qualitative terms, eighteen species then alluded to the lagoon - including all the Chondrichthyes (Selachii) - occur no more in the present-day, and fourteen species of Osteichthyes (Teleostei) were now inventoried (Nobre et al., 1912; Osório, 1912; Arruda et al., 1988; Rebelo, 1992).

This alteration is, certainly, a consequence of the deep environmental modifications of the lagoon, principally during the last half century. Changes in the system hydrodynamics, a consequence of the successive transformations in the entrance sea walls, and the increase of the pollution concentration, from industrial and urban sewerage effluent, are the main sources of the lagoonal abiotic and biotic variation.

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Table 1 - Species, and ecological components, of the ichthyophauna of the Ria de Aveiro described between 1912 and 1987. 1912a - Nobre et al. (1912); 1912b - Osório (1912); 1980 - Arruda et al. (1988); 1987 - Rebelo (1993)

COMPONENTS / Species	Time	1912 a	1912 b	1980	1987
SEDENTARY					
Atherina boyeri					x
Atherina presbyter		x	x	x	x
Gobius niger		x	x	x	x
Pomatochistus microps				x	
Pomatochistus minutus		x	x	x	x
Pomatochistus pictus				x	
Syngnathus abaster			x	x	x
Syngnathus acus		x	x	x	x
MARINE OCCASIONAL IN THE LAGOON					
Ammodytes tobianus		x	x	x	x
Aphia minuta				x	x
Belone belone		x	x	x	x
Boops boops		x	x		
Callionymus lyra			x	x	x
Ciliata mustela		x	x	x	x
Conger conger		x	x	x	
Coris julis			x		
Deltentosteus quadrimaculatus					x
Diplodus annularis					x
Diplodus sargus		x	x		x
Diplodus vulgaris				x	x
Echiichthys vipera		x	x	x	x
Engraulis encrasicholus			x	x	x
Entelurus aequoraeus				x	
Gaidropsarus mediterraneus		x	x		x
Gaidropsarus vulgaris		x	x		
Gobius ater					x
Gobius paganellus		x	x	x	x
Gobius strictus					x
Gymnammodytes cicerelus			x		
Hippocampus ramulosus		x	x		x
Hyperoplus lanceolatus		x		x	x
Labrus bergylta			x		
Labrus viridis					x
Lagocephalus lagocephalus			x		x
Lipophrys pholis		x	x		
Mullus surmulentus		x		x	
Mustellus mustellus		x	x		
Oedalechilus labeo					x
Pagellus acarne		x			
Pagellus bogaraveo		x			x
Parablennius gattorugine		x	x	x	x
Parablennius sanguinolentus		x			x
Pollachius pollachius			x		
Pollachius pollachius			x		
Psetta maxima				x	
Raja punctata		x	x		
Sardina pilchardus		x	x	x	x
Sarpa salpa			x		
Sciaena umbra		x			
Scomber scombrus		x	x		
Scophthalmus rhombus		x		x	x
Solea lascaris				x	x
Solea vulgaris				x	x
Sparus aurata		x	x	x	x
Spinachia spinachia			x		
Spondyliosoma cantharus		x		x	x
Sprattus sprattus		x	x	x	
Symphodus bailloni		x	x	x	x
Symphodus melops					x
Syngnathus typhle		x	x	x	x
Taurulus bubalis		x			x
Torpedo marmorata		x			
Trachurus trachurus		x		x	
Trigla lucerna		x	x	x	x
Trisopterus luscus		x	x		
MARINE DEPENDENTS OF THE LAGOON					
Chelon labrosus		x	x	x	x
Dicentrarchus labrax		x	x	x	x
Liza aurata		x	x	x	x
Liza ramada		x	x	x	x
Liza saliens					x
Mugil cephalus		x	x	x	x
Platichthys flesus		x	x	x	x
Solea senegalensis				x	x
FRESHWATER OCCASIONAL					
Barbus bocagei			x	x	
Carassius auratus		x			
Carassius carassius		x	x	x	x
Cobitis taenia				x	x
Gambusia affinis				x	x
Gasterosteus aculeatus		x	x	x	x
Micropterus salmoides				x	
Rutilus macrolepidotus		x	x	x	
CATADROMOUS					
Anguilla anguilla		x	x	x	x
ANADROMOUS					
Alosa alosa		x	x		
Alosa fallax		x	x	x	x
Petromyzon marinus		x	x		x

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DYNAMICAL PROCESSES AND THEIR INFLUENCE ON ECOLOGICAL CONDITIONS OF COASTAL WATERS OF THE BLACK SEA

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The given study is based on long-term investigations of water dynamical and chemo-biological processes in the coastal areas of the Black Sea. Polluted river run-offs, insufficiently purified domestic and industrial sewage discharged in shallow water sites, urban and rural runoffs and increasing recreation are responsible for deteriorated ecological conditions in these coastal waters of the Black Sea.

The augmentation of pollution over the near-shore area is closely related to advective and turbulent water transfer processes, which depend on superposition of multifactor impacts.

Among these factors are the following:

- anemobaric processes,
- instability of the main Black Sea current (MBSC) inducing synoptic and mesoscale eddies,
- inertial and breeze variations,
- shelf and internal waves,
- upwelling and downwelling.

Orographic characteristics are also of great importance in this context. Interaction between open sea and coastal waters results in the formation of a shelf front and a convergence zone. In estuarine areas and the Kertch Strait, the water dynamics are influenced by river-plume front phenomena. Variable courses of wind generate alternation of upwelling and downwelling and change the signs of coastal current eddies.

Near the Crimean southern coast 3 to 5 upwelling phenomena, lasting for several days, take place each year and successive series may happen in a month period. This results in low (30%) dissolved organic matter (DOC) concentrations and increased contents of nutrients. Hence, the water dynamics have a profound effect on the ecology, sometimes larger than anthropogenic impacts.

The predominant pattern - along the isobath - concerns the average coastal water transfer, which exhibits a 70-80% repetition. Turbulent diffusion is more intensive in along-shore currents, due to enhanced shear effects and inertial fluctuations of the current velocity. The nearer to the MBSC, the more pronounced is the repetition of along-shore water transfer and water mixing. Therefore, this area appears to be most suitable for the discharge purified sewage. Weakened water mixing and specific water circulation in such semi-closed bays, as the Sevastopol and Balaklava Bays, promote accumulation of pollutants and reduce the self-purification capacity. In these bays the nutrient contents were found to be greater than those in sewage discharge locations. Hence, any discharge into these bays should be strictly prohibited.

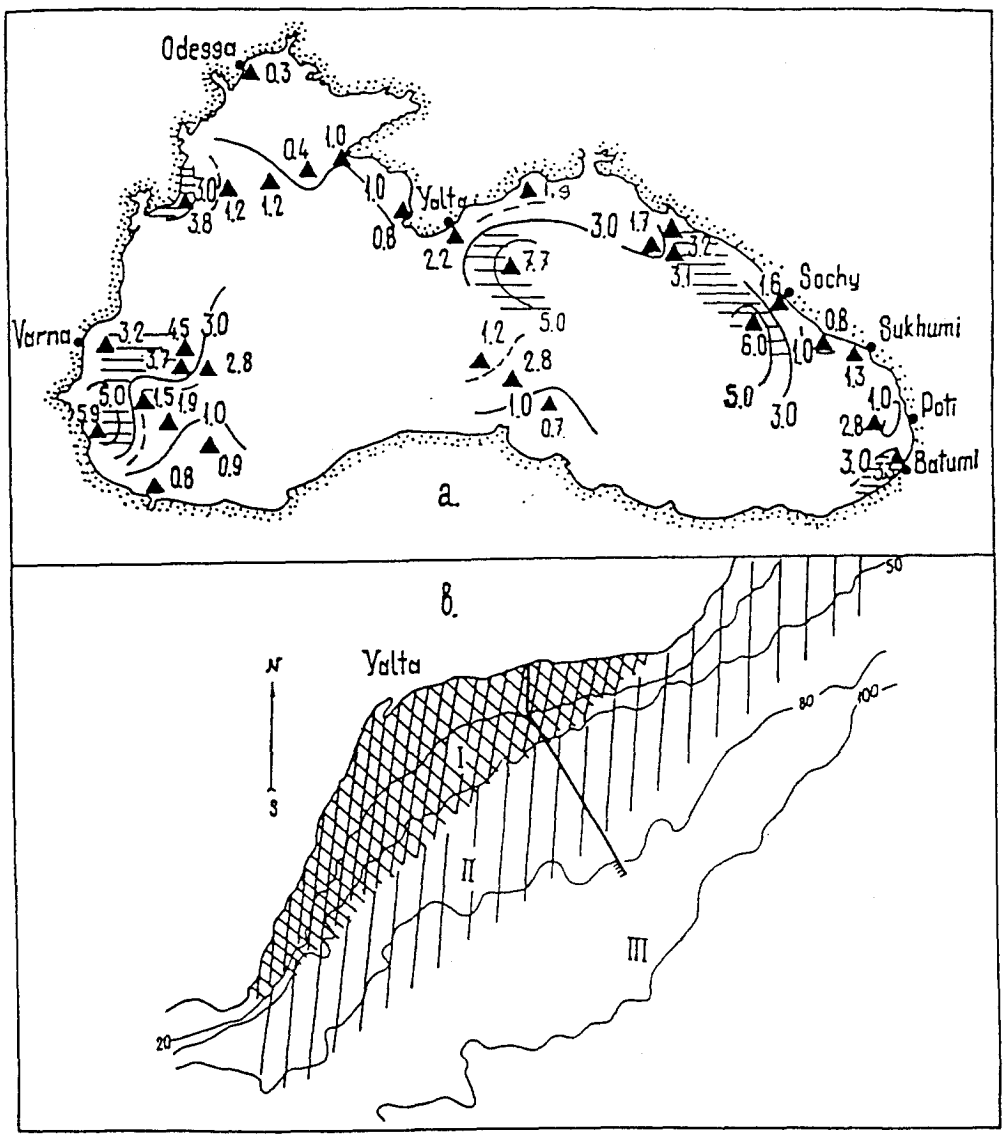
It is found that the quantity of oil-oxidizing bacterioplankton in the sea surface layer is inversely proportional to the intensity of horizontal mixing. A functional dependence of these parameters is obtained for the sea shelf regions. Accumulation of pollutants due to quasi-stationary anticyclonic eddies, occurring in the vicinity of capes, has been regularly observed near the capes Sarych, Khersones and Meganom; calculations were made using estimates of organic matter and nutrient content.

Our studies (Fig. 1) have also shown that, in the convergence zone of the Crimean and Bulgarian shelf fronts, many hydrochemical and hydrobiological parameters have sharp concentration gradients. At these places, drifting garbage, suspended matter and plankton were accumulating. The water dynamics are a determining factor in sustaining ecological conditions in coastal waters, subject to local anthropogenic impacts, e.g., sewage discharge. The correlation between water area and the extent of anthropogenic impact is also of much importance. With large-scale anthropogenic impacts, due to polluted river run-offs, coming into the north-western Black Sea, the influence of water dynamics is less obvious. A sharp increase in chemo-biological concentrations, such as those

of nutrients, organic matter, chlorophyll, phytoplankton numbers and biomass, yields high coefficients of variation which is a characteristic feature of the overlap between anthropogenic and hydrodynamic factors.

Adequate estimations of the importance of hydrodynamic factors should be made in order to prevent coastal waters from being dangerously polluted and to protect the resources of this area.

Fig. 1. A: Distribution of average values of the momentum horizontal turbulent exchange coefficients in surface layers of the Black Sea. B: Differentiation of the Yalta coastal zone according to the intensity of the water mixing, parameterized with parameters of turbulence, inertial fluctuations of current and effective diffusion.



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ÉVOLUTION LITTORALE LE LONG D'UNE CÔTE EN ÉMERSION RAPIDE, BAIE D'HUDSON, CANADA *Coastal evolution along a rapidly emerging shoreline, Hudson Bay, Canada*

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INTRODUCTION

Après le retrait des glaces wisconsiniennes, la côte orientale de la baie d'Hudson, Canada (Fig. 1) a été soumise à un relèvement glacio-isostatique très important (de l'ordre de 8 m/siècle vers 6000 B.P.). Au fur et à mesure de la régression marine, des dépôts littoraux ont été mis en place sur le socle précambrien. L'émersion des terres se poursuit encore actuellement à un rythme de 1 m/siècle. La côte actuelle est une côte basse, essentiellement rocheuse. Des littoraux meubles sont cependant fréquents dans les baies abritées et à l'embouchure des principales rivières.

Depuis 1991, deux sites côtiers ont été étudiés en détail: l'embouchure de la Grande rivière de la Baleine et le détroit de Manitounuk. Ces sites devaient être touchés par le projet d'aménagement du complexe hydroélectrique Grande-Baleine. Il était prévu de barrer la Grande rivière de la Baleine à 80 kilomètres de son embouchure et de rejeter les eaux de la centrale GB1 dans la petite baie de Kuugaapik, située dans la partie centrale du détroit de Manitounuk.

L'EVOLUTION DES LITTORAUX SABLEUX

L'embouchure de la Grande rivière de la Baleine est encadrée par des plages sableuses prolongées vers l'intérieur des terres par des dépôts littoraux soulevés qui témoignent de la baisse progressive du niveau marin relatif. La rive nord de l'embouchure est une pointe sableuse triangulaire qui s'avance à l'entrée de l'estuaire; c'est également le site du village de Whapmagoostui-Kuujjuaraapik (Poste-de-la-Baleine).

La comparaison des photographies aériennes a mis en évidence une progression de l'extrémité sud-ouest de la pointe sableuse de plus de 150 m entre 1972 et 1990; soit une avancée moyenne de plus de 8 m par année. Cette progradation vers le large est liée à des apports sédimentaires importants à l'embouchure de la Grande rivière de la Baleine qui dépose une partie de ses sédiments au niveau d'un delta sous-marin. Le long de la plage, une dune bordière embryonnaire s'est également développée pendant la même période.

L'étude détaillée et le suivi pluri-annuel de la zone supratidale le long de la plage de Whapmagoostui-Kuujjuaraapik ont permis de mieux comprendre les mécanismes favorisant la progression du rivage (Ruz et Allard, 1994). La berme des plus hautes mers est colonisée, à sa limite supérieure, par *Honkenya peploides*, seule espèce pionnière dans ce milieu difficile. Ces plantes forment des coussinets circulaires qui piègent le sable mis en mouvement en haut d'estran par les vents d'ouest et du sud-ouest. Ces monticules forment peu à peu des buttes coalescentes qui constituent une base pour l'édification d'une crête embryonnaire principalement colonisée par l'élyme des sables (*Elymus arenarius*). Cette crête, au fur et à mesure de son exhaussement par les apports de sables éoliens, devient une dune bordière stabilisée uniquement par des elymes et des pois maritimes (*Lathyrus japonicus*).

De nombreuses crêtes dunaires se sont ainsi mises en place au fur et à mesure de la baisse du niveau marin relatif. Ces crêtes sableuses ne sont pas des plages soulevées et leur élévation ne peut donc pas être reliée au niveau marin relatif.

A court terme, le mode d'évolution de cette plage est essentiellement lié aux apports sédimentaires provenant de la Grande rivière de la Baleine. Ces apports constants de sédiments favorisent les processus éoliens et la formation de dunes embryonnaires qui sont peu à peu stabilisées par la végétation, formant ainsi une nouvelle dune bordière en avant de la précédente. A plus long terme, la progression du rivage vers le large est due à la baisse du niveau marin relatif.

L'EVOLUTION DES LITTORAUX DE SEDIMENTS FINS

Situé à 20 km au nord-est du village de Whapmagoostui-Kuujjuaraapik, le détroit de Manitounuk est un des rares endroits abrités le long de la côte est de la baie d'Hudson. La côte est rocheuse le long des îles Manitounuk alors que la rive orientale du détroit, en pente douce, est constituée de dépôts meubles (Allard & Trembay, 1983). Malgré un faible marnage (1,45 m en moyenne et 1,95 m en période de vive-eau), une large zone intertidale (500-700 m) est exondée à marée basse. La partie supérieure de la zone intertidale est limitée soit par une mince plage sableuse, soit par une micro-falaise, ou par des accumulations de blocs à la base des affleurements rocheux et des drumlins. La micro-falaise est entaillée dans une basse terrasse qui correspond à des dépôts littoraux récemment émergés. Cette terrasse est épisodiquement inondée lors de tempêtes conjuguées à des hauts niveaux d'eau.

Les estrans de la partie centrale du détroit de Manitounuk sont caractérisés par une zonation morpho-sédimentologique. Une telle zonation parallèle au rivage est typique de ce type d'estran et se retrouve aussi bien dans les régions tempérées que froides. Des basses mers moyennes aux plus hautes mers, quatre principales zones morpho-sédimentaires ont été définies (Ruz et al., 1994). L'estran inférieur est essentiellement sableux et sillonné par des rides de courant. La partie médiane sablo-silteuse est parsemée de blocs de taille décimétrique, ce qui est une caractéristique particulière aux estrans des régions froides (Dionne, 1985). La partie supérieure de la zone intertidale est traversée par un chenal parallèle au rivage reliant entre elles des mares circulaires ou allongées. Ces chenaux servent d'exutoires aux eaux continentales et sont également empruntés par la marée. Les silts argileux prédominent dans cette zone. La limite supérieure de l'estran, qui correspond au niveau des hautes mers moyennes, est constituée d'argile silteuse recouverte par endroits de minces placages sableux.

Bien que cette région soit en voie d'émersion, on constate cependant une érosion de la ligne de rivage dans des secteurs côtiers où prédominent des sédiments fins. La comparaison des photographies aériennes de 1979 et de 1990 a mis en évidence un recul moyen de près de 1 m/an pour certains secteurs de la baie de Kuugaapik, alors que dans d'autres secteurs la ligne de rivage a reculé de près de 2 m/an. Même les petites plages sableuses reculent et envahissent la basse terrasse marécageuse. Le recul du rivage ne semble pas lié à des fluctuations eustatiques du niveau marin, mais il serait dû à une combinaison de processus spécifiques, comme le gel-dégel des sédiments intertidaux et de processus azonaux comme les vagues et les courants. Au printemps, et plus particulièrement lors de périodes où les températures sont nettement supérieures à la moyenne saisonnière, la fonte de la couche de gel saisonnier contenue dans les sédiments de la basse terrasse entraîne une sursaturation des sédiments et contribue au recul du trait de côte en provoquant l'effondrement de la micro-falaise le long des fentes de gel. Les sédiments sont ensuite mis en suspension par les vagues à marée haute et sont entraînés vers la zone infratidale par les courants de jusant. Le recul du rivage est accentué lors de crues de tempête qui peuvent provoquer une surélévation de plus d'un mètre du niveau de la mer.

CONCLUSION

A court terme, même si ce littoral est soumis à l'un des plus fort taux de relèvement isostatique au monde, les processus spécifiques à ce milieux subarctique, combinés aux processus azonaux, induisent par endroit un recul de la ligne de rivage comparable à celui enregistré dans des

régions côtières affectées par une hausse du niveau marin relatif.

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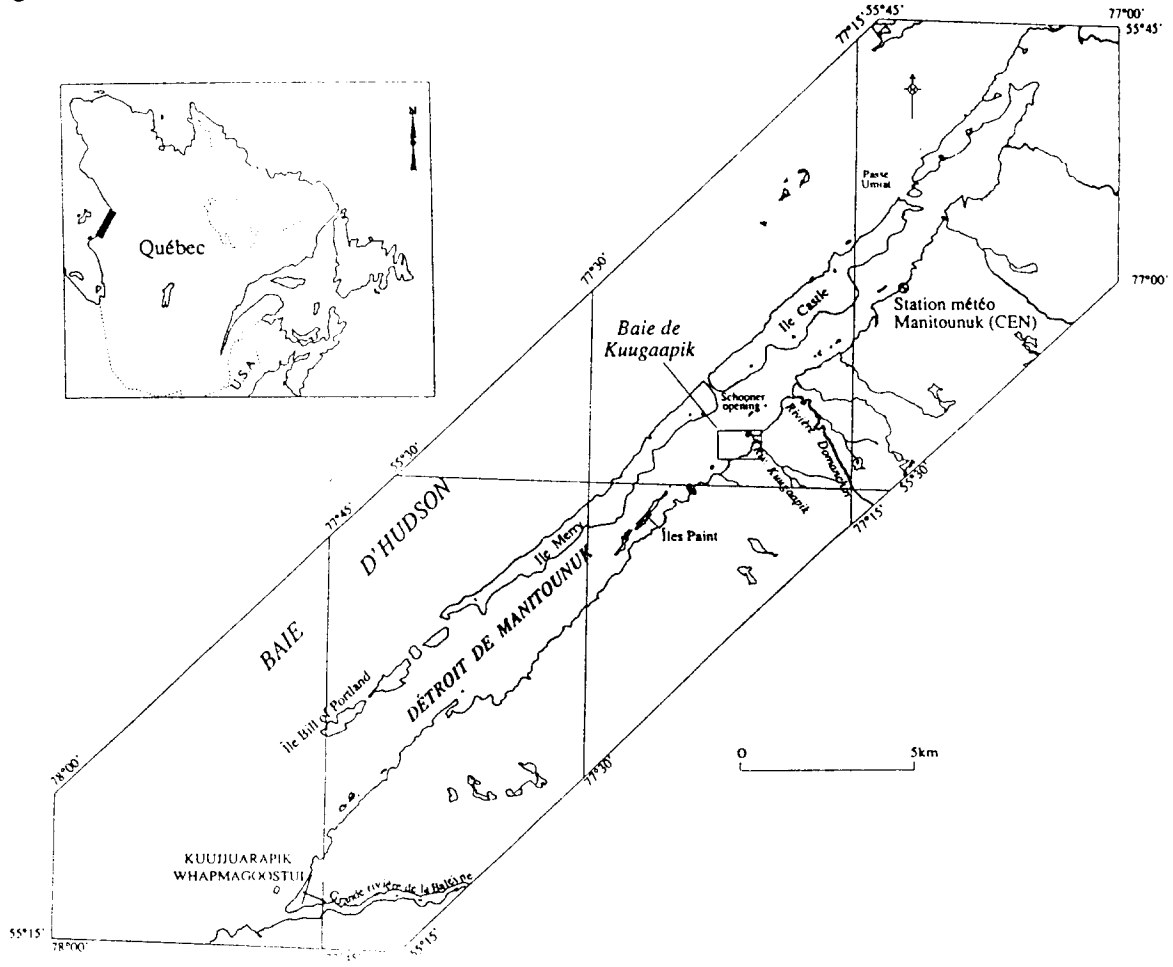
Fig. 1. Carte de localisation.



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THE INFLUENCE OF POLLUTION ON MARINE BENTHIC ALGAE OF THE AVACHA BAY (SOUTH EASTERN KAMCHATKA)

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The seasonal and annual ecological conditions of Avacha Bay (Pacific coast of Kamchatka) were investigated. The latest observations showed to some extent the reduction of the sea-water pollution index, as compared with previous years. From 1991 on, the Avacha Bay waters were reclassified from "very dirty" to "dirty". Nevertheless, the main polluting agent concentrations, i.e. oil products, phenols, detergents and heavy metal ions in the waters of the Bay exceeded the classifications 8-78; 14-81; 2-9 (Table 1) and 2-4 times the maximum permissible concentration (MPC). These toxicants are particularly dangerous because their highest concentrations occur in the summer-autumn period, when most benthic communities, including macrophytes, grow, accumulate biomass and reproduce. On the one hand, the most numerous and massive algae (Phaeophyta: *Laminaria bongardiana, L. gurjanovae, L. longipes, Alaria fistulosa, A. marginata*) can purify sea water by absorbing toxicants and making complexes with alginates in their fronds and thus inactivating poisons. But on the other hand, these algae themselves become toxic and unsuitable for continued us. Moreover kelp toxicants return again to the sea water and the destroyed parts of the fronds settle to the bottom. By decaying they are a secondary source of pollution and cause oxygen deficiency in the water. For the Avacha Bay's ecosystem, having been in an extreme unfavourable situation for a long time, the process of extinction of marine biota has become obvious. During our 10 years, observations in the Bay since 1984 to 1994 and analyses of the literary data since the beginning of the century up to 1980s (Savitch, 1914; Selinova, 1989), a constant decreasing tendency of the marine flora in the region has been observed. We distinguished a series of algae, mainly representatives of Rhodophyta (*Membranoptera beringiana, M. multiramosa, Phycodrys riggii, Hymenena ruthenica, Neoabbottiella araneosa, Neodilsea natashae, Beringia castanea, Odonthalia corymbifera, Neorhodomela oregona* etc.) which can be considered as rare or extinct in the Bay. *Pantoneura jurgensii* seems to have disappeared completely.

But in spite of the unfavourable ecological situations in the basin as a whole, there are some relatively undamaged ecotypes due to the unique geomorphological and hydrological conditions in the Bay. The marine benthic flora of the Avacha Bay is still relatively rich and diverse. We have found 120 species of macrophytes here, 16 of them being new for the basin and 9 new for the Pacific shore of Kamchatka (*Urospora elongata, Percursaria percursa, Porphyra gardneri, P. torta, Neoabbottiella araneosa, Palmaria callophylloides, Membranoptera multiramosa, Beringia castanea, Scagelia pylaisaei*).

Comparing algae-species composition of "very dirty" ecotypes (polytoxobic) with relatively pure (olygotoxobic) ones, we found out that pollution caused reduction of the species number up to 60% for Rhodophyta, 50% for Phaeophyta and 25% for Chlorophyta.

This is accompanied by serious changes in phytocenoses:

- in the character of dominance where pollution resistant species prevail over sensitive ones;
- in the number and correlation of the co-dominant species; and
- in the abrupt growth of a number of epiphytes.

Comparing littoral algae communities of two zones of Avacha Bay having relatively similar biotopes, we observed that phyto-associations of the type *Porphyra spp.- Fucus evanesces* with co-dominant species *Scytosiphon lomentaria, Petalonia fascia, Chordaria flagelliformis, Halosaccion glandiforme, Mastocarpus pacificus,*

Ulvaria splendens characteristic of the olygotoxobic zone in polytoxobic conditions, are replaced by associations: *Ulvaria splendens - Fucus evanescens*, while *Porphyra* becomes co-dominant, *Chordaria* increases in number, *Petalonia* and *Scytosiphon*, on the contrary, decrease, and *Halosaccion* and *Mastocarpus* have disappeared completely. Abrupt growth of the number of epiphytes (in 1.5-2 times as compared with pure zones) is also characteristic for the algae communities of "dirty" parts of the Bay.

The influence of pollution on macrophytes at the organism level (reproductive, morphologic, histologic, cellular, subcellular), such as teratogenic effects, sterilization, cellular anomalies etc., are not so obvious. We seldomly observed morphological anomalies, except in some representatives of Laminariales (*Agarum clathratum, Alaria marginata*), having laminae spirally twisted around midribs. But these cases of teratism can not be considered for sure to be caused by pollution, because anomalous specimens were sometimes found both in olygotoxobic zones as well as in polytoxobic ones. In most cases algae from "dirty" and relatively pure zones are similar in appearance, their morphological differences being within the limits of natural variation. We also failed to find evidence of pathologic changes when studying vegetative cells and tissues of macrophytes. This is probably because of the high recovery ability of marine benthic algae, which favours their survival even under extreme ecological conditions.

However, this is different for the algae's reproductive system, which appears to be more susceptible to the pollution damage than vegetative systems. Our observations on the red alga of the Avacha Bay *Palmaria stenogona* show a month-long delay in tetraspore production in specimens growing in "dirty" zones, as compared to normal ones. We observed a direct sterilizing effect by pollution on some representatives of rare species of Rhodophyta, having no more reproductive organs at all. This is probably the cause of reduction in number and even extinction of Rhodophyta with their highly specialized reproductive structures. Apparently the more primitive reproductive process in Chlorophyta makes them more resistant to pollution.

Nevertheless it is clear that immediate protective measures should be taken in order to prevent further extinction of marine biota in Avacha Bay.

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Table 1. Annual maximum and average classifications of dominant contaminants in the Avache Bay.

	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Maximum										
oil products	3700	3900	2500	800	3250	1750	1300	2400	1950	500
phenols		85	21	36	40	16	30	22	27	83
detergents	220	320	900	330	330	800	400	400	600	300
Average										
oil products	450	350	250	275	300	400	350	550	300	5
phenols		36	5	5	5	2	6	5	6	9
detergents	60	50	60	50	50	110	90	90	90	110

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A NEW POWER SUPPLY FOR HIGH RESOLUTION, MICROSEISMIC SURVEYS

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Acoustic systems (SBP, boomers, sparkers) are normally used to detect sedimentary structures and buried bedrock in marine and lacustrine environments. "Uniboom" and "Uniboom"-like devices use electro-mechanical transducers, achieving the highest vertical resolution (in most cases approaching 20 cm), with good or excellent penetration down to 200 m or more. Furthermore the "multiples" can be strongly reduced and sometimes eliminated if the proper acoustic geometry of the towed components is adopted. These systems require heavy power supplies draining several kW of AC current with high pulsing surge currents, capable of inducing large fluctuations in the line system. Thus, they require their own line or generator, and a different one for the processing-recording system. Therefore such systems are difficult (sometimes impossible) to be used on small boats.

Modern technology has allowed us to design, develop, build and successfully test the "Pulsar", the prototype of a new generation of power supplies for Uniboom, Uniboom-like and sparker systems. It overcomes most of the undesirable features of the power supplies, available on the market. The pulse length is also shorter than the pulse generated by other power supplies, and thus the records are better defined.

The Pulsar is about 75% lighter and requires less than 25% of the electrical power needed by the other power supplies on the market. No separate line or electric generator is required to power the processing-recording system: the Pulsar operates without generating any starting surge current.

The Pulsar's total weight is 52 kg and the specifications are the following:

- power requirement: AC, 1 or 3 phases, 100÷250 V, 45÷65 Hz; DC, 100÷270 V
- input power limit, adjustable from 1 to 2.5 kW (maximum), with no surge current
- efficiency, overall: 84% at full power; energy selectable from 150 to 900 J at 3.9 kV; maximum output: 2k J/s, 1kJ pp
- internal-external switch selectable trigger; repetition rate adjustable up to 10 pps
- HV connector provided for higher pulse energy with external capacitor bank

The Pulsar allows to run a survey with a pulse repetition rate of 2 pps and an output of 300 J, using as a generator for both the power supply and the processing-recording system: a small light, 1.5 kW Honda generator.

A "Pulsar plus" will be available soon, with up to 2 kJ output pp on 1 to 4 separate channels, selectable. A waterproof cabinet (to be moored on deck to reduce the HV cable length) with a remote display-switchboard-keyboard panel will also be available.

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DEFINING MANAGEMENT UNITS[1]

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INTRODUCTION

The concept of regional studies based on sediment cells has now become well established and such studies are increasingly used as the foundation for the preparation of management plans. By considering the natural processes within a sediment cell, alongside the use of resources, conservation and planning issues, suitable management strategies can, in principle, be developed. The variety and complexity of the coastal scene often make this impractical on a cell-wide basis. As a consequence, the concept of **'management units'** has developed; these being lengths of coast that exhibit coherent characteristics which can be separated as discrete units and, to a reasonable extent, managed independently.

There is therefore a need to be able to define appropriate management units. In order that policies are compatible with the natural environment, such units must clearly recognise the dominant processes. Similarly, the coastal resource, with its complex blend of sea and land use, conservation, natural habitat, amenity and recreation, also need to be analyzed in a way that contributes to some meaningful sub-division of the coast. Dealing with all these issues collectively in order to define management units can be unduly complex. It is often more practical to first define process and resource units independently and then combine these to derive meaningful management units.

CLASSIFICATION

Classification seeks to group attributes into discreet classes that are more amenable to analysis. Generally the data needs to be stored as original values, with classes derived from the raw data to meet specific interpretation and presentational needs. This avoids committing to one particular classification system and increases the value of the data for use in subsequent analyses. Many coastal attributes (particularly coastal resources) are of a descriptive nature and for these some form of direct classification is unavoidable. There are many examples of classification systems given in the literature, although these have in general been developed for specific subjects, e.g.:

- marine habitats (Salm and Clark, 1984)
- coastal habitats (NCC/NERC, 1979)
- aquaculture (Dutrieux and Guélorget, 1988)
- estuaries (Hume and Herendorf, 1988)
- coastal morphology (Cendrero, 1989)
- coastal works (Fleming and Townend, 1989)
- dune systems (Ranwell and Boar, 1986)

They do however provide a basis from which more focused classifications can be developed to meet the specific needs of coastal management. Table 1 illustrates such a classification of variables, as developed for the Anglian Sea Defence Management Study.

Combining the basic variables allows interpretive maps to be developed. This again may involve some further classification. For some combinations there may be suitable discreet definitions based on the underlying variables (*e.g. the yellow figure*). Whereas others will simply provide a relative magnitude such as high, medium and low (*e.g. the blue figure*).

ANGLIAN SEA DEFENCE MANAGEMENT STUDY

The Anglian Sea Defence Management Study was initiated to gain a better understanding of the

[1] For the mentioned coloured figures, please contact the author.

processes causing erosion, as a basis for a more strategic approach to the provision of sea defence. This entailed field measurements, a range of modelling studies and the establishment of a geographic information system (GIS). The ensuing analysis produced a number of insights and in particular highlighted the importance of variations in geology within the region.

During the first phase of the study data were extracted at one kilometre intervals and compiled in a spreadsheet. This allowed different types of data to be examined together as a function of location on the coast. A typical chainage diagram is shown in the *green figure*, which has been annotated with various anecdotal and observed information to help build the overall picture. This approach to defining management units is a little subjective but is highly flexible and responsive to local detail.

In the second phase of the project, more detailed data sets were prepared and much of the field data was added. The spatial nature of the data, in conjunction with the need to make this data routinely available for operational as well as strategic management, led to the adoption of GIS. This did however complicate the analysis. The data are spatially disparate; they are represented as points, lines and areas but cannot be spatially combined in their raw map form. It is therefore necessary to carry out some spatial reduction. Given that the aim is to derive management units along the shore, an appropriate reduction is on to the coastline. Within the GIS this was achieved using Intergraph's Grid Analyst software. Whilst this provides an area based form of presentation, it is in fact equivalent to the linear chainage approach of the first phase, except that the variables are mapped over their true extent along the coast, rather than constrained to definition at one kilometre intervals

The analysis within this study focused on processes, without particular regard to resource use issues. Following the method outlined above, a set of coastal units were defined. These were based on:

- coastal forcing - a combination of wave action and tidal action (*the blue figure*), and
- sediment potential - a description of the type and adequacy of beach forming material (*the yellow figure*) to give preliminary units (*the pink figure*).

In a qualitative sense, these units are akin to the conceptual beach model classification proposed by Masselink and Short (1993). The preliminary units were adjusted based on key geomorphological features, to arrive at the final units. In general, the units defined in this way were consistent with the units defined in the first phase but benefited from an improved resolution of the boundaries between units.

SOUTH FORELAND TO BEACHY HEAD SHORELINE MANAGEMENT PLAN

Following the completion of the Anglian Sea Defence Management Study, there was a recognition in the UK that the approach should be more widely adopted. Indeed the House of Commons Environment Committee made special mention of the approach that the study embodied. Since then the authorities responsible for coastal defences have formed groups which cover coastal cells or sub-cells and are now in the process of preparing Shoreline Management Plans (SMP's). These seek to promote a strategic approach to the provision of coastal defences, based on an understanding of the coastal processes. One such group covers the coast from South Foreland to Beachy Head.

The goal of the study is the plan, with no broader requirement to establish a GIS. Consequently the data collection and analysis has focused on the requirement to define management units and so avoided the time and cost overheads of setting up a fully configured and documented management system. This has been achieved by recognising the linear nature of the problem. The analysis undertaken for the Anglian study highlighted the constraints of spatial analysis with such a disparate range of data sets. This study therefore sought to combine the ease of mapping against a chainage (as in Phase 1 of the Anglian study), whilst retaining the freedom to map individual variables over their natural extent (as in Phase 2). The approach uses a simple database structure, where each variable is referenced to a start and

end chainage along a 'reference coastline'. Graphical presentations are then used to display the data in the form of an x-y graph, or overlaid as different coloured line segments on the reference line (or a straight line). The former provides an excellent way of (a) making a raid assessment of alongshore variations, and (b) looking at any mix of quantitative, ordinal and nominal data (the last two graphed using simple integer values based on their class intervals). Whilst the overlay facility allows new classifications to be developed by combining the raw data according to a specified algorithm (e.g. $A+2*B^2$).

For this length of coast there was little variation in tidal conditions and the coastal forcing was therefore dominated by the wave climate. In conjunction with the beach properties (width, erosion rate, sediment grading and key geomorphological features) these variables provided the definition of process units. Over the 90 km length of coast being considered, the main variation in resource use is between urban and open coast. These were refined by considering primary and secondary habitats, flood protection zones and ecological designations to derive the resource units. The final step was to combine process units with resource units to establish the management units. Generally the fit was good and only minor adjustments to unit boundaries were required to avoid unwarranted fragmentation or unduly short units.

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Table 1. Classification of variables, as developed for the Anglian Sea Defence Management Study.

Theme	Class	Value	Theme	Class	Value
Geomorphology	1	cliff	Alongshore wave energy (annual mean in kN/S)	1	0 - 500
	2	undefined		2	500 - 1000
	3	dune-beach complex		3	1000 - 1500
	4	dune		4	1500 - 2000
	5	beach ridge		5	>2000
	6	spit			
	7	marsh			
Landscape Character	1	plateau	Spring tidal range (m)	1	<2
	2	rolling		2	2 - 3
	3	lowland		3	3 - 4
				4	4 - 5
				5	5 - 6
				6	>6
Surface water catchment (sq km)	1	<2000	Nearshore tidal current residual squared (m^2/s^2)	1	0 - 0.01
	2	2000 - 5000		2	0.01 - 0.02
	3	>5000		3	0.02 - 0.03
				4	0.03 - 0.04
				5	0.04 - 0.05
				6	>0.05
Nearshore width (m)	1	>5000	HWM retreat rate (m/yr)	1	<0
	2	3000 - 5000		2	0 - 0.5
	3	1000 - 3000		3	0.5 - 1.0
	4	500 - 1000		4	1.0 - 1.5
	5	100 - 500		5	1.5 - 2.0
	6	<100		6	>2.0
Foreshore width (m)	1	>3000	Beach steepening (m/yr)	1	<-0.1
	2	1000 - 3000		2	-0.1 to +0.1
	3	500 - 1000		3	0.1 to 0.5
	4	100 - 500		4	0.5 to 1.0
	5	<100		5	1.0 to 2.0
	6	no foreshore		6	>2.0
Backshore width (m)	1	>500	Retreat/advance classification	1	-6 and -5
	2	300 - 500		2	-4
	3	100 - 300		3	-3 and -2
	4	50 - 100		4	-1,0 and +1
	5	<50		5	+2 and +3
	6	no backshore		6	+4
				7	+5 and +6
Mobile sediments	1	bedrock	Estuary/coast	1	estuary
	2	littoral/marine		2	open coast
	3	silts and clays			
Sub-surface sediments	1	bedrock	Width of flood protection zone (km)	1	1
	2	crag		2	1 - 3
	3	sand and gravels		3	3 - 5
	4	Cromer forest/till		4	>5
	5	till			
	6	silts and clays			
Extreme waves (1 in 100 year H_s in m)	1	0 - 2	Conservation sites	1	local
	2	2 - 4		2	national
	3	4 - 6		3	international
	4	6 - 8			
	5	>8			

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OBSERVATOIRE DE L'ENVIRONNEMENT LITTORAL ET MARIN MANCHE ET SUD MER DU NORD

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L'OBSERVATOIRE POURQUOI?

L'espace littoral est un milieu fragile, son aménagement équilibré suppose la prise en compte et la conciliation d'exigences a priori peu compatibles: le développement d'activités économiques créatrices d'emploi et la préservation du milieu naturel.

Savoir pour mieux gérer: telle est l'exigence qui s'impose aux chercheurs, aux aménageurs et aux décideurs qui travaillent sur cet espace. La multiplicité des acteurs, la dispersion du pouvoir décisionnel, des moyens et des données requièrent un lieu de rencontre et de transfert. Rassembler les informations éparses et difficilement accessibles, assurer le lien entre les acquis de la recherche et les besoins sur le terrain sont les missions de l'Observatoire de l'Environnement Littoral et Marin Manche et Sud Mer du Nord.

L'Observatoire du Littoral est un lieu d'échange et de communication situé à l'articulation de l'organisme de recherche et de l'acteur sur le terrain. Véritable structure d'interface et centre de ressources, il est destiné à valoriser les compétences de chacun, à structurer et diffuser l'information.

L'OBSERVATOIRE COMMENT?

Sans se substituer aux acteurs, l'Observatoire suscite le dialogue et apporte les moyens d'évaluer et de croiser les diverses approches. (Dans cet objectif, le rôle premier de l'Observatoire est celui d'un révélateur qui identifie et valorise les expériences et savoir-faire:

- compétences,
- données scientifiques et techniques,
- projets en cours.

Il localise les conflits d'usage et leurs conséquences (constitution de bases de données). (Il est ensuite le catalyseur qui suscite la réaction des acteurs en rapprochant l'offre et la demande en information. Il structure et diffuse les informations, notamment par le transfert des données scientifiques auprès des utilisateurs. De même, il traduit les préoccupations de ceux-ci aux chercheurs (bibliographie, synthèses, expertises, cartographies, bulletins...). Enfin, il est un animateur des réseaux d'acteurs qui encourage les échanges et les coopérations pour un enrichissement mutuel et la convergence des initiatives (tables rondes, conférences, missions d'étude...).

L'OBSERVATOIRE AVEC QUI?

Une équipe pluridisciplinaire de 8 personnes qui anime un réseau de compétences, avec l'aide et le conseil d'un comité scientifique et technique.

POUR QUI?

Administrations, Collectivités territoriales, Aménageurs, Décideurs, Associations, Entreprises, Chercheurs et tout intervenant sur le littoral.

VERS UN OBSERVATOIRE EUROPÉEN

Les régions riveraines de la Manche et de la Mer du Nord connaissent des conditions très comparables: fortes marées, activités halieutiques et industrielles, paysages fragiles, trafic maritime intense, pression démographique et touristique... et peuvent bénéficier de la réciprocité de leurs expériences. C'est dans cet esprit que progresse l'Observatoire: constituer un outil de référence pour les 140 km de côtes du Nord-Pas de Calais, depuis la frontière belge jusqu'au rivage de la baie d'Authie, qui invite ensuite les régions voisines à s'associer.

REPÈRE THÈME OBSERVATOIRE E.L.M.

Système d'information géographique littoral (Programme SIGLI) Structure et base de données

du SIG mis en oeuvre à l'Observatoire E.L.M. Dans le cadre de son programme SIGLI, l'Observatoire de l'Environnement Littoral et Marin, vient d'acquérir le logiciel Mac-Map pour la mise en place de son Système d'Information Géographique. Ce nouvel équipement permettra à la structure d'étoffer son action de transfert et de valorisation des données statistiques et géographiques du littoral de la région Nord/Pas de Calais et d'accentuer sa mission d'interface entre les scientifiques et les usagers. Les objectifs du Programme SIGLI.

Véritable outil complémentaire de ceux déjà en fonction (banques de données des usagers et des ressources scientifiques du littoral, conférences, stages, tables rondes,...) le SIG aura pour finalité de: Développer la connaissance du littoral: (En identifiant les éléments composant les milieux naturels et anthropisés en caractérisant leurs tendances d'évolution (trait de côte, végétation, patrimoine historique, urbanisation,...), par la production de données à l'échelle des collectivités, afin de permettre par la même occasion à celles-ci de se connaître, de se comparer, de se positionner. (En rendant accessible l'information, en valorisant et communiquant l'espace littoral par la production de cartes thématiques, de cartes de synthèse (brochures, plaquettes, bulletin d'informations scientifiques,...).

Assurer un suivi et une veille permanente (à partir de l'information existante recueillie et analysée):

- Déceler, évaluer, anticiper, alerter et mettre en lumière les dysfonctionnements, les déséquilibres, les conflits d'usage du sol pour apporter aux décideurs des conseils et un soutien dans la gestion de l'espace par la production d'une documentation cartographique synthétisant les problèmes concernés.
- Répondre aux besoins des projets concernant le littoral:

(i) En produisant des informations nécessaires à l'élaboration de diagnostics et adaptés aux acteurs, au montage des dossiers et à la gestion de projets d'aménagement du littoral.

(ii) En aidant à la décision par la modélisation et la simulation rendues possibles par les cartes de synthèse.

THÉMATIQUE ET ESPACE D'APPLICATION

La réflexion sur la configuration d'une base de données, étape précédant la mise en oeuvre d'un SIG, nous a amené à prendre en compte et à décliner les cinq thèmes de travail de l'Observatoire, définis préalablement lors de l'étude de faisabilité de la structure:

1. Paysages et patrimoine
2. Occupation humaine
3. Activités socio-économiques
4. Qualité de l'eau
5. Aménagement et défense du littoral.

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IMPORTANCE OF COASTAL CHANGES ON COASTAL ZONE CONDITIONS IN LONG ISLAND SOUND, USA: IDENTIFYING ASSOCIATIVE PARAMETERS FOR MANAGEMENT CRITERIA.

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Long Island Sound (LIS) is a 3200 km^2 system at 41 °N on the North American east coast. It is impacted by over 9 million coastal residents, heavily concentrated in New York City and its suburbs in

the western end. Channels have been dredged, shorelines built out, mud flats and tidal marshes lost, and nutrient and organic effluents increased.
These changes have caused oxygen depletion in bottom waters of the mainstem of the system, which has provided a strong, integrated systems-level signal for tracking the progress of eutrophication and for analyzing the susceptibility of systems to eutrophying conditions.
LIS provides a useful case study because it's oxygen supply is refreshed every winter and the ontogeny of processes repeat themselves every summer. Nutrient loading levels do not determine directly the magnitude of eutrophic impacts on systems.
Physical conditions set the stage for susceptibility. Stratification is the primary attribute. Its persistence in time and space determines the duration of isolation of bottom waters, hence it is a better measure than absolute pycnocline strength.
Deep basins tend to be more persistently stratified than shallow ones, and the volume of water affected is greater.
Effects are particularly strong in silled basins, where sluggish bottom waters have long residence times.
Deep basins which are stratified by salinity (Baltic, Chesapeake Bay), can have much more extended stratified periods than those stratified by temperature (LIS), but this criterion varies with latitude.
Tropical systems which are deep enough may be perpetually stratified by temperature.
The importance of river discharge depends as much on its location and distribution as on its magnitude and variability.
In LIS the effects are lessened because discharges are well downstream from the head where exchange is with brackish East River water.

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CHANGES IN MARINE COMMUNITY STRUCTURE IN AREAS OFFERED DIFFERENT LEVELS OF PROTECTION

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ABSTRACT
A marine protected area, Mombasa Marine Park and Reserve, was established along the Kenyan coastline in an area that was previously fished. The park indicates a fully protected zone, whereas the reserve is a partially protected multiple-use-area, where controlled fishing is allowed. Exclusion of fishermen was fully achieved in 1990. This study was conducted to compare predation, herbivory, fish species turnover, diversity and density between a fully protected area (park) and a partially protected area (reserve).
There was no statistically significant difference between the park and the reserve in terms of predation (Fig. 1 & 2). The difference in predation between the coral and sea grass zones was significant in the reserve. In the park one site (across the channel) was significantly different but the other (wreck) was not. In terms of herbivory, both park and reserve were not significantly different in general. The reserve did not show any difference in herbivory between the coral and sea-grass zone, but the park showed significant differences between the two-substrate types.
In both the park and reserve, the absolute species turnover levels off after 100 days. The highest species turnover is achieved after 400 m^2 in the park and at 200 m^2 in the reserve. The species-area relationship becomes asymptomatic at 600 m^2 for 14 species of damselfish and at 800 m^2 for 17 species of wrass.
For the families sampled, the park had a higher species density than the reserve. However, in terms of diversity, the two areas showed a

significant difference only for damselfish but not for wrass, with the reserve being more diverse than the former. The similarity indices between the park and reserve are 80.7% and 88.24% for wrass and damselfish, respectively.

Fig. 1. Predation analysis by dominant substrate cover among sites.

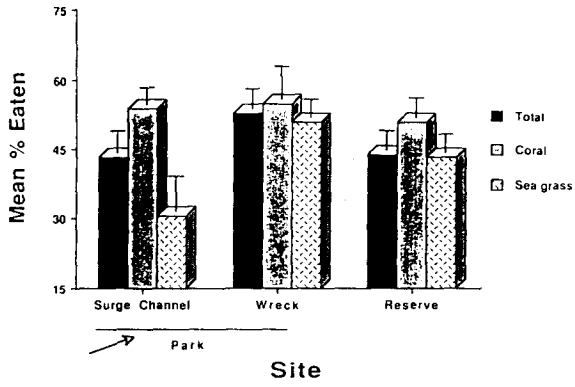

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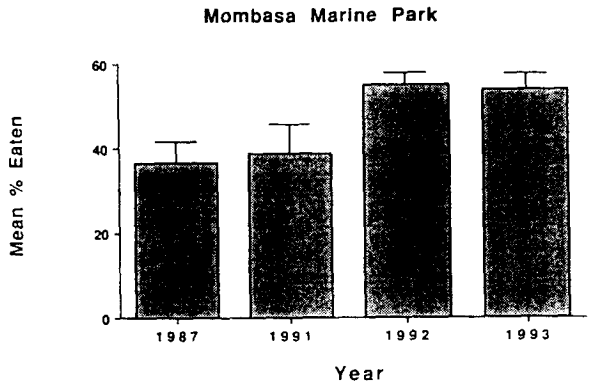
Fig. 2. Trends in predation for the Mombasa Marine Park over several years. Raw dat prior to 1993 were borrowed from Dr. Tim McClanahan. Error bars are SEM.



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HYDRO-ECOLOGICAL RESEARCH OF THE RIVER MOUTH ZONES OF NORTH-WEST COAST OF THE BLACK SEA

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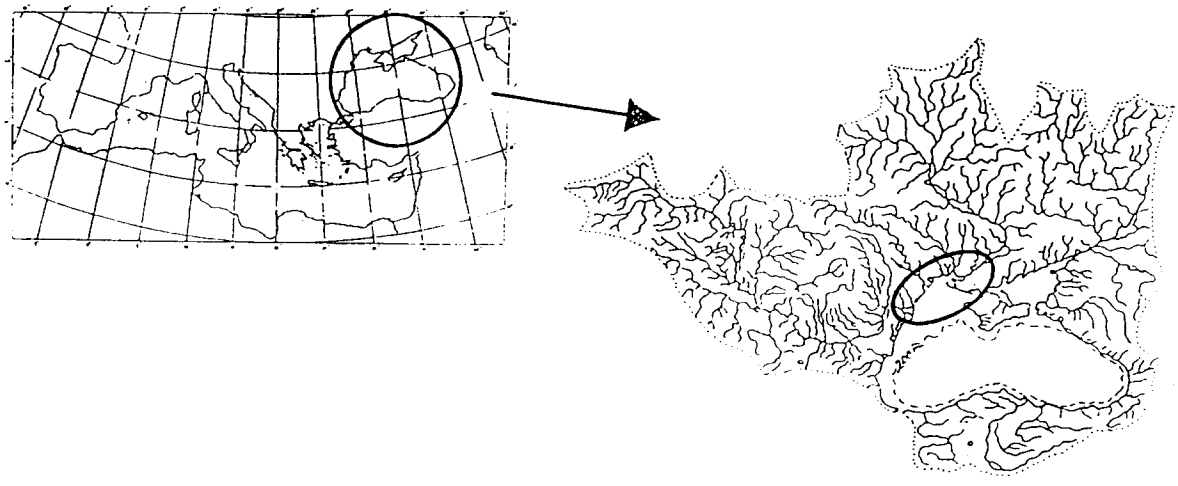
At the north-west coast of Black Sea are discharging the rivers Danube, Dniester and Dnieper (Fig. 1). The contribution of those rivers to the total fresh-water runoff to the Black Sea is nearly 70%. The anthropogenic changes of the water regime in the mouth zones, the decreasing runoff, the anthropogenic influence on its morphology and its thermic and glacial regime and some other hydrological characteristics have affected the ecological conditions of the rivers themselves and deltaic lakes, limans (= marshes), estuaries and the coastal zone. A number of main hydrological characteristics have been considered in this study from ecological point of view. The high turbidity of the water in the Danube delta is one of the most important characteristics of this system. On the other hand suspended matter concentrates toxicants (heavy metals, numerous organic substances), but on the one hand provides a medium for the river's self-purification (Fig. 2).

The adsorbing capacity of suspended matter is of functional importance for the coastal ecosystems, since these waters are used by different consumers. The creation of a cascade of river water storages in the Dnieper, caused a decreasing runoff and a seasonal transformation, which have a strong impact on the ecological situation in the delta and the estuary. A change of character and intensification of water-exchange processes have taken place.

To set up a detailed programme for water quality management in the Dnieper mouth zone is one of the most important environmental issues in the Ukraine (Fig. 2). The major problems for the Dniester mouth-zone ecosystem are increased water pollution and runoff transformation, caused by river-water storage. Because of this, the ability for self-purification of the deltaic and estuarine wetlands has decreased to a marked degree. The water management programme should, in particular, elaborate on artificial ecological flood regulation.

Fig. 1. Geographical situation



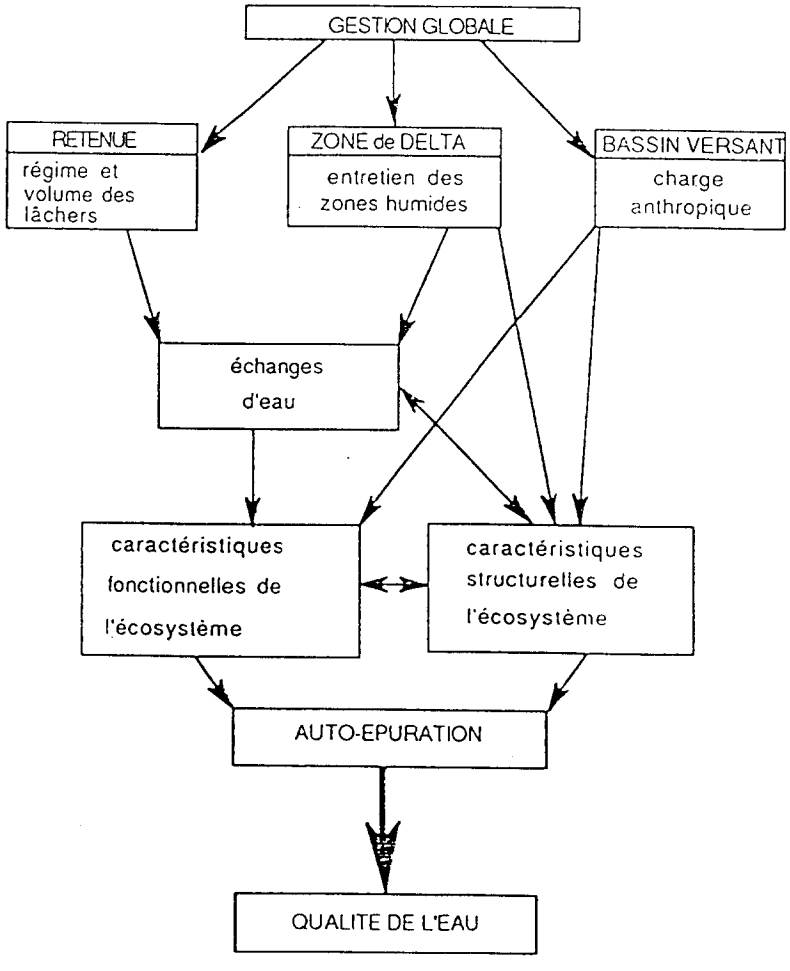


Fig. 2. Water quality management scheme of the Dniepr.

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POLLUTANT TRANSPORT IN THE COASTAL ZONE OF THE KERCH STRAIT AND THEIR INFLUENCE UPON HYDROBIONTS[1]

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The Kerch Strait connects the Sea of Azov and the Black Sea. The water exchange between those seas and the pollutant transfer from the Sea of Azov take place in this region. Regarding the economic activities on the coast, a detailed study of these exchange process is required, together with a programme on the improvement of the ecological situation in the Sea of Azov.

Until the end of 1950s, the Sea of Azov was one of the most productive basins of the World ocean. Regularly, several thousand tons of fish were being caught. The major catch concerned sturgeon. By the end of the 1960s, the chemical composition of sea water had drastically changed, which resulted in a sharp reduction of the fish productivity. In 1994 in the whole of Russia only one thousand tons of sturgeon were caught.

The major reason of this ecological catastrophe is:
- the intensive economic activity in the sea basin, i.e. the building of industrial enterprises which discharge crude waste waters to the sea,
- the construction of river-water storage basins and hydro-engineering complexes; and
- the development of rice culture and disposal of irrigation water, contaminated with pesticides and fertilizers.

In the Kerch Strait the water circulation takes place in the following way:
- The heavy saline Black Sea water penetrates the bottom water of the Sea of Azov,
- being compensated by a surplus of brackish surface water flowing from the Sea of Azov to the Black Sea.
- Winds intensify or weaken these processes, subject to their direction.

It seems that southern winds "pump" Black Sea water to the Sea of Azov and northern winds push Sea of Azov water to the Black Sea. In the first case, the strait is filled with rather clean Black Sea water, in the second one with rather polluted the Sea of Azov water. Thus, the wind is an essential factor with a great impact on the ecological conditions in the Kerch Strait and the adjacent areas.

By northern winds the major stream is directed from the Sea of Azov to the Black Sea, moving from the strait's entrance, near its northern narrows. Currents can have a velocity of 0.3-0.4 m/s. In gullies the velocity increases to 0.7-0.8 m/s. When the currents spread out in width, the velocity becomes 0.3-0.4 m/s. In the exit to the Black Sea these velocities diminish to 0.1-0.2 m/s.

For southern wind induced currents, the Black Sea water arrives in the strait. Its velocity increases from 0.1-0.2 m/s to 0.3-0.4 m/s. Near the island the current divides into two branches. Near the northern narrows, the velocity increases to 0.8 m/s. Having passed the narrows, the stream velocity declines sharply.

When the wind changes its direction or is absent, a weak unsteady current can be observed in the strait. Under these conditions Black Sea water flows into the Sea of Azov along the bottom and near the Caucasian coast, and the Sea of Azov water flows to the Black Sea near the Crimean shore.

[1] Water flora and fauna

The following sources of pollutants can be distinguished at the coasts of the Kerch Strait: the Kerch, Kavkaz and Krym ports and the Kerch town. Calculations have shown for pollutants discharged into the strait, that the probability of entering the Sea of Azov along the line of Kavkaz port to Krym port is 10^{-3} when southern winds blow, i.e. 0.1% of pollutants get to the Sea of Azov. The probability of pollutant penetration from the Kerch port is equal to 0.

The results of hydrochemical and geochemical investigations, carried out in the strait in spring 1994, shown in Table 1, demonstrate that:

- oil product concentrations in the strait are low, as compared to those of the Sea of Azov, where they are practically always higher than 0.05 mg/l.
- Copper is distributed rather evenly in the water of the strait. Its concentration varies but is almost everywhere above 1 μg/l. It originates from agricultural land in the Kuban river valley, where vineyards and fruit gardens are repeatedly sprayed with pesticides containing copper.
- The nickel, zinc, iron and mercury concentrations show large variations (Table 1).

In sediments, the same contaminants were measured, as additionally of 3,4 benzopyrene.

Approximate calculations have shown that, from the Sea of Azov through the Kerch Strait, annually about 2900 tons of oil products, 500 tons of iron, 400 tons of manganese, 100 tons of nickel, 30 tons of copper, 150 tons of zinc, 25 tons of lead and 0.2 tons of mercury are discharged to the Black Sea.

An estimate of the dissolved pollutant impact on flora and fauna was made according to the so-called threshold of adaptability or tolerance. The analysis in the strait has shown that manganese oppresses phytoplankton while copper and mercury oppress zooplankton. This can explain the observed reduction of fish productivity in the strait and in the Sea of Azov.

Table 1. Ranges of contaminant concentrations, spring 1994.

	Kerch Strait	
	Dissolved	Sediment
Oil products	0.01-0.05 mg/l	
Copper	0.7-2.7 μg/l	26-116 mg/kg
Nickel	0.5-22.5 μg/l	3-72 mg/kg
Zinc	0.5-18.2 μg/l	4-94 mg/kg
Iron	2-80 μg/l	2-44 mg/kg
Mercury	10^{-4}-2.74x10^{-2} μg/l	5x10^{-3}-0.32 mg/kg
3,4 Benzopyrene		1.3-2.5 mg/kg
	Sea of Azov	
	Dissolved	Sediment
Oil products	0.05 mg/l	
Copper	>1μg/l	

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PROPOSITIONS POUR L'AMÉNAGEMENT DE L'ENVIRONEMENT D'UN COMPLEXE LAGUNAIRE URBAIN, CÂMARA

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Le complexe lagunaire de Jacarepaguá est localisé dans un secteur d'expansion urbaine de la ville de Rio de Janeiro - Brésil, avec un miroir d'eau d'environ 14 km^2. Une population supérieur à 550 000 habitants se répand, actuellement, sur la plaine côtière de 140 km^2, dominée Baixada par Jacarepaguá.

L'occupation qu'a eu lieu dans les années 70 est en train de provoquer une série d'agressions à l'écosystème lagunaire dont le diagnostique ainsi que quelques propositions de récupération sont présentés dans ce travail. Parmi les causes principales de l'impact sur l'environnement dues à l'occupation accélérée nous pouvons citer les suivantes:

A-Dévastation de la couverture végétale du bassin de drainage;

B-Jetée des égouts domestiques et industriels sans traitement;

C-Jetée des résidus solides des ordures dans le raiseau de drainage;

D-Occupation de la partie bordière des lagunes, cours d'eau ainsi que des chenaux et

E-Absence de contrôle sur l'usage du sol avec l'expansion croissante des communautés des bidonvilles.

De cette façon, le système lagunaire a souffert de terribles déformation affectant son équilibre fonctionnel.

Parmi les transformations les plus frappantes nous pouvons énumérer les suivantes:

A-Procès accéléré d'accumulation de matière organique en plus de sédiment des lagunes, cours d'eau et chenaux;

B-Eutrophisation de ses eaux;

C-Perte croissante de la biodiversité de la faune et de la flore locale;

D-Diminution du miroir d'eau lagunaire;

E-Réduction de la capacité de pénétration par les marées et l'altération significative de la salinité à divers points du complexe lagunaire et

F-Contamination de la nappe phréatique.

Le milieu physique et le milieu anthropogène. Un tel diagnostique a eu pour objectif la caractérisation des principaux paramètres qu'interviennent dans ce procès d'occupation urbaine, ainsi que mieux comprendre les altérations introduites dans la dynamique fonctionnelle de l'environnement naturel.

Les aspects principaux qui ont été étudiés dans les deux domaines sont les suivants:

A-Milieu physique
- La géomorphologie
- La pédologie
- Le bassin hydrographique et le complexe lagunaire proprement dit
- La qualité de l'eau (Feema, 1991; Zee et al., 1991)
- Les procès dynamiques côtiers
- Les conditions météorologiques.

B-Milieu anthropogène
- L'usage du sol
- Sources de pollution.

La constatation de plusieurs déformations de l'équilibre lagunaire a amené à la formulation de plusieurs propositions d'actions de caractère éminent pour atténuer ou même proposer la réversion du procès de dégradation.

Parmi les plus urgentes, nous pouvons citer:

A-Système d'assainissement de base complet (raiseau des égouts, stations de traitement primaire et l'émissaire sousmarin).

B-Un plan de dragage afin d'augmenter la capacité de renouvellement des eaux ainsi que le volume d'eau dans les lagunes.
C-Un programme de reboisement sur les flancs des collines et la zone de bordure dans le but de protéger contre l'érosion.
D-Un projet pour augmenter la capacité de percolation de l'eau de mer vers l'intérieur des lagunes à travers l'étroite zone littorale (d'environ 200 m), qui les sépare, ayant pour but de promouvoir la circulation forcée de renouvellement des eaux intérieures stagnées.
E-Un programme pour surveiller et contrôler l'environnement des lagunes et leurs modifications face aux actions de l'homme.

Ce travail est le premier d'une série qu'a été développée par le Département d'Océanographie de l'Université de l'Etat de Rio de Janeiro, qu'envisage d'informer la communauté chargée de former l'opinion publique, d'orienter les services des secteurs gouvernementaux responsables et de développer une ligne de recherche techno-scientifique que puisse permettre aux étudiants universitaires d'avoir une vision pratique dans le cadre professionnel.

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17 Suppl.	Papers submitted to the Joint IOC/WMO Seminar on Oceanographic Products and the IGOSS Data Processing and Services System; Moscow, 2-6 April 1979.	E
18	IOC/UNESCO Workshop on Syllabus for Training Marine Technicians; Miami, 22-26 May 1978 (UNESCO reports in marine sciences, No. 4 published by the Division of Marine Sciences, UNESCO).	E (out of stock), F, S (out of stock), R
19	IOC Workshop on Marine Science Syllabus for Secondary Schools; Llantwit Major, Wales, U.K., 5-9 June 1978 (UNESCO reports in marine sciences, No. 5, published by the Division of Marine Sciences, UNESCO).	E (out of stock), E, S, R, Ar
20	Second CCOP-IOC Workshop on IDOE Studies of East Asia Tectonics and Resources; Bandung, Indonesia, 17-21 October 1978.	E
21	Second IDOE Symposium on Turbulence in the Ocean; Liège, Belgium, 7-18 May 1979.	E, F, S, R
22	Third IOC/WMO Workshop on Marine Pollution Monitoring; New Delhi, 11-15 February 1980.	E, F, S, R
23	WESTPAC Workshop on the Marine Geology and Geophysics of the North-West Pacific; Tokyo, 27-31 March 1980.	E, R
24	WESTPAC Workshop on Coastal Transport of Pollutants; Tokyo, 27-31 March 1980.	E (out of stock)
25	Workshop on the Intercalibration of Sampling Procedures of the IOC/ WMO UNEP Pilot Project on Monitoring Background Levels of Selected Pollutants in Open-Ocean Waters; Bermuda, 11-26 January 1980.	E (superseded by IOC Technical Series No. 22)
26	IOC Workshop on Coastal Area Management in the Caribbean Region; Mexico City, 24 September-5 October 1979.	E, S
27	CCOP/SOPAC-IOC Second International Workshop on Geology, Mineral Resources and Geophysics of the South Pacific; Nouméa, New Caledonia, 9-15 October 1980.	E
28	FAO/IOC Workshop on the effects of environmental variation on the survival of larval pelagic fishes. Lima, 20 April-5 May 1980.	E
29	WESTPAC Workshop on Marine Biological Methodology; Tokyo, 9-14 February 1981.	E
30	International Workshop on Marine Pollution in the South-West Atlantic; Montevideo, 10-14 November 1980.	E (out of stock) S
31	Third International Workshop on Marine Geoscience; Heidelberg, 19-24 July 1982.	E, F, S
32	UNU/IOC/UNESCO Workshop on International Co-operation in the Development of Marine Science and the Transfer of Technology in the context of the New Ocean Regime; Paris, 27 September-1 October 1982.	E, F, S
32 Suppl.	Papers submitted to the UNU/IOC/UNESCO Workshop on International Co-operation in the Development of Marine Science and the Transfer of Technology in the Context of the New Ocean Regime; Paris, 27 September-1 October 1982.	E
33	Workshop on the IREP Component of the IOC Programme on Ocean Science in Relation to Living Resources (OSLR); Halifax, 26-30 September 1963.	E
34	IOC Workshop on Regional Co-operation in Marine Science in the Central Eastern Atlantic (Western Africa); Tenerife, 12-17 December 1963.	E, F, S
35	CCOP/SOPAC-IOC-UNU Workshop on Basic Geo-scientific Marine Research Required for Assessment of Minerals and Hydrocarbons in the South Pacific; Suva, Fiji, 3-7 October 1983.	E
36	IOC/FAO Workshop on the Improved Uses of Research Vessels; Lisbon, 28 May-2 June 1984.	E
36 Suppl.	Papers submitted to the IOC/FAO Workshop on the Improved Uses of Research Vessels; Lisbon, 28 May-2 June 1984.	E
37	IOC/UNESCO Workshop on Regional Co-operation in Marine Science in the Central Indian Ocean and Adjacent Seas and Gulfs; Colombo, 8-13 July 1985.	E
38	IOC/ROPME/UNEP Symposium on Fate and Fluxes of Oil Pollutants in the Kuwait Action Plan Region; Basrah, Iraq, 8-12 January 1984.	E
39	CCOP (SOPAC)-IOC-IFREMER ORSTOM Workshop on the Uses of Submersibles and Remotely Operated Vehicles in the South Pacific; Suva, Fiji, 24-29 September 1985.	E
40	IOC Workshop on the Technical Aspects of Tsunami Analysis, Prediction and Communications; Sidney, B.C., Canada, 29-31 July 1985.	E
40 Suppl.	First International Tsunami Workshop on Tsunami Analysis, Prediction and Communications, *Submitted Papers*, Sidney, B.C., Canada, 29 July - 1 August 1985.	E
41	First Workshop of Participants in the Joint FAO/IOC/WHO/IAEA/UNEP Project on Monitoring of Pollution in the Marine Environment of the West and Central African Region (WACAF/2); Dakar, Senegal, 28 October-1 November 1985.	E
43	IOC Workshop on the Results of MEDALPEX and Future Oceanographic Programmes in the Western Mediterranean; Venice, Italy, 23-25 October 1985.	E
44	IOC-FAO Workshop on Recruitment in Tropical Coastal Demersal Communities; Ciudad del Carmen, Campeche, Mexico, 21-25 April 1986.	E (out of stock) S
44 Suppl.	IOC-FAO Workshop on Recruitment in Tropical Coastal Demersal Communities, *Submitted Papers*; Ciudad del Carmen, Campeche, Mexico, 21-25 April 1986.	E
45	IOCARIBE Workshop on Physical Oceanography and Climate; Cartagena, Colombia, 19-22 August 1986	E
46	Reunion de Trabajo para Desarrollo del Programa "Ciencia Oceánica en Relación a los Recursos No Vivos en la Región del Atlántico Sud-occidental"; Porto Alegre, Brazil, 7-11 de abril de 1986.	S
47	IOC Symposium on Marine Science in the Western Pacific: The Indo-Pacific Convergence; Townsville, 1-6 December 1966.	E
48	IOCARIBE Mini-Symposium for the Regional Development of the IOC-UN (OETB) Programme on 'Ocean Science in Relation to Non-Living Resources (OSNLR)'; Havana, Cuba, 4-7 December 1986.	E, S
49	AGU-IOC-WMO-CPPS Chapman Conference: An International Symposium on 'El Niño'; Guayaquil, Ecuador, 27-31 October 1986.	E
50	CCALR-IOC Scientific Seminar on Antarctic Ocean Variability and its Influence on Marine Living Resources, particularly Krill (organized in collaboration with SCAR and SCOR), Paris, France, 2-6 June 1987.	E
51	CCOP/SOPAC IOC Workshop on Coastal Processes in the South Pacific Island Nations; Lae, Papua New Guinea, 1-8 October 1987.	E

No.	Title	Languages
52	SCOR-IOC-UNESCO Symposium on Vertical Motion in the Equatorial Upper Ocean and its Effects upon Living Resources and the Atmosphere; Paris, 6-10 May 1985.	E
53	IOC Workshop on the Biological Effects of Pollutants; Oslo, 11-29 August 1986.	E
54	Workshop on Sea-Level Measurements in Hostile Conditions; Bidston, UK, 28-31 March 1988	E
55	IBCCA Workshop on Data Sources and Compilation, Boulder, Colorado, 18-19 July 1988.	E
56	IOC-FAO Workshop on Recruitment of Penaeid Prawns in the Indo-West Pacific Region (PREP); Cleveland, Australia, 24-30 July 1988.	E
57	IOC Workshop on International Co-operation in the Study of Red Tides and Ocean Blooms; Takamatsu, Japan, 16-17 November 1987.	E
58	International Workshop on the Technical Aspects of the Tsunami Warning System; Novosibirsk, USSR, 4-5 August 1989.	E
58 Suppl.	Second International Workshop on the Technical Aspects of Tsunami Warning Systems, Tsunami Analysis, Preparedness, Observation and Instrumentation. *Submitted Papers*; Novosibirsk, USSR, 4-5 August 1989.	E
59	IOC-UNEP Regional Workshop to Review Priorities for Marine Pollution Monitoring Research, Control and Abatement in the Wider Caribbean; San José, Costa Rica, 24-30 August 1989.	E, F, S
60	IOC Workshop to Define IOCARIBE-TRODERP proposals; Caracas, Venezuela, 12-16 September 1989.	E
61	Second IOC Workshop on the Biological Effects of Pollutants; Bermuda, 10 September-2 October 1988.	E
62	Second Workshop of Participants in the Joint FAO-IOC-WHO-IAEA-UNEP Project on Monitoring of Pollution in the Marine Environment of the West and Central African Region; Accra, Ghana, 13-17 June 1988.	E
63	IOC/WESTPAC Workshop on Co-operative Study of the Continental Shelf Circulation in the Western Pacific; Bangkok, Thailand, 31 October-3 November 1989.	E
64	Second IOC-FAO Workshop on Recruitment of Penaeid Prawns in the Indo-West Pacific Region (PREP); Phuket, Thailand, 25-31 September 1989.	E
65	Second IOC Workshop on Sardine/Anchovy Recruitment Project (SARP) int he Southwest Atlantic; Montevideo, Uruguay, 21-23 August 1989.	E
66	IOC *ad hoc* Expert Consultation on Sardine/Anchovy Recruitment Programme; La Jolla, California, USA, 1989.	E
67	Interdisciplinary Seminar on Research Problems in the IOCARIBE Region; Caracas, Venezuela, 28 November-1 December 1989.	E (out of stock)
68	International Workshop on Marine Acoustics; Beijing, China, 26-30 March 1990.	E
69	IOC-SCAR Workshop on Sea-Level Measurements in the Antarctica; Leningrad, USSR, 28-31 May 1990.	E
69 Suppl.	IOC-SCAR Workshop on Sea-Level Measurements in the Antarctica; *Submitted Papers*; Leningrad, USSR, 28-31 May 1990.	E
70	IOC-SAREC-UNEP-FAO-IAEA-WHO Workshop on Regional Aspects of Marine Pollution; Mauritius, 29 October - 9 November 1990.	E
71	IOC-FAO Workshop on the Identification of Penaeid Prawn Larvae and Postlarvae; Cleveland, Australia, 23-28 September 1990.	E
72	IOC/WESTPAC Scientific Steering Group Meeting on Co-Operative Study of the Continental Shelf Circulation in the Western Pacific; Kuala Lumpur, Malaysia, 9-11 October 1990.	E
73	Expert Consultation for the IOC Programme on Coastal Ocean Advanced Science and Technology Study; Liège, Belgium, 11-13 May 1991.	E
74	IOC-UNEP Review Meeting on Oceanographic Processes of Transport and Distribution of Pollutants in the Sea; Zagreb, Yugoslavia, 15-18 May 1989.	E
75	IOC-SCOR Workshop on Global Ocean Ecosystem Dynamics; Solomons, Maryland, USA, 29 April-2 May 1991.	E
76	IOC/WESTPAC Scientific Symposium on Marine Science and Management of Marine Areas of the Western Pacific; Penang, Malaysia, 2-6 December 1991.	E
77	IOC-SAREC-KMFRI Regional Workshop on Causes and Consequences of Sea-Level Changes on the Western Indian Ocean Coasts and Islands; Mombasa, Kenya, 24-28 June 1991.	E
78	IOC-CEC-ICES-WMO-ICSU Ocean Climate Data Workshop Goddard Space Flight Center, Greenbelt, Maryland, USA, 18-21 February 1992.	E
79	IOC/WESTPAC Workshop on River Inputs of Nutrients to the Marine Environment in the WESTPAC Region; Penang, Malaysia, 26-29 November 1991.	E
80	IOC-SCOR Workshop on Programme Development for Harmful Algae Blooms; Newport, USA, 2-3 November 1991.	E
81	Joint IAPSO-IOC Workshop on Sea Level Measurements and Quality Control; Paris, 12-13 October 1992.	E
82	BORDOMER 92: International Convention on Rational Use of Coastal Zones. A Preparatory Meeting for the Organization of an International Conference on Coastal Change; Bordeaux, France, 30 September-2 October 1992.	E
83	IOC Workshop on Donor Collaboration in the Development of Marine Scientific Research Capabilities in the Western Indian Ocean Region; Brussels, Belgium, 12-13 October 1992.	E
84	Workshop on Atlantic Ocean Climate Variability; Moscow, Russian Federation, 13-17 July 1992.	E
85	IOC Workshop on Coastal Oceanography in Relation to Integrated Coastal Zone Management; Kona, Hawaii, 1-5 June 1992.	E
86	International Workshop on the Black Sea; Varna, Bulgaria 30 September - 4 October 1991.	E
87	Taller de trabajo sobre efectos biologicos del fenómeno «El Niño» en ecosistemas costeros del Pacifico Sudeste; Santa Cruz, Galápagos, Ecuador, 5-14 de octubre de 1989.	S only (Summary in E, F, S)
88	IOC-CEC-ICSU-ICES Regional Workshop for Member States of Eastern and Northern Europe (GODAR Project); Obninsk, Russia, 17-20 May 1993.	E
89	IOC-ICSEM Workshop on Ocean Sciences in Non-Living Resources; Perpignan, France, 15-20 October 1990.	E
90	IOC Seminar on Integrated Coastal Management; New Orleans, USA. 17-18 July 1993.	E
91	Hydroblack'91 CTD Intercalibration Workshop; Woods Hole, USA. 1-10 December 1991.	E
92	Réunion de travail IOCEA-OSNLR sur le Projet « Budgets sédimentaires le long de la côte occidentale d'Afrique » Abidjan, Côte d'Ivoire, 26-28 juin 1991.	F
93	IOC-UNEP Workshop on Impacts of Sea-Level Rise due to Global Warming. Dhaka, Bangladesh, 16-19 November 1992.	E
94	BMTC-IOC-POLARMAR International Workshop on Training Requirements in the Field of Eutrophication in Semi-Enclosed Seas and Harmful Algal Blooms, Bremerhaven, Germany, 29 September - 3 October 1992.	E
95	SAREC-IOC Workshop on Donor Collaboration in the Development of Marine Scientific Research Capabilities in the Western Indian Ocean Region; Brussels, Belgium, 23-25 November 1993.	E
96	IOC-UNEP-WMO-SAREC Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; Zanzibar, United Republic of Tanzania, 17-21 January 1994.	E
96 Suppl. 1	IOC-UNEP-WMO-SAREC Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; *Submitted Papers* 1. Coastal Erosion; Zanzibar, United Republic of Tanzania 17-21 January 1994.	E
96 Suppl. 2	IOC-UNEP-WMO-SAREC Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts; *Submitted Papers* 2. Sea Level; Zanzibar, United Republic of Tanzania 17-21 January 1994.	E
97	IOC Workshop on Small Island Oceanography in Relation to Sustainable Economic Development and Coastal Area Management of Small Island Development States; Fort-de-France, Martinique, 8-10 November, 1993.	E
98	CoMSBlack '92A Physical and Chemical Intercalibration Workshop; Erdemli, Turkey, 15-29 January 1993.	E
99	IOC-SAREC Field Study Exercise on Nutrients in Tropical Marine Waters; Mombasa, Kenya, 5-15 April 1994.	E
100	IOC-SOA-NOAA Regional Workshop for Member States of the Western Pacific - GODAR-II (Global Oceanographic Data Archeology and Rescue Project); Tianjin, China, 8-11 March 1994.	E
101	IOC Regional Science Planning Workshop on Harmful Algal Blooms; Montevideo, Uruguay, 15-17 June 1994.	E
102	First IOC Workshop on Coastal Ocean Advanced Science and Technology Study (COASTS); Liège, Belgium, 5-9 May 1994.	E
103	IOC Workshop on GIS Applications in the Coastal Zone Management of Small Island Developing States; Barbados, 20-22 April 1994.	E
104	Workshop on Integrated Coastal Management; Dartmouth, Canada, 19-20 September 1994.	E
105	BORDOMER 95: Conference on Coastal Change; Bordeaux, France, 6-10 February 1995.	E
105 Suppl.	Conference on Coastal Change: Proceedings; Bordeaux, France, 6-10 February 1995	E
106	IOC/WESTPAC Workshop on the Paleographic Map; Bali, Indonesia, 20-21 October 1994.	E
107	IOC-ICSU-NIO-NOAA Regional Workshop for Member States of the Indian Ocean - GODAR-III; Dona Paula, Goa, India, 6-9 December 1994.	E
108	UNESCO-IHP-IOC-IAEA Workshop on Sea-Level Rise and the Multidisciplinary Studies of Environmental Processes in the Caspian Sea Region; Paris, 9-12 May 1995.	E
108 Suppl.	UNESCO-IHP-IOC-IAEA Workshop on Sea-Level Rise and the Multidisciplinary Studies of Environmental Processes in the Caspian Sea Region; *Submitted Papers*; Paris, 9-12 May 1995.	E
109	First IOC-UNEP CEPPOL Symposium; San José, Costa Rica, 14-15 April 1993.	E
110	IOC-ICSU-CEC Regional Workshop for Member States of the Mediterranean - GODAR-IV (Global Oceanographic Data Archeology and Rescue Project) Foundation for International Studies, University of Malta, Valletta, Malta, 25-28 April 1995.	E

No.	Title	Languages
111	Chapman Conference on the Circulation of the Intra-Americas Sea; La Parguera, Puerto Rico, 22-26 January 1995.	E
112	IOC-IAEA-UNEP Group of Experts on Standards and Reference Materials (GESREM) Workshop; Miami, USA, 7-8 December 1993.	E
113	IOC Regional Workshop on Marine Debris and Waste Management in the Gulf of Guinea; Lagos, Nigeria, 14-16 December 1994.	E
114	International Workshop on Integrated Coastal Zone Management (ICZM) Karachi, Pakistan; 10-14 October 1994.	E
115	IOC/GLOSS-IAPSO Workshop on Sea Level Variability and Southern Ocean Dynamics; Bordeaux, France, 31 January 1995.	E
116	IOC/WESTPAC International Scientific Symposium on Sustainability of Marine Environment: Review of the WESTPAC Programme, with Particular Reference to ICAM Bali, Indonesia, 22-26 November 1996	E
117	Joint IOC-CIDA-Sida (SAREC) Workshop on the Benefits of Improved Relationships between International Development Agencies, the IOC and other Multilateral Intergovernmental Organizations in the Delivery of Ocean, Marine Affairs and Fisheries Programmes; Sidney B.C., Canada, 26-28 September 1995.	E
118	IOC-UNEP-NOAA-Sea Grant Fourth Caribbean Marine Debris Workshop; La Romana, Santo Domingo, 21-24 August 1995.	E
119	IOC Workshop on Ocean Colour Data Requirements and Utilization; Sydney B.C., Canada, 21-22 September 1995.	E
120	International Training Workshop on Integrated Coastal Management; Tampa, Florida, U.S.A., 15-17 July 1995.	E
121	Atelier régional sur la gestion intégrée des zones littorales (ICAM); Conakry, Guinée, 12-22 décembre 1995.	F
122	GLOBEC-IOC-SAHFOS-MBA Workshop on the Analysis of Time Series with Particular Reference to the Continuous Plankton Recorder Survey; Plymouth, U.K., 4-7 May 1993.	E
123	Second IOC Regional Science Planning Workshop on Harmful Algal Blooms in South America; Mar del Plata, Argentina, 30 October - 1 November 1995.	E/S