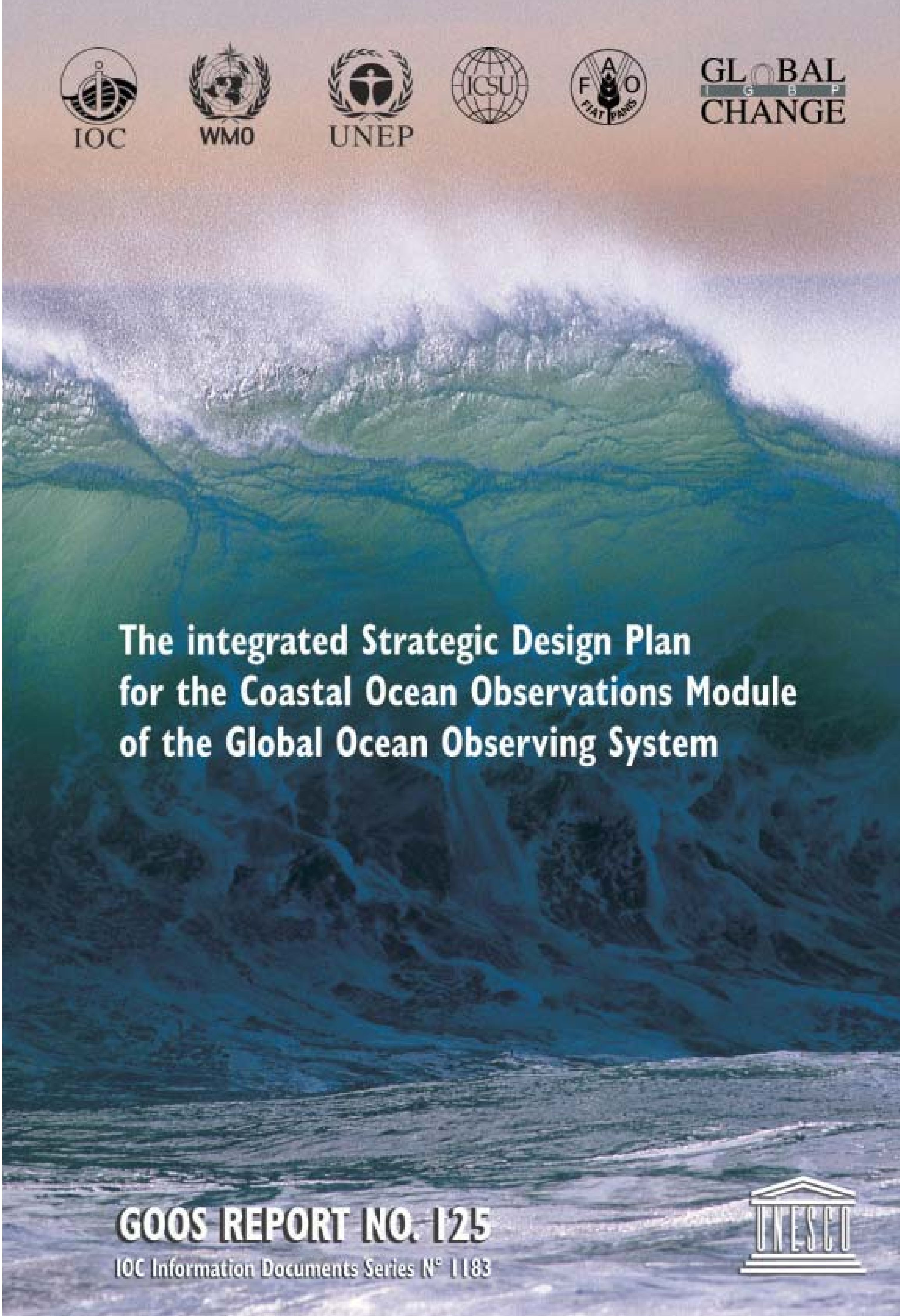

IOC WMO UNEP ICSU FAO GLOBAL CHANGE IGBP

The integrated Strategic Design Plan for the Coastal Ocean Observations Module of the Global Ocean Observing System

GOOS REPORT NO. 125

IOC Information Documents Series N° 1183

UNESCO

The Integrated, Strategic Design Plan for the Coastal Ocean Observations Module of the Global Ocean Observing System

UNESCO 2003

Layout and design by Eric Loddé and Jonathan Wyss.

Acknowledgments
This report is the result of the hard work of many people. The Coastal Ocean Observations Panel would like to thank the invited experts, the IOC secretariat and the following persons for comments and suggestions for improvements to an earlier draft of this plan: Eric Anderson, Dan Baird, Willem Behrens, Anthony Bowen, Erik Buch, Allyn Clarke, Hans Dahlin, Paul DiGiacomo, Peter Douglas, Henrik Enevoldsen, Lev Fishelson, Jon Grant, Mark Johnson, W. Michael Kemp, Frank Muller-Karger, Juha-Markku Leppänen, Jerry Miller, John Moisan, Amani Ngusaru, Worth Nowlin, Rodrigo Núñez, Temel Oguz, Jozef Pacyna, Pierre Pepin, Will Perrie, Ian Perry, David Prandle, Wilson Schaeffer, Anne-Maree Schwarz, Fred Short, Michael Sissenwine, Peter Smith, Charles Tang, Qisheng Tang, Stephanie Turner, P. Nalin Wikramanayake, and Clive Wilkinson. Special thanks are due to Nic Flemming who provided a final edit of the plan.

Meetings of the panel were funded by IOC, UNEP, WMO, FAO, ICSU with additional funds provided by the French IOC committee, the Netherlands Organisation for Scientific Research (NOW), the Natural Environment Research Council (UK), the National Oceanic and Atmospheric Administration (USA), UNESCO's Regional Bureau for Science in Europe (Venice), and the US Office of Naval Research International Field Office (London).

For bibliographic purposes, this document should be cited as follows:

> The Integrated, Strategic Design Plan for the Coastal Ocean Observations Module of the Global Ocean Observing System
> GOOS Report No. 125; IOC Information Documents Series N°1183; UNESCO 2003
> (Executive Summary included in English, French, Russian and Spanish)

The document is also available at http://ioc.unesco.org/goos/docs/doclist.htm

Printed in 2003 by UNESCO
By the United Nations Educational, Scientific and Cultural Organization
7, Place de Fontenoy, 75 352 Paris 07 SP, France

(SC-2003/WS/13)

Table of Contents

Executive Summary

THE GLOBAL OCEAN OBSERVING SYSTEM

International agreements and conventions call for safety at sea, effective management of the marine environment, and sustainable utilization of its resources. Achieving the important and challenging goals of these agreements depends on the ability to rapidly detect and provide timely predictions of changes[1] in a broad spectrum of marine phenomena that affect (1) the safety and efficiency of marine operations; (2) the susceptibility of human populations to natural hazards; (3) the response of coastal ecosystems to global climate change; (4) public health and well being; (5) the state of marine ecosystems; and (6) the sustainability of living marine resources. We do not have these capabilities today. The purpose of establishing a Global Ocean Observing System (GOOS) is to develop these capabilities.

The sponsors of GOOS are the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the United Nations Environment Programme (UNEP), the World Meteorological Organization (WMO), and the International Council for Science (ICSU). GOOS is envisioned as an operational, global network that systematically acquires and disseminates data and data products on past, present and future states of the marine environment. The observing system is being developed in two related and convergent modules: (1) a global ocean module concerned primarily with detecting and predicting changes in the ocean-climate system and improving marine services (led by the Ocean Observations Panel for Climate (OOPC), which is jointly sponsored by World Climate Research Programme (WCRP), the Global Climate Observing System (GCOS); and GOOS) and (2) a coastal module concerned with the effects of large scale changes in the ocean-climate system and of human activities on coastal ecosystems, as well as improving marine services (led by the Coastal Ocean Observations Panel (COOP), which is sponsored jointly by the Food and Agriculture Organization of the United Nations (FAO), the International Geosphere-Biosphere Programme (IGBP) and GOOS).

This report presents recommendations of the Coastal Ocean Observations Panel (COOP) for the design of the coastal module of GOOS. It is divided into three sections:

(1) Rationale and goals (Prologue, Chapters 1 and 2),
(2) Design (Chapters 3, 4, 5 and 6), and
(3) Initial guidelines for formulating an Implementation Plan (Chapter 7).

The design plan describes the vision for an integrated and sustained observing system for the coastal ocean, defines the elements of the system, and describes how they relate to each other to achieve an operational system. The plan provides a framework for how the community of nations can make more cost-effective use of collective resources to address, in a more timely fashion, environmental issues and problems of mutual concern. This is the first step toward the formulation of an implementation plan which is expected to be completed by the end of 2004.

[1] Change - "to cause or turn or pass from one state to another; to alter or make different, to vary in external form or essence" (Webster's New Twentieth Century Dictionary, Unabridged Dictionary). Thus, if one is to detect and predict change, one must be able to detect and predict "states." In addition, the word "change" does not imply a particular time or space dimension. Changes occur over a broad spectrum of scales (e.g., seconds to centuries) and variability on one scale is change on another.

Rationale and Goals

Ecosystem goods and services are more concentrated in the coastal zone than in any other region of the globe. Rapid increases in human uses of coastal resources and global changes in the ocean-climate system are making the coastal zone more susceptible to natural hazards, more costly to live in, and of less value to national economies. Conflicts between commerce, recreation, development, environmental protection, and the management of living resources are becoming increasingly contentious and politically charged. The social and economic costs of uninformed decisions are increasing accordingly. An integrated system of observations and analysis is needed to provide the data and information required to achieve six goals:

(1) Improve the safety and efficiency of marine operations, whether conducted by governments, agencies, or commercial companies;
(2) More effectively control and mitigate the effects of natural hazards;
(3) Improve the capacity to detect and predict the effects of global climate change on coastal ecosystems;
(4) Reduce public health risks;
(5) More effectively protect and restore healthy ecosystems; and
(6) Restore and sustain living marine resources.

Achieving these goals depends on developing the capability to rapidly detect and predict a broad spectrum of coastal phenomena from changes in sea state, coastal flooding and sea level rise to increases in the risk of disease, habitat modification, harmful algal blooms and declines in fisheries. Although each goal has unique requirements for data and information, they have many data needs in common. Likewise, the requirements for data communications management are similar across all six goals. Thus, an integrated approach to the development of a multi-use observing system is both sensible and cost-effective.

Conceptual Design

Rapid detection and timely prediction depend on the establishment of an operational observing system that routinely and continuously provides required data and information in the form, and on time scales, specified by the users. Such a system must efficiently link three essential subsystems to ensure the timely and routine delivery of data and information to users: (1) a monitoring (sensing) subsystem, (2) a subsystem for data acquisition, management and dissemination, and (3) a subsystem for data assimilation and analysis based on scientific understanding.

In so doing, the coastal module must be designed to address many issues, including the diversity of the coastal phenomena encompassed by the six goals and ecosystem theory which posits that the phenomena of interest are related through a hierarchy of interactions. In this context, the design must also take into account the following global considerations:

- Design, implementation, and development of the observing system must be guided by the data and information needs of user groups;
- The phenomena of interest are typically local expressions of changes (e.g., ENSO events, land-based sources of pollution, extraction of living resources) that propagate from large to small scales across national jurisdictions and across the boundaries between air, sea and land;
- Although each of the six goals has some unique data requirements, they have many data requirements in common;
- Global standards and protocols for observations, data exchange, and data management are required to ensure rapid and timely access to data and information;
- Many of the elements required to build the Observing System are in place and have been for a long time;
- Mechanisms for permanent and ongoing evaluations of the System in terms of cost-effectiveness, efficiency, quality control, and the timely provision of data and information must be established; and
- Those elements of the observing system required to improve marine services, improve the efficiency of marine operations, and forecast natural hazards are more developed than those required for ecosystem-based environmental protection and management of living resources.

Regional considerations include the following:

- Priorities and the capacity to contribute to and benefit from the observing system vary among nations and regions;
- Most international agreements and conventions that target environmental protection and the management of living marine resources are regional in scope;
- Nations and Regional bodies provide the most effective venues for identifying user groups, product development, and marketing.

Thus, design and implementation must respect the fact that priorities vary among regions and should leave system design on the regional scale to stakeholders in the regions. At the same time, the six goals of the coastal module of GOOS have many common requirements. Consequently, a global network of observations can provide economies of scale that will allow regional observing system to be more cost-effective. This report proposes a collaboration between the management of the common global network of observations and the Regional GOOS Alliances. Such a structure will have beneficial effects on the whole design and management of GOOS.

A Global Forum for Regional Observing Systems

Clearly, the coastal module must include both regional and global scale components. This can best be established by providing a mechanism for national GOOS programmes and GOOS Regional Alliances to play significant roles in (1) coordinating the development of a global network of observations, data management, and analysis; (2) establishing common standards and protocols for measurements, data exchange, data management and analysis; (3) facilitating the transfer of technology and knowledge; and (4) setting priorities for capacity building. In this design, the global network

- Measures and manages a set of common variables that are required by most, if not all, regional systems (the common variables, Chapter 4);
- Establishes a network of reference and sentinel stations; and
- Links coastal observations to global observations and interfaces global and coastal models (Chapter 5).

Regional observing systems are critical building blocks of the coastal module. The global network will not, by itself, provide all (or even most) of the data and information required to detect the state and predict changes in the phenomena of interest. There are categories of variables that are important globally, but the variables measured and the time-space scales of measurement change from region to region depending on the nature of the coastal zone and on user needs. These include variables in the categories of stock assessments, essential fish habitats, marine mammals and birds, invasive species, harmful algae, and chemical contaminants. For these categories, and for variables such as sea ice that are restricted to certain regions of the globe, decisions concerning exactly what to measure, the time-space scales of measurement, and the mix of observing techniques are best made by stakeholders in the regions affected. Similarly, aspects of forecasting for coastal industries will depend upon the existence of offshore oil and gas exploitation, major ports, ferry routes, tourist resorts, and recreational centres. Guided by regional priorities, regional observing systems provide data and information that are tailored to the requirements of stakeholders, especially those required to manage fisheries and land-based sources of pollution. This is likely to involve increases in the resolution at which common variables are measured (e.g., to 1 km or less) as well as the measurements of additional variables at finer scales. In this way, regional observing systems both contribute to and benefit from the global network.

The global coastal network that contributes to the cost-effectiveness of regional observing systems and links regional observing systems with each other and the global ocean-climate observing systems is the focus of the COOP design plan.

The Primacy of Data Management and Product Development

Reducing the time required to acquire, process and analyse data of known quality is a major goal that requires the development of an integrated data management and communications subsystem. The objectives are to serve data in both real-time and delayed mode and to enable users to exploit multiple data sets from many different sources. This will require a hierarchical distributed network of national, regional and global organizations that function with common standards, reference materials and protocols for quality control; enable rapid access to and the exchange of data (e.g., metadata standards); and long-term data archival. Such a network will develop in an incremental way by linking and integrating existing national and international data centres and management programmes. The IOC committee for the International Ocean Data and Information Exchange (IODE) and the data management programme area of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) have the potential to oversee the coordinated development of the integrated data management subsystem (Chapter 6).

User groups and the data streams and products they require must guide the development of the observing system. At the same time, rapid access to multi-disciplinary data from many sources will catalyse modelling and product development. Thus, high priority must be placed on the establishment of mechanisms to involve user groups on a continuing basis in the definition of products and in the establishment, operation and development of the coastal module.

National GOOS Programmes and GOOS Regional Alliances (GRAs) provide the primary venue for identifying user groups, specifying data and information requirements, and refining data-products over time based on user feedback and new knowledge. Production, advertising and marketing data products are essential to the development of broad user demand and, therefore, to the development of the observing system. The primary marketing and outreach tools presently available are the GOOS Products and Services Bulletin and the JCOMM Bulletin. These report products and product development activities and provide a means for users to comment on the quality and usefulness of GOOS products.

The Observing Subsystem

The proposed global network is intended to measure and manage a relatively small set of "common" variables that are required by most, if not all, of the regional observing systems (Chapter 4, Annexes IV and V). Although it is likely that the common variables will emerge as the GRAs build the global coastal network over time, it is useful to select a provisional set of variables to help guide the design and implementation of the initial global coastal network. The recommended common variables are sea level, water temperature and salinity, vector currents, surface waves, dissolved oxygen and inorganic nutrients, attenuation of solar radiation, bathymetry, changes in shoreline position, sediment size and organic content, benthic biomass, phytoplankton biomass, and faecal indicators. These variables were selected based on data requirements of the six goals and the number of user groups that would benefit from the data and information. This "best-guess" list is important in that it provides insight into what the common variables are likely to be and highlights the importance of improving capacity to sense changes in biological and chemical variables and the development of operational models for biogeochemical and ecological processes. The physical forces on structures and floating systems are an important part of the forecasting services to marine operators, and these products are already quite advanced and dealt with in other publications. The modelling aspects of physical parameters are discussed in Chapter 5. Given the importance of environmental factors in terms of both detection and prediction of the phenomena of interest, it is not surprising that these dominate the provisional list for the coastal module.

A mix of techniques will be needed to provide the required data streams. These fall into three general categories: remote sensing (spatially synoptic observations), *in situ* autonomous sensing (high resolution time series), and discrete sampling followed by laboratory analysis (for many chemical and biological variables). Elements of the monitoring subsystem should include (1) networks of coastal laboratories, (2) the global network of tide gauges, (3) fixed platforms, moorings and autonomous vehicles, (4) research and survey vessels dedicated to sustained observations, (5) volunteer observing ships, and (6) remote sensing from land-based platforms, satellites and aircraft.

Linking Observations and Models

Monitoring and modelling are mutually dependent processes, and the development of the fully integrated system will require an ongoing synergy between monitoring, advances in technology, and the formulation of predictive models (Chapter 5). Models will play critical roles in the implementation, operation and development of the observing system. They are important tools used to estimate quantities that are not observed directly with known certainty, i.e., predict past (hindcasts), present (nowcasts), and future (forecasts) states of coastal marine and estuarine systems and the errors associated with such predictions. Note that the concept of a nowcast requires extremely rapid delivery and processing of data in real time, or near real time.

An overview of the current status of data assimilation and modelling for marine services and natural hazards, living marine resources, public health, and ecosystem health (Chapter 5) shows the advanced state of modelling for marine services and natural hazards relative to those available for detecting and predicting changes in phenomena that require measurements of biological and chemical variables. This underscores the importance of research for the development of the coastal module.

Building the System

The development of both the global ocean and coastal components of GOOS are critically dependent on selectively and effectively linking, enhancing and supplementing existing programmes (Chapter 7). The global coastal network will come into being through a combination of national, regional and global processes. Although some elements of the system will be global in scale from the beginning (e.g., GLOSS, observations from space), national and regional coastal observing systems will be the building blocks of the global coastal network. GOOS Regional Alliances (GRAs) are being established to plan and implement regional observing systems that will become the building blocks of the coastal module (Chapter 3, section 3.1). GRAs are encouraged to build the coastal module by establishing partnerships with National GOOS Programmes, Regional Seas Conventions, Regional Fishery Bodies, Large Marine Ecosystem Programmes, and other bodies as appropriate.

Implementation, operation and evolution of a sustained observing system, such as the World Weather Watch, will require government mechanisms to ensure that candidate systems or elements of systems pass through four stages of development:

(1) The development of new knowledge, technologies and models through research;
(2) Repeated testing in pilot projects to ensure reliability and acceptance by the research and operational communities;
(3) Pre-operational use to ensure that incorporation into the observing system leads to value-added products; and
(4) Incorporation into an operational observing system that is sustained.

This must be a selective process, and criteria for migrating the building blocks of GOOS from research to operational stages based on user needs must be established. The first step in implementing the coastal module of GOOS should be improved sharing of existing data and products from observing system elements to initiate their integration into an observing system. Historical data and ongoing data streams exist in large numbers, but many are not now readily accessible to the many potential users.

Research and the Development of an Operational Observing System

The scientific and technical foundation for the design of the coastal module are provided by research programmes including those of the IGBP (Land-Ocean Interactions in the Coastal Zone, LOICZ; the GLOBal ECosystem experiment, GLOBEC; and the Joint Global Ocean Flux Study, JGOFS), the Census of Marine Life (CoML), Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB), the International Long-Term Ecosystem Research (I-LTER) programme, and the Sensor Intercomparisons and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS). The knowledge and technologies generated by these and other research programmes will be required to realize the full potential of the observing system. The observing system will, in turn, provide guaranteed and continuous data on the environment that will be of enormous value to marine science and education in much the same way that data required for weather forecasting benefit the science of meteorology and that numerical weather predictions benefit the environmental sciences as a whole.

Priorities for research and development include the following:

- Formulate ecosystem models for more rapid assimilation and analysis of biological and chemical data. The goal is to develop these into operational models that can be used to guide development of the system, determine climatologies for the common variables, and provide more timely detection and prediction of changes in the phenomena of interest.
- Establish requirements for remote sensing of the common variables and enhance remote sensing of coastal waters. Continue the deployment of ocean observing satellites and develop new satellite-based sensors for improved, higher resolution observations of the common variables in coastal environments.
- Establish requirements for *in situ* sensing of key variables and enhance *in situ* sensing in coastal waters to include more rapid detection of biological and chemical variables with greater resolution and real-time telemetry.

COOPERATION, COORDINATION AND COLLABORATION

The Integrated Global Observing Strategy involves the establishment of three linked observing systems, the Global Climate Observing System (GCOS), Global Terrestrial Observing System (GTOS), and GOOS – all taken together known as G3OS. From the perspective of the coastal module, GCOS is expected to provide data required to quantify atmospheric forcings; GTOS is expected to provide data required to quantify land-based inputs; and the global ocean module of GOOS is expected to provide open ocean boundary conditions and data required to quantify basin-scale forcings.

Implementing the coastal module will require a sophisticated level of cooperation, coordination and collaboration among nations and existing programmes to ensure the emergence of a global network as more national and regional systems come on line. A critical aspect of this process will involve harmonizing the need for global coordination with user needs based on national and regional priorities. At present, there is no formal international mechanism in place to promote and guide this process. An intergovernmental commission, such as the Joint Technical Commission on Oceanography and Marine Meteorology (JCOMM with the appropriate advisory bodies), will be needed to facilitate multi-lateral agreements and to address legal issues that will arise from implementation of UNCLOS and other international conventions.

Résumé analytique

LE SYSTÈME MONDIAL D'OBSERVATION DE L'OCÉAN

Conventions et accords internationaux prônent la sécurité en mer, la gestion efficace du milieu marin et l'utilisation durable de ses ressources. Les importants et ambitieux objectifs fixés par ces accords ne pourront être atteints que si l'on parvient à détecter rapidement et à prévoir en temps voulu les changements[1] enregistrés par un large éventail de phénomènes marins qui ont une incidence sur (1) la sécurité et l'efficacité des opérations en mer ; (2) la vulnérabilité des populations humaines aux risques naturels ; (3) la réaction des écosystèmes côtiers aux changements climatiques mondiaux ; (4) la santé et le bien-être public ; (5) l'état des écosystèmes marins ; (6) la pérennité des ressources marines vivantes. Nous n'avons pas à ce jour les capacités nécessaires. La mise en place du Système mondial d'observation de l'océan (GOOS), qui a pour organismes de parrainage la Commission océanographique intergouvernementale (COI) de l'UNESCO, le Programme des Nations Unies pour l'environnement (PNUE), l'Organisation météorologique mondiale (OMM) et le Conseil international pour la science (CIUS), vise à les développer. Le GOOS est conçu comme un réseau opérationnel mondial d'acquisition et de diffusion systématiques de produits et données sur l'état passé, présent et futur du milieu marin. Il est mis en place sous la forme de deux modules interdépendants et convergents, à savoir : (1) un module océanique mondial essentiellement chargé de détecter et de prévoir les changements du système océan-climat, d'améliorer les services océaniques (sous la direction du Groupe sur les observations océaniques pour l'étude du climat (OOPC), qui est coparrainé par le Programme mondial de recherche sur le climat (PMRC), le Système mondial d'observation du climat (SMOC) et le GOOS) et (2) un module côtier chargé d'étudier les effets des changements à grande échelle du système océan-climat et des activités humaines sur les écosystèmes côtiers, ainsi que les moyens d'améliorer les services océaniques (sous la direction du Groupe des observations relatives aux océans et aux zones côtières (COOP), qui est coparrainé par l'Organisation des Nations Unies pour l'alimentation et l'agriculture (FAO), le Programme international sur la géosphère et la biosphère (PIGB et le GOOS). Le rapport présente les recommandations du COOP pour la conception du module côtier du GOOS. Il est divisé en trois sections :

1. Fondements et objectifs (prologue, chapitres 1 et 2),
2. Conception (chapitres 3, 4, et 6) et
3. Principes directeurs initiaux applicables à la formulation d'un plan de mise en oeuvre (chapitre 7).

Le plan conceptuel décrit comment l'on se représente un système intégré et durable d'observation de l'océan côtier, en définit les éléments et indique comment ils s'articulent entre eux pour donner un système opérationnel. C'est un schéma de la manière dont la communauté des nations peut rentabiliser davantage l'utilisation des ressources collectives pour s'atteler en temps plus opportun aux questions et problèmes

[1] Changer - "transformer en quelque chose d'autre, faire passer à un autre état ; modifier quelque chose, le rendre différent ; subir une modification d'aspect, de forme, de nature, devenir différent" (Larousse encyclopédique). Pour détecter ou prédire un changement il faut, par conséquent, pouvoir détecter et prédire des "états". En outre, le terme "changement" n'implique pas une dimension temporelle ou spatiale particulière. Il se produit des changements à de très nombreuses échelles (par exemple de quelques secondes à plusieurs siècles) et ce que l'on appelle variabilité à une échelle est un changement à une autre.

environnementaux d'intérêt mutuel. C'est le premier pas vers la formulation d'un plan de mise en oeuvre qui devrait être achevé d'ici à fin 2004.

FONDEMENTS ET OBJECTIFS

Les écosystèmes fournissent davantage de biens et de services dans la zone côtière que dans toute autre région du globe. L'augmentation rapide des modes d'utilisation des ressources côtières par l'homme et les changements à l'échelle planétaire du système océan-climat rendent cette zone plus vulnérable aux risques naturels, y renchérissent le coût de la vie et diminuent sa valeur pour les économies nationales. Les rivalités d'intérêt entre commerce, loisirs, développement, protection de l'environnement et gestion des ressources vivantes sont sources de litiges de plus en plus nombreux et prennent un caractère de plus en plus politique. Le coût social et économique de décisions prises sans disposer de renseignements pertinents s'accroît en conséquence. Il faut un système intégré d'observation et d'analyse afin de fournir les données et informations nécessaires pour atteindre les six objectifs ci-après :

1. améliorer la sécurité et l'efficacité des opérations en mer, qu'elles soient menées par des gouvernements, des organisations ou des entreprises commerciales ;
2. lutter contre les effets des catastrophes naturelles et les atténuer plus efficacement ;
3. améliorer la capacité à détecter et prévoir l'incidence des changements climatiques à l'échelle mondiale sur les écosystèmes côtiers ;
4. réduire les risques pour la santé publique ;
5. protéger ou restaurer plus efficacement la salubrité des écosystèmes ;
6. régénérer les ressources marines vivantes et en assurer la pérennité.

La réalisation de ces objectifs est fonction du développement de la capacité à détecter et prédire rapidement un large éventail de phénomènes côtiers qui vont de modifications de l'état de la mer, d'inondations côtières et de l'élévation du niveau de la mer jusqu'à une augmentation du risque de maladies, des modifications de l'habitat, des efflorescences algales nuisibles et une diminution des pêches. Bien que chacun de ces objectifs exige des données et informations spécifiques, ils peuvent nécessiter de nombreuses données communes. De même, leurs impératifs de gestion de la communication des données sont similaires. Une approche intégrée de la mise en place d'un système d'observation polyvalent est par conséquent à la fois judicieuse et rentable.

CONCEPTION DU SYSTÈME

La détection rapide et la prévision en temps voulu dépendent de la mise en place d'un système d'observation opérationnel qui fournisse régulièrement et en continu les données et l'information requises sous la forme, et à l'échelle temporelle, spécifiées par les utilisateurs. Pour garantir aux utilisateurs la fourniture régulière et en temps voulu de données et d'information, un tel système doit associer efficacement trois sous-systèmes essentiels, à savoir : (1) un sous-système de surveillance (détection), (2) un sous-système d'acquisition, gestion et diffusion des données et (3) un sous-système d'assimilation et d'analyse des données reposant sur leur compréhension scientifique.

Ce faisant, il faut concevoir le module côtier de manière à répondre à de nombreuses questions, notamment la diversité des phénomènes côtiers relevant des six objectifs fixés et la théorie des écosystèmes en vertu de laquelle toute une gamme d'interactions relie les phénomènes étudiés. Dans ce contexte, la conception du système doit également prendre en compte les considérations générales ci-après :

- la conception, la mise en oeuvre et le développement du système d'observation doivent être fonction des données et de l'information nécessaires aux groupes d'utilisateurs ;
- les phénomènes étudiés sont généralement des manifestations locales de changements (par exemple le phénomène ENSO, les sources terrestres de pollution, l'extraction de ressources vivantes) qui se propagent en passant de grandes à de petites échelles et en traversant juridictions nationales et limites entre mer terre et eau ;
- bien que ces six objectifs exigent chacun des données spécifiques, beaucoup leurs sont communes ;
- des normes et protocoles mondiaux d'observa-

tion ainsi que d'échange et de gestion des données sont nécessaires pour garantir un accès rapide et en temps voulu aux données et à l'information ;
- beaucoup des éléments indispensables pour constituer le système d'observation sont d'ores et déjà en place, et ce, depuis longtemps ;
- il faut établir des mécanismes d'évaluation permanente et continue du système sur les plans de la rentabilité, de l'efficacité, du contrôle de la qualité, et de la fourniture en temps voulu des données et de l'information ;
- les éléments du système d'observation nécessaires pour améliorer les services océaniques et l'efficacité des opérations en mer ainsi que pour prévoir les risques naturels sont plus développés que ceux nécessaires à la protection écosystémique de l'environnement et à la gestion des ressources vivantes.

Les considérations régionales portent notamment sur les points suivants :

- les priorités et la capacité à contribuer au système d'observation et en tirer parti varient d'un pays et d'une région à l'autre ;
- la plupart des conventions et accords internationaux visant à protéger l'environnement et assurer la gestion des ressources marines vivantes ont une portée régionale ;
- les organismes nationaux et régionaux sont les instances les plus appropriées pour recenser les groupes d'utilisateurs, décider du développement des produits et de leur marketing.

Par conséquent conception et mise en oeuvre doivent respecter le fait que les priorités varient selon les régions et devraient laisser aux participants régionaux le soin d'élaborer le système à leur échelle. Dans le même temps, les six objectifs du module côtier du GOOS ont de nombreuses exigences communes. C'est pourquoi un réseau mondial d'observation peut créer des économies d'échelles qui permettront d'améliorer la rentabilité du système régional d'observation. Le présent rapport propose que les responsables de la gestion du réseau mondial commun d'observation collaborent avec les alliances régionales pour le GOOS, ce qui aura des répercutions bénéfiques sur l'ensemble de la conception et de la gestion de ce dernier.

UN FORUM MONDIAL DE SYSTÈMES RÉGIONAUX D'OBSERVATION

Le module côtier doit indubitablement comprendre aussi bien des composantes à l'échelle régionale que mondiale. Le meilleur moyen d'y parvenir est de mettre en place un mécanisme qui permette aux programmes nationaux et aux alliances régionales pour le GOOS de jouer un rôle significatif dans plusieurs directions : (i) coordonner le développement d'un réseau mondial d'observation, de gestion des données et d'analyse ; (ii) mettre en place des normes et protocoles internationaux de mesure, d'échange et de gestion des données, et d'analyse ; (iii) faciliter le transfert de technologie et des connaissances ; (iv) établir des priorités pour le renforcement des capacités. Dans ce dispositif, le réseau mondial:

- mesure et gère une série de variables communes nécessaires à la plupart des systèmes régionaux, voire tous (variables communes, chapitre 4) ;
- il met en place un réseau de références et de stations sentinelles ;
- et crée des liens entre observations côtières et mondiales et établit des interfaces entre modèles mondiaux et côtiers (chapitre 5).

Les systèmes régionaux d'observation sont des composantes fondamentales du module côtier. Le réseau mondial ne fournira pas à lui seul toutes les données et informations requises pour détecter l'état des phénomènes étudiés et en prévoir les changements (ni même la majorité d'entre elles). Certaines catégories de variables sont importantes à l'échelle mondiale, mais les variables étudiées et les échelles spatiotemporelles de mesure changent d'une région à l'autre selon la nature de la zone côtière et les besoins des utilisateurs. C'est notamment le cas des variables concernant l'évaluation des stocks de poissons, les habitats essentiels de ces derniers, les mammifères et oiseaux marins, les espèces envahissantes, les algues nuisibles et les polluants chimiques. Pour ces catégories de variables, comme pour celles relatives par exemple à la glace de mer, qui n'intéressent que certaines régions du globe, les participants des régions concernées sont les mieux placés pour décider exactement quoi mesurer, à quelles échelles spatiotemporelles et grâce à quelle association de techniques d'observation. De même, les prévisions destinées aux industries côtières dépendront par certains aspects de l'existence de plates-formes d'exploitation pétrolière et gazière off shore, de grands ports, de routes de navigation pour les ferries, de lieux de villégiature et de centres de loisirs. En se basant sur les priorités régionales, les systèmes régionaux d'observation fournissent des données et informations adaptées aux besoins des parties prenantes, en particulier celles nécessaires à la gestion des pêcheries et des sources terrestres de pollution. Pour cela il faudra probablement mesurer les variables communes avec une meilleure résolution (d'un kilomètre ou moins par exemple) et en mesurer d'autres à des échelles plus fines. C'est ainsi que, les systèmes régionaux d'observations peuvent à la fois apporter leur contribution au réseau mondial et en tirer parti.

Le réseau côtier mondial, qui contribue à la rentabilité des systèmes régionaux d'observation et les relie entre eux et avec les systèmes mondiaux d'observation océan climat, est thème central du Plan conceptuel du COOP.

Primauté de la gestion des données et du développement des produits

Réduire la durée nécessaire pour acquérir, traiter et analyser des données de qualité connue est un objectif essentiel qui exige la mise en place d'un sous-système intégré de gestion des données et de communication pour fournir des données aussi bien en temps réel qu'en différé et permettre aux utilisateurs d'exploiter des ensembles de données multiples provenant de nombreuses sources différentes. Il faudra à cette fin un réseau hiérarchisé réparti rassemblant des organisations nationales, régionales et mondiales qui utilisent des normes, matériels de référence et protocoles communs de contrôle de la qualité ; permettent d'accéder rapidement aux données et de les échanger (par exemple normes applicables aux métadonnées) ; et un archivage des données à long terme. Un tel réseau se développera progressivement en reliant et intégrant des centres de données et programmes de gestion nationaux et internationaux existants. Le Comité de la COI sur l'Echange international des données et de l'information océanographiques (IODE) et la partie du Programme de la JCOMM consacrée à la gestion des données permettent de superviser le développement coordonné du sous-système intégré de gestion des données (chapitre 6).

Les groupes d'utilisateurs et les flux et produits de données dont ils ont besoin doivent orienter le développement du réseau d'observation. Simultanément, l'accès rapide à des données multidisciplinaires provenant de nombreuses sources accélérera la modélisation et l'élaboration de produits. C'est pourquoi un degré élevé de priorité doit être accordé à la création de mécanismes visant à assurer la participation permanente de groupes d'utilisateurs à la définition des produits et à la mise en place, au fonctionnement et au développement du module côtier.

C'est essentiellement dans le cadre des programmes nationaux et des alliances régionales pour le GOOS (ARG) que l'on peut identifier les groupes d'utilisateurs, préciser les besoins en données et information et affiner les produits de données au fil du temps à partir des informations fournies en retour par les utilisateurs et de nouvelles connaissances. La production, le marketing des produits de données et la publicité qui leur est faite sont indispensables à un fort accroissement de la demande et par conséquent au développement du système d'observation. Les principaux instruments actuellement disponibles pour assurer le marketing et élargir les groupes d'utilisateurs sont le Bulletin des produits et services du GOOS et le Bulletin de la JCOMM. Ils rendent compte des produits et des activités de développement les concernant et offrent aux utilisateurs la possibilité de commenter la qualité et l'utilité des produits du GOOS.

Le sous-système d'observation

Le réseau mondial proposé a pour objet de mesurer et de gérer un ensemble relativement restreint de variables "communes" nécessaires à la plupart des systèmes régionaux d'observation, voire tous (chapitre 4 annexe IV et V). On assistera probablement à l'émergence de variables communes à mesure que les alliances régionales pour le GOOS construiront avec le temps un réseau côtier mondial mais il est néanmoins utile d'en sélectionner provisoirement une série dont s'inspireront la conception et la mise en oeuvre du réseau côtier mondial initial. Celles recommandées sont le niveau de la mer, la température et la salinité de l'eau, les courants vectoriels, les ondes de surface, la teneur en oxygène dissout et les nutriments inorganiques, l'atténuation du rayonnement solaire, la bathymétrie, l'évolution de la ligne de rivage, la taille des sédiments et leur contenu organique, la biomasse benthique, la biomasse phytoplanctonique et les indicateurs fécaux. Ces variables ont été choisies en fonction des données nécessaires aux six objectifs fixés et du nombre de groupes d'utilisateurs susceptibles d'en profiter. La liste établie suppute au mieux les besoins. Son importance réside dans le fait qu'elle donne une idée des variables communes probablement nécessaires et montre à quel point il importe d'améliorer la capacité de détecter les modifications des variables biologiques et chimiques et d'élaborer des modèles opérationnels représentant les processus biogéochimiques et écologiques. L'évaluation des forces physiques qui s'exercent sur les structures et systèmes flottants constitue une part importante des services de prévision rendus aux opérateurs maritimes et ce type de produits est déjà très au point et abordé dans d'autres publications. Les différents aspects de la modélisation des paramètres physiques sont étudiés au chapitre 5. Compte tenu de l'importance des facteurs environnementaux pour la détection comme pour la prévision des phénomènes étudiés, la place prépondérante qu'ils occupent dans la liste provisoire établie pour le module côtier n'a rien de surprenant.

Il faudra combiner différentes techniques, relevant de trois grandes catégories générales, pour fournir les flux de données requises à savoir : la télédétection (observations synoptiques spatiales), la détection autonome *in situ* (séries temporelles à haute résolution) et l'échantillonnage discret suivi d'une analyse en laboratoire (pour de nombreuses variables chimiques et biologiques). Le sous-système de surveillance devrait notamment comprendre (1) des réseaux de laboratoires côtiers, (2) le réseau mondial de marégraphes, (3) des plates-formes fixes, des mouillages et des véhicules autonomes, (4) des navires de recherche et de surveillance chargés d'effectuer des observations sur la durée, (5) des navires d'observation bénévoles et (6) des plates-formes terrestres, satellites et aéronefs de télédétection.

Liaison entre observations et modèles

La surveillance et la modélisation sont des processus interdépendants et la mise en place du système pleinement intégré exigera une synergie constante entre surveillance, progrès technologiques et formulation de modèles prévisionnels (chapitre 5). Les modèles joueront un rôle essentiel dans la mise en oeuvre, le fonctionnement et le développement du système d'observation. Ils sont très utiles pour évaluer quantitativement des facteurs qui ne sont pas directement observés avec un degré de certitude connu, par exemple l'état passé (prévisions a posteriori), présent (prévisions immédiates) et futur (prévisions à terme) des systèmes marins côtiers et des estuaires, ainsi que les erreurs qui vont de pair. Il convient de noter que la notion de prévision immédiate exige la fourniture extrêmement rapide des données et leur traitement en temps réel ou quasi réel.

Un coup d'œil à la situation actuelle en matière d'assimilation et de modélisation des données concernant les services océaniques et les risques naturels, les ressources marines vivantes, la santé publique et la santé des écosystèmes (chapitre 5) montre que la modélisation est plus avancée pour les services océaniques et les risques naturels que pour la détection et la prévision des changements qui affectent les phénomènes exigeant la mesure de variables biologiques et chimiques, ce qui souligne l'importance de la recherche pour le développement du modèle côtier.

Mise en place du système

Pour développer les deux composantes mondiales du GOOS, océanique et côtière, il est absolument indispensable de lier entre eux, d'améliorer et de compléter de manière sélective et efficace des programmes existants (chapitre 7). C'est l'association de processus nationaux, régionaux et mondiaux qui donnera le jour au réseau côtier mondial. Bien que certains éléments du système soient à l'échelle planétaire dès le départ (par exemple, le GLOSS, les observations depuis l'espace), ce sont des systèmes nationaux et régionaux d'observation côtière qui constitueront le système côtier mondial. Des alliances régionales pour le GOOS (ARG) sont instaurées pour concevoir et établir des systèmes d'observation régionaux qui deviendront les éléments constitutifs du module côtier (chapitre 3, section 3.1). On les encourage à mettre en place le module côtier grâce à des partenariats avec des programmes nationaux pour le GOOS, des Conventions sur les mers régionales, des organes régionaux responsables des pêches, des programmes relatifs aux grands écosystèmes marins et d'autres instances, selon les besoins.

La mise en oeuvre, le fonctionnement et l'évolution d'un système permanent d'observation analogue à la Veille météorologique mondiale nécessitera des mécanismes gouvernementaux pour s'assurer que chaque système, ou élément de système, candidat passe par quatre étapes de développement :

1. élaboration de connaissances, technologies et modèles nouveaux par le biais de la recherche ;
2. essais répétés dans le cadre de projets pilotes afin de garantir la fiabilité des systèmes ou éléments de système et de s'assurer de leur acceptation par les milieux opérationnels et de la recherche ;
3. utilisation préopérationnelle afin de s'assurer que leur intégration au système d'observation donne des produits à valeur ajoutée ; et
4. intégration à un système opérationnel permanent d'observation.

Ce processus doit être sélectif et des critères pour faire passer les éléments constitutifs du GOOS du stade de la recherche au stade opérationnel doivent être établis en fonction des besoins des utilisateurs. Dans un premier temps, la mise en oeuvre du module côtier du GOOS devrait consister à améliorer le partage des données et produits provenant d'éléments de systèmes d'observation afin d'en amorcer l'intégration dans un système global. Les données historiques et les flux permanents de données existent en grand nombre mais à ce jour beaucoup ne sont pas facilement accessibles aux nombreux utilisateurs potentiels.

Recherche et développement en vue de la mise en place d'un système d'observation opérationnel

Les fondements scientifiques et techniques de la conception du module côtier sont fournis par des programmes de recherche, notamment ceux du PIGB (Interaction terre-océan dans les zones côtières, LOICZ ; dynamique des écosystèmes océaniques à l'échelle mondiale, GLOBEC ; Etude conjointe des flux océaniques mondiaux, JGOFS), l'Inventaire de la vie marine (CML), L'écologie et l'océanographie des efflorescences algales nuisibles à l'échelle mondiale (GEOHAB), le Programme international de recherche à long terme sur les écosystèmes (I-LTER) et les Etudes SIMBIOS (*Sensor Intercomparisons and Merger for Biological and Interdisciplinary Oceanic Studies*). Les connaissances et technologies issues de ces programmes de recherche, et d'autres, seront nécessaires pour comprendre toutes les possibilités qu'offre le système d'observation.
Celui-ci fournira à son tour en permanence des données garanties sur l'environnement extrêmement précieuses pour l'océanologie et l'enseignement en sciences de la mer comme, dans une large mesure, les données nécessaires à la prévision du temps profitent à la météorologie ou comme les prévisions météorologiques numériques sont utiles aux sciences de l'environnement dans leur ensemble.

Les priorités en matière de recherche et développement sont notamment :

- de formuler des modèles écosystémiques permettant une assimilation et une analyse plus rapide des données biologiques et chimiques. L'objectif est d'en faire des modèles opérationnels susceptibles d'être utilisés pour orienter le développement de systèmes, déterminer des valeurs climatologiques pour les variables communes et détecter et prévoir en temps plus opportun les variations des phénomènes étudiés ;
- de définir les besoins de télédétection des variables communes et d'améliorer les méthodes de télédétection des eaux côtières. De continuer à lancer des satellites d'observation de l'océan et à mettre au point de nouveaux capteurs embarqués sur des satellites afin d'obtenir de meilleures observations, à plus haute résolution, des variables communes dans les milieux côtiers ;
- de définir les modalités de détection in situ de variables clés et d'intensifier la détection in situ dans les eaux côtières afin notamment de détecter plus rapidement des variables biologiques et chimiques avec une résolution plus élevée et au moyen de la télémétrie en temps réel.

Coopération, coordination et collaboration

La stratégie mondiale intégrée d'observation suppose la mise en place de trois systèmes liés d'observation, le Système mondial d'observation du climat (SMOC), le Système global d'observation terrestre (GTOS) et le GOOS, connus sous l'appellation commune de G3OS. En ce qui concerne le module côtier, le SMOC devrait fournir les données nécessaires pour chiffrer les forçages atmosphériques ; le GTOS celles requises pour chiffrer les apports d'origine terrestre ; et le module du GOOS relatif à l'océan mondial indiquer les conditions à la limite de la haute mer et fournir les données nécessaires pour chiffrer les forçages à l'échelle de bassins.

Mettre en oeuvre le module côtier exigera une coopération, une coordination et une collaboration très complexe entre les pays et entre les programmes existants afin d'assurer l'émergence d'un système mondial à mesure que de nouveaux systèmes nationaux et régionaux entrent en service. L'harmonisation des besoins de coordination à l'échelle mondiale et des besoins des utilisateurs en fonction des priorités nationales et régionales constituera un aspect crucial de ce processus. Actuellement, il n'existe pas de mécanisme international officiel pour le promouvoir et l'orienter. Il faudra une commission intergouvernementale comme la Commission technique mixte d'océanographie et de météorologie maritime (JCOMM, dotée d'organes consultatifs appropriés) pour faciliter la conclusion d'accords multilatéraux et s'occuper des questions juridiques que suscitera l'application de l'UNCLOS et d'autres conventions internationales.

Resumen

EL SISTEMA MUNDIAL DE OBSERVACIÓN DE LOS OCÉANOS

Los acuerdos y convenciones internacionales preconizan la seguridad en el mar, la ordenación eficaz del medio ambiente marino y el aprovechamiento sostenible de sus recursos. El logro de los objetivos de esos acuerdos, que son importantes y constituyen un reto, depende de la capacidad de detectar con rapidez y suministrar oportunamente predicciones de los cambios[1] en una amplia gama de fenómenos marinos que afectan 1) la seguridad y eficacia de las operaciones marinas; 2) la vulnerabilidad de las poblaciones humanas a los riesgos naturales; 3) la respuesta de los ecosistemas costeros al cambio climático mundial; 4) la salud y el bienestar públicos; 5) el estado de los ecosistemas marinos; y 6) la sostenibilidad de los recursos marinos vivos. Hoy día no tenemos esas capacidades. La finalidad del establecimiento de un Sistema Mundial de Observación de los Océanos (GOOS) es desarrollarlas.

Los patrocinadores del GOOS son la Comisión Oceanográfica Intergubernamental (COI) de la UNESCO, el Programa de las Naciones Unidas para el Medio Ambiente (PNUMA), la Organización Meteorológica Mundial (OMM) y el Consejo Internacional para la Ciencia (ICSU). El GOOS está concebido como una red operativa mundial que acopia y difunde sistemáticamente datos y productos de datos sobre estados pasados, presentes y futuros del medio marino. El sistema de observación se está estableciendo mediante dos módulos relacionados y convergentes: 1) un módulo de los océanos mundiales dedicado principalmente a la detección y predicción de los cambios en el sistema océano-clima y al mejoramiento de los servicios marinos (dirigido por el Panel de Observación del Océano en relación con el Clima (OOPC), patrocinado conjuntamente por el Programa Mundial de Investigaciones Climáticas (PMIC), el Sistema Mundial de Observación del Clima (SMOC) y el GOOS) y 2) un módulo costero dedicado a los efectos de los cambios a gran escala en el sistema océano-clima y de las actividades humanas en los ecosistemas costeros, así como al mejoramiento de los servicios marinos (dirigido por el Panel sobre Observaciones de los Océanos y las Zonas Costeras (COOP), patrocinado conjuntamente por la Organización de las Naciones Unidas para la Agricultura y la Alimentación (FAO), el Programa Internacional sobre la Geosfera y la Biosfera (IGBP) y el GOOS).

En este informe se presentan las recomendaciones del Panel sobre Observaciones de los Océanos y las Zonas Costeras (COOP) para el diseño del módulo de las zonas costeras del GOOS. Está dividido en tres secciones:

1) fundamentos y objetivos (Prólogo, Capítulos 1 y 2)
2) diseño (Capítulos 3, 4 , 5 y 6) y
3) directrices iniciales para la elaboración de un plan de ejecución (Capítulo 7).

En el plan detallado se expone la concepción de un sistema de observación integrado y permanente de

---

[1] Cambio: "paso de un estado a otro; alteración o diferencia, variación de la condición o apariencia física o moral" (traducción libre del artículo "change" del Webster's New Twentieth Century Unabridged Dictionary, NDT). Así pues, para detectar y predecir el cambio, se deben poder detectar y predecir "estados". Además, la palabra "cambio" no entraña una dimensión temporal o espacial particular. Los cambios ocurren en una amplia gama de escalas (segundos o siglos, por ejemplo) y la variabilidad en una escala supone un cambio en otra.

las aguas oceánicas costeras, se definen los elementos del sistema y se explica cómo se relacionan éstos unos con otros para constituir un sistema operativo. El plan proporciona un marco cuyo objeto es que la comunidad o los países hagan un uso de los recursos colectivos más eficaz en relación con los costos, para tratar de modo más oportuno asuntos y problemas ambientales de interés común. Éste es el primer paso hacia la formulación de un plan de ejecución que se espera terminar para fines de 2004.

FUNDAMENTOS Y OBJETIVOS

Los bienes y servicios de los ecosistemas están más concentrados en las zonas costeras que en cualquier otra región del planeta. El rápido aumento de los usos de los recursos costeros y los cambios mundiales en el sistema océano-clima están volviendo las zonas costeras más vulnerables a los riesgos naturales, más caras y de menor valor para las economías nacionales. Los conflictos entre el comercio, las actividades recreativas, el desarrollo, la protección ambiental y la ordenación de los recursos vivos se están volviendo cada vez más polémicos y su carga política es cada vez mayor. Están aumentando en consecuencia los costos sociales y políticos de decisiones mal fundamentadas. Se requiere un sistema integrado de observaciones y análisis que aporte los datos e informaciones necesarios para el logro de los seis objetivos siguientes:

1) mejorar la seguridad y eficacia de las operaciones marinas llevadas a cabo por los gobiernos, los organismos o las empresas comerciales;
2) vigilar y atenuar más eficazmente los efectos de los riesgos naturales;
3) mejorar la capacidad para detectar y predecir los efectos del cambio climático mundial en los ecosistemas costeros;
4) reducir los riesgos para la salud pública;
5) proteger y restaurar más eficazmente los ecosistemas sanos; y
6) restaurar y preservar los recursos vivos marinos.

El logro de estos objetivos depende de que se desarrolle la capacidad de detectar y predecir con rapidez una amplia gama de fenómenos costeros, como por ejemplo los cambios en el estado del mar, las inundaciones costeras y el aumento del nivel del mar, los mayores riesgos de enfermedad, la modificación de los hábitats, las floraciones de algas nocivas y la disminución de los recursos pesqueros. Aunque cada objetivo requiere datos e informaciones específicos, todos tienen muchas necesidades de datos en común. Asimismo, las necesidades en materia de gestión de comunicaciones de datos son análogas para los seis objetivos. Así pues, un enfoque integrado del establecimiento de un sistema de observación de usos múltiples es a la vez pertinente y eficaz en relación con los costos.

DISEÑO CONCEPTUAL

La detección rápida y la predicción oportuna dependen del establecimiento de un sistema de observación operativo que proporcione de modo rutinario y continuo datos e informaciones en la forma y en las escalas cronológicas especificadas por los usuarios. A fin de garantizar el suministro oportuno y periódico de datos e informaciones a los usuarios, ese sistema debe enlazar eficazmente tres subsistemas esenciales: a) un subsistema de vigilancia (detección), 2) un subsistema de acopio, gestión y difusión de datos, y 3) un subsistema de asimilación y análisis de datos basado en la comprensión científica.

Con tal fin, el módulo de las zonas costeras debe diseñarse para hacer frente a muchos problemas, como por ejemplo los fenómenos costeros comprendidos en los seis objetivos y la teoría de los ecosistemas que postula que los fenómenos de interés están relacionados mediante una jerarquía de interacciones. En ese sentido, el diseño debe tomar en cuenta también las consideraciones generales siguientes:

- Las necesidades de los grupos de usuarios en materia de datos e información deben determinar el diseño, la aplicación y la elaboración del sistema de observación.
- Los fenómenos de interés suelen ser expresiones locales de cambios (los fenómenos relacionados con El Niño y la Oscilación Austral (ENSO), las fuentes de contaminación terrestres, la explotación de los recursos vivos, por ejemplo) que se propagan desde escalas grandes hasta escalas más pequeñas pasando a través de las jurisdicciones nacionales y de los límites entre el aire, el mar y la tierra.

- Si bien a cada uno de los seis objetivos corresponden necesidades de datos específicas, éstos tienen muchas necesidades de datos en común.
- Se requieren normas y protocolos mundiales relativos a las observaciones, el intercambio y la gestión de datos para garantizar un acceso rápido y oportuno a los datos y la información.
- Muchos de los elementos que se necesitan para establecer el sistema de observación ya están en su lugar y lo han estado desde hace tiempo.
- Se deben establecer mecanismos para efectuar evaluaciones permanentes y continuas del sistema en relación con su rentabilidad, su eficacia, el control de calidad y el suministro oportuno de datos e información.
- Los elementos del sistema de observación que se requieren para mejorar los servicios marinos y la eficacia de las operaciones marinas y predecir los riesgos naturales están más desarrollados que los exigidos por una protección ambiental y una ordenación de los recursos vivos basadas en los ecosistemas.

Entre las consideraciones regionales, cabe citar las siguientes:

- Las prioridades y la capacidad para contribuir al sistema de observación y aprovecharlo son distintas según los países y las regiones.
- La mayoría de los acuerdos y convenciones internacionales de protección del medio ambiente y de ordenación de los recursos marinos vivos son de alcance regional.
- Los organismos nacionales y regionales son los medios más eficaces de determinar los grupos de usuarios, elaborar productos y comercializarlos.

Así pues, el diseño y la ejecución deben respetar el hecho de que las prioridades varían según las regiones, por lo que se debe dejar el diseño del sistema en el plano regional a los interesados de las respectivas regiones. Al mismo tiempo, los seis objetivos del módulo de las zonas costeras del GOOS tienen muchos requisitos en común. Por consiguiente, una red mundial de observaciones podría aportar economías de escala que permitirían a los sistemas de observación regionales ser más eficaces en relación con los costos. En este informe se propone una colaboración entre la gestión de la red de observaciones mundial común y las alianzas regionales del GOOS. Esa estructura tendrá efectos positivos en todo el diseño y la gestión del GOOS.

Un Foro Mundial de Sistemas de Observación Regionales

El módulo de las zonas costeras deberá incluir, desde luego, componentes a escala tanto regional como mundial. El mejor modo de conseguirlo es a través de un mecanismo que permita a los programas nacionales y a las Alianzas Regionales de GOOS un rol significativo en (1) la coordinación del desarrollo de una red mundial de observaciones, gestión y análisis de datos; (2) el establecimiento de normas y protocolos comunes para las mediciones, el intercambio y la gestión de datos; (3) facilitar la transferencia de conocimientos y de tecnología; y (4) fijar prioridades para la creación de capacidades. En este diseño, la red mundial :

- mide una serie de variables comunes que la mayoría de los sistemas regionales necesitan, cuando no todos, y se ocupa de su gestión (las variables comunes, véase el Capítulo 4);
- establece una red de referencia compuesta de estaciones centinelas; y
- establece vínculos entre las observaciones relativas a las zonas costeras y las observaciones mundiales y conecta los modelos mundiales con los de las zonas costeras (Capítulo 5);

Los sistemas de observación regionales son componentes esenciales del módulo de las zonas costeras. La red mundial no proporcionará por sí misma todos los datos e informaciones (o ni siquiera la mayor parte de ellos) que se necesitan para detectar el estado y predecir los cambios de los fenómenos de interés. Algunas categorías de variables son importantes a escala mundial, pero las variables medidas y las escalas espaciales y cronológicas de medición cambian de una región a otra según la índole de la zona costera y las necesidades de los usuarios. Se trata de variables relativas a las evaluaciones de las poblaciones, los principales hábitats de los peces, los mamíferos y aves marinos, las especies invasoras, las algas nocivas y los contaminantes químicos. Para estas categorías y para las variables como los hielos oceánicos que están limitadas a determinadas regiones del planeta, los interesados de las regiones en cuestión son los más aptos para adoptar las decisiones relativas a lo que hay que medir exactamente, las escalas espaciales y cronológicas de medición y la combinación de técnicas de observación que se han de utilizar. Asimismo, algunos aspectos de la predicción para las industrias de las zonas costeras dependerán de la existencia de instalaciones de explotación de petróleo y gas en alta mar, puertos importantes, rutas de transbordadores, centros turísticos y recreativos. Basándose en las prioridades regionales, los sistemas de observación regionales suministran datos e información que se ajustan a las necesidades de los interesados, en especial en materia de ordenación de los recursos pesqueros y de vigilancia de las fuentes de contaminación terrestres. Esto puede suponer aumentos en la resolución a la que se miden las variables comunes (por ejemplo, hasta 1 km o menos), así como las mediciones de variables suplementarias a escalas más reducidas. De ese modo, los sistemas de observación regionales contribuyen a la red mundial y al mismo tiempo sacan provecho de ella.

El plan detallado del COOP está centrado en la constitución de una red mundial de zonas costeras que contribuya a la rentabilidad de los sistemas de observación regionales y que los vincule entre sí y con los sistemas mundiales de observación del océano y el clima.

La primacía de la gestión de datos y la elaboración de productos

Reducir el tiempo necesario para acopiar, tratar y analizar datos de calidad conocida es uno de los principales objetivos cuyo logro supone el establecimiento de un subsistema integrado de gestión de datos y comunicaciones. Los objetivos son proporcionar datos en tiempo real y de modo diferido y permitir a los usuarios explotar múltiples series de datos procedentes de múltiples fuentes distintas. Esto exigirá una red distribuida jerárquicamente de organizaciones nacionales, regionales y mundiales que funcione con normas, materiales de referencia y protocolos de control de calidad comunes, permita un rápido acceso a los datos y su intercambio (normas sobre metadatos, por ejemplo) y archive los datos a largo plazo. Esa red crecería por incremento gradual vinculando e integrando los centros de datos y los programas de gestión nacionales e internacionales existentes. El Comité de la COI de Intercambio Internacional de Datos e Información Oceanográficos (IODE) y la serie de programas de gestión de datos de la JCOMM ofrecen la posibilidad de supervisar el desarrollo coordinado del subsistema integrado de gestión de datos (Capítulo 6).

El sistema de observación debe desarrollarse teniendo en cuenta los grupos de usuarios y los flujos de datos y los productos que éstos requieren. Al mismo tiempo, el rápido acceso a datos pluridisciplinarios procedentes de distintas fuentes propiciará la modelización y la elaboración de productos. Por consiguiente, se debe conceder una elevada prioridad al establecimiento de mecanismos de participación permanente de los grupos de usuarios en la definición de productos y en el establecimiento, el funcionamiento y el desarrollo del módulo de las zonas costeras.

Los programas nacionales del GOOS y las alianzas regionales del GOOS son el principal medio de determinar los grupos de usuarios, especificar los requisitos en materia de datos e información y perfeccionar los productos de datos con el tiempo, basándose en las reacciones de los usuarios y en los nuevos conocimientos. La producción, la promoción publicitaria y la comercialización de los productos de datos son esenciales para suscitar una mayor demanda entre los usuarios y, por ende, para el desarrollo ulterior del sistema de observación. Los principales instrumentos de comercialización y divulgación de que se dispone en la actualidad son el boletín de productos y servicios del GOOS y el boletín de la JCOMM. En estas publicaciones se facilita información sobre productos y sobre actividades de elaboración de productos, y se brinda a los usuarios la posibilidad de formular comentarios sobre la calidad y la utilidad de los productos del GOOS.

El subsistema de observación

La red mundial propuesta tiene por objeto medir y administrar una serie relativamente pequeña de variables “comunes” necesarias para la mayoría de los sistemas de observación regionales, cuando no todos (Capítulo 4, Anexos IV y V). Aunque es probable que las variables comunes vayan apareciendo en el tiempo, a medida que las Alianzas Regionales de GOOS construyen la red mundial, es útil seleccionar una serie provisional de variables para ayudar a orientar el diseño y la instalación iniciales de la red mundial de zonas costeras. Las variables comunes recomendadas son el nivel del mar, la temperatura y salinidad del agua, las corrientes vectoriales, las olas de superficie, el oxígeno disuelto y los nutrientes inorgánicos, la atenuación de la radiación solar, la batimetría, los cambios en la posición de la línea costera, el tamaño de los sedimentos y el contenido orgánico, la biomasa bentónica, la biomasa del fitoplancton y los indicadores fecales. Estas variables se seleccionaron sobre la base de las necesidades en materia de datos de los seis objetivos y del número de grupos de usuarios que aprovecharían los datos e informaciones. Esta lista, elaborada según los criterios más plausibles, es importante porque permite tener una idea de lo que pueden ser las variables comunes y porque destaca la importancia de mejorar la capacidad para detectar los cambios en las variables biológicas y químicas y de elaborar modelos operativos para los procesos biogeoquímicos y ecológicos. Las fuerzas físicas que se ejercen sobre las estructuras y los sistemas de flotación son una parte importante de los servicios de predicción para los agentes marítimos, y esos productos están ya bastante avanzados y se tratan en otras publicaciones. Los aspectos relativos a la modelización de los parámetros físicos se tratan en el Capítulo 5. Habida cuenta de la importancia de los factores ambientales en cuanto a la detección y la predicción de los fenómenos de interés, no es sorprendente que éstos predominen en la lista provisional del módulo de las zonas costeras.

Será preciso combinar una serie de técnicas para proporcionar los flujos de datos que se requieren. Éstas se pueden clasificar en tres categorías: la teledetección (observaciones espacialmente sinópticas), la detección autónoma in situ (series cronológicas de alta resolución) y el muestreo diferenciado seguido del análisis de laboratorio (para muchas variables químicas y biológicas). El subsistema de vigilancia debe comprender, entre otros, los elementos siguientes: 1) las redes de laboratorios costeros, 2) la red mundial de mareómetros, 3) las plataformas y las boyas fijas, y los vehículos autónomos, 4) los buques de investigación y estudio que efectúan observaciones continuas, 5) los buques de observación voluntarios y 6) la teledetección desde plataformas terrestres, satélites y aeronaves.

Vinculación de las observaciones y los modelos

La vigilancia y la modelización son procesos recíprocamente dependientes y el establecimiento del sistema plenamente integrado exigirá una sinergia continua entre la vigilancia, los adelantos tecnológicos y la formulación de modelos de predicción (Capítulo 5). Los modelos desempeñarán una función decisiva en la ejecución, el funcionamiento y el desarrollo del sistema de observación. Se trata de instrumentos importantes que se utilizan para estimar las cantidades que no se observan directamente con certeza reconocida, esto es, para predecir los estados pasados (información retrospectiva), actuales (información actual) y futuros (información prospectiva) de los sistemas marinos costeros y los estuarios, así como los errores asociados a tales predicciones. Cabe observar que el concepto de información actual requiere un suministro y un tratamiento extremadamente rápidos de los datos en tiempo real, o en tiempo casi real.

Una perspectiva general de la situación actual de la asimilación y modelización de los datos para los servicios marinos y los riesgos naturales, los recursos marinos vivos, la salud pública y la salud de los ecosistemas (Capítulo 5) muestra el estado avanzado de la modelización para los servicios marinos y los riesgos naturales en relación con la existente para la detección y predicción de los cambios en fenómenos que requieren mediciones de variables biológicas y químicas. Esto destaca la importancia que reviste la investigación para el desarrollo del módulo de las zonas costeras.

Constitución del sistema

La elaboración de los componentes del GOOS relativos tanto a los océanos mundiales como a las zonas costeras depende en gran medida de que los programas existentes se vinculen, se mejoren y se completen de modo selectivo y eficaz (Capítulo 7). La red mundial de zonas costeras se creará mediante una combinación de procesos nacionales, regionales y mundiales. Si bien algunos elementos del sistema serán mundiales en cuanto a su escala desde el principio (el GLOSS, las observaciones desde el espacio, por ejemplo), los sistemas de observación nacionales y regionales serán los elementos constitutivos de la red mundial de zonas costeras. Las alianzas regionales del GOOS se están estableciendo para planificar y establecer sistemas de observación regionales que se convertirán en los componentes básicos del módulo costero (Capítulo 3, Sección 3.1). Se alienta a las alianzas regionales del GOOS a que constituyan el módulo de las zonas costeras estableciendo relaciones de colaboración con los programas nacionales del GOOS, las convenciones sobre los mares regionales, los organismos regionales encargados de la actividad pesquera, los programas sobre los grandes ecosistemas marinos y otros organismos, según proceda.

El establecimiento, el funcionamiento y la evolución de un sistema de observación permanente, como la Vigilancia Meteorológica Mundial, exigirán mecanismos gubernamentales que garanticen el paso de los sistemas candidatos o los elementos de sistemas por las cuatro etapas de desarrollo siguientes:

1) la formulación de nuevos conocimientos, tecnologías y modelos mediante la investigación;
2) la experimentación reiterada en proyectos piloto para garantizar la fiabilidad y la aceptación por parte de los investigadores y los usuarios;
3) el uso preoperativo con objeto de que la incorporación al sistema de observación conduzca a la elaboración de productos con valor añadido; y
4) la incorporación a un sistema de observación operativo permanente.

El proceso debe ser selectivo y se deben establecer los criterios para el paso de los componentes básicos del GOOS de la fase de investigación a la fase operativa, partiendo de las necesidades de los usuarios. El primer paso para establecer el módulo de las zonas costeras del GOOS debe ser un mejor intercambio de los datos y productos disponibles procedentes de elementos de sistemas de observación, a fin de iniciar su integración en un sistema de observación. Existe una gran cantidad de datos históricos y de flujos de datos en curso, pero en la actualidad muchos de ellos no son de fácil acceso para los numerosos usuarios posibles.

Investigación y desarrollo de un sistema de observación operativo

El fundamento científico y técnico para el diseño del módulo de las zonas costeras lo suministran programas de investigación como el IGBP (Interacción Tierra-Océano en las Zonas Costeras, LOICZ; Dinámica de los Ecosistemas Oceánicos Mundiales, GLOBEC; y el Estudio Conjunto de los Flujos Oceánicos Mundiales, JGOFS), el Inventario de la Vida Marina (CML), el Programa Científico Internacional sobre la Ecología y la Oceanografía Mundiales de las Floraciones de Algas Nocivas (GEOHAB), el programa internacional de investigación a largo plazo sobre los ecosistemas y el *Sensor Intercomparisons and Merger for Biological and Interdisciplinary Oceanic Studies* (SIMBIOS). Para que el sistema de observación desarrolle plenamente su potencial se requerirán los conocimientos y las tecnologías generados por estos y otros programas de investigación. El sistema de observación proporcionará a su vez datos garantizados y continuos sobre el medio ambiente que revestirán un enorme valor para la ciencia y la educación marinas, del mismo modo que los datos necesarios para las predicciones meteorológicas son de provecho para la ciencia de la meteorología y que las predicciones meteorológicas numéricas son de provecho para las ciencias del medio ambiente en su totalidad. Las prioridades en materia de investigación y desarrollo serán, entre otras, las siguientes:

- Elaborar modelos de ecosistemas para una asimilación y un análisis más rápidos de los datos biológicos y químicos. El objetivo es integrar estos últimos en modelos operativos que puedan utilizarse para orientar el desarrollo del sistema, determinar las climatologías para las variables comunes y detectar y predecir de modo más oportuno los cambios en los fenómenos de interés.
- Establecer los requisitos para la teledetección de las variables comunes y mejorar la teledetección de las aguas costeras. Proseguir la instalación de satélites de observación de los océanos y elaborar nuevos sensores en los satélites para efectuar mejores observaciones y de más alta resolución de las variables comunes en los medios costeros.
- Establecer los requisitos para la detección *in situ* de las principales variables y mejorar las observaciones *in situ* en las aguas costeras, a fin de incluir una detección más rápida de las variables biológicas y químicas con una mayor resolución y una telemetría en tiempo real.

Cooperación, coordinación y colaboración

La Estrategia de Observación Mundial Integrada supone el establecimiento de tres sistemas de observación relacionados entre sí: el Sistema Mundial de Observación del Clima (SMOC), el Sistema Global de Observación Terrestre (GTOS) y el GOOS, que se conocen todos juntos como G3OS. A los efectos del módulo de las zonas costeras, se espera que el SMOC proporcione los datos necesarios para cuantificar la dinámica atmosférica; se espera que el GTOS proporcione los datos necesarios para cuantificar las aportaciones terrestres; y se espera que el módulo de los océanos mundiales del GOOS proporcione las condiciones y los datos relativos a las zonas adyacentes en alta mar necesarios para cuantificar la dinámica a escala de las cuencas.

La implementación del módulo de las zonas costeras requerirá un alto grado de cooperación, coordinación y colaboración entre países y programas existentes, a fin de conseguir el establecimiento de una red mundial conforme vayan apareciendo más sistemas nacionales y regionales. Un aspecto decisivo de este proceso será la armonización de la necesidad de una coordinación mundial con las necesidades de los usuarios, basándose en las prioridades nacionales y regionales. En la actualidad, no existe ningún mecanismo internacional oficial que promueva y oriente este proceso. Se necesitará una comisión intergubernamental, como la Comisión Técnica Mixta sobre Oceanografía y Meteorología Marina (JCOMM, con sus correspondientes órganos consultivos) para facilitar los acuerdos multilaterales y resolver los problemas jurídicos que plantea la aplicación de la Convención de las Naciones Unidas sobre el Derecho del Mar y otras convenciones internacionales.

Рабочее резюме

Глобальная система наблюдений за океаном

Международные соглашения и конвенции призывают к обеспечению безопасности на море, эффективному управлению морской средой и устойчивому использованию ее ресурсов. Решение важных и серьезных задач, поставленных в этих документах, зависит от возможности быстрого выявления и обеспечения своевременного прогнозирования изменений[1] в широком спектре явлений, связанных с морской средой, которые сказываются на следующем: (1) безопасность и эффективность морских операций; (2) уязвимость населения в случае стихийных бедствий; (3) реакция прибрежных экосистем на изменение климата; (4) охрана здоровья и благосостояние населения; (5) состояние морских экосистем; и (6) устойчивость живых морских ресурсов. **Сегодня мы такими возможностями не располагаем.** Задаче развития таких возможностей служит создание Глобальной системы наблюдения за океаном (ГСНО). Спонсорами ГСНО являются Межправительственная океанографическая комиссия (МОК) ЮНЕСКО, Программа Организации Объединенных Наций по окружающей среде (ЮНЕП), Всемирная метеорологическая организация (ВМО) и Международный совет по науке (МСНС). ГСНО задумана как оперативная глобальная сеть, которая на систематической основе обеспечивает получение и распространение данных и продуктов данных о прошлом, настоящем и будущем состоянии морской среды. В основе развития этой системы наблюдений находятся два взаимосвязанных и все более сближающихся модуля: (1) глобальный океанический модуль, прежде всего связанный с выявлением и прогнозированием изменений в системе океан-климат и с совершенствованием морских услуг (руководство этим модулем осуществляет Группа по океаническим наблюдениям за климатом (ООПК), спонсорами которой являются Всемирная программа по исследованию климата (ВПИК), Глобальная система наблюдений за климатом (ГСНК) и ГСНО); и (2) прибрежный модуль, связанный с влиянием крупномасштабных изменений в системе океан-климат и с антропогенным влиянием на прибрежные экосистемы, а также с совершенствованием морских услуг (руководство этим модулем осуществляет Группа по наблюдению за прибрежными районами (КООП), спонсорами которой являются Продовольственная и сельскохозяйственная Организация Объединенных Наций (ФАО), Международная программа по геосфере/биосфере (МПГБ) и ГСНО). В настоящем докладе содержатся рекомендации КООП по разработке прибрежного модуля ГСНО. Доклад состоит из трех частей:

1. обоснование и цели (вступление и главы 1 и 2)
2. разработка (главы 3, 4, 5 и 6)
3. первоначальные руководящие принципы для подготовки Плана реализации (глава 7).

План разработки содержит характеристику подхода к комплексной устойчивой системе наблюдений за прибрежными районами океана, определение элементов этой системы, а также описание характера их взаимодействия в интересах выхода на уровень оперативной системы. План обеспечивает ту основу, на которой международное сообще-

1. “Изменять - вызывать переход из одного состояния в другое; преобразовывать или делать иным; изменяться - приобретать другую внешнюю форму или содержание” (*Уэбстер, Полный новый словарь двадцатого века - Webster’s New Twentieth Century Dictionary, Unabridged Dictionary*). Таким образом, для выявления и прогнозирования изменений надо иметь возможность выявлять и прогнозировать “состояние”. Помимо этого, слово “изменение” не подразумевает конкретных временных или пространственных характеристик. Изменения происходят в самых различных масштабах (от секунд до столетий), и то, что является переменчивостью в одних масштабах, оказывается изменением в других.

ство может более рентабельно использовать коллективные ресурсы в целях более своевременного решения экологических вопросов и проблем, представляющих взаимный интерес. Это служит первым шагом к подготовке плана реализации, который должен быть завершен к концу 2004 г.

Обоснование и цели

Товары и услуги экосистем в большей степени сосредоточены в прибрежных районах, чем в любых других регионах мира. Быстрое расширение использования человеком прибрежных ресурсов и глобальные изменения в системе океан-климат делают прибрежные зоны более уязвимыми в случае стихийных бедствий, более дорогостоящими для проживания в них и менее ценными для национальной экономики. Конфликты между сферами таких интересов, как бизнес, досуг, развитие, охрана окружающей среды и управление живыми ресурсами, становятся все более острыми и приобретающими политическую окраску. Соответственно растет и социально-экономическая цена, которую приходится платить за противоречащие друг другу решения. Необходима комплексная система наблюдений и анализа для обеспечения данных и информации, которых требует достижение следующих шести целей:

1. повышение уровня безопасности и эффективности морских операций, причем проводимых как правительствами, так и учреждениями или частными компаниями;
2. повышение эффективности предупреждения стихийных бедствий и уменьшения их последствий;
3. совершенствование потенциала для выявления и прогнозирования воздействия глобального изменения климата на прибрежные экосистемы;
4. уменьшение опасностей, угрожающих здоровью населения;
5. обеспечение более эффективной защиты и восстановления экосистем;
6. восстановление и сохранение живых морских ресурсов.

Достижение этих целей зависит от развития возможностей быстрого выявления и прогнозирования широкого круга явлений в прибрежных районах, начиная с изменения уровня моря, затопления побережий и подъема уровня моря и кончая опасностями, связанными с болезнями, изменением среды обитания, вредоносным цветением водорослей и уменьшением вылова рыбы. Хотя для достижения каждой цели требуются свои специфические данные и информация, необходим и большой объем данных общего для них характера. Аналогичным образом, единые потребности существуют и в отношении управления распространением данных в рамках всех шести целей. Таким образом, комплексный подход к развитию системы наблюдения, обеспечивающей данные для множественных форм использования, является как весьма актуальным, так и рентабельным.

Разработка концепции

Быстрое выявление и своевременное прогнозирование зависят от создания системы оперативных наблюдений, обеспечивающей постоянное и непрерывное предоставление необходимых данных и информации в той форме и в тех временных масштабах, которые конкретно требуются пользователям. Такая система должна обеспечивать эффективную увязку трех важнейших подсистем для гарантированного своевременного предоставления данных и информации потребителям на постоянной основе: (1) подсистемы мониторинга (зондирования); (2) подсистемы для получения данных, управления ими и их распространения; (3) подсистемы для синтеза и анализа данных на основе их научного понимания.

При этом прибрежный модуль должен быть разработан таким образом, чтобы отвечать решению многих вопросов, включая многообразие явлений в прибрежной зоне, охватываемых шестью целями, а также теорию экосистем, согласно которой представляющие интерес явления взаимосвязаны иерархией взаимодействий. В связи с этим при разработке должны также учитываться следующие соображения глобального характера:

- разработка, реализация и развитие системы наблюдений должны ориентироваться на потребности групп пользователей в данных и информации;
- представляющие интерес явления являются характерным местным проявлением изменений (например явления ЭНСО, наземные источники загрязнения, истощение живых ресурсов), которые переходят из крупных масштабов в меньшие, не считаясь ни с национальными границами, ни с границами между атмосферой, морем и сушей;

- хотя для достижения каждой цели требуются свои специфические данные и информация, необходим и большой объем данных общего для них характера;
- для обеспечения быстрого и своевременного доступа к данным и информации требуются глобальные стандарты и протоколы в области наблюдений, обмена данными и управления ими;
- многие элементы, необходимые для создания системы наблюдений, уже существуют, причем давно;
- необходимо создать механизмы для постоянного и непрерывного проведения оценок системы с точки зрения ее рентабельности и эффективности, контроля качества и своевременного предоставления данных и информации;
- те элементы системы наблюдений, которые нужны для совершенствования морских услуг, повышения эффективности морских операций и прогнозирования стихийных бедствий, более развиты, чем элементы, необходимые для охраны окружающей среды на основе принципа экосистем и для управления живыми ресурсами.

Соображения регионального характера включают следующие:

- приоритеты и возможности участия в системе наблюдений и извлечения из нее преимуществ у разных стран и регионов не одинаковы;
- большинство международных соглашений и конвенций об охране окружающей среды и управлении живыми морскими ресурсами имеют региональную сферу действия;
- задачам выявления групп пользователей, разработки продуктов и маркетинга в наибольшей степени отвечают национальные и региональные органы.

Таким образом, разработка и реализация должны учитывать различия в приоритетах у разных регионов и оставлять разработку системы в региональном масштабе на усмотрение заинтересованных сторон в регионе. Одновременно в рамках шести целей прибрежного модуля ГСНО существует много общих потребностей. Следовательно, **глобальная сеть наблюдений может обеспечить значительную экономию средств, что повысит рентабельность региональных систем наблюдений.** В настоящем докладе предлагается развивать сотрудничество между руководством глобальной сети наблюдений и региональными альянсами ГСНО. Такая структура принесет пользу разработке и управлению ГСНО в целом.

Глобальное объединение региональных систем наблюдений

Очевидно, что прибрежный модуль должен включать компоненты как регионального, так и глобального масштаба. Наиболее эффективно этого можно добиться на основе объединения региональных систем в глобальную прибрежную сеть наблюдений и управления данными. В рамках такой структуры глобальная сеть:

- обеспечивает измерения и управление по ряду общих переменных параметров, которые необходимы для большинства региональных систем, если не для всех из них (общие переменные параметры – см. главу 4);
- выступает в качестве информационно-справочной сети и сети станций слежения;
- устанавливает международные стандарты и протоколы для проведения измерений, обмена данными и управления ими;
- обеспечивает взаимную увязку прибрежных наблюдений с глобальными, а также взаимодействие глобального и прибрежного модулей (глава 5); и
- содействует созданию потенциалов.

Региональные системы наблюдений являются важнейшими компонентами для создания прибрежного модуля. Глобальная сеть сама по себе не обеспечит ста процентов (или даже большинства) данных и информации, не обходимых для определения состояния и прогнозирования представляющих интерес явлений. **Существуют категории переменных параметров, имеющих глобальную значимость, однако измеряемые переменные параметры и пространственно-временные масштабы измерений в разных регионах не одинаковы и зависят от характера прибрежной зоны и от потребностей пользователей. Сюда входят переменные параметры, касающиеся оценок объема разных категорий живых ресурсов, основных форм среды обитания рыбы, морских млекопитающих и птиц, инвазивных видов, вредоносных водорослей и химических загрязняющих веществ. По таким категориям, равно как и по таким переменным параметрам, которые актуальны для немногих регионов (например морской лед), решения о том, что именно следует измерять и в каких пространственно-временных масштабах, а также о комплексе методики наблюде-**

ний должны приниматься заинтересованными сторонами в соответствующих регионах. Аналогичным образом, аспекты прогнозирования для отраслей промышленности в прибрежной зоне будут зависеть от наличия нефтегазовых морских разработок, крупных портов, паромных маршрутов, туристических курортов и центров отдыха. Руководствуясь региональными приоритетами, региональные системы наблюдений обеспечивают данные и информацию, увязанные с потребностями заинтересованных сторон, в особенности в том, что касается управления рыболовством и наземных источников загрязнения. Скорее всего, это повлечет за собой увеличение разрешающей способности измерений по общим переменным параметрам (например, до одного километра или даже менее), а также потребует измерений по дополнительным переменным параметрам в меньших масштабах. При этом региональные сети наблюдений будут вносить свой вклад в глобальную сеть и одновременно пользоваться ее преимуществами.

Глобальная прибрежная сеть, способствующая повышению рентабельности региональных систем наблюдений и обеспечивающая их увязку друг с другом и с глобальными системами наблюдений за океаном и климатом, находится в центре внимания плана разработки КООП.

Развитие управления данными и продуктов – главная задача

Сокращение времени, требуемого для получения, обработки и анализа данных известного качества, является одной из основных целей, требующей развития комплексной подсистемы управления данными и коммуникации. Задача состоит в предоставлении данных как в режиме реального времени, так и в режиме отсрочки, а также в том, чтобы дать пользователям возможность использовать наборы множественных данных из многих различных источников. Это потребует широкой иерархической сети национальных, региональных и всемирных организаций, которая действует на основе общих стандартов, справочных материалов и протоколов по контролю качества и обеспечивает быстрый доступ к данным и управление ими (например стандарты метаданных), а также их долгосрочное хранение. Такая сеть будет развиваться по пути своего увеличения, подсоединяя и присоединяя к себе существующие национальные и международные центры данных и программы управления. Комитет МОК по международному обмену океаническими данными и информацией (МООД) и программная область ОКОММ, связанная с управлением данными, могли бы следить за скоординированным развитием такой комплексной подсистемы управления данными (глава 6).

Развитие системы наблюдений должно направляться группами пользователей, а также потоками данных и продуктов, которые им нужны. Одновременно быстрый доступ к многодисциплинарным данным из многих источников будет активизировать создание моделей и разработку продуктов. Таким образом, высокоприоритетное внимание следует уделить созданию механизмов привлечения групп пользователей на постоянной основе к определению продуктов и к созданию, работе и развитию прибрежного модуля.

Национальные программы и региональные альянсы ГСНО обеспечивают максимально эффективное и постоянное выявление групп пользователей, уточнение потребностей в данных и информации и доработку продуктов данных на основе обратной связи с пользователями и новых знаний. Основными средствами маркетинга и распространения информации в настоящее время служат Бюллетень продуктов и услуг ГСНО и Бюллетень ОКОММ. Они сообщают сведения о продуктах и мероприятиях по их разработке, предоставляя пользователям возможность высказать свои соображения о качестве и пользе продуктов ГСНО.

Подсистема наблюдений

Задачей предлагаемой глобальной сети является проведение измерений и деятельности по управлению в отношении сравнительно небольшого набора “общих” переменных параметров, которые требуются большинству региональных систем наблюдений, если не всем из них (глава 4, приложения IV и V). Хотя вполне вероятно, что общие переменные параметры будут выявляться по ходу развития и становления глобального объединения систем целесообразно определить предварительный набор переменных параметров, что помогло бы сориентировать разработку и реализацию глобальной при- брежной сети на начальном этапе. Рекомендуемыми общими переменными параметрами являются уровень моря, температура и соленость воды, векторные течения, волны на поверхности моря, растворенный кислород и неорганические питательные вещества, ослабление солнечной радиации, батиметрия, изменения береговой линии, объем и органическое содержание отложений, бентическая биомасса, биомасса фитопланктона и показатели фекального загрязнения. Эти переменные параметры были отобраны на основе потребностей в данных в рамках шести целей, а также на основе числа пользователей, которые были бы заинтересованы в получении таких данных и информации. Этот "умозрительный" перечень имеет важное значение в том плане, что он позволяет понять, какими могут быть общие переменные параметры, и указывает на необходимость наращивания потенциала с целью выявления изменений в биологических и химических переменных параметрах, а также разработки оперативных моделей для биогеохимических и экологических процессов. Физические силы, воздействующие на структуры и плавучие системы, играют важную роль с точки зрения предоставления морским операторам услуг по прогнозированию, и эти продукты уже хорошо разработаны и освещаются в других публикациях. Аспекты моделирования физических параметров излагаются в главе 5. С учетом важного значения экологических факторов для выявления и прогнозирования представляющих интерес явлений неудивительно, что они будут занимать ведущее место в предварительном списке для прибрежного модуля.

Для обеспечения потоков необходимых данных потребуется комплекс различной методики. Она разделяется на три общие категории: дистанционное зондирование (наблюдения с метеорологических спутников), автономные наблюдения на местах (серии по временным рядам наблюдений с высокой разрешающей способностью) и выборочные измерения с последующим лабораторным анализом (по многим химическим и биологическим переменным параметрам). Элементы подсистемы мониторинга должны включать следующее: (1) сети береговых лабораторий; (2) глобальную сеть мареографов; (3) неподвижные, заякоренные и автономные платформы; (4) научно-исследовательские суда, занимающиеся постоянными наблюдениями; (5) добровольные суда наблюдений; и (6) дистанционное зондирование с наземных платформ, спутников и самолетов.

Увязка наблюдений и моделей

Мониторинг и моделирование являются взаимозависимым процессом, и развитие полностью интегрированной системы потребует обеспечения постоянного синергетического эффекта между мониторингом, современной технологией и разработкой прогностических моделей (глава 5). Последние будут играть важнейшую роль в реализации, оперативной деятельности и развитии системы наблюдений. Они служат ценными средствами, использующимися для количественных оценок явлений, не подлежащих прямому наблюдению, то есть они позволяют прогнозировать прошлое, нынешнее и будущее состояние прибрежной морской среды и устьев рек, а также ошибки, связанные с таким прогнозированием. Отметим, что прогнозирование нынешнего состояния среды требует крайне быстрого представления и обработки данных в режиме реального времени или времени, близкого к реальному.

Обзор сегодняшнего состояния ассимиляции данных и моделирования в интересах морских служб и предупреждения стихийных бедствий, живых морских ресурсов, охраны здоровья населения и здоровья экосистем (глава 5) свидетельствует о высоком уровне моделирования в интересах морских служб и предупреждения стихийных бедствий по сравнению с имеющимися моделями для выявления и прогнозирования изменений явлений, которые требуют измерения биологических и химических переменных параметров. Это говорит о важном значении проведения научных исследований в поддержку развития прибрежного модуля.

Создание системы

Развитие и глобального океанического, и прибрежного компонентов ГСНО в решающей степени зависит от выборочной и эффективной увязки, укрепления и дополнения существующих программ (глава 7). Глобальная прибрежная сеть будет создана на основе комбинации национальных, глобальных и региональных процессов. Хотя некоторые элементы этой системы будут глобальными по своему масштабу с самого начала (например ГЛОСС, наблюдения из космоса), национальные и региональные системы наблюдений за прибрежной зоной будут компонентами создания глобальной прибрежной сети. Создаются региональные альянсы ГСНО для планирования и реализации региональных систем наблюдений, которые станут элементами создания гло-бального объединения систем (глава 3, раздел 3.1). К региональным альянсам ГСНО обращен призыв создавать прибрежный модуль путем установления, по мере необходимости, партнерских связей с национальными программами ГСНО, конвенциями о региональных морях, региональными органами по рыболовству, программами по крупным морским экосистемам и другими органами.

Реализация, оперативная деятельность и развитие устойчивой системы наблюдений, такой, как Всемирная служба погоды, потребуют правительственных механизмов для обеспечения того, чтобы системы или элементы систем, выступающие в качестве кандидатов, проходили четыре стадии развития:

1. развитие новых знаний, технологий и моделей путем проведения научных исследований;
2. постоянное тестирование в рамках пилотных проектов для обеспечения надежности этих знаний, технологий и моделей и их принятия научным и оперативным сообществами;
3. их использование на стадии, предшествующей оперативной, с целью гарантировать, что их интеграция в систему наблюдений приведет к появлению продуктов с добавленной стоимостью; и
4. их интеграция в систему оперативных наблюдений, обладающую устойчивостью.

Этот процесс должен носить селективный характер, причем следует установить критерии для перевода составляющих компонентов ГСНО из научно-исследовательской стадии в оперативную на основе потребностей пользователей. Первым шагом в реализации прибрежного модуля ГСНО должно быть более совершенное совместное использование существующих данных и продуктов элементов систем наблюдений, с тем чтобы начать их интеграцию в систему наблюдений. Исторические данные и сегодняшние потоки данных существуют в большом объеме, однако беспрепятственный доступ ко многим из них у большого числа потенциальных пользователей отсутствует.

Научные исследования и разработки, связанные с системой оперативных наблюдений

Научно-техническую основу для разработки прибрежного модуля обеспечивают научные программы, включая программы МПГБ (Взаимодействие между сушей и океаном в прибрежной зоне - ЛОИКЗ; Глобальная динамика океанических экосистем - ГЛОБЕК; Совместное изучение потоков мирового океана - СИПМО), Перепись морской жизни (СМЛ), Глобальная экология и океанография вредоносного цветения водорослей (ГЭОХАБ), международная программа “Долгосрочное изучение экосистем (И-ЛТЕР), а также программа “Взаимное сопоставление и объединение данных дистанционного зондирования в интересах междисциплинарных и океанических исследований” (СИМБИОЗ). Знания и технологии, создаваемые на основе этих и других научных программ, потребуются для всесторонней реализации системы наблюдений. Последняя же, в свою очередь, будет на постоянной и гарантированной основе обеспечивать экологические данные, представляющие огромную ценность для морских наук и образования в их области - во многом подобно тому, как данные, необходимые для прогнозов погоды, опираются на метеорологическую науку, а метеорологические прогнозы в цифровом формате пользуются достижениями экологических наук в целом.

Приоритеты для научных исследований и разработок будут включать следующие направления:

- разработка моделей экосистем для более быстрой ассимиляции и анализа биологических и химических данных. Задача состоит в создании на этой основе оперативных моделей для использования с целью направлять развитие системы, определять климатологии для общих переменных параметров и обеспечивать более современное выявление и прогнозирование изменений в явлениях, представляющих интерес;
- установление потребностей в дистанционном зондировании общих переменных параметров и развитие дистанционного зондирования в прибрежных водах. Дальнейшее развертывание сети спутников для наблюдений за океаном, а также разработка новых средств дистанционного зондирования в целях проведения более совершенных, с более высокой разрешающей

способностью, наблюдений за общими переменными параметрами в прибрежной среде;
- установление потребностей в наблюдениях на местах за основными переменными параметрами и укрепление возможностей для таких наблюдений в прибрежных водах, включая более быстрое измерение биологических и химических переменных параметров с более высокой разрешающей способностью и телеметрию в режиме реального времени.

Сотрудничество, координация и совместная деятельность

Комплексная стратегия глобальных наблюдений подразумевает создание трех взаимосвязанных систем наблюдений: Глобальной системы наблюдений за климатом (ГСНК), Глобальной системы наблюдений за сушей (ГСНС) и Глобальной системы наблюдений за океаном (ГСНО), которые вкупе носят название ГСН-3. В перспективе прибрежного модуля ожидается, что ГСНС будет обеспечивать данные, необходимые для количественного измерения параметров атмосферных явлений, ГСНС - явлений на суше, а глобальный океанический модуль ГСНО - данные, касающиеся пограничных условий в открытом океане, и данные, необходимые для количественного измерения параметров явлений в масштабе бассейнов.

Реализация прибрежного модуля потребует высокого уровня сотрудничества, координации и совместной деятельности стран и существующих программ для обеспечения формирования глобальной системы по мере того, как к ней будут присоединяться все новые и новые национальные и региональные системы. Важнейшим аспектом этого процесса будет согласование потребностей в глобальной координации с потребностями пользователей, основывающимися на национальных и региональных приоритетах. В настоящее время нет официального международного механизма, который направлял бы этот процесс и способствовал его развитию. Для содействия заключению многосторонних соглашений и решения правовых вопросов, связанных с осуществлением ЮНКЛОС и других международных конвенций, потребуется создать межправительственную комиссию, подобную Объединенной технической комиссии по океанографии и морской метеорологии (ОКОММ), вместе с соответствующими консультативными органами.

Prologue

The Mandate to Establish a Global Ocean Observing System

Intergovernmental agreements that provide the legal basis for GOOS or stipulate national obligations for cooperation include (1) the 1982 UN Convention on the Law of the Sea (UNCLOS, including the 1995 U.N. Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks), (2) Regional Seas Conventions, (3) the Jakarta Mandate, (4) the Ramsar Convention on Wetlands, (5) the Global Plan of Action on Land-Based Sources of Pollution, (6) the Safety of Life at Sea (SOLAS) Convention, (7) the Second World Climate Conference, and (3) two conventions and a programme of action signed at the 1992 UN Conference on Environment and Development (UNCED) in Rio de Janeiro (the Framework Convention on Climate Change, Convention on Biodiversity, and the Programme of Action for Sustainable Development or *Agenda 21*).

The mandate to establish a Global Ocean Observing System (GOOS) was articulated and ratified as an international consensus in 1992 with the signing of the Framework Convention on Climate Change, the Convention on Biodiversity, and the Programme of Action for Sustainable Development (*Agenda 21*) at the UN Conference on Environment and Development (UNCED) in Rio de Janeiro. In particular, *Agenda 21* calls for the establishment of a global ocean observing system that will enable effective management of the marine environment and sustainable utilization of its natural resources. Effective management and sustained utilization of the marine environment and its resources depend on our ability to detect and predict changes in the status of coastal ecosystems and living resources and their socio-economic consequences. We do not have this capability today. Successful implementation of the observing system will increase the value to society of research and monitoring in marine and estuarine ecosystems, in part by providing the data and information required to meet the conditions of existing international treaties and conventions and in part by providing the means to routinely assess and anticipate changes in the status of coastal ecosystems and living resources on national to global scales.

Design and Implementation

The development of GOOS requires an internationally accepted framework for linking, enhancing and supplementing existing monitoring and research programmes. Agencies of the UN, including the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the United Nations Environment Programme (UNEP), and the World Meteorological Organization (WMO), are working together, and with the International Council for Science (ICSU), as Sponsors, to design and implement the GOOS. GOOS is one component of the Integrated Global Observing Strategy (IGOS) that also serves the space agencies through the Committee on Earth Observation Satellites (CEOS), the Integrated Geosphere-Biosphere Programme (IGBP), and the World Climate Research Programme (WCRP). In addition to GOOS, IGOS comprises the Global Climate Observing System (GCOS), the Global Terrestrial Observing System (GTOS), the World Weather Watch (WWW), and the Global Atmosphere Watch (GAW).

The effort to design the system and make the transition from concept to reality is led by the GOOS Steering Committee (GSC). Overall responsibility for the development of GOOS is delegated by the Sponsors to the IOC, which is advised by the joint IOC-WMO-UNEP Intergovernmental Committee for GOOS (I-GOOS). I-GOOS is responsible for the formulation of policies and assists in gaining government approval of and support for implementation. The system is being developed by the Ocean Observations Panel for Climate (OOPC) and the Coastal Ocean Observations Panel (COOP). COOP is the result of the merger of the Coastal-GOOS (C-GOOS), Health Of The Oceans (HOTO), and Living Marine Resources (LMR) panels (IOC, 1998a).

In 1999, an Action Plan was formulated for coordinating the *in situ* and satellite-based observations required to improve global scale weather forecasting (e.g., ENSO events and their effects regional patterns of rainfall and the frequence of tropical cyclones) and long-term climate predictions (IOC/WMO, 1999). The Action Plan gave rise to the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) by the IOC and the WMO. For the first time, coordination of and commitments for operational oceanography are under the aegis of an intergovernmental organization. JCOMM-1 met in Iceland in 2001.

The Coastal Module of GOOS

The design and implementation of the coastal module of GOOS will significantly improve the ability of participating nations to achieve their goals and the goals of international agreements and conventions for environmental protection, sustainable resources, healthy coastal marine and estuarine ecosystems, safe and efficient marine operations, and periodic assessments of the status of marine ecosystems. To these ends, the terms of reference for the Coastal Ocean Observations Panel are as follows:

(1) Integrate and refine the design plans drafted by the HOTO, LMR, and the C-GOOS panels to develop a unified plan for a coastal module of GOOS that will provide the data and information required for more rapid detection and timely prediction of the effects of global climate change and human activities on

- coastal marine services (safe and efficient marine operations and coastal hazards);
- public health and safety;
- the health of coastal marine and estuarine ecosystems; and
- the sustainability of living marine resources.

(2) The unified plan shall be consistent with the GOOS Design Principles.

(3) Develop mechanisms for more effective and sustained involvement of user groups in the design and implementation of the coastal module of GOOS.

(4) Develop mechanisms that enable effective synergy between research and the development of a sustained observing system for coastal marine and estuarine ecosystems.

(5) Formulate an implementation plan that is coordinated with the OOPC plan for climate services, research and marine services with due emphasis on

- integrated observations;
- data and information management;
- data assimilation and modelling for the pur poses of prediction and product develop ment;
- capacity building; and
- national, regional, and global promotion of objectives and benefits of the observing system.

(6) Establish criteria and procedures for selecting observing system elements on global and regional scales, and recommend the elements that will constitute the initial observing system.

(7) Define procedures for ongoing evaluation of system components, reliability of data streams, access to data, and applications.

The design of coastal GOOS must take into account the changing mix of ecosystem types that constitute the coastal environment in different regions of the world and the time-space scales that characterize the phenomena of interest within them. In addition, although the emphasis is on "coastal", the terms of reference for COOP make it clear that the observing system should extend into the deep sea to the extent that global carbon and nitrogen cycles, fisheries, the transport and effects of contaminants, and mineral exploration and extraction are not restricted to coastal ecosystems. Consequently, the boundary between coastal and deep-sea ecosystems cannot be fixed geographically and will depend on the nature of the phenomenon to be detected or predicted. In archipelago seas and semi-enclosed sea basins the coastal module of GOOS will observe the whole sea basin from coast to coast between adjacent states.

1. Introduction

The importance of establishing the coastal module is related to two global patterns: (1) ecosystem goods and services are concentrated in coastal marine and estuarine systems relative to terrestrial and open ocean systems (Costanza et al., 1997; Daily et al., 2000); and (2) the number of people living, working, and playing within 100 km of the coastline is high and increasing rapidly relative to more inland locations (Hinrichsen, 1998; Small et al., 2000; Nicholls and Small, 2002). Today, there are over 5 billion people on earth, about 38% of whom live in the coastal zone within 100 km of the coastline at elevations less than 100 m (Small and Nicholls, 2003). The global population is predicted to more than double by 2050 with the greatest increases occurring in the coastal zone (United Nations, 1996). As the number and density of people living in the coastal zone increases, the demands on coastal systems to support commerce, living resources, recreation, and living space and to receive, process, and dilute the effluents of human society will continue to grow, e.g., land-based sources account for about 80% of the annual input of contaminants to the coastal ocean (UNEP, 1995).

Coastal ecosystems are experiencing unprecedented changes as indicated by the occurrence of or increases in a diversity of phenomena that represent a broad spectrum of variability in time, space and ecological complexity (Table 1.1). Apparent increases in the occurrence of many of these phenomena indicate profound changes in the capacity of coastal ecosystems to support goods and services. They are making the coastal zone more susceptible to natural hazards, more costly to live in, and of less value to national economies. Thus, it is likely that, in the absence of a system for improved detection and prediction of the phenomena of interest and their environmental and socio-economic affects, conflicts between commerce, recreation, development, environmental protection, and the management of living resources will become increasingly contentious and politically charged. The social and economic costs of uninformed decisions will increase accordingly (Chapter 2).

1.1 Purpose and Scope

The purpose of the coastal module of GOOS is to establish a sustained and integrated ocean observing system that makes more effective use of existing resources, new knowledge, and advances in technology to provide the data and information required to:

(1) Improve the safety and efficiency of marine operations;
(2) More effectively control and mitigate the effects of natural hazards;
(3) Improve the capacity to detect and predict the effects of global climate change on coastal ecosystems;
(4) Reduce public health risks;
(5) More effectively protect and restore healthy ecosystems; and
(6) More effectively restore and sustain living marine resources.

Table 1.1. Drivers of change (natural and anthropogenic forcings) and associated phenomena of interest in coastal marine ecosystems that are the subject of the coastal module of GOOS. Much of the reasoning behind this table is explained later in Chapters 4 and 5, and Annexes III and IV. Although a distinction is made between natural and anthropogenic forcings, there are few if any "natural" forcings that do not have a human signature of some sort (e.g., climate change, river and ground water discharge, nutrient enrichment). Sea ice and certain tropical phenomena are omitted because they are not truly global in occurrence (Chapter 3; Figure 3.1).

	FORCINGS
"Natural"	• Global warming and sea level rise • Storms and other extreme weather events • Seismic events • Ocean scale currents • Waves, tides and storm surges • River and ground water discharges
Anthropogenic	• Physical restructuring of the environment • Alteration of the hydrological cycle • Harvesting living and nonliving resources • Alteration of nutrient cycles • Sediment inputs • Chemical contamination • Inputs of human pathogens • Introductions of non-native species
	PHENOMENA OF INTEREST
Marine Services, Natural Hazards and Public Safety	• Fluctuations in sea level • Changes in sea state • Changes in surface and sub-surface currents • Coastal flooding events • Changes in shoreline and shallow water bathymetry
Public Health	• Seafood contamination • Increasing abundance of pathogens (in water, shellfish)
Ecosystem Health	• Habitat modification and loss • Changes in biodiversity • Eutrophication • Changes in water clarity • Harmful algal events • Invasive species • Biological affects of chemical contaminants • Disease and mass mortalities of marine organisms • Chemical contamination of the environment
Living Resources	• Abundance of exploitable living marine resources • Harvest of capture fisheries • Aquaculture harvest

Achieving these goals depends on more timely detection and prediction[2] of local phenomena that reflect the structure and function of coastal[3] ecosystems and the external forcings that impinge on them (Table 1.1). This requires observations and estimates (usually model calculations) of physical and ecosystem properties and processes, of interactions among coastal marine and estuarine ecosystems, and of exchanges across the land-sea boundary, the air-sea interface, and the boundary between shelf and deep-sea waters (Figure 1.1). Thus, the design of the coastal module of GOOS must take into consideration both the complex nature of the coastal environment and the multiple forcings that impinge on them (e.g., Chelton et al., 1982; Steele, 1985; Powell, 1989; NRC, 1994; Cloern, 1996).

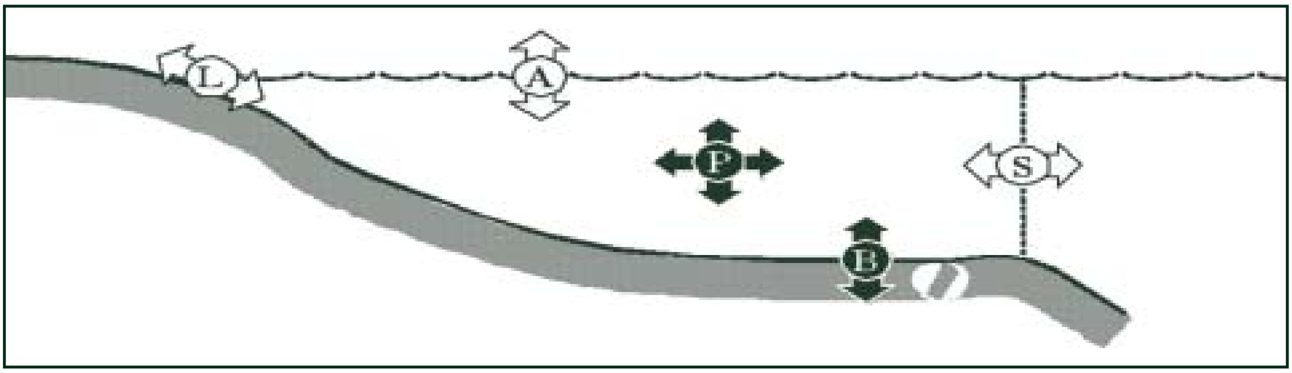

Figure 1.1. Changes in the phenomena of interest reflect both the internal (physical, biological, chemical and geological) dynamics of coastal ecosystems and exchanges of energy and matter with terrestrial, atmospheric and deep ocean systems. This schematic reflects the context of limited-area numerical models used to predict changes in properties and processes. To understand and predict changes in coastal ecosystems, it is often necessary to quantify the states and rates of exchanges at the land-sea boundary (L), the air-sea interface (A), and the boundary used to delineate the coastal environment and the deep sea (S). Within coastal ecosystems, both benthic (B) and pelagic (P) properties and processes must be measured.

1.2 Large Scale External Forcings

Although the phenomena of interest tend to be local in scale, they are globally ubiquitous a pattern that suggests they are, more often than not, local expressions of larger scale forcings of natural origin, anthropogenic origin, or both. External forcings include inputs of energy (e.g., winds, tides, currents and waves, solar radiation) and materials (e.g., freshwater, sediments, nutrients, organic matter, contaminants, organisms) from terrestrial, atmospheric, and oceanic sources (Figure 1.1). In addition to the combined effects of these inputs, the effects of human activities are increasing rapidly in magnitude and complexity due to changing inputs related to rapid increases in population density, human alterations of hydrological and nutrient cycles and associated increases in the inputs of nutrients and contaminants from land-based sources, destruction of marine and estuarine habitats, commercial and recreational fisheries, and introductions of invasive species and pathogens. Large scale forcings that impact socio-economic systems, coastal ecosystems, and living marine resources include the following:

- Basin scale oscillations such as the El Niño-Southern Oscillation (e.g., Barber and Chavez, 1986; Dayton and Tegner, 1984; Wilkinson et al., 1999; Kudela and Chavez, 2000; Arcos et al., 2001), the North Pacific Decadal Oscillation (e.g., Francis and Hare, 1994), and the North Atlantic Oscillation (e.g., Pearce and Frid, 1999);

- Global climate change including global warming, sea level rise, and changes in the hydrological cycle (e.g., Bolin et al., 1986; Mikolajewicz et al., 1990; Barry et al., 1995; Warrick et al., 1996; Najjar et al., 2000);

2 For the purposes of the coastal module of GOOS, "prediction" is defined in its broadest sense to include nowcasts and forecasts as well as estimates (interpolating, extrapolating) of quantities or distributions that are not directly observed.

3 For the purposes of the coastal module, "coastal" refers to regional mosaics of habitats including intertidal habitats (mangroves, marshes, mud flats, rocky shores, sandy beaches), semi-enclosed bodies of water (estuaries, sounds, bays, fjords, gulfs, seas), benthic habitats (coral reefs, seagrass beds, kelp forests, hard and soft bottoms) and the open waters of the coastal ocean to the seaward limits of the Exclusive Economic Zone (EEZ), i.e., from the head of tide to the outer limits of the EEZ. The "coastal zone" refers to the land margin within 100 km of the coastline or less than 100 m above mean low tide, which ever comes first (Small et al., 2000; Nicholls and Small, 2002).

- Changes in inputs of water, sediments, nutrients and contaminants (chemicals and pathogenic organisms) from coastal drainage basins due to human activities (e.g., Limburg and Schmidt, 1990; Vitousek et al., 1997; Jickells, 1998; Howarth et al., 1991; Howarth et al., 2000);
- Extraction of living marine resources (e.g., Houde and Rutherford, 1993; Pauly et al., 1998; Jackson et al., 2001); and
- Introductions of human pathogens, non-native species, and oil spills related to the globalisation of commerce (e.g., shipping – ballast water discharge, seafood shipments) and the translocation of species from one region to another (e.g., Carlton, 1996 and references therein).

The importance of quantifying these forcings in the design of the coastal module of GOOS underscores the need for an integrated approach that coordinates the development of the coastal module of GOOS with the ocean-climate module, GTOS (Annex VI), and the development of the IGOS.

1.3 Ecosystem Dynamics

The structure and function of marine ecosystems are, to a great extent, dependent on physical processes. Changes in biological, chemical and geological properties and processes are related through a hierarchy of physical-ecological interactions that can be represented by robust models of ecosystems dynamics (Section 5 and Nihoul and Djenidi, 1998; Hofmann and Lascara, 1998; Rothschild and Fogarty, 1998; Robinson, 1999; Liu et al., 2000; Cloern, 2001, Moll and Radach, 2001). Coastal ecosystems are constrained by irregular coastlines and a shallow, highly variable bathymetry. Within coastal ecosystems, interactions between intertidal, benthic and pelagic communities enhance nutrient cycles, primary productivity and the capacity of coastal ecosystems to support goods and services relative to oceanic systems. Physical and biological processes resonate over shorter time scales (higher frequencies) and over a broader spectrum of variability compared to both terrestrial and deep, open ocean systems. Consequently, populations and processes in coastal ecosystems are more variable on smaller space and shorter time scales than is typical for either oceanic or terrestrial ecosystems.

The time-space relationships of turbulent mixing, generation times of marine organisms, life histories, home ranges, and trophic dynamics suggest a close coupling between physical and biological processes over a broad range of time (hours - decades) and space (1 -1000 km) scales (Figure 1.2). Biological and physical processes exhibit characteristic scales of variability that are related in a multidimensional continuum of time, space and ecological complexity (Gardner et al., 2001), i.e., large spatial scales tend to be associated with long time scales and with greater biodiversity, and small scales tend to be associated with short time scales and with less biodiversity (e.g., Odum, 1971; Diamond and May, 1976; Steele, 1985; Dickey, 1991; Costanza et al., 1993). On the scale of the ocean basins and their circulations, the distribution and abundance of species are related to water mass distributions, large scale current regimes, mesoscale eddies, and frontal systems. At smaller scales, the abundance and distribution of organisms are related to interactions between turbulent mixing and biological attributes such as motility, mechanisms of nutrient uptake and feeding, and patterns of reproduction and development. Thus, the scale-dependent linkage of ecological processes to the physical environment is fundamental to understanding and predicting spatial and temporal variability and pattern (e.g., variance spectra and fragmentation, time-space substitution) and size-dependent trophic interactions from small organisms with short generation times (e.g., bacteria and phytoplankton) to large organisms with longer generation times (e.g., macrobenthic and fish populations).

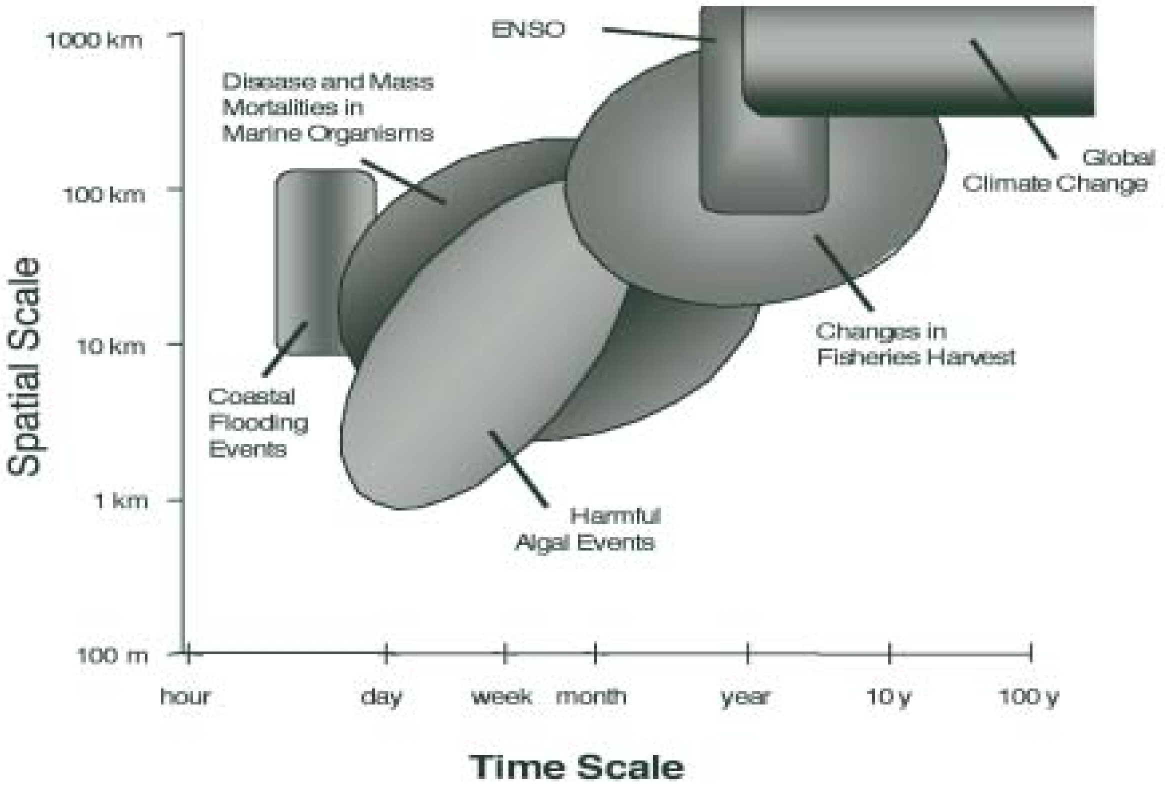

Figure 1.2. Temporal and spatial scales for selected forcings and phenomena of interest. The forcings and phenomena of interest exhibit characteristic scales of variability that, when taken together, form a broad continuum of variability from hours to decades and meters to thousands of kilometres. Most of the phenomena of interest are local expressions of larger scale forcings of natural origin, anthropogenic origin, or both. Thus, a broad spectrum of variability from global to local scales must be observed to quantify and predict the effects of large scale forcings on coastal ecosystems.

1.4 An Ecosystem-Based Approach

Clearly, changes in or the occurrence of the phenomena of interest reflect both the structure and function of coastal ecosystems and the external forcings that impinge on them. Thus, managing and mitigating the effects of human activities and climate in an ecosystem context is emerging as a unifying theme for environmental protection, resource management, and integrated coastal area management (NRC, 1999a and b; Sherman and Duda, 1999; UNEP, 2001; and Chapter 2 of this report). Implementing an ecosystem-based approach requires the ability to engage in adaptive management[4], a process that depends on the capability to routinely and rapidly detect changes in the phenomena of interest and to provide timely predictions of them. We do not have this capability today. While many physical processes are forecast on a routine basis, the frontier of development, and the biggest demand, is for operational ecosystem models required for adaptive management.

[4] The formulation and implementation of environmental policies is an iterative procedure that acknowledges uncertainty rather than the implementation of "static" answers. Adaptive management is the process by which decisions are made based on the current state and projected changes in the state of the environment, as well as on economic and social considerations. Implementation of the adaptive management approach requires continuous monitoring and rapid assessments of changing ecological and economic conditions.

BOX 1.1. FISHERIES MANAGEMENT

The Intergovernmental Reykjavik Declaration on Responsible Fisheries committed signatory States, inter alia, to "advance the scientific basis for developing and implementing management strategies that incorporate ecosystem considerations and which will ensure sustainable yields while conserving stocks and maintaining the integrity of ecosystems and habitats on which they depend." Thus, ecosystem-based fishery management explicitly takes into account fishing effects on critical habitat, trophic structure and ecosystem function, and the role of physical environmental forcing. In this context, the "Workshop on the Ecosystem Approach to Management and Protection of the North Sea" (Oslo, 15-17 June, 1998) identified monitoring as a key component of an ecosystem approach (Sætre et al., 2001).

Although efforts to understand fisheries in an ecosystem context have increased in recent years, species-specific management continues to be the norm in most regions. However, the global escalation in fishing pressure on fish populations and increasing recognition of the importance of direct and indirect effects of fishing on the carrying capacity of ecosystems for living resources has led to greater emphasis on learning how to manage fisheries in an ecosystem context (NRC, 1999a; UNEP, 2001).

Preservation of biodiversity is an essential component of this approach. Ecosystem-based management seeks to overcome the limitations of single-species management which does not account for the effects of harvesting both target and non-target species, of changes in trophic dynamics, and of habitat-related impacts. Ecosystem-based management is predicated on the recognition that ecosystems provide a broad spectrum of goods and services that are essential to the integrity of the biosphere and to human welfare. Management of living marine resources, therefore, requires consideration of both the need to sustain harvests and the need to sustain ecosystem processes that support biodiversity and maintain water quality.

A new approach is needed that enables adaptive management through routine, continuous and rapid provision of data and information over the broad spectrum of time-space scales required to link ecosystem (local) scale changes to basin and global scale forcings. We are, in fact, on the cusp of a revolution that will make such an approach feasible. The revolution is occurring on two related fronts: (1) advances in observing and modelling capabilities and (2) the emergence of operational oceanography. Key drivers of rapid increases in observing and modelling capabilities are advances in data communications and computing power; remote and *in situ* sensing; the capacity to measure key physical, biological and chemical variables synoptically in time and space; and methods for linking observations to models. These advances are, for the first time, making it possible to visualize changes in the four dimensions of space and time and to quantify the effects of anthropogenic and climatic forcings. The time is right to establish an integrated ocean observing system that capitalizes on current and emerging technologies and knowledge.

1.5 THE RESEARCH BASE

The diversity of issues to be addressed and their complex and interdisciplinary nature also underscore the importance of synergy between research programmes and the development of the coastal module. Research programmes and observing systems are mutually dependent processes that define a continuum of related activities. The observing system will be of limited value if it is not based on sound science and designed to improve through research and development (improved understanding, models, sensor technologies, assimilation techniques). Likewise, research is of limited value if it is not conducted in the context of larger scale observations in both time and space (long term time-series, synoptic observations on large spatial scales). Although both research programmes and observing systems may have many elements in common, the development of the observing system is driven by societal needs while research programmes are driven by scientific hypotheses. The purpose of the observing system is to detect and predict patterns of change. In contrast, the purpose of environmental research is to test hypotheses concerning the causes and consequence of environmental changes. Thus, environmental research programmes are finite in duration while the observing system must be sustained in perpetuity. These considerations have important implications for the design and implementation of the observing system.

1.6 Cooperation, Coordination and Collaboration

Establishing the coastal module of GOOS requires unprecedented levels of cooperation, coordination and collaboration among government ministries and agencies, regional bodies, and existing research and monitoring programmes. By building on existing activities, capabilities, and infrastructure, and by using a phased implementation approach, work can start immediately to achieve the vision. New technologies, past investments, evolving scientific understanding, advances in communications and data processing, and pressing societal needs combine to provide both the opportunity and the motivation to initiate an integrated observing system for coastal waters immediately. The major pieces missing are an internationally accepted global design; international commitments of assets and funds; and partnerships among nations, regional associations, institutions, data providers and users.

This report proposes the strategic design for the global component of the coastal module of GOOS. It is divided into three sections: (1) rationale and goals (Prologue, Chapters 1 and 2), (2) design (Chapters 3, 4, 5 and 6), and (3) initial guidelines for formulating an Implementation Plan (Chapter 7). The plan presents a vision for the coastal module of GOOS; defines the three subsystems that constitute an integrated system of observations, data management and analysis; and describes how they relate to each other to achieve an operational system. It articulates a framework for coordinating the development of an international system that makes more cost-effective use of collective resources to assess the state of the marine environment, to detect changes more rapidly, and to provide more timely predictions of changes and their impacts on society. This is the first step toward the formulation of an implementation plan which is expected to be completed by the end of 2004.

2. Coastal Ecosystems: The Human Dimension

As discussed in Chapter 1, increasing human activity in the coastal zone is a major driver of changes in the phenomena of interest in coastal waters. The latter are related to rapid increases in population density, human alterations of hydrological and nutrient cycles and associated increases in the inputs of nutrients and contaminants from land-based sources, destruction of marine and estuarine habitats, commercial and recreational fisheries, and introductions of invasive species and pathogens. A recent report by the United Nations Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) concludes that, although there have been some notable successes in controlling the effects of human activities on land-based sources of marine pollution that have improved water quality in some coastal ecosystems (e.g., sewage treatment in developed countries), the global degradation of the marine environment continues and is intensifying in many places (GESAMP, 2001a).

Beginning with a summary of human demographics and the value of coastal ecosystems, this chapter describes a broad spectrum of human activities and related environmental changes, the management of which would benefit from an integrated ocean observing system. Emphasis is placed on human activities and their impacts on marine and estuarine ecosystems rather than on the market value of goods and services provided by coastal systems. Improvements in safety and efficiency marine operations that depend primarily on the measurement and analysis of physical variables are discussed elsewhere (e.g., Adams et al., 2000; Droppert et al., 2000).

Human activities and their environmental consequences are treated in five broad categories: (1) human modifications and physical alterations of the coastal zone and associated contaminant inputs; (2) introductions of non-native species; (3) oil spills; (4) human health risks; and (5) harvesting living marine resources. The central theme is the role of human-induced stressors in the coastal environment. Although the potential consequences of sea level rise are not addressed explicitly, the effects of human activities on coastal habitats should be considered in this context. Most estimates of global mean sea level rise are in the range of 38 to 55 cm over the next 100 years (Warrick et al., 1996). According to Nicholls and Leatherman (1995), a 1 m rise in sea level (the worse case scenario) will affect 6 million people in Egypt with a loss of 15% of agriculture land, 13 million in Bangladesh with a drop of 16% in rice production, and 72 million in China with a loss of a million km^2 or more of agriculture land. In addition to direct land-loss, sea level rise is expected to exacerbate current trends of habitat loss (tidal marshes, sea grasses, coral reefs) and declines in fisheries, alter erosion patterns, damage coastal infrastructure, contaminate wells and coastal aquifers with salt, and affect the efficiency of sewage treatment systems in coastal cities with resulting impacts on public health (WHO, 1996).

2.1 Human Population Dynamics

2.1.1 Population Growth in the Coastal Zone

The rapid increase in population density along the world's 450,000 km of coast line (Pinet, 1999) is a striking feature of human demographics that characterizes the last 2000 years of human development and growth (Chapter 1). The present population of coastal areas exceeds the total global population of just fifty years ago (Bowen and Crumbley, 1999).

Although estimates of the proportion of the human population living in the coastal zone vary widely (30% – 50%, e.g., GESAMP, 2001b; Small and Nicholls, 2003; Shuval, 2003), it is clear that coastal populations are large and growing rapidly within 100 km of the coastline at altitudes less than 100 m (Small et al., 2000). The rapid increase in population density along the world's coastlines reflects both indigenous growth and migrations from inland areas (NOAA, 1998). The latter is a consequence of seasonal increases in population (tourism, migrant workers) and more permanent increases as migrants become residents.

The last decades of the 20th Century witnessed unprecedented growth in tourism and recreation along the shoreline. By most measures, recreational use of the coastal zone has become the world's largest economic sector and a major source of revenue for infrastructure development and improvement. The World Tourism Organization estimates nearly 700 million international arrivals during 2000, an increase of 7.4 % over 1999. Receipts from international tourism are estimated to be 476 billion USD, a growth of 4.5 % over the previous year. Since 1985, the number of international tourist arrivals has more than doubled.

BOX 2.1. POPULATIONS AT RISK

Coastal populations are impacted by a variety of natural hazards including erosion, saltwater intrusions, subsidence, tsunamis and floods due to both storm surges and rivers. Exposure to such natural hazards is expected to increase due to both increases in population density in low lying coastal areas and the effects of global climate change (e.g., sea level rise and possible increases in the frequency of extreme weather events). Recent estimates of the global distribution of people show the following (Nicholls and Small, 2002; Small and Nicholls, 2003):

(1) The number of people inhabiting the near-coastal zone (within 100 km of the shoreline – distance – and 100 m of mean sea level – height) is about 1.9 10^9 or about 38% of the 1990 global population (a figure that is considerably lower than is often quoted, e.g., Hinrichsen, 1998).

(2) About 40% of the near-coastal population inhabits 4% of the near-coastal land area at local populations densities of about 1,000 people km^2. The most densely populated near-coastal areas are in Europe and south, southeast and east Asia. Thus, despite the concentration of people near coasts, the majority of land area within the near-coastal zone is relatively sparsely populated.

(3) While eleven of the world's fifteen largest cities (> 10,000 people km^2) are located in the near-coastal zone, only about 10% of the near-coastal populations live in these cities. Most of the exposed population is in small cities and in rural settings such as densely populated deltaic areas (1,000 people km^2). However, urbanization is expected to continue at rapid rates, and these patterns are likely to change.

Although analyses such as this reveal important patterns, there is considerable uncertainty associated with these and other estimates of population densities in the coastal zone (Small et al., 2000). We know that coastal populations are growing and urbanizing, but current exposure to natural hazards is poorly quantified. This is partly due to the lack of a consistent definition of the "coastal zone." In addition, while quantifying populations exposed directly to natural hazards is conceptually straightforward, indirect exposure, including wider socio-economic impacts, is not. For example, storm surges directly affect life and livelihoods within a short distance of the shoreline while indirect impacts may be much broader if infrastructure and services such as waste water treatment facilities, ports, agriculture, and power plants are incapacitated.

More accurate estimates of population distribution are not only important for estimating risks of exposure to natural hazards, they provide a measure of the direct human pressure on the coastal zone. Consequently, improved estimates of coastal population and hazard exposure would benefit many user groups from the insurance industry and policy makers responsible for sustainable development to those concerned with improving regional estimates of the effects of global climate change and the design of global observing systems.

Coastal migration is associated with significant cultural transformations in the countries experiencing it. Most migration is from rural to urban environments. Two thirds of cities with over 2.5 million inhabitants and 14 of the world's "megacities" (> 10 million people) are within 100 km of the coast. The rapid growth of large cities along the coastline is associated with unique cultural, economic, and environmental characteristics and problems (World Bank, 1991; UN, 1998). As described in the following sections, the development of coastal megacities and the rapid increase in number of people in the coastal zone are causing changes in coastal ecosystems that are important to the health, safety and well being of human populations on a global scale.

2.1.2 Value of Ecosystem Goods and Services in the Coastal Zone

Recognition of the unintended consequences of human activities on coastal ecosystems has led to increased interest in understanding the costs of environmental degradation and the value of more enlightened management. A major reason people are attracted to coastal environments is related to access to goods and services from natural resources and recreation, to aesthetic appreciation (Table 2.1). Based on a comprehensive assessment of the value of ecosystem goods and services on a global scale, Costanza et al. (1997) concluded that their global value is on the order of 33 trillion USD per year. Significantly, their estimates suggest that marine ecosystems provide 64% of these goods and services with coastal systems, which account for about 10% of the world's surface area, providing 38% of the global total. Although controversial, this and other analysis (e.g., Daily et al., 2000) clearly establish the importance of coastal ecosystems in terms of their value to society.

Major efforts have been initiated to refine such estimates and to develop an accepted methodology for determining the value of non-marketable goods and services. An approach gaining broad support within the coastal community is the establishment of ecosystem values based on three categories of use (Turner and Adger, 1995; Turner, et al., 2000; Cesar, 2000). As summarized in Table 2.1, direct use values are market-based; indirect use values are goods and services provided by ecosystems that cannot be bought and sold in the market place; and non-use values are based on cultural and aesthetic factors that transcend the view of nature as a collection of marketable objects. Natural systems hold intrinsic values that can only be articulated in their contribution to social, cultural, psychological, and aesthetic needs. It is only through recognition that natural systems provide value through all three of these classes that an effective assessment can be made of their value to society. Table 2.1 summarizes these categories as they are related to these critical coastal habitats. Similar tabulations could be made for other coastal habitats such as tundra coasts, polar coasts, Mediterranean coasts, etc.

Table 2.1. Values provided by coral reefs, tidal marshes and mangrove forests.

DIRECT USE VALUES	
Capture Fisheries	• Provide protected, spawning environment for commercially and recreationally valuable species. Seventy-five percent of commercially caught species in tropical systems spend some time in mangroves or are dependent on food chains traced to mangrove systems. Coral environments provide up to 25% of total fin-fish production in developing countries (Souter and Linden, 2000).
Tourism/Recreation	• Provide active recreational values to recreational divers and hunters. Provide passive recreations value to naturalists. Florida reefs contribute an estimated 1.6 billion USD to local economies (Birkeland, 1997).
Manufactured Products	• Provide hardwood for construction, charcoal and wood chips (mangroves). Provide coral jewellery and construction material for jetties and other coastal structures, (corals).
Pharmaceutical and Biotechnology Products	• Provide a rich resource for the development of medicines and other products. Half of all cancer research is concentrating on active compounds from marine organisms (Fenical, 1996).
INDIRECT USE VALUES	
Flood Protection/Coastal Stabilization	• Provide flood control for coastal and estuarine systems and shoreline protection from erosion by oceanic swells and tropical storms. Estimates in eastern England estimate the stabilization and protection value of coastal river wetlands at 45 USD per meter of bank (RAMSAR, 2001). Near Boston, the flood control value of the 3,800 hectares of the Charles River are estimated to provide 17 million USD annual value (Tiner, 1984).
Nutrient Cycling/Toxics Retention	• Provide depositional environments for sediment-bound nutrients. Wetland plants recycle nutrients limiting introduction to coastal waters. For certain toxics wetland systems can serve to reduce inputs to coastal/marine waters.
Groundwater Replenishment	• Provide replenishment to underground aquifers. In Florida, a single 223,000 hectare swamp has been valued at 25 million USD per year for freshwater recharge/storage value (RAMSAR, 2001).
Biological Support/Habitat	• Provide value in the form of biodiversity.
NON-USE VALUES	
Cultural and aesthetic	• Provide cultural and aesthetic value that help define the history and culture of coastal communities.

2.2 Physical Alterations of the Coastal Zone

Habitat modification and loss are among the clearest effects of increasing human activities in the coastal zone. A comprehensive treatment of this subject and associate contaminant inputs and their effects is not attempted here. Rather, examples given below illustrate the broad scope of human impacts on coastal habitats. We emphasize that the message is not to forego development in the coastal zone, but to engage in scientifically informed development that considers both critical (short-term) and chronic (long-term) impacts of human activities on environmental quality and the quality of life. Sustained development of the coastal zone requires sustained observations that provide the data and information needed to realize the benefits of fostering a symbiotic relationship between economic vitality and ecosystem health.

2.2.1 Land-use and Land-based Sources of Pollution

Recognizing that the Global Terrestrial Observing System (GTOS) will explicitly address land-use practices and that coordination with GTOS is critical to achieving the goals of GOOS (Annex VI), this section provides an overview of land-use practices in the coastal zone that significantly affect coastal marine and estuarine ecosystems by modifying or destroying critical habitats or by altering fluxes of water, sediments, nutrients, chemical contaminants, and human pathogens from land to estuarine and marine systems. A thorough review of land-based sources and human activities affecting the health and uses of coastal marine and estuarine systems may be found in GESAMP (2001a). Three categories of land-use are discussed: urban development, the construction of dams, and agriculture.

Urban development (including the construction of roads and causeways, land reclamation, and hardening the shoreline) and agriculture alter the coastal zone through deforestation and the destruction or modification of critical habitats including tidal wetlands (mangrove forests, marshes, mud flats) and coral reefs. It has been estimated, for example, that 50% of the world's tidal wetlands have been lost due to human activities (Spalding et al., 1997; Kelleher et al., 1995; Gilbert and Janssen, 1998; Mitsch et al., 1994; Tiner, 1984; CEC, 1995). Such changes not only cause declines in species diversity and living resources, they make coastal populations more susceptible to natural hazards; increase the fluxes of water, sediments and nutrients from land to the sea; and decrease the aesthetic value of coastal environments.

The construction of dams has been practiced for thousands of years as a means to store water for human consumption and irrigation, control flooding, and generate electricity. At least 45,000 dams have been built, and nearly half of the world's rivers have at least one large dam (5-15 meters high with reservoirs of more than 3 million m^3). More than 300 "giant" or "major" dams (at least 150 meters) have been constructed. Although dams have made significant contributions to human development, unintended environmental impacts include alteration of nutrient cycles, salt contamination of freshwater supplies, declines in coastal fisheries, and increases in coastal erosion (Soares, 1998).

In addition to its impacts on coastal zone habitats, the development of modern agriculture was made possible by the use synthetic inorganic fertilizers, the production and application of which has increased nearly 10 fold over the last 50 years on a global scale. This has altered the global nitrogen cycle and lead to a rapid increase in the flux of nitrogen and phosphorus to coastal waters via surface runoff, groundwater discharge and atmospheric deposition (Vitousek et al., 1997; Howarth, 1998). These processes, and increases in the discharge of sewage wastes, are the primary causes of coastal eutrophication and associated declines in water quality (e.g., oxygen depletion, increases in turbidity), loss of critical habitats such as coral reefs and sea grass beds (NRC, 2000), and declines in living marine resources. Over-enrichment of coastal waters may also be increasing the probability of harmful algal events, the growth of non-native species, and losses of biodiversity (NRC, 2000). Consequently, the flux of nutrients from land-based sources is considered to be a major cause of environmental degradation in coastal marine and estuarine ecosystems (e.g., Howarth et al., 2000). Nutrient enrichment is rapidly increasing in developing countries and is considered by many to be among the most significant pollution problems in coastal ecosystems.

Concurrent increases in pesticide use in agriculture have also resulted in chemical contamination of estuarine and marine environments and living resources. Pesticides (e.g., aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, mirex, toxaphene) are classified as persistent organic pollutants (POPs). The primary routes by which these compounds are delivered to coastal ecosystems are surface runoff and point source discharges. For the oceans as a whole, wind-borne atmospheric deposition accounts for over 90% of total inputs (Duce et al., 1991).

Other major land-based sources of POPs include releases of industrial chemicals (e.g., PCBs, hexachlorobenzene, dioxins and furans) and petroleum hydrocarbons. Oil contamination is addressed in section 2.4 below.

2.2.2 Dredging and Trawling

Two major activities that physically alter subtidal habitats are dredging and bottom trawling. Clark

(1977) characterized dredging as the "single greatest threat to coastal ecosystems." In addition to dredging, bottom trawling can have a significant impact on soft bottom habitats and the organisms that inhabit them. Watling and Norse (1998) estimate that about 60% of the global continental shelf area has been swept by bottom trawls. The long-term impacts of this are unknown but are likely to be substantial.

Dredged sediments currently constitute between 80% and 90% (by volume) of all anthropogenic materials dumped into the ocean. Several hundred million m^3 of coastal sediments are dredged and disposed of annually worldwide (Pinet, 1999). And, while large-scale capital construction and port maintenance dredging receives most attention, it is important to note that the cumulative effect of small scale dredging for a broad range of coastal development projects may equal or exceed larger scale activities.

2.3 Introductions of Non-native Species

Today, shipping transports 80% of all commodities traded globally. An unintended consequence is the introduction of non-native species. For the first time, whole plankton communities are being transported on a global scale between continents as ships take on and discharge their ballast water. Today, it is estimated that 80,000 vessels carry 12 billion tons of ballast water yearly holding the potential to carry in excess of 4,500 different species.

The economic cost of these introductions can be high. The Black Sea anchovy fishery had been valued at 250 million USD/year before its collapse as a consequence of the invasion of the ctenophore *M. leidyi* (Harbison and Volovik, 1994). In the United States two introduced mollusk species have been particularly devastating. The zebra mussel was first found in Lake St. Clair after having been introduced through the dumping of European ballast water in the Great Lakes. It has since spread into much of the eastern United States where densities have reached as high as $70{,}000/m^2$ in some locations. High mussel densities can clog water intake and filtration systems in various coastal installations and deprive indigenous species of food, oxygen and space. It is estimated that zebra mussels cause upwards of 5 billion USD in damage and associated control costs annually. Costs associated with the introduction of the Chinese clam in San Francisco bay have been estimated to reach 1 billion USD annually (Pimentel et al., 1999).

2.4 Petroleum Hydrocarbons

In addition to fouling shorelines, petroleum hydrocarbons are toxic to many marine organisms (marine mammals, seabirds, fishes) and can reduce growth, alter feeding behaviour, and lower reproductive success.

Although accidental oil pollution from massive discharges from oil tankers and rigs tend to be spectacular and alarming (e.g., 1989 Exxon Valdez in the Gulf of Alaska; 1979-80 blow out of Ixtoc in the Bay of Campeche; Saddam Hussein's intentional release of oil from Kuwait's Sea Island storage facility and destruction of over 600 oil wells in 1991), these events account for only about <50% of the release of petroleum hydrocarbons to the global ocean (Hinrichsen, 1998; National Safety Council, 1998). Oil pollution from land-based sources and "routine" operations of ships (ballast water, bilge slops, and tank washing) and oil rigs (seepage, oil-based muds used for drilling) account for most of the remainder.

Much of the oil discharged into the ocean accumulates in shallow benthic sediments and the intertidal zone where it can foul shorelines; cause mass mortalities (marine mammals and seabirds) and habitat loss (destruction of mangrove forests and sea grass beds); contaminate living marine resources (filter feeding bivalves in particular); inhibit growth; alter feeding behaviour; and lower reproductive success (Hinrichsen, 1998; National Safety Council, 1998). Light oils such as naphtha and gasoline are especially toxic to marine life and people who consume contaminated fish and shellfish.

Box 2.2. Oil Pollution of the Marine Environment

Mediterranean Sea
Some 600 million m-tons of petroleum products (20% of the world's supply) are shipped into and through the Mediterranean Sea every year. About 1 million m-tons per year are released into the Sea. Of this, about 50% comes from routine ship operations. The remaining 50% comes from land-based sources via surface runoff (Pastor, 1991; Pearce, 1995; Buckley, 1992).

North Sea
Oil and gas platforms account for 75% of the oil pollution in the North Sea (MacGarvin, 1990) via seepage and the intentional release of oil-based drilling muds (used to ease the passage of the drill and shaft through deep layers of bottom sediment and rock). About 2,000 km^2 of seafloor in the United Kingdom's portion of the N. Sea are contaminated with oil-based muds and cuttings, and biological effects on marine organisms have been documented up to 5 km from platforms. Cod, saithe and haddock caught within this zone contain elevated levels of hydrocarbons in their tissues, and filter feeders such as mussels have 10 times the tissue burden of mussels from uncontaminated areas (North Sea Task Force, 1993).

Gulf of Alaska
The worst oil spill in U.S. history occurred in Prince William Sound in 1989 when the Exxon Valdez went aground and spilled 257,000 barrels of crude oil producing an oil slick 26,000 km^2 and contaminating 250 km of coastline (Lewis, 1989). About 5,000 sea otters, 300,000 seabirds, and 300 bald eagles perished. Commercial fishing, valued at 130 million USD (salmon, halibut, herring, shellfish), crashed completely and effects on shallow water and intertidal plant and animal communities are expected to be long-lasting (Steiner, 1995).

Gulf of Mexico
The world's largest oil spill occurred in the Bay of Campeche when the Ixtoc exploratory well blew out in June, 1979. Over the next 290 days (until the well was capped), 475,000 m-tons of oil were released into the Gulf's waters. Hundreds of oil-soaked crustaceans were washed up on gulf beaches, but the full extent of the ecological disaster was not assessed (Henrichsen, 1981).

Arabian Gulf (Persian Gulf)
At the end of the 1991 Gulf War, the valves of Kuwait's Sea Island storage facility were opened sending 4 – 8 million barrels of oil into the Gulf, creating an oil slick 3,000 km^2 in area and contaminating 560 km of shoreline in Kuwait and Saudi Arabia (including all mangrove forests and 90% of intertidal marshes). A mass mortality of seabirds (about 30,000 cormorants and terns) was documented and damage to the Saudi coastline was estimated to be on the order of 700 million USD (UNEP, 1992a, b).

2.5 The Coastal Ocean and Human Health

Four categories of contaminants directly are risks to human health: (1) naturally occurring biotoxins produced by marine organisms; (2) indigenous bacteria (3) non-indigenous viruses and bacteria; and (4) chemicals contaminants (metals, hydrocarbons, POPs, radionuclides). Consumption of contaminated seafood is the primary route of human exposure, but illness also occurs through direct exposure to contaminated seawater (e.g. bathing) and inhalation of aerosols. The distributions of and human exposure to waterborne contaminants depend on interactions between human activities (e.g., sewage discharge, swimming, seafood consumption), ocean circulation, the growth and distributions of marine organism, and the weather (NRC, 1999b). This reality underscores the importance of developing an integrated approach to monitoring and controlling public health risks in the coastal zone that encompasses the effects of ocean processes on the distribution and abundance of human pathogens and toxic agents (IOC, 2001).

2.5.1 Marine Vectored Disease

The cost of marine-vectored public health risk is substantial. Globally, Shuval (2003) estimated that exposure to pathogens by bathing in contaminated seawater and consuming contaminated seafood resulted in losses of 8.8 billion USD/year during the 1990s. Much of this can be attributed to the discharge of untreated sewage. Inputs of untreated sewage are not only a major cause of coastal eutrophication, they are a major source of human pathogens that increase human health risks associated with swimming and the consumption of seafood from contaminated environments. Consequently, sewage treatment has been a high priority in most developed countries where municipal wastewater treatment is provided for 60% to 90% of the population (WRI, 1998). However, in the vast majority of developing countries, sewage treatment prior to discharge into coastal waters is much less common. In fact, the proportion of populations served by treatment facilities in developing countries has decreased over the last three decades as increases in treatment have not been able to keep pace with population growth. As recently as 1975, sewage treatment was provided for more than 70% of the urban population living in developing countries (GESAMP, 2001b). Today, that number is less than 50%. When both urban and rural populations are included, it is estimated that sewage treatment is not provided for nearly 70% of the global population (UNEP/GPA, 2000). Improvements in sewage treatment and coastal ecosystem management would reduce this loss by a substantial percentage. Although such estimates are rough, they illustrate the potential socio-economic benefits of an integrated ocean observing system.

Seafood consumption accounts for 11%, 20% and 70% of food-borne diseases in the U.S., Australia and Japan, respectively (Eyles, 1986; NAS, 1999). A recent review of the reported outbreaks of food-borne disease in the U.S. concluded that seafood consumption is the major source of food-borne disease in general (CSPI, 2002). Preliminary estimates of the cost of consuming raw or lightly steamed shellfish from contaminated waters (sewage, marine biotoxins) suggest that economic losses are on the order of 16 billion USD annually (Shuval, 2003).

The number of marine-beach bathing days has been estimated (for both international and domestic coastal tourists) to be about 1.7 billion per year (Shuval, 2003). A visit to the beach is probably the single most direct and visceral contact most people have with the coastal ocean. Its value to an individual clearly includes and transcends its economic value. Shuval (2003) estimated that the excess risk of suffering from gastroenteritis, respiratory, and eye disease is greater than 200 million cases per year globally with economic losses on the order of 1.5 billion USD per year. Although these are rough estimates, it is clear that quantitative and comprehensive treatment of socio-economic costs and benefits require more efficient and sustained observations to establish trends, to implement cost-effective controls, and to evaluate the efficacy of such controls.

2.5.2 Harmful Algal Events

Harmful algal events can impose significant impacts both on the health of humans and on coastal flora and fauna. Toxic events caused by microalgae and other protozoans are having negative socio-economic impacts on a global scale. Socio-economic costs associated with harmful algal events include the closure of shellfish beds, seafood contamination and health risks, and declines in tourism. Examples include the following (GEOHAB, 1998):

- During 1987-1993, the estimated cost to the U.S. was over 35 million USD per year. When economic multipliers are taken into account, the estimated cost increases to over 100 million USD per year.
- In Japan, the average economic loss to the aquaculture industry caused by noxious blooms is about 1 billion yen per year due to both mass mortalities and contamination of shellfish with PSP and DSP toxins. Efforts to decrease nitrogen and phosphorus in water and sediments have led to a decrease in frequency of mass mortalities and contamination.
- In Mexico, 45% of the environmental emergencies reported in 1996 were associated with toxic algal blooms. Toxin analysis revealed levels well above standards of the World Health Organization, and economic losses were substantial due to seizure of molluscs from the market and hospitalisation.
- Since the first record of a toxic dinoflagellate bloom in 1983, over 2000 PSP poisoning cases in the Philippines have caused 115 deaths with economic losses of 10 million Philippine Pesos for each PSP event.

Extrapolation of these experiences to the more than 50 countries that experience significant harmful algal events suggests that the socio-economic impact of these events is significant.

2.6 Harvesting Living Marine Resources

Living marine resources have sustained human cultures for millennia as an essential source of protein and a cornerstone of maritime commerce and trade. The fishery resources of the sea were long thought to be inexhaustible. However, increasing fish harvests have resulted in declines in many previously abundant fish and shellfish populations, and it is clear that human consumption is outstripping the production capacity of the world's wild fisheries (e.g., Pauly et al., 1998). With widespread over-capitalization and associated declines in catch per unit effort, the ecological, economic, and social consequences of overexploitation have become increasingly manifest. A change in how fisheries are managed is clearly needed. Two attributes of the system are particularly important in terms of developing new management strategies for sustaining marine fisheries. First, seafood markets have become internationally linked making clear the need to better integrate management efforts globally. Second, there is a clear need for the implementation of ecosystem-based fishery management practices, with effective enforcement of regulations, limits, and the establishment of marine protected areas (Pauly et al, 2002).

The last fifteen years has been witness to major changes in the global seafood industry (FAO, 2000). About 47% of current capture fisheries characterized as fully exploited and are at or near the estimated maximum sustainable production potential. Nearly 28% of current capture fisheries are characterized as overexploited, depleted, or recovering from depletion while 25% are classified as under-exploited or moderately exploited As the demand for fish-protein has increased and capture fisheries have become unsustainable under current fishing practices, aquaculture has taken on an increasingly central role in meeting demand, particularly in developing countries. At the same time, international trade in seafood has become more diverse creating an exceptionally porous international market.

Of particular note is the period 1984-1994 when major changes in the global structure of the industry occurred. During this decade seafood production (capture fisheries and aquaculture) increased from 89 million tons to 120 million tons. Capture fisheries increased by only 17% during this period and have levelled off in recent years. In contrast, aquaculture production expanded by 170% accounting for 60% of the total 31 million ton increase during the decade (FAO, 2000). Aquaculture currently accounts for 30% of seafood consumption worldwide (FAO, 2000). In developed countries, aquaculture production increased by 25% (2.8 million tons in 1984 to 3.5 million tons in 1994) while capture fishery landings declined by 26% (42 million tons in 1984 to 31 million tons in 1994). In contrast, the production of both capture fisheries and aquaculture increased in developing countries by 34% and 68% respectively (FAO, 2000). These trends toward a global, interdependent harvest of capture and aquaculture fisheries highlight the need to establish a global strategy to understand the interplay between market forces and changes in coastal ecosystems.

3. Conceptual Design

3.1 The Global Coastal Network

This Design Plan for the coastal module considers many factors. These include (1) the need to address a broad diversity of phenomena encompassed by the six goals (Chapter 1, Section 1.1); (2) the six goals of the coastal module have data and information requirements in common; (3) the phenomena of interest tend to be local expressions of larger scale forcings; (4) ecosystem theory posits that the phenomena of interest are related through a hierarchy of interactions; and (5) the kinds of ecosystems and resources that constitute the "coastal ocean" and priorities for detection and prediction differ among regions[5] . In addition, the design of the coastal module must take into consideration the following:

- Most international agreements and conventions that target marine pollution and living marine resources are regional in scope (Prologue);
- National and regional bodies provide the most effective venue for identifying user groups and specifying their data and information requirements.

Thus, the design plan for the coastal module respects regional differences and leaves the design and implementation of regional observing systems to stakeholders in their respective regions. At the same time, to the extent that the six goals of the coastal module of GOOS have many data requirements in common, a global network of observations provides economies of scale that minimizes redundancy and allows regional observing system to be more cost-effective. To these ends, the coastal module includes both global and regional scale components that link global, regional and local scales of variability through a hierarchy of observations, data management and models. Such a linked hierarchy can best be established through a mechanism such as the GOOS Regional Forum that allows national GOOS programmes and GOOS Regional Alliances (GRAs) to play significant roles in (1) the development of the global coastal network; (2) the establishment of common standards and protocols for measurements, data management, and analyses; (3) facillitates the transfer of technology and knowledge; and (4) the determination of priorities for capacity building.

The global network measures and processes variables that are required by most regional systems (Figure 3.1). These are the common variables[6] . Depending on national and regional priorities, GOOS Regional Alliances (GRAs) may increase the resolution at which common variables are measured, supplement common variables with the measurement of additional variables, and provide data and information products that are tailored to the requirements of stakeholders in the respective regions. Thus, GRAs both contribute to and benefit from the global network.

It must be emphasized that the global network will not, by itself, provide all of the data and information required to detect and predict changes in or the occurrence of many of the phenomena of interest (Table 1.1). There are categories of variables that are important globally, but the variables measured and the time-space scales of measurement change from

5 The scientific, scale-dependent definition of a region is the next larger scale that must be observed to understand the local scale of interest. Regions generally do not recognize national jurisdictions. Thus, understanding and predicting changes in the phenomena of interest requires international collaboration in most cases.

6 A variable is defined as a property or rate that has a range of values and can be measured with known precision and accuracy (temperature, salinity, current speed and direction, chlorophyll-a concentration, etc.).

region to region. These include stock assessments for fisheries management; biologically structured habitats (coral reefs, seagrass species, intertidal marshes and mangrove forests); marine mammals, turtles and birds; harmful algae, and contaminants. Decisions on what variables to measure (e.g., species of fish to be targeted for management purposes, species of chemical contaminants), the time and space scales of measurements, and the mix of observing techniques are best made by stakeholders in each region. Thus, the establishment of regional observing systems will be critical to detecting and predicting most of the phenomena of interest in the public health, ecosystem health and living marine resources categories.

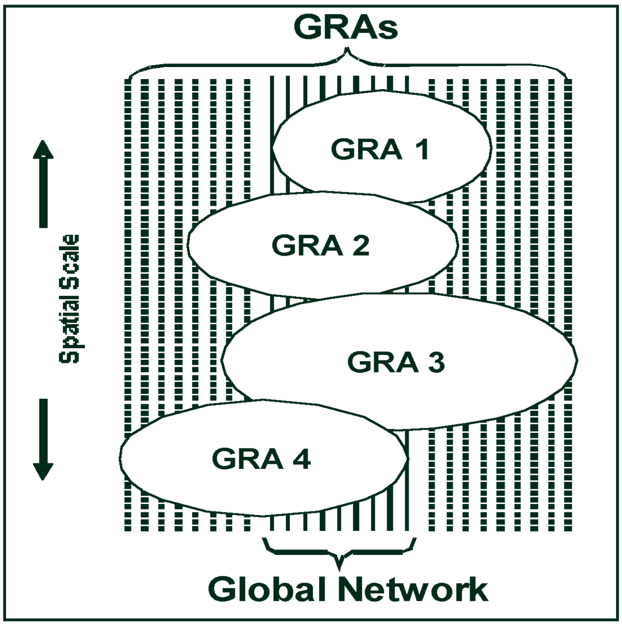

Figure 3.1. Schematic relationship between the global network and GOOS Regional Alliances (GRAs). Solid vertical lines represent the 14 common variables that would be measured and processed as part of the global network (Chapter 4). Dashed lines represent regional enhancements by GRAs (discs), such as sea ice in polar regions, or coral characteristics in the tropics. Geographic boundaries of regional systems will not be fixed in space; they may overlap; and they will be determined by the time and space scales of the phenomena of interest that are high priorities in each region.

The global network of coastal observations is the focus of this design plan. In addition to economies of scale and improved cost-effectiveness, the global network establishes, maintains, and improves the observational, data management and modelling infrastructure that benefits national and regional observing systems in several important ways:

- optimise data, information and technology exchange;
- facilitate capacity building;
- provide a network of reference stations and sites (including "sentinel" stations that provide advanced warnings of events and trends and enable adaptive monitoring for improved detection and prediction);
- establish internationally accepted standards and protocols for measurements, data dissemination and management;
- link the large scale network of observations for the ocean-climate module to the local scales of interest in coastal ecosystems and provide information on open boundary conditions and atmospheric forcings; and
- provide the means for comparative ecosystem analysis required to understand and predict variability on local scales of interest.

The selection of a provisional set of common variables for the global coastal network is described in Chapter 4.

3.2 A Multi-Purpose Observing System

The problem of detecting and predicting the present state and changes in coastal environments has many facets, and comprehensive characterization of all changes on a global scale is clearly not possible. However, it is feasible to develop an inclusive and effective approach for detecting and predicting the effects of external forcings on many of the phenomena of interest (Table 1.1; Annex II). The importance of physical processes in structuring the pelagic environment and scale-dependent linkages of ecological processes to the physical environment (Chapter 1) suggest there is a relatively small set of variables that, if measured with sufficient resolution for extended periods over sufficiently large areas, will serve many needs from forecasting the effects of tropical storms and harmful algal events on short time scales (hours to days) to predicting the environmental consequences of human activities and climate change on longer time scales (years to decades). These are the "common" variables.

The design and phased implementation of the coastal module will be guided by the following considerations (Figure 3.2):

(1) The data requirements for improved climate prediction and coastal marine services are, for the most part, common to all of the themes to be addressed by the coastal module. Safe and efficient coastal marine operations and the mitigation of natural hazards require accurate nowcasts and timely forecasts of storms and coastal flooding; of coastal current-, wave-, and ice-fields; and of water depth, temperature and visibility. The set of variables that must be measured and assimilated in near real time include barometric pressure, surface wind vectors, air and water temperature, sea level, stream flows, surface currents and waves, and ice extent. The use of models in supporting forecasts for coastal marine operations by government agencies and commercial companies is discussed in Section 5.2.1.

(2) In addition to these variables, minimizing public health risks and protecting and restoring coastal ecosystems require timely data on environmental variables needed to detect and predict changes habitats and in biological, chemical and geological properties and processes, e.g., distributions of habitat types, concentrations of nutrients, suspended sediments, contaminants, biotoxins and pathogens; attenuation of visible light; biomass, abundance and species composition of plants and animals; and habitat type and extent. Mitigating the effects of natural hazards and reducing public health risks also requires a predictive understanding of the effects of habitat loss and modification (barrier islands, tidal wetlands, sea grass beds, etc.) on the susceptibility of coastal ecosystems and human populations to them.

(3) In addition to data on the state of marine ecosystem, the demands of protecting living marine resources and managing harvests (of wild and farmed stocks) in an ecosystem context require timely information on population (stock) abundance, distribution, age- (size) structure, fecundity, recruitment rates, migratory patterns, and mortality rates (including catch statistics).

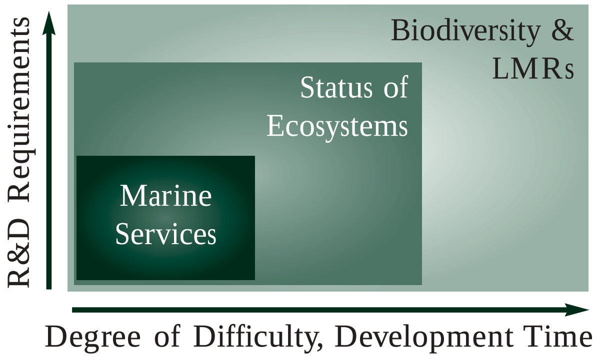

Figure 3.2. Time-dependent development of a fully integrated observing system. Predictions of most of the phenomena of interest require the same physical and meteorological data acquired for effective marine services and forecasting natural hazards. Those elements of the observing system required for improved marine services and forecasts of natural hazards are most developed (including the required operational models) while those required for ecosystem-based management of living resources are least developed. Given current capabilities and the importance of physical processes to the phenomena of interest in the ecosystem health and living marine resources categories, initial development of the global system will target the measurement and processing of physical variables and those biological and chemical variables that can be measured routinely and for which products can be clearly defined. As feasible, non-physical variables should be incorporated now. As technologies and procedures for rapid measurement and analysis of additional biological and chemical properties are developed, they will be incorporated into the system.

As discussed in Chapter 7, Figure 3.2 provides a conceptual framework for the phased implementation of the coastal module recognizing that (1) all of the major goals can and must be addressed from the beginning and (2) current operational capabilities from sensors to models dictate initial emphasis on marine services, climate prediction, and natural hazards. Thus, the system will be designed to evolve and incorporate biological and chemical variables as new technologies, knowledge and operational models are developed.

3.3 Elements of an End-To-End Observing System

Both detection and prediction depend on the development of an integrated and sustained observing system that effectively links measurements to data management and analysis for more timely access to data and delivery of environmental information (Nowlin et al., 1996, 2001; Malone and Cole, 2000). The system must be integrated to provide multi-disciplinary (physical, chemical and biological) data and information to many user groups. Linking user needs to measurements to form an end-to-end, user-driven system requires a managed, two-way flow of data and information among three essential subsystems (Figure 3.3):

- The observing subsystem (networks of platforms, sensors, sampling devices, and measurement techniques) to measure the required variables on the required time and space scales;
- The communications network (data dissemination and access) and data management subsystem (telemetry, protocols and standards for quality assurance and control, data dissemination and exchange, archival, user access); and
- The data assimilation, analysis and modelling subsystem.

The *observing subsystem* for the global coastal network is described in more detail in Chapter 4. It consists of the global infrastructure required to measure the common variables and transmit data to the communications network and data management subsystem. The infrastructure consists of the mix of platforms, samplers, and sensors required to measure the common variables with sufficient spatial and temporal resolution to capture important scales of variability in four dimensions. This will require the synthesis of data from remote sensing and *in situ* measurements involving various combinations of six categories of monitoring elements: (1) a network of coastal laboratories; (2) the global network of coastal tide gauges (GLOSS); (3) fixed platforms, moorings, drifters and underwater vehicles; (4) research and survey vessels, ships of opportunity (SOOP) and voluntary observing ships (VOS, SeaKeepers); (5) remote sensing from satellites and aircraft; and (6) remote sensing from land-based platforms. Many of these observing technologies are already deployed to some extent, and a global approach is needed to obtain the necessary integration.

Data communications and management link measurements to applications (Chapter 6). The six monitoring elements must be linked from the beginning by an integrated data management structure. The objective is to develop a system for both real-time and delayed mode data that allows users to exploit multiple data sets and data products from disparate sources

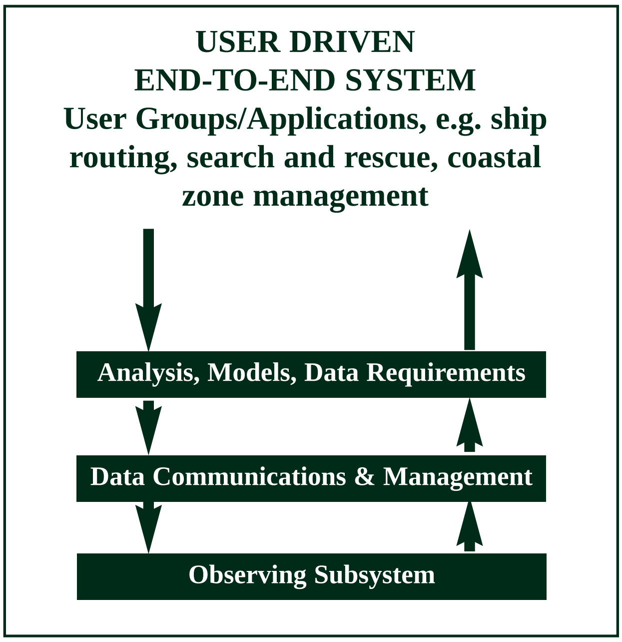

Figure 3.3. The observing system consists of three subsystems the development of which is driven by user-requirements, technical capabilities, and the sustainable investments in infrastructure (capitalization) and operations (including the required technical expertise). Note that, depending on capabilities and needs, user groups may access data from any one or all of the subsystems directly.

in a timely fashion. The development of this component of the system should be the highest priority for implementation.

Data assimilation and modelling are critical components of the observing system (Chapter 5). Real-time data from remote and *in situ* sensors will be particularly valuable in that data telemetered from these sources can be analysed to (1) produce more accurate estimates of the distributions of state variables, (2) develop, test and validate models, and (3) initialise and update models for improved forecasts of coastal environmental conditions and, ultimately, changes in the phenomena of interest in the categories of ecosystem and public health and living marine resources. A variety of modelling approaches (statistical, empirical, theoretical, numerical) will be required.

4. The Initial Subsystem for Coastal Observations

4.1 The Common Variables

The global coastal system will measure and manage a relatively small set of common variables that are required by most regional observing systems to detect or predict changes in phenomena of maximum interest to users (Table 1.1). This requires an objective procedure for selecting the properties and processes (i.e., variables) that, when measured globally, best serve to describe the present state and predict changes in the coastal ocean. Consistent with the GOOS Design Principles (IOC, 1998b), the variables must be reported in a timely fashion (real time or delayed mode as required) and suitable for measurement in a global system of sustained, routine, and reliably calibrated observations.

Many types of variables merit consideration for inclusion in the Coastal Module (Annex IV). Some are already measured routinely in many parts of the world; others are recognized as being important for describing or predicting dynamic processes or significant trends, but are not measured systematically in coastal environments; and still others are measured more for research than for routine operations. All should be considered for inclusion, either as common variables for the global coastal system or in regional systems operated by GRAs. An important task is to develop a procedure for rationalizing a long list of measurable properties and processes into a small set of common variables to be measured globally. This must be guided by the need to detect and predict, in a global context, the state of coastal marine systems and changes that occur in them.

Comprehensive characterization of all changes on a global scale is not possible. However, it is feasible to develop an inclusive and effective approach to characterizing the effects of external forcings on phenomena of primary interest to users. The process begins with a ranking procedure, followed by a review of results, then practical evaluation.

4.2 Selecting the Common Variables

The common variables have been selected using a systematic process based on an objective procedure that addresses the needs of users, followed by a consensus-based review derived from the expertise and experience of a broad range of scientists. The goal is to identify the minimum number of variables that must be measured to detect and predict changes that are important to the maximum number of user groups. This was accomplished by identifying *user groups*, *phenomena of interest*, *predictive models*, and *variables to detect or predict change* (Table 4.1). Then, variables were ranked according to the number of phenomena they can help to detect or predict. To emphasize the importance of users, each phenomenon was weighted by the number of user groups interested in it. The procedure is described in detail in Annex IV.

It is important to note that, although the process itself is objective, the results are subjective to the extent that the selection of user groups, phenomena of interest, predictive models and candidate variables influences the outcome. As described in Annex IV, care was taken to ensure that the lists were representative if not comprehensive. In particular, the list of user groups was intended to be a reasonable and balanced sampling of the spectrum of user groups that are likely to benefit from the Coastal Module; lists of phenomena and models were based on Table 1.1 and models described in Chapter 5 (which were likewise selected to be representative). Also, many variables were exempted from the process for selecting common variables, either because they will be measured as part of other global observing systems or because they require regional approaches and will be considered in the design of national and regional observing systems (Section 3.1, Fig 3.1., and Box 4.1).

Box 4.1. Variables Measured as Part of Other Integrated Global Observing Systems And Shared by the Coastal Module

Many variables that will be measured as part of the global coastal system were not considered in the selection of common variables for one of two reasons: (1) they are or will be measured as part of other global observing systems, or (2) the variable is better considered regionally, either because it is not global in extent or because the measurement depends on geographic location. GOOS Regional Alliances publish information on locally important variables and sources of data and data products.

Some observing system variables will be measured by other observing systems, but not necessarily on the scales required by the global coastal system or regional systems. They include meteorological variables (GCOS, OOPC), pCO_2 (OOPC/GCOS); surface and groundwater transports of water, nutrients, sediments and contaminants (GTOS) and remotely sensed properties of surface waters, including ocean colour (CEOS and IGOS). For many of the same reasons that they were included in their respective observing systems, they are also needed to describe and predict change in coastal environments. Observations of these variables are thus essential to the Coastal Module of GOOS, and these shared variables will be included in the design of the global coastal system. The COOP, working in collaboration with GRAs, must specify observing requirements (spatial and temporal resolution, precision and accuracy) for coastal ecosystems. For example, the IGOS Ocean Theme (2000) describes current remote sensing capabilities (research and operational) and requirements for the global ocean (open ocean case 1 waters for the most part). The next step is to extend this analysis into the coastal environment (shallow, closer to the land margin, higher frequency variability — case 2 waters for the most part) and to specify requirements for *in situ* measurements for both validation of remotely sensed data products and the detection of changes in four dimensions. These issues will be addressed in the COOP implementation plan.

Variables to be considered by GOOS Regional Alliances (GRAs)

Many variables are demonstrably important for detecting and predicting change in coastal systems, but they are not appropriate for global implementation. They are:

- Variables of regional significance that are not global in extent (e.g., sea ice);
- Categories of variables that would be defined or measured differently depending on geographic location (e.g., chemical contamination including oil spills, extent of biologically structured habitat; including coral reefs, oyster reefs, mangrove forests, sea grass beds, and kelp beds).

Although these categories of variables were not considered for the global coastal system (Table 4.2), they are essential to describing current state and predicting changes in coastal regions, and it is expected that they will be considered for implementation by GRAs.

Table 4.1. Lists used in the process for selecting common variables.

User Groups	Phenomena of Interest	Predictive Models	Variables to Detect State or Predict Change
Shipping	Sea state, forces on structures	Storm surges	Attenuation of solar radiation
Marine energy and mineral extraction	Coastal flooding	Waves	Changes in bathymetry
Insurance and re-insurance	Surface currents	Currents	Benthic biomass
Coastal engineers	Rising sea level	Coastal erosion, sediment transport	Benthic species diversity
Fishers (commercial, recreational, artisanal)	Changes in shoreline and shallow water bathymetry	Risk assessment: seafood consumption	Biological oxygen demand
Agriculture	Chemical contamination of seafood	Risk assessment: direct contact	Neutral red assay
Aquaculture	Human pathogens in water and shellfish	Chemical contamination of seafood	Cytochrome p450 (biomarker: oil)
Hotel - restaurant industry	Habitat modification and loss	Habitat modification / loss	Cholinesterase (pesticides)
Consulting companies	Eutrophication / oxygen depletion	HABs - population dynamics	Metallothionein (trace metals)
Fisheries management	Changes in species diversity	Anoxia / hypoxia	Currents
Search and rescue	Biological responses to contaminants (pollution)	Invasive species	Dissolved inorganic nutrients (N, P, Si)
Port authorities and services	Harmful algal events	Pollution effects - population	Dissolved oxygen
Weather services	Invasive species	Water quality model	Eh in sediment
Government agencies responsible for environmental regulation (pollution issues)	Water clarity	Capture fishery production / sustainability	Faecal indicators
Freshwater management/damming	Disease and mass mortalities in marine organisms	Aquaculture production / sustainability - finfish	Fisheries: Landings and effort
Public health authorities	Chemical contamination of the environment (includes oil spills)	Aquaculture production / sustainability - shellfish	Nekton biomass
National security (including navies)	Harvest of capture fisheries	Sequential population analysis	Incident solar radiation
Wastewater management	Aquaculture harvest	Community dynamics	Nekton species diversity
Integrated coastal management	Abundance of exploitable living marine resources	Ecosystem dynamics	Particulate organic C & N
Emergency response agencies		Oil slick transport and dispersal	pH
Tourism, Ecotourism			Phytoplankton biomass (chlorophyll)
Conservation groups (including environmental NGOs)			Phytoplankton species diversity > 20 µm
Consumers of seafood			Primary production
Recreational swimming			Salinity
Recreational boating			Sea level
News media			Sediment grain size, organic content
Educators			Changes in shoreline position
Scientific community			Surface waves
Charting, navigational services			Total organic C and N
			Total suspended solids
			Water temperature
			Zooplankton biomass
			Zooplankton species diversity
			Coloured dissolved organic matter - CDOM
			Seabird abundance
			Seabird diversity

4.2.1 Results of the ranking exercise

A total of 36 variables were ranked (Table 4.2). Given the general importance of physical processes, it is not surprising that the top six were physical variables. The second group of six was dominated by benthic variables, and the third group of seven was dominated by chemical and biological properties of the water column. It is noteworthy that benthic variables (sediment grain size and organic content, benthic biomass, Eh in sediments, and benthic species diversity) received high rankings, a result that reflects the importance of benthic-pelagic coupling in coastal ecosystems (Chapter 1).

Table 4.2. Ranks of the common variables after the first complete ranking exercise. The variables are ranked according to the number of phenomena of interest that they can help to detect and predict, with each phenomenon weighted by the number of user groups interested in it (see Annex IV). Final ranks are consistent with the better rank for detection or prediction.

RANK	VARIABLE	RANK	VARIABLE
1	Sea level	19	Coloured dissolved organic matter – CDOM
2	Water temperature	20	Fisheries: Landings and effort
3	Currents	21	Primary production
4	Changes in bathymetry	22	Total organic C and N
5	Salinity	23	Neutral red assay
6	Surface waves	24	Incident solar radiation
7	Sediment grain size, organic content	25	Total suspended solids
8	Benthic biomass	26	Cholinesterase (pesticides)
9	Changes in shoreline position	27	Cytochrome p450 (e.g., oil)
10	Dissolved oxygen	28	Metallothionein (trace metals)
11	Eh in sediment	29	Zooplankton biomass
12	Benthic species diversity	30	Particulate organic C and N
13	Dissolved inorganic nutrients (N, P, Si)	31	Zooplankton species diversity
14	Phytoplankton biomass (chlorophyll)	32	Biological oxygen demand
15	Phytoplankton species diversity > 20 µm	33	pH
16	Attenuation of solar radiation	34	Seabird diversity
17	Nekton species diversity	35	Nekton biomass
18	Faecal indicators	36	Seabird abundance

The combined rankings in Table 4.2 provide a basis for selecting the common variables, but they do not reveal exactly how many variables should be retained in the final list. Breaks in the distributions of ranked scores for both detection and prediction guided the decision to include the 14 top-ranked variables in a preliminary list of common variables (Annex IV).

4.3 Revisions Based on Scientific Experience and Expertise

Results of the matrix process are the first step toward and a principal guide for identifying the common variables for the global coastal system. The next step was to review the preliminary list of 14 variables to ensure that selection of common variables based on the rankings was acceptable to all Panel members based on their expertise and experience. Variables were retained if it was felt they could be measured with sufficient resolution to provide the information required to detect or predict changes in a timely fashion. Compelling reasons for adding variables to the list also were considered. Reasons would include large benefit relative to the cost for making the measurement and the degree to which its measurement would increase the value of measurements already on the list.

Upon review, the decision was made to include faecal indicators (rank 19) and the attenuation of solar radiation (rank 16) and to drop benthic species diversity and sediment Eh. The rationale for making these changes are as follows:

- As documented in Chapter 2, the economic and public health impacts of contamination by sewage are severe. This contamination is tracked by routine measurements of faecal indicators. The benefit of including faecal indicators in the list of common variables, and the relative ease and low cost of implementation, justifies inclusion of faecal indicators in the list of common variables.
- Observations of the attenuation of solar radiation reveal much more than the light available for water column or benthic photosynthesis — they reflect changes in the constituents of the water column as influenced by eutrophication and sediment load. Secchi depth, a simple measure of attenuation, has been measured routinely for many decades and is demonstrably useful for documenting change in coastal environments. Requirements for capacity building are minimal and cost is almost nothing. In regions of the developing world influenced by changes in land use, this may be one of the only quantitative measures of water quality that could be made with adequate resolution to document change. Comparison with more discriminating radiometric measures of attenuation can be made routinely. Thus, the attenuation of solar radiation is included in the list of common variables.
- Although biological diversity is clearly an important parameter of ecosystem health and the carrying capacity of ecosystems for living resources, the identification and enumeration of species globally is a major challenge: target species groups will vary from region to region and the methods and expertise required are not suitable at this time for incorporation into a global system of routine observations using time-tested, standard techniques.
- The routine measurement of sediment Eh in a global system may be problematic due to problems with instrument reliability and the need for vertically resolved measurements. This, and the fact that the measurement is somewhat redundant with dissolved oxygen, led to the decision to drop Eh from the list of common variables, with the recognition that this and other variables may be added to the system as technology advances.

The Panel also decided to list sediment grain size and organic content as two separate variables, bringing the number of recommended common variables to 15 (Table 4.3; Annex IV). This list of variables for the global coastal system is supplemented by the shared variables from other observing systems (Box 4.1; Table 4.3).

Table 4.3. Common variables recommended by the Panel to be measured as part of the global coastal system (Annex IV). Additional variables, shared with other observing systems, are also recommended for inclusion in the global coastal system.

PHYSICAL	CHEMICAL	BIOLOGICAL
Sea level Temperature Salinity Currents Surface waves Bathymetry Shoreline position Sediment grain size Attenuation of solar radiation	Sediment organic content Dissolved inorganic nitrogen, phosphorus, silicon Dissolved oxygen	Benthic biomass Phytoplankton biomass Faecal indicators

Variables Measured as Part of Other Integrated Global Observing Systems and Recommended to be Shared by the Coastal Module

Meteorological Variables (GCOS, OOPC)	**Chemical Variable (*Atmosphere / Ocean*) (OOPC/GCOS)**	**Remotely Sensed Variables at the Sea Surface (CEOS, IGOS)**	**Land Margin Variables (GTOS)**
Air temperature Vector winds Humidity Wet and dry precipitation Incident solar radiation	pCO_2	Temperature Salinity Elevation (currents) Roughness (winds) Ocean colour (chlorophyll, attenuation of solar radiation)	Surface and Groundwater Transports of: • Water • Nutrients • Sediments • Contaminants

This procedure for selecting common variables is only a first step in deciding which measurements will be included in the global coastal system. Clearly, the full list of common variables will emerge as the coastal module develops over time. The purpose of this exercise was to determine at the outset the most useful variables to observe without considering in detail the methods of measurement, their feasibility, or their impact on the ability to detect present state or predict changes in a timely fashion. These issues will be addressed in the implementation plan.

4.4 Evaluating the Potential Common Variables

The procedure for identifying common variables did not address explicitly the requirements to characterize changes in coastal ecosystems by assessing exchanges at boundaries and internal dynamics (Chapter 1, Figure 1.1), nor was it intended to provide the capability for comprehensive descriptions of the status or changes in ecosystem characteristics. This is because the global coastal system is but one element of the Coastal Module, designed to contribute to and benefit from the regional elements. It is thus important to examine the list of common and shared variables, along with variables not included in the list, to determine what aspects of ecosystem change the global coastal system could detect and predict, and what must be provided by regional elements. This evaluation should reveal what the global coastal system can provide to regional and national elements, and it should highlight the observations that must be made by regional elements in order to characterize coastal ecosystems effectively.

4.4.1 Classification of Variables

Following a classification based on Figure 1.1, variables are listed in Table 4.4 according to the environmental context of each measurement. An additional and no less important category is added, biotic assessments. This category includes a broad range of observations that generally require direct manipulation or taxonomic identification of organisms. These taxonomic, physiological and biochemical characteristics of organisms and communities reflect environmental forcings and integrate responses over ecologically relevant scales. They are also some of the most direct measures of living marine resources and environmental impacts of contaminants and environmental forcings, exactly what the Coastal Module is designed to detect and predict. The list of biotic assessments would be much longer if it included more fisheries data and variables to be considered by GOOS Regional Alliances.

It can be concluded from examination of the classified variables that sustained and systematic measurement and analysis of the 15 common variables, together with those shared with other global observing systems, will provide descriptions of external drivers (forcings), exchanges across major boundaries, and the internal dynamics of coastal systems, thereby detecting and predicting change, mostly in the physical and chemical environment and lower trophic levels, all of which exert bottom-up control on ecosystems. It is also very clear that biotic processes and the status of higher trophic levels will not be characterized as part of the global coastal network. This highlights the importance of measuring and processing biological and chemical variables by GOOS Regional Alliances that are then analysed in the context of global system data and socio-economic and public health indicators to gain an integrated view of the status of and changes in coastal ecosystems.

Table 4.4. Variables organized into the classification scheme consistent with Figure 1.1, with the addition of biotic assessments (observations that generally require direct manipulation or taxonomic identification of organisms). The recommended common variables are in bold, as well as those recommended for sharing with other global observing systems (greater resolution may be required for the global coastal system). Many variables are not exclusive to one category.

CONTEXT	VARIABLES
Air-Sea	Sea level Water temperature Currents Salinity Surface waves *Shared with other systems:* Meteorological variables: (air temperature, vector winds, humidity, wet and dry precipitation, incident solar radiation) pCO_2 Remotely sensed variables: (temperature, salinity, currents, winds, ocean colour)
Water Column and Shelf-Ocean	Water temperature Currents Salinity Dissolved oxygen Dissolved inorganic nutrients Phytoplankton biomass (chlorophyll) Attenuation of solar radiation Faecal indicators Coloured dissolved organic matter Primary production Total organic C and N Total suspended solids Zooplankton biomass Particulate organic C and N Biological oxygen demand pH Nekton biomass
Land-Sea	Sea level Changes in shoreline position Faecal indicators *Shared with other systems:* Surface and groundwater transports of water, nutrients, sediments and contaminants (including faecal indicators)
Benthic	Changes in bathymetry Sediment grain size Sediment organic content Benthic biomass Eh in sediment
Biotic Assessments	Benthic species diversity Phytoplankton species diversity (> 20 μm) Nekton species diversity Fisheries landings and effort Neutral red assay Cholinesterase assay (pesticides) Cytochrome p450 (e.g., oil) Metallothionein (trace metals) Zooplankton species diversity Seabird diversity Nekton biomass Seabird abundance

The initial list of variables for the global coastal system will be updated in the implementation plan through an impact versus feasibility (I-F) analysis of potential techniques for each variable. Impact is a subjective assessment of the relative value of the technique for making quality measurements of the variable in question with adequate resolution on the required time-space scales. Feasibility is an appraisal of the degree to which observational techniques can be used in a routine, sustained and cost-effective fashion, i.e., the extent to which they are operational. For many common variables, more than one measurement technique will be identified depending on regional capacities and the applications for which the variable is used. Once the I-F analysis is completed for each variable, techniques will be categorized in one of the following four categories: suitable for incorporating into the observing system now (operational), suitable for pre-operational testing, ready for evaluating as part of a pilot project, or requires additional research and development (Section 7.3). When different measurement systems are employed, comparability of measurements must be assured. The same I-F analysis will be applied to the variables measured as part of other integrated global observing systems and recommended to be shared by the Coastal Module. Additional common variables may be added as they are needed and routine measurements become feasible.

4.5 Elements of the Observing System

Measurements from both the global and regional observations systems provide data from three general sources: discrete sampling followed by measurements (e.g., samples of water, sediments, or organisms are collected and taken to a laboratory where measurements are made); *in situ* sensing (the sensor is in the environment where the measurement is made); and remote sensing (from satellites, aircraft, and land-based platforms). Discrete sampling and *in situ* measurements such as profiles of salinity and temperature may be made from docks, small boats, ships, and fixed platforms. Autonomous *in situ* measurements can be made from fixed platforms, drifters, gliders, autonomous vehicles, and remotely operated vehicles. Remote sensing provides context for *in situ* measurements, and combination of remote and *in situ* measurements are required for detecting and predicting changes in 4-dimensions. *In situ* sensing also provides critical ground-truth information for remote sensors. Coastal observatories for *in situ* and remote sensing are expected to become important components of the observing subsystem as the technologies for these platforms and associated sensors develop (Glenn et al., 2000b).

The elements of the global and regional observing systems must be linked to form an integrated system of observations. These elements include: (1) network for coastal observations; (2) the global network of coastal tide gauges; (3) fixed platforms, moorings, drifters, and underwater vehicles; (4) research and survey vessels, SOOP and VOS; (5) remote sensing from satellites and aircraft; and (6) remote sensing from land-based platforms.

4.5.1 Network for Coastal Observations

The coastal network links local communities, academic research laboratories, government laboratories (operational and research laboratories), industries, environmental NGOs and universities to record and disseminate information on local changes in the context of regional and global scales of variability. It is anticipated that the network will provide the infrastructure for capacity building and the opportunity for all interested countries to contribute and participate in a meaningful way. It has been designed to interface directly with the data flows and management scheme but it should be realized that implementing the coastal module on a global scale will be a major challenge.

The proposed structure of the Network for Coastal Observations involves three levels of participation with two-way flows of data and information:

(1) Level 1 would involve concerned citizens, environmental groups, NGOs, high schools and similar organizations. These participants would require the support and assistance from Regional GOOS Alliances. Participants would need to be trained and provided with the means (e.g., instruments, supplies, kits) for sampling, making measurements (in some cases), and recording results (data and meta data; see Section 7.4). Data would be communicated (electronically or otherwise) to a level 2 participant capable of storing and transmitting data electronically. It is important that the principles of capacity building are applied here.

(2) Level 2 would include institutions such as industries, hydrographic services, coastal administrations, universities and navies that have the resources and expertise to routinely collect samples, to measure the required variables (in some cases), and to store and transmit data in electronic formats in a timely fashion. Training and the development of common protocols for measurements, metadata, and data exchange will also be important at this level (see Section 7.3 and 7.4). Participants at this level directly or indirectly involve the greatest diversity of user groups. One important potential advantage of involving these organizations would be inclusion of the vast amount of data that are collected routinely in the near-shore region but are not generally available outside the region (e.g. compliance monitoring).

(3) Level 3 would include operational government agencies with statutory responsibility for marine environmental management and safety, research laboratories, which may in some cases also be universities and would function as regional hubs (which may also function as regional synthesis or application centres) providing general guidance, training and advice to level 1 and level 2 participants. They will link schools, environmental groups, industry and operational agencies in a given region. Hubs will be linked to form a global network that may also function as the communication network for the global system (Section 6.3.2). They will have all of the capabilities of level 1 and 2 participants, but with a broader spectrum of expertise and resources to design and implement measurement programmes and to store and analyse diverse data types from many sources. The organizations in Level 3 may also add to the network by (i) providing analytical services to level 1 and level 2 providers; (ii) implementing standards for data quality; and (iii) providing an interdisciplinary or time-space context for more robust interpretations of data.

Coastal laboratories provide access to local marine and estuarine ecosystems, and they can be equipped with the facilities to support many of the sampling approaches of the observing system described above. Consequently, regional networks of coastal laboratories in some countries will address a broad range of issues that are critical to the successful implementation of the Coastal Module. These include the following:

- *Establish long-term time series observations to capture important high and low frequency variability* - Measurements of many biological and chemical variables in sustained time-series are feasible and cost-effective in ecosystems that are near coastal laboratories. These capabilities are critical to the successful development of index sites (see below), coastal observatories, ocean colour algorithms for case 2 waters, calibration and maintenance of *in situ* sensors, and land-based remote sensing. There are also already a significant number of established time-series stations taking a variety of physical, chemical and biological measurements. It is critical to the success of GOOS that these stations become an integral part of the Coastal Module.
- *Support the development of "test beds"* - The development of sensing and communications technologies are critical to the evolution of a fully implemented, multidisciplinary observing system that includes the measurement of key biological and chemical properties and real-time telemetry of data for timely forecasts. The relatively easy access to coastal sites makes the coast an excellent area for testing technologies and methodologies used in the wider GOOS effort.
- *Promoting public awareness and support* - Coastal laboratories often engage in public outreach activities that can be used to raise community awareness of marine environments, changes occurring in them, and the benefits of ocean observations.

Additionally, level 2 and 3 participants may provide the support base for coastal observatories and index sites where variables are intensely monitored, new technologies are tested and experiments are conducted on scales which allow the development of a predictive understanding of the processes controlling ecosystem change. The unique and critical aspects of index sites are as follows:

- Multiple variables and rate processes are measured on the time and space scales required to determine and model the causes and consequences of environmental variability and change;
- Baseline or reference conditions are established as a means to resolve long-term change from short-term variability (e.g., the development of climatologies for biological and chemical variables);
- Procedures are developed to integrate diverse data from different sources collected on different time and space scales to visualize change in four dimensions;
- Test sites are established to accelerate the development of new sensor technologies and dynamic models to test hypotheses and predict changes; and
- Technologies and models are transferred from research to operational modes to improve the capacity of the observing system to serve the needs of a broader mix of users.

Index sites provide a critical link between large-scale survey and monitoring programmes and the basic research required to understand causal relationships and predict change in coastal waters. They may incorporate observatories or test beds. Some laboratories running index sites may also function as regional synthesis or application centres, where activities such as the integration of remote sensing information into regional data sets are centred. Index sites, such as those designated by LOICZ and coastal sites of the Long Term Ecosystem Research network (LTER), should be strategically located to determine how external forcings (e.g., inputs from river drainage basins and ocean basin scale changes such as ENSO events and the NAO and PDO) are expressed in coastal ecosystems.

4.5.2 The Global Network of Coastal Tide Gauges

The 1997 Implementation Plan for the Global Sea Level Observing System (GLOSS) called for the establishment of a global core network of approximately 270 stations with a roughly even global distribution and of which approximately two thirds are in operation. The plan also defined sets of gauges for altimeter calibration, for the monitoring of long-term trends in sea level and ocean circulation. The plan calls for data collection with delays of between 1-12 months and recognizes the importance of the global network to the calibration of satellite measurements.

GLOSS has agreed in principle to measure selected common variables at gauged sea level sites. The schedule for reporting data would have to be accelerated. The most straightforward variables to monitor are air pressure, salinity and water temperature. Air pressure is particularly important in the analysis of sea level data because of the inverse relationship between air pressure and sea level, i.e., a 1 mb increase in air pressure is associated with a 1 cm decrease in sea level. (It should be noted that there has been a reduction in air pressure measurements by meteorological agencies for several years in the tropics, and the addition of the proposed new tide gauge sites might help to rectify this problem.) In some cases it may be possible to equip GLOSS stations with sensors not only for air pressure, salinity and temperature but also for wind, waves, currents, chlorophyll a, nutrient concentrations and optical properties. The advantages of such enhancements are obvious, and the approach is consistent with the GOOS design philosophy of building on existing infrastructure.

In addition to GLOSS there are a number of other groups undertaking work on sea level that is relevant to the coastal module of GOOS. For example, the International GPS Service for Geodynamics (IGS) is beginning to add continuous GPS to tens of tide gauges around the world. One goal is to define the absolute vertical position of the tide gauges to within a few cm in order to calibrate and validate measurements of sea level by satellite-borne altimeters. Another goal is to measure the vertical rate of displacement of the tide gauges on time scales of decades. If accuracies of better than 1 mm/year over a 10-year period could be achieved it may be possible to separate the effects of vertical crustal movement from oceanic effects and allow for better predictions of sea level rise.

The GLOSS system provides the sea level data for the global COOP. In addition, there are other local tide gauges operated by national agencies which can provide additional data within the structure of GRAs, sometimes with real time delivery of data and the use of models to forecast regional sea level patterns.

4.5.3 Fixed Platforms, Moorings, Drifters, and Underwater Vehicles

There have been significant improvements over the last decade in the instrumentation for measuring water properties from fixed platforms, moorings, vertical profilers, remotely operated vehicles (ROVs), autonomous underwater vehicles (AUV), surface autonomous vehicles, gliders and drifting buoys (Dickey et al., 1998, 2002; Glenn et al., 2000b). Moorings can now provide routine measurements of meteorological (wind, air pressure, temperature, humidity, incident solar radiation) and physical variables (water temperature and salinity, currents). Sensors have also been developed for sustained autonomous measurements of dissolved oxygen, nutrients, pH, and a variety of optical properties including fluorescence, turbidity, ocean colour and attenuation of solar radiation. Although many of these sensors are commercially available and have been deployed for extended periods, they are not generally operational in the sense of providing guaranteed data streams during sustained, routine use in coastal water. Progress in this direction has been good, however. There have also been developments in telemetry that allow users to communicate with remote platforms in coastal waters to download data and change sampling strategy (e.g. Chavez et. al., 1999).

There are several benefits of enhancing the distribution of instrumentation, fixed platforms, offshore moored buoys and autonomous mobile sensor systems. They include:

- More accurate predictions of extreme marine weather;
- Improved nowcasts and forecasts of wind and air pressure fields that can be used to drive hydrodynamic models;
- Detection of transient events and subsurface features that would be missed by discrete sampling or remote sensing;
- More rigorous calibration and validation of satellite remote sensing (e.g. winds, surface temperature, currents, sea level, estimates of chlorophyll from ocean colour) and continuity of data on cloudy days;
- An expanded database of ocean variability which will improve our understanding of how the coastal ocean works, including ecosystem dynamics, and accelerate the development and validation of predictive models.

One group of offshore platforms that could carry additional sensors is the moored buoys and fixed stations used by the World Weather Watch (WWW) to monitor atmospheric variability over the ocean (programmes of the IOC-WMO Data Buoy Cooperation Panel). Another set of offshore platforms is the rigs used for hydrocarbon exploitation. Such platforms contribute to the WWW in many areas, and EuroGOOS has developed a monitoring network based on fixed structures in the North Sea.

Surface drifters are effective tools for tracking currents in the open ocean and in coastal waters. Position is reported by satellite and the drifters can be equipped with sensors for temperature, salinity, incident solar radiation and ocean colour, so they can be used to track the dynamics of local features. The advantages of drifters include relatively low cost and easy deployment. However, drifters are inherently uncontrollable and measurements are not easily verified after extended deployments. Autonomous vehicles such as gliders offer the advantages of both drifters (access to waters away from fixed platforms or ships) and fixed platforms (opportunity for calibration and maintenance). They can measure many variables and show strong potential for incorporation into measurement systems for the coastal module of GOOS.

Biofouling and corrosion affect the quality of measurements taken above and below the ocean surface. In addition to frequent maintenance, a few steps, such as the use of copper, mechanical wipers and other anti-fouling measures, can be taken to minimize the problem. Vandalism has been recognized as a major threat to observational systems by the international community. The problems of both vandalism and biofouling may be solved to some extent through the use of bottom mounted profiling packages that spend a significant amount of time below biologically active surface layers.

4.5.4 Ships of Opportunity and Voluntary Observing Ships

Ships of Opportunity (e.g., SOOP) and Voluntary Observing Ships (VOS) provide valuable oceanographic and meteorological data on a global scale. These ships make important contributions to the World Weather Watch and hence weather forecasting. The OOPC has included Ships of Opportunity and Voluntary Observing Ships as an important part of their observing strategy for the global ocean.

In coastal ecosystems, the use of ferries (e.g., "Ferry Box" project of EuroGOOS), and privately owned vessels operating in coastal waters (e.g., Seakeepers) making specific measurements are two examples of ship-based observation systems. These systems use custom made measurement modules to collect data such as sea surface temperature, salinity, oxygen, nitrate, sound velocity, fluorescence, light attenuation and light scattering, redox levels, pH, coloured dissolved organic material, turbidity, and chlorophyll. Assuming the problem of calibration of sensors can be addressed, routine measurement of conditions along critical corridors, sounds and straits would be particularly valuable to the Coastal Module.

4.5.5 Research Vessels and Repeat Surveys

There are many repeat surveys by research vessels, for example, in the Northwest Atlantic, where standardized ecosystem surveys (for abundance, species composition, size, age, maturity, diseases, and trophic linkages of finfish and some shellfish; measures of primary productivity; zooplankton volume and species; and physical variables) are made from research vessels for hundreds of representative stations covering thousands of square kilometers, up to six times per year, with some time series forty years long. Many other examples can be found worldwide. Incorporating these types of data streams as well as measurements from other vessels including fishing industry vessels will increase the availability and coverage of data to the Coastal Module considerably and will increase the ability of the Coastal Module to have biological data incorporated into the observing system. The continuation of time-series and establishment of new time-series are critically important to documenting changes in coastal environments. Research ships, albeit cost-intensive, will also in future support considerably the Coastal Module with standardized surveys on monitoring lines and grids. These level 3 contributions also provide data on broader space and time-scales and interdisciplinary interpretation of monitoring variables.

There is also the potential to use industry vessels from water authorities, oil and gas exploration companies, and the fishing industry, which maintain lines of quasi-permanent stations on critical sections along which hydrographic and biological variables are monitored. Underway sensing systems such as continuous plankton recorders (i.e., Sir Alister Hardy Foundation for Ocean Science) could be installed on the vessels that conduct these sections. The data from regular surveys could be usefully combined with the underway measurements to provide estimates of integral fluxes of quantities like mass and nutrients along the shelves as well as early detection of regime shifts that affect the structure and function of marine ecosystems. Such fluxes, in combination with data from other sources, could be most useful in providing boundary conditions or limited area models of the shelf. Cross-shelf transects ("corridors") will also be needed to determine environmental trends and cross-shelf gradients between land and the open ocean.

4.5.6 Remote Sensing from Land-based Platforms

High frequency radar systems using "ground waves" such as CODAR have been developed to estimate surface current and wave fields that are useful for a variety of purposes including ship routing and near-shore navigation, search and rescue, fishing operations, the mitigation of oil spills, and forecasts of harmful algal bloom trajectories. These systems can achieve a dynamic range of 200 km or more from the shore line with a spatial resolution of order 0.5 km and near real-time data telemetry (e.g., 20 minute delay time). The less developed "sky wave" system potentially can have a range of thousands of kilometres.

Land-based radiometers can be used to map surface temperature over a range of a few kilometres. Finally, video cameras with time-lapse capability also can be used to monitor variations in sea state averaged over several wave periods. This has allowed, for example, spatial patterns in beach morphology to be monitored and related to external forcing functions such as incident wave energy.

4.5.7 Remote Sensing from Satellites and Aircraft

A suite of satellites and satellite technologies is available for remote sensing of the marine environment. Active and passive sensors are able to detect visible, infrared, and microwave portions of the electromagnetic spectrum to measure four basic properties of the ocean: ocean colour, temperature, height and roughness. Such measurements are used to observe surface distributions of common variables as follows:

- Ocean-colour sensors monitor the spectral properties of water-leaving radiance in the visible domain to describe the distributions of several properties in the surface layer of the ocean, including Chl a, the penetration of sunlight and the concentration of suspended sediments (Annex V).
- Both infrared (IR) and microwave sensors are used to monitor sea surface temperature (SST). As for ocean-colour, infrared sensors cannot see through clouds. Passive microwave sensors can measure SST through clouds but with less accuracy and spatial resolution.
- Microwave sensors can be used to detect sea surface height (ocean topography, altimetry), surface waves (altimeters and synthetic aperture radar, SAR), winds at the sea surface (ocean vector winds, scatterometry) and sea ice (SAR). Microwave radiometry may also provide the means to measure sea surface salinity.

For references to sources of information on existing marine remote programmes by various national space agencies see CEOS Publications, IGOS "Ocean Theme", and EuroGOOS Publications No.6 and 16.

The importance of remote sensing and the integration of remote and *in situ* sensing for long-term observations are well established for the open ocean (IOC, 1998a; www.igospartners.org). Extending and improving (e.g., greater spatial and temporal resolution) these capabilities for applications in near-shore, coastal waters is critical to the development of the coastal module of GOOS. ■

5. Combining Observations and Models

The term model is used here in the broadest sense. It is taken to cover simple statistical relationships (e.g. rules of thumb, dose-response relationships, multiple and multivariate regression models), more sophisticated statistical constructs (e.g. state space models, neural networks, virtual population analyses, network analysis), dynamical models based on first principles (e.g. storm surge models, numerical ecosystem models in both Lagrangian and Eulerian form) and, finally, coupled models of the biotic and abiotic components of the marine ecosystem (e.g. coupled atmosphere-ocean-wave-sediment-biogeochemistry models).

Modelling and the making of observations are complementary activities. The blending of time-dependent dynamical models and observations is becoming increasingly important in oceanography and is usually referred to as data assimilation. It is used to update the model's state, parameters and forcing in a manner that is consistent with the observations. Models with a data assimilation capability have been developed for physical conditions on continental shelves and in the deep ocean, and specially designed programmes are being carried out to test their effectiveness (e.g. GODAE). Data assimilation is not restricted to physical models; traditional nutrient-phytoplankton-zooplankton models also are developing the capacity to use data more effectively.

The goals of this chapter are to define the role of models in the design and operation of the coastal observing system (section 5.1), and provide a rough assessment of their predictive capabilities (section 5.2). Data assimilation is discussed in section 5.3 and some problems and opportunities for coastal modelling are discussed in the final section.

5.1 The Role of Models

5.1.1 Estimating the State of the Marine Environment

The main value of models is in the estimation of quantities that are not observed directly. As discussed below, models can be used to interpolate between, and extrapolate, observations that are sparsely distributed in space or time. The more advanced interpolation-extrapolation methods use data assimilation techniques to blend, in an optimal fashion, observations and dynamical models. This can lead to high-resolution gridded reconstructions of conditions that prevailed during earlier periods. Models can also be used to estimate the present and, more importantly, future states of the coastal ocean and its living resources. The estimation of past, present and future states is generally referred to as hindcasting, nowcasting and forecasting, respectively[7] .

Hindcasting generally refers to the reconstruction of historical conditions based on all available data for a given period. It has many applications. One is the reconstruction of past population sizes of exploited fish species using information on observed catches and some basic biology. Another application that is especially relevant to GOOS is the development of 'climatologies' for specified periods. The determination of the mean, second and higher moments of variability are of fundamental importance to environmental science and are required products for engineering design (Koblinsky and Smith, 2001). Climatologies are

[7] All three types of estimation procedure are described by the generic term "prediction" in this document. See Chapter 1, footnote 1.

also required for effective management of coastal resources and as a background against which to interpret recent changes in marine ecosystems. Hindcasts from physical models can be used to synthesize scattered measurements of variables such as water temperature, salinity, sea level, nutrients and radio-nuclides, and produce consistent estimates of the three dimensional state of coastal systems. Such information can be used to interpret, for example, changes in the abundance of commercially important fish stocks, the frequency and magnitude of harmful algal blooms, trends in the loss of coral reefs, and the spatial and temporal extent of bottom water oxygen depletion. Nowcasting provides an estimate of the present state of coastal marine ecosystems and living resources, using all information available up to the present time. For example, nowcasts are used to assess the current status of exploited fish stocks, to ensure safe navigation in shallow water and can be used to guide adaptive sampling of marine ecosystems based on real-time estimates of current conditions. Forecasting the future state of the coastal marine ecosystem and living resources is arguably the most important application of models. For example, models have been used for many years to forecast storm surges and wave spectra with a lead-time of hours to days. Models have also been used for decades in fisheries science to forecast abundance of commercially important fish stocks with lead times of years. Models can also be used to generate plausible climate change 'scenarios', taking into account both natural variability and anthropogenic forcing. The schematic for a generic nowcast-forecast system, based on a numerical ecosystem model of the global coastal ocean, is shown in Figure 5.1.

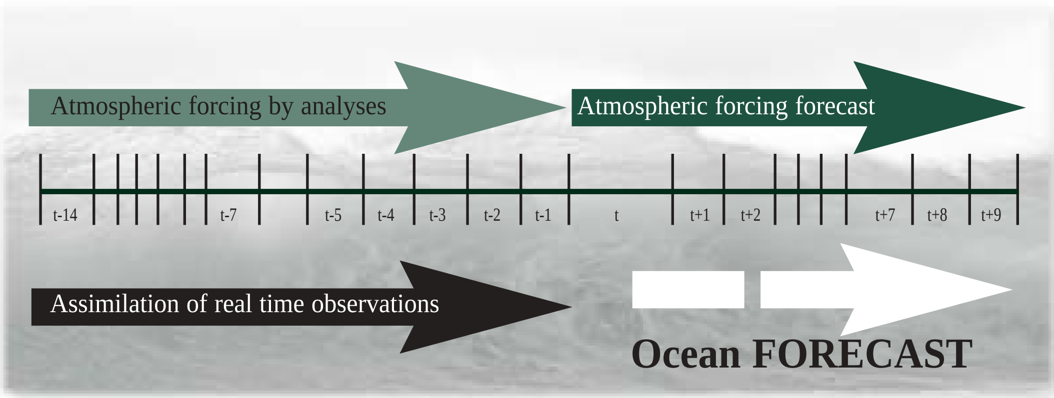

Figure 5.1.. Schematic of a nowcasting and forecasting system for a numerical model of the global and coastal ocean ecosystem. Up to day t-1, observations are assimilated into a numerical model of the ocean forced by atmospheric analyses and a 'nowcast' is produced. The blending of data and models before day t produces 'hindcasts' or analyses. At day t the atmospheric forcing is switched to forecast, the observations do not correct the model anymore and an ocean forecast is produced.

5.1.2 Toward a Predictive Understanding

The development of a fully integrated observing system will require a strong and ongoing interaction between the groups responsible for establishing and running the observing system and the modellers. Scientists interested in fundamental questions about how marine systems work also have an important role to play. A brief discussion of the connections between observing, modelling and understanding marine systems is given below:

Observations ↔ Models: Models of marine ecosystems cannot function without observations; they are needed to specify initial and boundary conditions and help set model parameters. Conversely, models can be used to monitor the quality of real-time data streams and detect (and rectify) problems with sensors and data telemetry. Models can help determine what to measure and at what resolution, and also help design more effective ocean observing systems. For example Observing System Simulation Experiments (OSSEs) simulate data from various designs in order to assess the effectiveness of the designs in making predictions.

Observations ↔ Understanding: For most of its history, oceanography has been a descriptive science dependent on *in situ* measurements for the identification, and understanding, of important phenomena and processes. Similarly, marine biology and ecology have progressed as a result of observational and process studies carried out on limited time and space scales. More recently, satellite-based sensors have provided spatially synoptic observations of surface properties that have significantly advanced our understanding of the oceans and marine plant life on global scales. Conversely, scientific understanding helps determine what to measure and at what resolution. It also helps to identify keystone and surrogate variables that can be used as indicators of future changes that are easier to measure than the primary variables of interest (e.g., the male sex characteristics of female gastropods as an indicator of marine pollution).

Understanding ↔ Models: The development of GOOS will depend on continued advances in understanding and the formulation of more robust models. The interplay between models and understanding often leads to the identification of causal linkages among variables that can be used to build predictive models based on a mechanistic understanding of the structure and function of ecosystems. Models often provide the clearest expression of what is understood about complex systems (e.g., ecosystems in which the flows of energy and nutrients are governed by non-linear interactions among many different kinds of organisms and their environment) and often provide the most effective way of formulating and testing hypotheses about how such systems work.

Observing, modelling and scientific enquiry are mutually dependent activities. The users of GOOS data and its products will benefit directly from all three activities. If one activity fails to develop it will most certainly hinder development of the coastal observation module.

5.2 Overview of Models

The coastal module is designed to provide the information required to more effectively manage and mitigate the effects of human activities and climate variability on marine services and public safety, living marine resources, public health, and ecosystem health. A very brief overview of selected models for each of these four themes is given below. The intent is not to provide comprehensive reviews but rather an indication of the scope of the models and their products, their operational status and predictive capabilities.

A summary of the typical data requirements for the models discussed below is given in Table 5.1. Summaries of typical model products, and an assessment of operational status and skill, are given in Tables 5.2 and 5.3 respectively.

Table 5.1. Summary of typical data requirements for the models mentioned in the text.

Model	Typical data requirements
Storm Surges	Wind stress, air pressure, precipitation, river runoff, sea level, bathymetry
Shoreline Change	Waves, sediment grain size, sea level, wind, freshwater sediment load, bathymetry, coastline geomorphology, currents, human alterations
Currents and Hydrography	High-resolution atmospheric forcing, sea level, temperature, salinity, currents, river runoff, bathymetry
Surface Waves	Winds, air temperature, surface temperature, waves, sea level, ice cover
Sea Ice	Ice properties and ice velocity, under-ice temperature and salinity, wind and air temperature over ice, currents, snow thickness, bathymetry
Tsunamis	Seismic activity, sea level, bathymetry
Single Species	Catch (by age group or size class if possible), size-dependent growth rates (if catch by size class is used), maturation rates, natural mortality rates, time series of catch and effort, mean weights of size or age classes, stock-recruit relationships
Multiple Species	Catch (by species, age group or size class if possible), size-dependent growth rates (if catch by size class is used), maturation rates, natural mortality rates, time series of species-specific catch and effort, mean weights of size or age classes, stock-recruit relationships, composition of the diet by size or age class
Ecosystem	In addition to currents, hydrogaphy and nutrients, flows of materials (e.g. carbon) or energy among ecosystem components, which could include detritus, primary producers, microzooplankton, mesozooplankton, macrozooplankton, benthos, fish, nektonic invertebrates, marine mammals, seabirds, and harvesters
Faecal Pollution	Faecal coliform bacteria enetrococci concentrations, wind, currents, hydrography, distribution and description of waste treatment and outfalls, location of shellfish breeding and harvesting areas, location of beaches
Health Risk/Dose-Response	Official statistics and/or prospective epidemiological studies of enteric/gastrointestinal/enterovirus and respiratory disease occurrence among individuals exposed and not exposed to bathing waters of known indicator organism concentration, and exposed and not exposed to raw shellfish of known focal indicator/virus concentrations
Water Quality	Hydrological and atmospheric forcing, dissolved inorganic nutrients, phytoplankton chlorophyll, dissolved and particulate organic matter, toxic contaminants, dissolved oxygen, zooplankton, suspended sediments, water clarity, benthic nutrient regeneration, oxygen demand
Water Clarity	Spectral irradiance and light scattering at several depths, concentrations of dissolved organic matter, suspended sediments, phytoplankton pigments
Aquaculture	In addition to currents, hydrography and dissolved inorganic nutrients, food supply, turbidity, concentrations of particulate organic matter, phytoplankton biomass (e.g., chlorophyll-*a*), sea level, bathymetry
Ecotoxicology	Specific contaminants and/or their metabolites, various measures of population-level consequences

Table 5.2. Typical products (available and planned) from the models mentioned in the text.

Model	Typical Products
Storm Surges	Warnings of coastal flooding with a lead-time of hours to days
Shoreline Change	Predictions of shoreline and nearshore evolution in response to external forcing
Coastal Currents and Hydrography	Hindcasts, nowcasts and forecasts of coastal ocean currents and temperature and salinity fields
Surface Waves	Forecasts of wave conditions with lead times of hours to days
Sea Ice	Short-term and seasonal forecasts of ice properties and ice motion
Tsunamis	Forecasts of tsunami arrival with lead times of minutes to hours
Single Species	Reconstruction of past and present abundance levels, forecasts of abundance under different management strategies
Multiple Species	Time-varying patterns of predation mortality, optimal (sustainable) levels of harvest for exploited communities, evaluation of harvesting strategies for multi-species assemblages
Ecosystem	Indicators of ecosystem status, evaluation of impacts of harvesting strategies on non-exploited resources, evaluation of impacts of global change on exploited and non-exploited resources
Focal Pollution	Evaluation of whether beaches/shellfish harvesting areas and shellfish meet local/regional/international health guidelines and standards. Help establish the optimum combination of waste treatment level, length and depth of outfall sewers, and the number of multiple discharge manifold pipes at the end of outfalls
Health Risk/Dose-Response	Estimates of increased incidence of gastroenteritis and respiratory infections caused by bathing in contaminated water, and infectious diseases from consuming raw shellfish harvested in faces-contaminated waters
Water Quality	Cornerstones for large-scale expenditures aimed at mitigating the effects of anthropogenic nutrient inputs
Water Clarity	Standardized water clarity calculations and analysis of remotely sensed images
Aquaculture	Information required to help manage aquaculture operations and regulate their environmental impacts
Ecotoxicology	Predictions of the fate and effects of anthropogenic chemicals with limited application as routine ecotoxicological tools in natural ecosystems

Table 5.3. Assessment of the overall operational status, complexity and predictive capabilities of the models mentioned in the text. L = low, M = medium, H = high.

Model	Operational Status	Complexity	Predictive Skill
Storm Surge	Operational	M	H
Shoreline Change	Pilot to pre-operational	M - H	L
Currents and Hydrography	Pilot to pre-operational	H	M
Surface Waves	Operational	H	H
Sea Ice	Operational	H	M - H
Tsunamis	Operational	M	M - H
Single Species	Operational	L - M	H
Multiple Species	Pilot	M - H	L - M
Ecosystem	Research and development	M	L
Focal Pollution	Pre-operational	M	M
Health Risk/Dose-response	Research and development	M	M
Water Quality	Pre-operational	H	M
Water Clarity	Operational	L - H	M
Aquaculture	Pilot	L - H	M - H
Ecotoxicology	Pre-operational	L - H	L - M

It is important to note that the focus of this section is models that are relevant to global scale or ubiquitous problems. This does not mean that site-specific ecosystem models and the variables that define them are not important. They are. The choice of models simply reflects the focus of the design plan on a global system (Chapters 1 and 3) and, to a large extent, the selection of global system variables (Chapter 4). Local models, often at very high resolution (less than 1 km) and with extra site-specific variables, are the responsibility of the GRAs.

Box 5.1. Characteristics of Operational Models

Given users will demand results of known quality, all models that are termed operational should have the following characteristics:

- Clear and complete documentation describing the underlying concepts (equations where appropriate), simplifying assumptions, inputs and model outputs;
- Quantitative descriptions of model-data misfits based on rigorous validation using all available historical synoptic data by;
- An institution or organization that is responsible for the model's routine operation and its quality and continuity of forecasts;
- A clearly identified funding pipeline for the next decade.

Thus, operational models will have moved through the research and development, pilot project, and pre-operational stages before being certified as operational. These preliminary stages are required so that pilot projects can generate definitive validation tests that are executed during the pre-operational stage.

5.2.1 Marine Services and Public Safety

This is the theme for which operational models are most advanced and for which the most useful and reliable products are available. For example, useful forecasts have been made of storm surges and sea state for decades. More recently three-dimensional models of the deep ocean and adjacent shallow seas are being used to nowcast and forecast the vertical and horizontal structure of currents, temperature, salinity, sea ice, and sea level. Ocean models are also being coupled with atmospheric forecast models to allow for the air-sea exchange of momentum, heat and water and thereby achieve more realistic nowcasts and forecasts of the coupled atmosphere-ocean system (Figure 5.2).

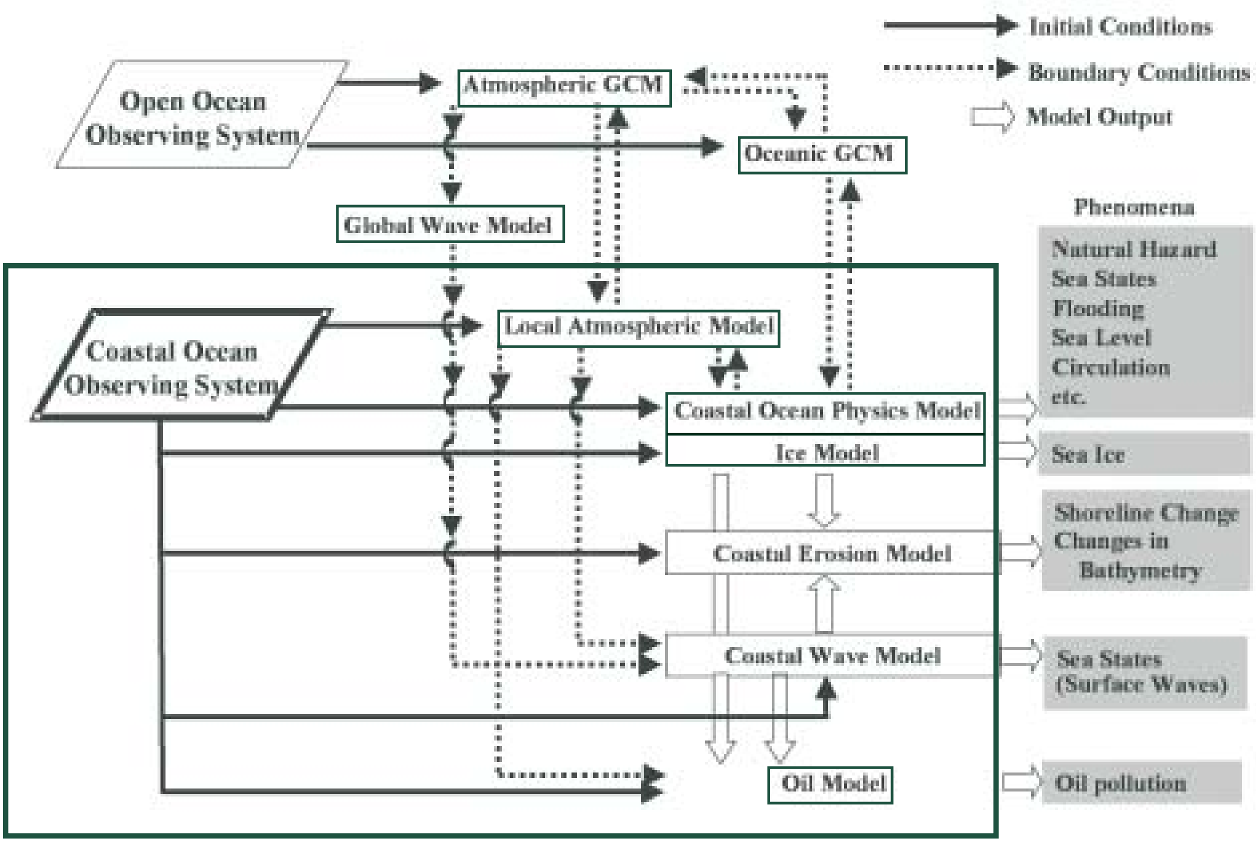

Figure 5.2. Schematic showing the relationships among open and coastal ocean observations and the various types of models used to produce forcing functions (time dependent boundary conditions), analyses and forecasts.

Ocean and shelf models can be coupled with 'application' modules to predict, for example, sediment transport, ice formation, advection-diffusion of passive and active tracers, the trajectories of oil slicks and search-and-rescue targets, and high-resolution port hydrodynamics. They can also be coupled with biogeochemical process models and water quality models to predict the evolution of primary and secondary producers and, for example, anoxia and hypoxia. Work is underway to couple ocean-shelf models with hydrological models of river basins and thereby achieve more realistic forecasts of terrestrial sources of freshwater and hence coastal flooding. Models are also being developed for shallow water (less than 10 m in depth) where complex, non-linear processes like wave breaking must be tackled. Brief summaries are given below of some of the more specialized forecast models that fall under the heading of Marine Services and Public Safety.

Storm Surges

Given the tremendous loss of life that can accompany coastal flooding[8] , considerable effort has been expended in developing effective schemes for forecasting storm surges (e.g. Pugh, 1987). As a consequence many regions now have effective surge forecast models that provide warnings of coastal flooding with a lead-time of hours to about one day. For the North Sea, for example, a storm tide warning service operated by the U.K. Meteorological Office provides not only flooding alerts for coastal communities but also information that helps determine if the Thames Barrier is to be raised to protect London from flooding. (Flather (2002) reviews the operational systems that are presently used for real-time forecasting of surges for northwest Europe.)

The horizontal decorrelation scale of storm surges is generally much larger than that of non-tidal currents or the velocities of advected, buoyant objects like oil slicks or life-rafts[9]. One consequence of this differ-

8 6,000 lives were lost in Galveston Texas in 1900, 2,000 around the southern North Sea in 1953 and 500,000 in Bangladesh in 1970.

9 Spatial differences in sea level are related to horizontal integrals of surface currents and wind stress and therefore tend to be of larger scale than current or wind.

ence in scale is that it is generally easier to forecast changes in sea level associated with surges than surface currents or trajectories as long as accurate forecasts of the wind and air pressure fields are available. In fact for extra-tropical regions with relatively wide continental shelves (e.g. northwest European Shelf, eastern Canadian Shelf) it has been shown that relatively simple, depth-integrated models with constant water density can provide useful surge forecasts. A case in point is the east coast of Canada where a simple model of this type is now run operationally and can provide surge forecasts that are accurate to within about 10 cm with a lead-time of about 1 day. (Good examples of the accuracy of operational surge forecasts for a range of coastal environments for the east and west coasts of the U.S.A. can be obtained from http://www.nws.noaa.gov/tdl/etsurge).

Shoreline Change

Most models of shoreline change have been simple "line models" that have focused on how the shoreline changes with variations in deep-water wave conditions and wave transformation processes related to shoaling, refraction, diffraction and frictional dissipation, changes in sediment supply, and even the placement of engineering structures in the nearshore zone. More sophisticated numerical models calculate patterns of shoreline erosion and accretion due to the long-shore sediment transport, and thereby the time-evolution of the shoreline shape and position. (See Komar (1998) and references therein.)

The most advanced models are fully three-dimensional and calculate cross-shore sediment transport and profile changes, as well as alongshore sediment transport rates. Further development of three-dimensional models will require a better understanding of a number of complex nearshore phenomena and processes including infragravity and edge waves, and the processes responsible for generation of complex bottom topography such as systems of nearshore bars.

Predicting coastal erosion, including the erosion of cliffs, is a much more difficult problem than predicting the effect of wave action on sedimentary coastlines. A number of additional factors have to be taken into account including, for example, the combined effect of waves and sea ice in some higher latitude regions.

Coastal Currents and Hydrography

Three-dimensional hydrostatic and non-hydrostatic models are now used routinely to forecast coastal ocean currents and temperature and salinity fields on continental shelves (Brink and Robinson, 1998). The numerical scheme underlying the models can be based on finite elements, which allows the horizontal resolution to be increased in areas of particular interest, or finite differences in which case it is possible to nest higher resolution submodels within larger scale models that provide the required open boundary conditions. In some cases it is computationally advantageous for the larger-scale model to be based on physics that is simplified relative to the nested submodel. For example coastal models must include a free surface to predict tides (and in some situations may relax the hydrostatic assumption) while larger scale, deep ocean models (to which coastal models may be coupled) often have a rigid lid and are usually hydrostatic (Haidvogel and Beckman, 1998).

In contrast to storm surge models, current models are usually baroclinic and calculate the full three-dimensional structure of all hydrodynamic state variables including horizontal currents, sea level, temperature and salinity. This class of model is thus suitable for coupling with models of, for example, marine biogeochemistry, water quality, and hydrology (including submodels of river catchment basins that can ultimately forecast river runoff and thereby extend the predictability of coastal models). It is expected that new technologies (e.g. AUVs, HF radars) and 'coastal' satellite sensors will increase the forecast skill of these models in the near future.

Surface Waves

Operational forecasting for the open ocean is usually made using a global model domain with rather coarse horizontal resolution in order to capture the remote generation of wind waves and their great-circle propagation toward the coast as swell. Wave forecasting on regional scales requires finer spatial resolution and careful treatment of the local coastal boundary and bottom topography. A coastal version of the third-generation wave models (which allow for nonlinear wave-wave interaction directly) has been developed to deal with these issues (e.g., Booij et al., 1999).

The typical resolution of the present coastal wave models is between 10 and 30 km. User requirements are becoming more diversified and finer temporal/spatial information about the coastal wave field is required. The computer burden of third generation wave models has made it difficult to increase spatial resolution in shallow water. To overcome this difficulty, a new third-generation coastal wave model with much finer spatial resolution (better than 1 km) has been developed and is undergoing testing and evaluation by the research community. As the coast is approached a number of additional phenomena can become important and sophisticated models, some now commercially available, have been developed by the nearshore engineering community.

As for surges, the primary driver of wave models is the wind and the need for accurate wind forecasts cannot be overemphasized. Initial conditions for wave models are determined from *in situ* measurements and remotely sensed observations. Precise wave information along coastal lines and accurate bottom topography are also essential in coastal wave models.

Sea Ice

Sea ice can interfere with offshore activities such as offshore drilling, marine transportation, fishing and search and rescue missions and can pose a serious human threat in high latitude oceans. Similarly the freeze-up of harbours and rivers can also affect the economy and quality of life of people living in high latitude coastal communities.

Sea-ice models predict the formation, concentration and thickness distribution, internal pressure, and the velocity of sea-ice. Many models have been developed over the past 40 years. The early models considered only the thermodynamics of sea-ice and wind forcing of ice over an inactive ocean. However during ice formation and growth, brine is rejected from the ice resulting in an increase in surface salinity. During ice melt, freshwater is released into the upper ocean. The change in the upper-ocean properties can in turn change the heat and water transfer rates at the ice-water interface, and hence the ice distribution. Failure to include such feedbacks between the ocean and sea ice can lead to large errors in model predictions.

Improvements in sea ice models have come from coupling sea-ice and ocean models, better numerics and data, improved parameterisations of ice rheology and ice-ocean and ice-atmosphere processes. Coupled ice-ocean models for ice prediction have been developed and implemented for many coastal areas including the Baltic Sea (Haapala and Leppaeranta, 1996), east coast of Canada (e.g. Yao et al., 2000, Saucier and Dionne, 1998) and the Arctic Ocean (Riedlinger and Preller, 1991). Further improvements of regional sea-ice models will include coupling to large-scale ice-ocean models, coupling to atmospheric boundary layer models, and data assimilation.

Oil Spills

Oil pollution from both land and ocean-based sources can pose a serious threat to coastal ecosystems (section 2.4). Once a marine spill has occurred, sophisticated models can be used to forecast its trajectory, evolution and environmental impact (e.g. French, 1998).

Physical conditions in the upper layer of the ocean control, to a large extent, the fate of surface slicks. The surface flow, which is forced by a range factors (e.g. local wind and waves, tides, density gradients, deep ocean effects), determines the horizontal movement of the oil. While drifting with the surface flow, the slick can be diffused by turbulent motions and modified by many physical/chemical/biological processes including spreading, evaporation, emulsification, entrainment, sedimentation, biochemical decay and contact with coastlines and sea ice (Spaulding, 1988). Advection and weathering of surface slicks can be usefully forecast with lead times of about a week by the present generation of models, some of which are commercially available. (The processes controlling the breakdown of hydrocarbons into relatively benign products on time scales of months are relatively poorly understood.). Three-dimensional models are also now being used to predict the entrainment and subsurface transport of the oil, and its possible resurfacing (e.g. French, 1998).

Oil forecast models require good initial conditions for the spill including its extent, volume and chemical properties. These models also require forcing at their surface and lateral boundaries. The coastal ocean observing system has an important role to play in providing data to regional atmospheric-ocean-wave models (Figure 5.2) that will lead to better forecasts of surface winds, currents and wave conditions.

Tsunamis

The surface elevation generated by a sharp vertical motion of the sea floor during an earthquake can radiate waves away from deep ocean source regions. Given that such seismically-excited motions have wavelengths of order 100 km, they propagate as shallow water waves in the deep ocean and enter coastal waters as a tsunami. While propagating across the deep ocean, their amplitude is small (order 1 meter) compared to their wavelength. This implies gentle slopes of the sea surface and difficulty of detection using conventional methods. As the tsunami approaches shallow water however their amplitude can amplify leading to severe flooding and devastation with serious loss of life. Although tsunamis are rare, their impact is so profound that they are treated as a serious threat in the coastal zone.

To model the generation of a tsunami a source model is used to determine the initial vertical displacements of the sea surface caused by earthquakes or other seismic activities. The subsequent propagation of the tsunami is modelled based on the shallow-water wave equation. It is believed that linear theory can accurately predict the propagation of the tsunami in depths exceeding 500 m; in coastal seas shallower than about 50 m, other dynamical effects, such as advection of momentum and bottom friction, must be taken into account. To simulate the shoaling and flooding of the tsunami, it is important to specify accurately both the nearshore bathymetry and the coastline (e.g., Shuto, 1991).

When a tsunami is generated in the far field (i.e. distances greater than about 1000 km), it can take several hours to travel to the coastal region of interest. Information on the tsunami propagation from remote sites can be usefully monitored by arrays of widely separated coastal tide gauges and used to initialise the propagation model (e.g. the International Tsunami Warning System was established to forecast the arrival of tsunamis in remote parts of the Pacific basin (http://ioc.unesco.org/iocweb/activities/tsunami.htm).

5.2.2 Living Marine Resources

The development of conceptual and mathematical models has played a central role in marine biology and ecology as a tool for synthesis, prediction, and understanding. This activity has encompassed the development of models for single species, multi-species communities, and for whole ecosystems (e.g. Hofmann and Lascara, 1998; Hofmann and Friedrichs, 2002). The use of models has proven especially important because marine systems are typically not amenable to controlled experimental manipulation and alternate strategies involving the interplay of observation and modelling are critical. For applied problems such as fishery management and environmental protection, models are essential for predicting outcomes of proposed management actions (e.g., Moll and Radach, 2001; and Fischer et al., 2000).

The development of hindcasts, nowcasts, and forecasts of the status of living marine resources is an integral component of fishery research and management. These models depend on an extensive existing observing system designed to monitor catches, fishing effort, and demographic characteristics of the catch (size and/or age structure). In many areas, fishery-independent scientific surveys have also been conducted to monitor ecosystem status. The most common type of model used for hindcasts and nowcasts is sequential population analysis in which the abundance and survival rates for each age or size class of a population are determined (e.g. Quinn and Deriso 1999). Other models of production processes at the population level are routinely used to set management targets and limits to exploitation and to evaluate the effects of alternative management actions.

Considerable attention has recently been directed to the development of models and management strategies to meet broader ecosystem-based management strategies (including protection of vulnerable habitats, preservation of ecosystem structure and function). The coastal module of GOOS can make an important contribution to the development of model and management strategies directed at these higher levels of organization (multispecies and ecosystem levels) by complementing the existing extensive efforts in place to monitor population trends in exploited living marine resources.

Multiple Species Dynamics

Explicit representation of species groups or assemblages in multi-species models has been undertaken in a number of marine systems (Hollowed et al., 2000; Whipple et al., 2000). Most often, these models consider interactions among members of identified communities of organisms and typically span a limited number of trophic levels. Predator-prey and competitive interactions have been most extensively modelled. In contrast to individual species models, these models provide explicit representations of interacting species and can be used, therefore, to examine the implications of changes in the relative abundance of species within biological communities.

Multi-species sequential population analysis is an extension of sequential population analysis that can be used to account for the effects of predator-prey interactions in an exploited community (Hollowed et al., 2000; Whipple et al., 2000). The features of the models follow the single species structure outlined above with the addition of information on the diet of the species in the model. These models allow a partitioning of natural mortality into a predation component and a component due to other sources of mortality such as disease. Estimates of total consumption of a prey item are treated as a removal term just as harvesting represents a loss term. Multi-species sequential population analyses are data intensive and have been employed in fewer settings than their single species counterparts. Examples of regional applications include the North Sea and the Georges Bank region of the Northwest Atlantic.

Extension of single species production models to assemblages of interacting species have been applied in both non-structured (bulk biomass) and demographically structured forms. These models typically include explicit terms for various forms of biological interactions, particularly competition and predation with the objective of determining the community-wide effects of exploitation. This approach recognizes that, in a community of interacting species, the yield of all species cannot be simultaneously maximized since changes in the abundance of each species affect the abundance of interacting species.

Non-structured multi-species models have included forms in which individual species are not explicitly modelled and only the total yield from an assemblage of interacting species is considered and biological interactions are implicit. These models have been employed particularly where separation by species is not possible (e.g., high diversity tropical fisheries, Ralston and Polovina, 1982). Other forms include specific consideration of competition and predation in an extension of the classical Lotka-Volterra equations incorporating harvesting mortality. The yield of individual species as well as the total yield from all species is modelled.

Multi-species analogues of age- or stage-structured production models have been less commonly employed. These models do permit consideration of age, or size, specific processes that can be critical in devising management strategies. For example, predation mortality is often highest on pre-recruits and models that explicitly consider the biological interactions in the stock-recruitment relationship are more realistic.

Ecosystem Dynamics

Models of whole ecosystems have been developed for some marine systems with direct consideration of nutrient inputs and representation of each trophic level from primary producers through top predators (e.g. Pauly et al., 2000; Baretta et al., 1995). Because of the complexity of these ecosystems, aggregate species groups are often used to represent at least some trophic levels, thus reducing the overall number of compartments in the model to a more manageable size, e.g. phytoplankton in two or three size classes, microzooplankton, gelatinous macrozooplankton, copepods, filter feeding fish, and predatory fish. The recognized importance of the development of ecosystem-based management approaches highlights the need to develop operational ecosystem models for the purposes of fisheries management. Ecosystem-based management recognizes the importance of essential fish habitats, multi-species interactions, and nutrient cycling as parameters of the growth, abundance and distribution of exploitable fish stocks. Accordingly, it is critical to understand and predict both direct and indirect effects of human activities on marine ecosystems including the following:

(1) alterations in food web structure and changes in biodiversity that may result from fish harvests or

nutrient over enrichment (thereby altering food supplies or predation rates);

(2) habitat loss or modification due to human activities or natural hazards (thereby decreasing rates of recruitment and increasing exposure to predators); and

(3) introductions of non-native species that may reproduce and grow (and outcompete native fish stocks, produce biotoxins that cause mass mortalities of fish or make fish toxic to humans, or modify essential fish habitat).

Models have been developed of energy flow and utilization in marine ecosystems, using information on standing stocks of individual species, or aggregate trophic groups, and the flows of energy or material between the living and non-living (e.g. detritus) components of the ecosystem. Analytical approaches have been used to yield outputs on some functional properties of the ecosystems, such as the magnitude of recycling, flow diversity, and the efficiency of energy flows. The advantage of standardized approaches is that comparative analyses across many ecosystem types are possible within a common framework.

Ecosystem network models provide static snapshots of ecosystem processes under certain mass balance assumptions. Dynamic ecosystem simulation models have also been developed and applied to these fishery systems (Hollowed et al., 2000; Whipple et al., 2000; Pauly et al., 2000). Typically these models provide high resolution on the upper trophic levels (particularly exploited species) with more aggregated system representations at lower trophic levels.

5.2.3 Public Health

Models that have been developed to predict human health effects and related impacts (hospitalisation, death etc.) from environmental data are useful as long as due consideration is given to their limitations. Of these, perhaps the most significant is the reality that current models are able to provide useful predictions mainly when the pathology is caused by exposure to a single agent, e.g., poisoning caused by a biotoxin produced by a species of harmful algae. However, for many diseases that are related to seafood consumption or environmental exposure, other factors may be involved. For example, the extent to which neurobehavioural deficits are caused by prenatal exposure to methyl mercury from contaminated seafood is difficult to quantify statistically because many other environmental and genetic factors may also be involved. With this limitation in mind, examples are given below of the use of models in addressing two important public health issues.

Predicting Dispersion of Faecal Indicators and Pathogens

Predictive models have been developed by engineers and marine scientists to estimate the dilution, dispersion and decline of faecal pollution indicator organisms from wastewater discharges to the sea. These models take into consideration the three main mechanisms involved: (1) dilution by turbulent mixing; (2) advective transport; and (3) the rate of decay of the pollutant, decrease in toxicity of the organism, or mortality (including the rate of dormancy) as a function of environmental factors such as photochemical oxidation, increases in salinity, predation, and starvation.

Experience with the use of such models and conventional wisdom indicates that the maximum degree of dilution obtainable by the jet plume discharge to the surface is in the order of 10:1. The additional dilution obtainable by dispersion and diffusion through the advective flow and lateral movement of the plume after it has risen to the surface is usually no more than an additional 10:1 to 20:1, so the concentration of a pathogen by dilution alone may be on the order of 100:1 to 200:1. In addition, although bacterial mortality rates vary as a function of local conditions, numerous field studies indicate that the rates at which the concentration of active bacteria decline, expressed as T90 (the time for 90% reduction in concentration), ranges from 60 to 120 minutes.

If standards for the acceptable bacterial levels for bathing or shellfish harvesting have been established by regulatory agencies, then it is possible to use these dilution-bacterial mortality models to help establish the optimum combination of waste treatment level, length and depth of the outfall sewer, and the number of the multiple discharge manifold pipes at the end of the outfall required to meet or exceed such standards.

Health Risk Related to Marine Toxins

Since 1977, researchers at the University of Miami's Rosenstiel School of Marine and Atmospheric Science have developed a database (Ciguafile) of ciguatera cases that is among the largest in the world. Spatial density analysis of the data revealed hotspots near Puerto Rico and the Bahamas that are being used to map ciguatoxic reefs and can be used to calculate health risks based on statistical models. GIS allows for linkages and analysis of databases on oceanographic environmental conditions. Such maps provide a means to explore relationships between environmental factors and the distribution of risk, thereby developing a more mechanistic understanding that can be used to develop and improve models of health risks associated with diseases such as ciguatera.

5.2.4 Ecosystem Health

Numerous international conventions and agreements focus on protecting and restoring healthy ecosystems. Changes in the following phenomena are widely accepted indicators of changes in the condition or health of marine and estuarine ecosystems: (1) habitat modification and loss, (2) loss of biodiversity, (3) eutrophication and chemical contamination (declines in water quality), (4) harmful algal events, (5) invasions of non-native species, and (6) diseases in and mass mortalities of marine organisms. Currently, an enormous range of models is available to predict the effect of anthropogenic impacts on ecosystem health. This section reviews the current status of modelling for eutrophication (water quality, water clarity, aquaculture) and ecotoxicology associated with chemical contamination.

Water Quality

Water quality models represent a class of numerical simulation models used to assess and forecast responses of water quality variables to changes in loading rates (e.g. nutrients, organic matter, toxic contaminants) from point and diffuse sources in coastal watersheds (e.g., Cerco and Cole 1993). These models often serve as cornerstones for large-scale expenditures aimed at mitigating the effects of anthropogenic nutrient inputs. The structure of these models is similar to coupled biophysical models used in oceanographic simulations (e.g., Fasham et al., 1990, Sarmiento et al., 1993), with external inputs (hydrological and climatological) driving the model and physical circulation computed to transport materials that are also altered by biogeochemical kinetic processes (e.g., Cerco and Cole, 1993). Modern water quality models also employ relatively sophisticated representations of fundamental ecological and biogeochemical processes occurring in sediments and associated exchanges of nutrients, oxygen and organic matter between sediments and overlying water (e.g., DiToro, 2001).

Most water quality models emphasize "bottom-up" (nutrient) control on biogeochemical processes with minimal focus on "top-down" (consumer) control and ecological feedback processes that influence flows of energy and nutrients and link primary producer and consumer populations (e.g., Kemp and Bartleson, 1991, Ross et al., 1993, Kremer et al., 2000). Such models are usually calibrated and validated using historical data. Available large data sets derive and drive these models, though calibration is usually done using informal trial-and-error methods or linear optimisation programming approaches (e.g., Lung, 1989). Generally, more formal data assimilation methods (section 5.3, Lawson et al., 1996) have not been applied to water quality modelling. Although water quality models are typically very well calibrated for dissolved oxygen and phytoplankton blooms, they are seldom checked against basic parameters such as total primary production or respiration that define and constrain dynamics of coastal ecosystems.

Water Clarity

Water clarity models are used to describe the light field at a given depth in order to feed into phytoplankton or benthic plant productivity models. Since models of water clarity rely on the predictably of light behaviour with depth depending on the relative quantities of absorbing and scattering components, they are also used to understand the constituents of the water which contribute to a change in water clarity over a given time period. The constituents that can be monitored optically are suspended solids, dissolved organic matter, and phytoplankton biomass. Water clarity models range from relatively simple mathematical relationships based on the physical behaviour of light in water to more complex algorithms associated with remote sensing.

Aquaculture

Models for coastal aquaculture operations fall into one of two categories: (1) those used to evaluate the environmental impacts of aquaculture on coastal ecosystems (e.g. excess organic loading from sedimentation of faeces or excess food, regeneration of ammonia, removal of suspended organic matter), and (2) those used to estimate growth rate and maximum sustainable yield in terms of numbers of organism and/or their biomass. The latter often employ models similar to LMR models.

Mass balance equations that treat the culture area or volume as consumers of organic matter (food) and producers of organic matter (biomass and waste) are at the heart of most aquaculture models. Such models are coupled to hydrodynamic models that supply and remove food and wastes. Models of sedimentation may contain more complex hydrodynamics because it is necessary to resolve the benthic boundary layer in order to parameterise deposition and resuspension. Moreover, these models may be extended to the consequences of increased carbon or nitrogen loading for which benthic submodels of nutrient regeneration are necessary (Chapelle et al., 2000).

The form of these models varies from box models (e.g. Dowd, 1997) to three dimensional circulation models coupled to ecosystem models (e.g. Pastres et al., 2001). Correspondingly, the hydrodynamic component ranges from bulk flushing times to exchange coefficients to matrices of current velocities on a model grid. A recent development in these models has been their incorporation of GIS as a means of running the model or integrating output (Pastres et al., 2001). This allows model output in the form of maps depicting seston depletion, growth, and biodeposition.

In addition to the physical model, a bioenergetic model of the culture species is often used to estimate biomass production and waste output based on food supply. These models are robust at predicting growth from a given set of food conditions, since the bioenergetics of most cultured species are well documented (e.g. Grant and Bacher, 1998). Depending on the goal of the model, there may be submodels for other ecosystem components including nutrients, phytoplankton and zooplankton. Recent studies have focused on the effects of the culture hardware (lines, nets, anchors) on circulation which is especially relevant in heavily utilized, shallow bays.

Overall, models of aquaculture impact and seston depletion have reached the stage of being actively used for both the management of aquaculture operations and the regulation of their environmental impacts. It is important to note however that (1) although the required software is becoming commercially available, significant investment is required to implement monitoring programmes and develop circulation models that are, for the most part, site-specific; (2) waste production models suffer from some of the same empirical weaknesses as sediment transport models in that erosion thresholds and sinking speeds of natural particles are often not well known.

Ecotoxicology

In recent decades, significant effort has been devoted to determining the transport, availability, fate, relative toxicities, and biological effects of a diverse range of anthropogenic chemicals. A key feature of ecotoxicology is its reliance on the use of models of various kinds to extrapolate from laboratory studies to the field, from individuals to communities, and from effects of single chemicals to multiple effects of complex mixtures, i.e., to extrapolate from experimental observations to effects in nature.

Many efforts to model toxicity rely heavily on dose-response relationships. By establishing relationships between chemical exposure and toxicity in the laboratory, toxicity thresholds, concentrations at which 50% of the test population dies, etc. can be predicted and used with appropriate safety factors for environmental legislation. Mechanisms of toxicity have also been studied using models of receptor-ligand interaction. These early models are the foundation from which more elaborate attempts have been made to predict toxicity and make risk assessments (Klaasen and Eaton, 1991).

Models have been developed to predict exposure, biological affects, and the consequences of remedial action (Whelan et al., 1987). A variety of models is available for determining the persistence of organic pollutants (Roberts et al., 1981), the fate of inorganic compounds (e.g. Dolan and Bierman, 1982), the speciation of metals (e.g. MINTEQAI – Brown and Allison, 1987) and chemical spills (Brown and Silver, 1986). There are also available models that estimate exposure to environmental pollutants (Mackay, 1991; OECD, 1989).

Efforts have been made to model the toxicity of chemicals to give at least some insight into potential effects. One of the most highly developed approaches is based on Quantitative Structure-Activity Relationships (QSARs; Nendza, 1998). Based on empirical extrapolations, these models are used to estimate the parameters relating to fate and effects and hence identify contaminants of particular concern. With regard to biological effects, models are available for predicting pollutant-induced changes at all levels of biological organization (see Levine et al., 1989). Models of molecular and toxicological mechanisms were briefly alluded to earlier.

In recent years, models that have been developed primarily for studying population dynamics in an ecological context have been modified for use in ecotoxicology. This has permitted preliminary investigations of the relationships between pollutant exposure and population-level consequences (Suter, 1993) which are tuned to reflect the impact of varying degrees of environmental stress, whether natural or anthropogenic, on the population in question.

Similarly, at the community and ecosystem levels, models exist for predicting changes in structure and function that have been validated to varying degrees (Barnthouse, 1993). The key to using these models in an ecotoxicological context is to provide evidence that pollutants specifically contribute to the observed or predicted changes in populations, communities and ecosystem.

In summary, an enormous range of models are available to predict both the fate and effects of anthropogenic chemicals. However, at this stage our lack of understanding and in some cases our ability to measure relevant parameters, has hampered their application as routine ecotoxicological tools in natural ecosystems.

Advances in ecotoxicological modelling have been thwarted both by a lack of understanding of numerous biological and ecological processes, and by technical limitations which have prevented proper field validation of model predictions. In the confines of the laboratory such models usually operate quite well. However, ecotoxicological models for application at the level of individuals and above, that are relevant in the assessment and prediction of changes in ecosystem structure and function, have proved extremely difficult to establish.

5.3 Data Assimilation

Data assimilation is a numerical procedure for combining observations and dynamical models. It has long been an essential component of weather forecasting where it is used to continuously reinitialise forecast models based on differences between previous forecasts and newly available data (Daley, 1991). Modern data assimilation techniques have also been used to reconstruct the three dimensional state of the global atmosphere over the last 50 years in what are usually referred to as reanalyses (e.g. the NCEP reanalysis, Kistler et al., 2000).

Data assimilation has uses beyond hindcasting, nowcasting and forecasting. It can provide a quality control mechanism for operational observing systems. Specifically assimilation models can identify, in an operational mode, suspect observations and possibly reject them based on comparison with corresponding model predictions, taking into account the statistical distributions of the errors. A sequence of bad observations can help identify a faulty instrument that needs to be repaired in a timely fashion. Adjoint models are part of four dimensional, variational (4DVar) assimilation schemes. They can be used to assess the value of observations made at arbitrary locations and times and, in principle, be used to improve the design of observing systems.

Data assimilation schemes are most advanced for atmospheric models although the data assimilative physical oceanographic models are closing the gap (e.g. Robinson 1999, Lozano et al., 1996). In fact many of the more advanced techniques, such as extended and ensemble Kalman filtering, 4DVar and the incremental approach[10] , have already been tried

[10] The incremental approach uses a simpler model and its adjoint to guide a more sophisticated model along a trajectory that is consistent with observations.

for shelf seas and oceans. Data assimilation has not been used widely in the modelling of non-physical properties of coastal ecosystems (Robinson and Lermusiaux, 2002). However, this will likely change over the next decade with the increasing power of computers and new observations from the coastal observing system.

The predictability of coastal ecosystems is limited by (1) errors in specifying the external forcing, (2) uncertainties in the initial and open boundary conditions, including lateral boundaries for coastal models (and trophic levels for ecosystem models), (3) the complexity, and inherent nonlinearity, of coastal ecosystems which can make even the formulation of a quantitative model challenging. When attempting to make forecasts, data assimilation is used primarily to help reduce uncertainties in the initial and open boundary conditions.

The basic idea behind data assimilation is straightforward, particularly if explained in Bayesian terms using concepts such as prior and posterior distributions. The devil of course is in the details, particularly when it comes to assimilating sparse, noisy data into highly non-linear, computationally expensive models. The assimilation of data into coastal ecosystem models presents a number of technical problems including:

- The strongly non-linear form of ecosystem models. This can cause strong feedbacks across multiple trophic levels and possibly chaotic behaviour.
- The high dimensionality of complex ecosystem models. For circulation models, the dimension of the state space is 5. It could be larger by at least an order of magnitude for complex ecosystem models. This means the specification of error biases and covariances will be difficult (assuming a statistical description of errors in terms of first and second moments is even adequate). It also means the 'optimal' solution will be hard to find (multiple minima will likely exist in the penalty function to be minimized) and error bars will require extensive computation.
- The long memory of some components of the coastal ecosystem. This will make specification of initial conditions difficult.
- Rapid variability in both space and time (e.g. rip currents, edge waves, river plumes, patchy harmful algal blooms). High-resolution models are required.
- Computational costs. Data assimilation often comes down to the inversion of large matrices. The assimilation of data into complex ecosystem models will require advances in supercomputers and parallel architectures. Modern assimilation techniques such as the ensemble Kalman filtering and the incremental approach will probably play an important role.
- Extremes. Many users are interested in extreme events (e.g. sea levels with long return periods, concentration of a pollutant above a high threshold). This will complicate both the forward modelling and the assimilation, including possibly the definition of the penalty function.

Recent developments in the extraction of information from observations include neural network and genetic algorithms. These techniques have not generally been compared with the more traditional methods of data assimilation. Neural networks and genetic programming should arguably be used in addition to the classical field estimation techniques to pre- or post-process the observations and/or determine the values of free parameters in the numerical models.

In summary, the role of data assimilation in bringing together models and data in order to increase the predictability of marine ecosystems, help design better observing systems and control the quality of data, makes it of central importance to COOP.

5.4 Conclusions and Discussion

Models will play a critical role in the design and operation of the coastal observing system and the generation of products. There will be considerable overlap of interest and activity between the range of models developed and operated in a standardised global mode, and smaller scale, higher resolution models that include variables specific to a region, an estuary, or the near-shore environment. The latter will typically be developed within the GRAs, although the same model might be used or shared between several GRAs. Coastal models also require information on the terrestrial inputs and so close coordination of the activities of COOP with GCOS and GTOS will be required for both model development and operations. If the coastal module is to realize its full potential, modelling must be integrated ab initio into the observing system's design, operation and ongoing evaluation. Although the above overview of models is not comprehensive, it is possible to draw the following conclusions.

A large number of models are being used to address a wide range of coastal issues. The models are used to predict, for example, storm surges and waves, the size of fish stocks, and the effect of nutrient pollution on coastal ecosystems. This presents both opportunities and challenges for implementation of the coastal module. The models have been developed to solve real problems so the links between modellers and users are being made and much useful infrastructure is already in place. This is not the case of a modelling solution looking for a problem to solve. On the other hand, the range of models and their data requirements makes the design of an integrated observing system a complex task, arguably a challenge far greater that that faced in the design and implementation of the global ocean module of GOOS.

Most of the models described under Marine Services and Public Safety are either fully operational or pre-operational and data assimilation is well advanced. For the remaining three themes (living marine resources, public health, and ecosystem health), an operational capability is generally at least five years away and data assimilation has yet to have a significant impact. This is an important reason for designing the observing system to both predict changes and make the observations required to develop and validate non-physical models as they become operational.

Accurate atmospheric forcing fields are essential if the physical models and their many application modules are to make useful predictions. In fact when the preliminary ranking of common variables was performed with meteorological variables included, wind was found to be the most important variable for prediction. Unfortunately the coastal zone is a difficult place to make atmospheric forecasts with its rugged orography and strong land-sea contrasts of temperature, humidity and surface roughness. The present generation of regional atmospheric models has a horizontal resolution of about 20 km. This is arguably too coarse in coastal regions, particularly when attempting to forecast the trajectories of buoyant objects, like oil slicks, harmful algal blooms, and liferafts, or the effect of processes that depend on higher order moments of the wind like local wave generation and the breakdown of vertical stratification. The development of high resolution, and possibly non-hydrostatic, atmospheric models will be critical to the successful development of the coastal module.

Data assimilation will play an increasingly important role in the design and operation of the observing system and the generation of products for users. This is entirely consistent with the situation in weather and open ocean forecasting. However, data assimilation poses a number of problems that are particularly acute in the coastal zone including (1) the high space-time variability of the coastal and nearshore physical environment (e.g. tides, river outflows), (2) the multidisciplinary aspects of ecosystem models, (3) the practical difficulties of making observations on the appropriate scales, and (4) developing observing, modelling and assimilation strategies to deal with highly episodic and extreme events.

It is also important to recognize that all aspects of data assimilation for biological and chemical processes will be dependent on improvements in capabilities for measuring appropriate variables on scales that must be resolved to develop and validate models. Promising approaches include sensing of chlorophyll concentration from satellites and moorings, automated nutrient analysers, and acoustic systems for assessing distributions of zooplankton and fish.

Community models have proven to be very useful in oceanography. Examples include, but are not limited to, the Princeton Ocean Model (used widely for shelf problems over the last decade) and the Parallel Ocean Programme (POP, developed by the Los Alamos National Laboratory and used for deep ocean studies). Such models are used by broad communities of scientists for fundamental research and the generation of useful products such as operational forecasts of surface currents and sea level. A similar community-based approach would also accelerate the development of models for biogeochemical problems.

Ongoing and systematic evaluation of the modelling-assimilation system will be essential for the coastal module to be effective. At least two levels of evaluation will be required. The first type of evaluation is an internal evaluation of model skill based on well-defined and internationally accepted metrics. For physical variables defined at fixed points (e.g. coastal sea level), this will usually be straightforward (e.g. root mean square difference between observed and forecast sea level). For forecast quantities like the position of fronts, the probability of the occurrence of a harmful algal bloom, and more complex quantities forecast by integrated ecosystem models, the situation becomes even more difficult. Generally accepted metrics will have to be defined however if progress in modelling is to be quantified. Again it will be worthwhile learning from the experience of the atmospheric forecasters who not only have to evaluate skill in forecasting point measurements but also precipitation fields which have patchiness characteristics that, superficially at least, are similar to those of biological variables like phytoplankton biomass. Coordination of efforts in defining metrics with deep ocean modellers will similarly be useful. The second type of evaluation will provide a measure of the usefulness of the model products. This will necessarily involve the users and may be more qualitative than the internal evaluation, at least initially. This external evaluation will be facilitated by the development of user-oriented model products, software interfaces and visualization tools that allow users to explore the model output.

As mentioned above, the oceanographic community is moving toward coupled models, e.g. shelf and deep ocean, shelf and atmosphere, water properties and harmful algal blooms. It would appear useful to think about coupling shelf models with basin scale models developed under the auspices of the OOPC. Simply put, the coastal models need the basin scale models for open boundary conditions; the basin scale models need the shelf models to simulate correctly processes such as cross shelf exchange and buoyancy input from rivers, as well as to transform open ocean predictions into forms of interest to users. Two-way coupling of models is not an easy task; it must solve a number of problems including different space-time resolutions of models, different physics and parameterisations, and different numerical schemes. Collaboration of deep ocean and coastal modellers at an early stage in the development of the coastal observing system would appear a sensible move and one that could, in the first instance, be achieved through exchange of personnel, specialized workshops, modelling networks, and joint COOP-OOPC pilot projects. Tangible products that could result from such a collaboration include community models and application modules for use by the scientific community.

For observations and models to manifest their full effect on the reasoned and effective development of coastal policy, additional efforts to link to socio-economic factors must be made. Recent efforts to utilize a Driver-Pressure-State-Impact-Response (DPSIR) model show some promise in this regard (Figure 5.3; Annex X). Within this framework, data describing larger-scale social dynamics (drivers), human forcing on environmental systems (pressures), the social benefits gained and costs imposed (impacts) by changes to environmental conditions (state) are conceptually linked to responsive regulatory approaches (responses). While still at an early evolutionary stage this approach could serve to build more operational models and serve as an organizing framework for the articulation and analysis of a broad suite coastal system and socio-economic indicators.

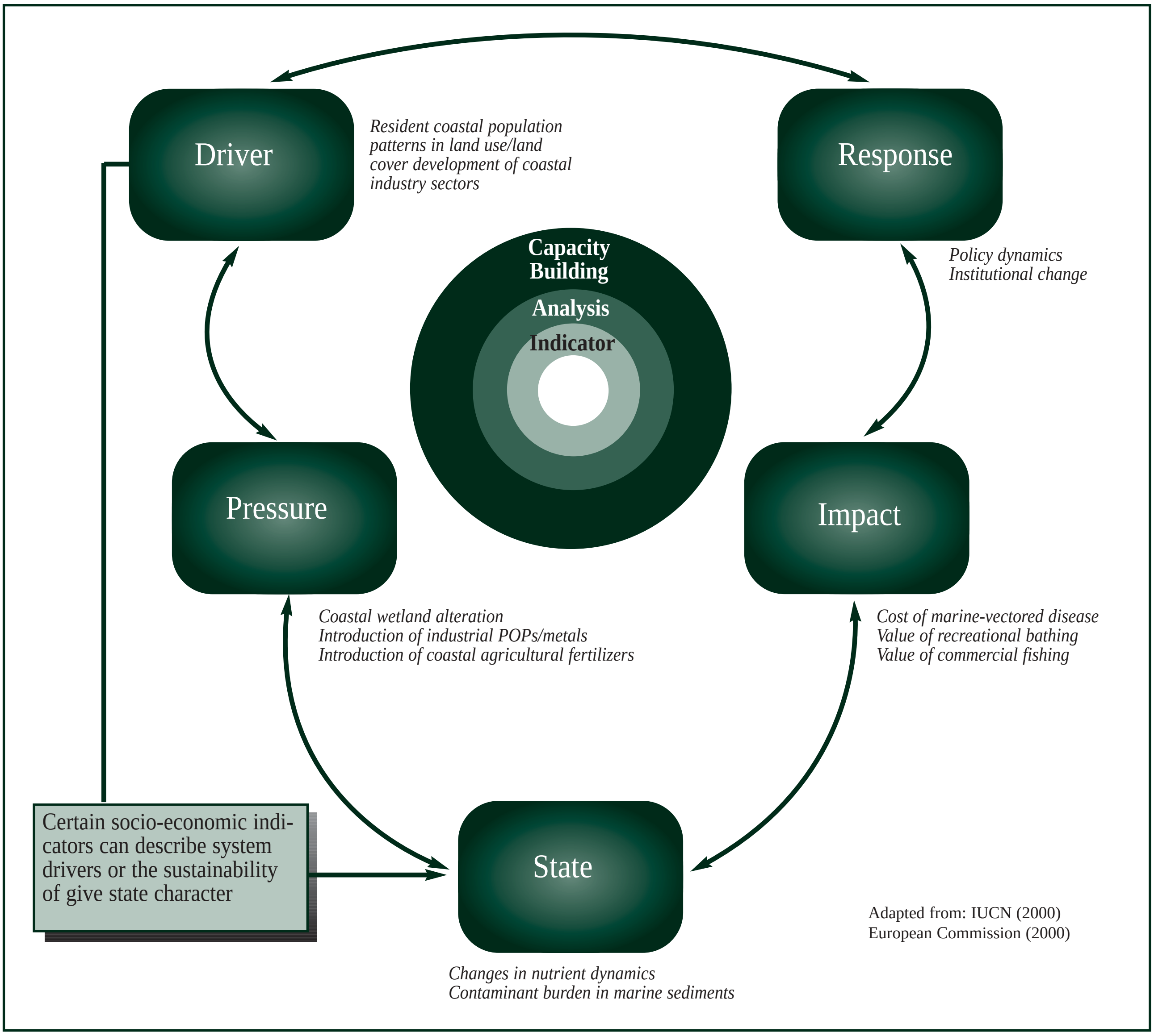

Figure 5.3. Schematic showing the Driver-Pressure-State-Impact-Response model.

6. Data Management and Communications Subsystem

6.1 Objectives

The objective is to develop an integrated data management and communications system (DMAC) that efficiently transmits large volumes of multi-disciplinary data (in real-time, near-real-time, and delayed modes) from many sources (*in situ* measurements, autonomous *in situ* sensors, remote sensors) directly to users for a broad diversity of applications including data assimilating models that process the measurements into maps, plots, forecasts, and environmental statistics (e.g., climatologies). The system should provide a user interface which allows non-experts or external customers to access data and obtain answers to practical questions, as well as providing the professional scientist, engineer, or value-added specialist, with a mechanism for manipulating, merging, processing, and modelling data to achieve specialised products. The data management system is also an essential tool for assessing, designing, managing and up-grading GOOS. To these ends, the development of DMAC must be coordinated with the development of the observing and modelling subsystems to ensure that there are no delays in achieving operational status.

This chapter sets for a framework and guidelines for the establishment of such an integrated DMAC system. It aims to raise awareness of important data management issues. Mechanisms are recommended for establishing, maintaining and assessing the observing system; and guidelines are provided for capacity building in data management and communication.

6.2 Background

The interface with the coastal module of GOOS for most users will occur through the data management and communications system. Contributors of data should be able to transmit data into the system with a minimum obligation to convert their data to specialized data formats or re-structuring of data sets, provided basic conditions of data quality and metadata standards are met. While it may be possible to provide a single portal for data users for one-stop access, this will inevitably be a simplified front end for the data management system that supports all the GOOS activities in the coastal ocean. Local access points will tend to focus first on national or regional (GRA) data sources and models for coastal waters in their vicinity. A centralised access point which is suitable for all types of customers, requesting data from any coast in the world, and designed to a common standard, may itself be an unattainable ideal. It is more likely that such a contact point will direct the user to other more specialized or regional product delivery centres, or would be restricted to a limited number of variables. The construction of specialized customer-related access points can then be carried out by delegated teams of experts who know the needs of different customers define the user software which is most suited to them.

Previous chapters have shown that the data management services needed to support the many facets of activity in the Coastal Ocean are themselves complex (Figure 6.1). In the open ocean, globally, and for the terrestrial hinterland, there will be adjacent services which provide boundary conditions and long-term forecasts. These services include the data management system for GCOS, the ocean component of GOOS, OOPC, and the data services of GTOS on land. Each GOOS Regional Alliance (GRA) will develop its own data services, and individual agencies, laboratories, and commercial organizations may provide additional special products in this context. GRA coastal services will interface with global data systems for GOOS.

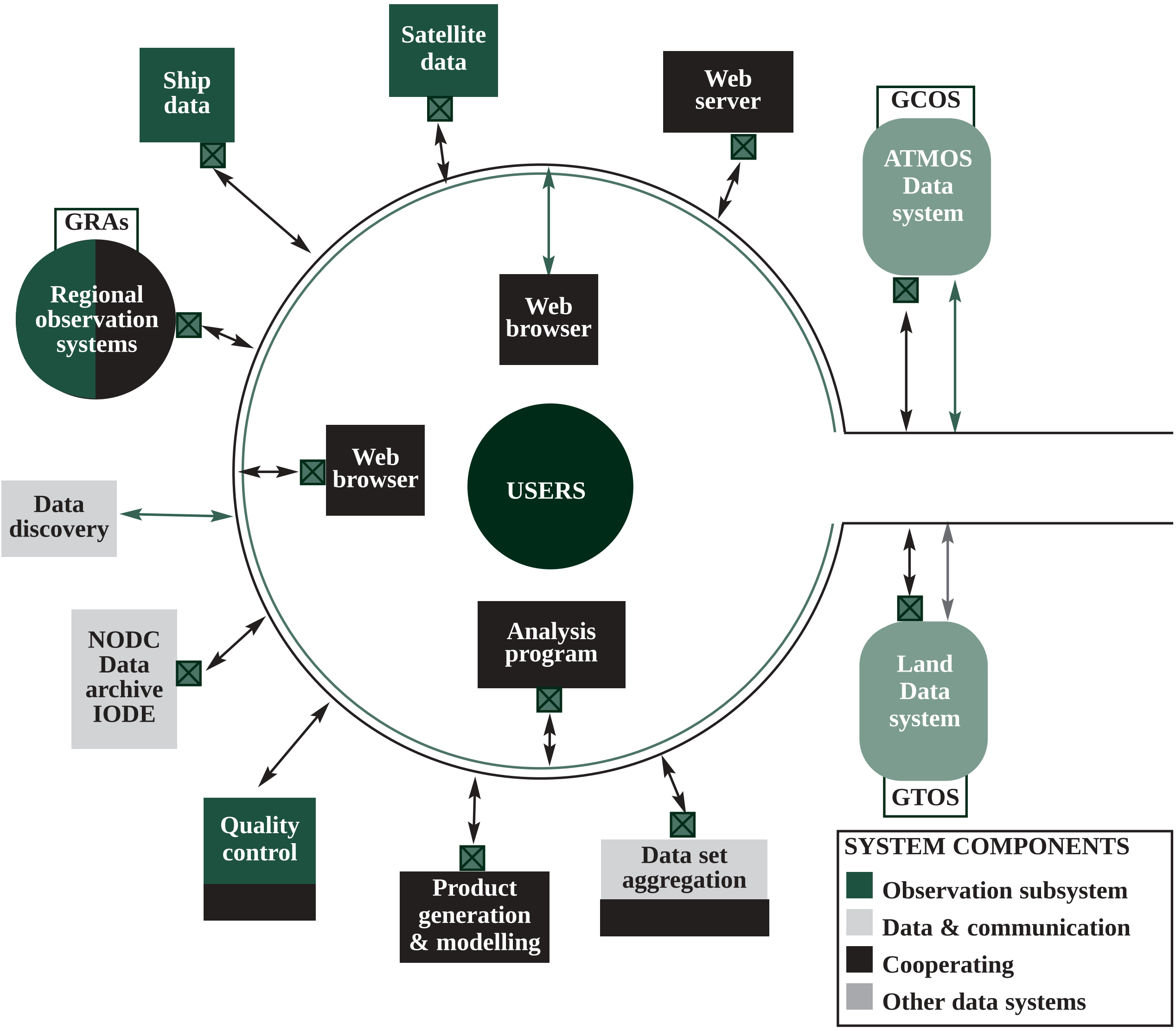

Figure 6.1. Functional components of the Data Management and Communication System for the coastal module of GOOS. (Modified from the OCEAN.US, 2002, p. 85).

The data management system will provide facilities for two data tracks, one in real-time (or near-real-time) and one in delayed mode. Both tracks may be based on the same data sources and transmission systems, but the data follow different routes and are processed differently depending on user requirements (Figure 6.2). The delayed mode track may also involve data from measurements that take time to complete. Real-time data transmission implies that measurements are made automatically and transmitted to users within minutes to hours for nowcasts and timely forecasts (before the phenomena have changed beyond the limits of predictability, see Chapter 5). Where a process changes slowly, data delivery may take longer. Near-real-time implies a delay in data processing, usually of days to months, so that the user receives a higher quality product, and one that is valuable for management or understanding of the process, but is too late to use as a forecast. Delayed mode data can be processed to the highest levels of quality control, analysed for errors, checked for long-term stability and consistency of trends, and archived for long-term use. This process may take months to years.

The real-time track will transmit data in an automated way to modelling centres so that data can be incorporated in models which provide nowcasts and forecasts, as described in Chapter 5. Rapid transmission of data is essential if the products described in

Chapter 5 are to be generated. This capability exists in only a few regions and is currently limited to meteorological and physical data. The delayed mode track provides the highest level of data quality control. The real-time data and model products can also be checked after first use for up-grading and additional quality control to ensure that all relevant data are preserved for final archival. Similarly, climatic data and standardised anomalies and statistics can be provided to the modellers from the archived data and time series in order to compute expected values and anomalies.

This pattern of different rates of data delivery is stable, economic, and efficient. It is stable because there is an inevitable trade-off between speed of delivery, latency, and the ability to carry out the most detailed quality control, or process the most difficult data types. Thus the data presented to real-time modellers comprises a limited range of variables, (at present mostly physical variables), and the accuracy may be restricted, while some observations have to be discarded because of suspected errors which could be corrected given more time. Nevertheless, the value of processing data in time to make forecasts is such that it is worth accepting these limitations.

Given more time, the same data from the same instruments can be checked more exhaustively, marginal data can be corrected and included in the data set, and extra error-checking procedures can be run, sometimes depending upon the availability of other data types, or instrument recalibration. The enhanced accuracy is valuable, because long-term data sets and time-series used to detect climate variability and climate change must not include avoidable random errors or statistical bias. Also, instrumental data which cannot yet be automated, including many chemical and biological parameters, can be included in delayed mode archives. As instrumentation improves it should be possible to include more of these variables in the real-time data track. This approach to data management is economic and efficient, because the same suite of instrumentation, and the same data transmission technology, provides both the real time and the delayed mode data.

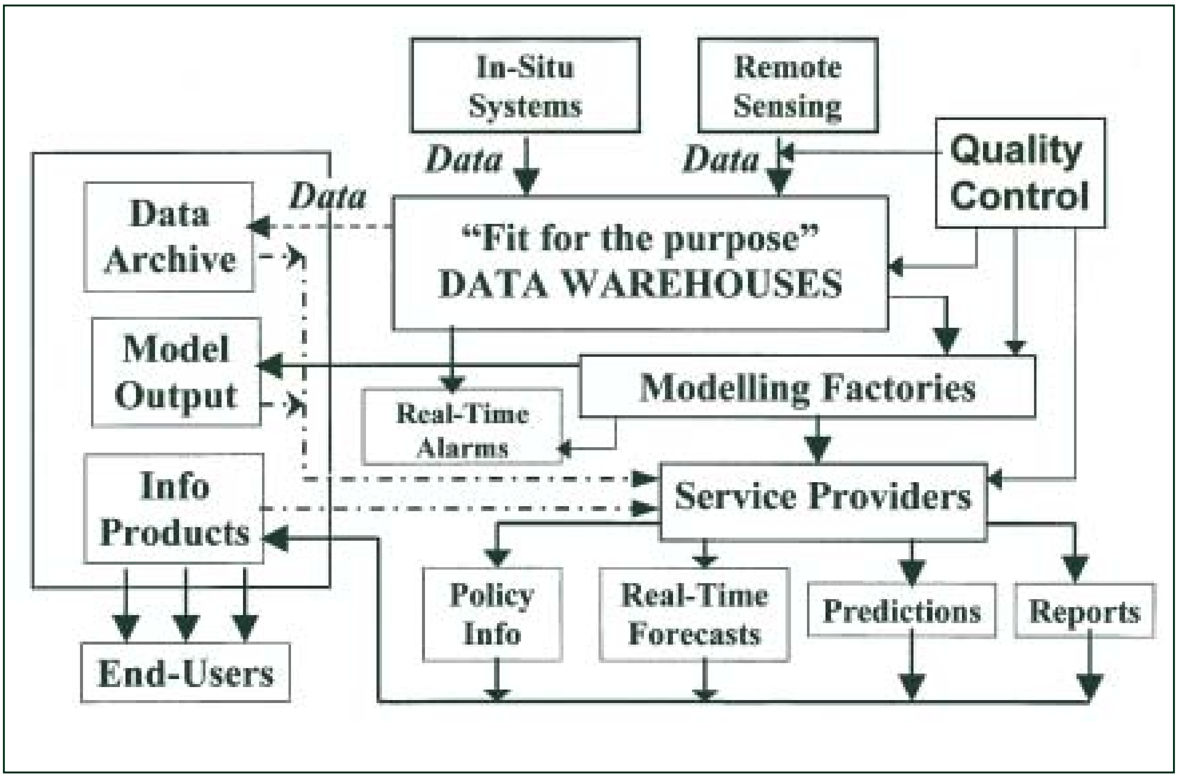

Figure 6.2. Diagram of tracks for real-time and delayed mode data flow from instrumentation to user (from Alan Edwards, personnal communication).

Effective coordination will be a high priority in developing the system. Collaboration and cooperation among data providers will be facilitated, so that data products conform as far as possible to GOOS norms and standards. Well-defined methods of data collection, data formats and data archiving, as well as data exchange practices must be established, along with methods for controlling and assuring the quality of these data and meta-data.

6.3 Data Policy

The coastal GOOS data policy will be consistent with the GOOS design principles, the IOC data policy (IOC Resolution I.9, 1961), and the policy of free exchange of meteorological data (at the cost of retrieval only) of World Weather Watch and WMO (WMO Resolution 40), and the data principles established by JCOMM. Accordingly, the coastal GOOS data policy will be based on the following guidelines:

- Full and open sharing and exchange of coastal GOOS relevant data and products for all users in a timely manner at the lowest possible cost.
- Archival preservation of all coastal GOOS data, through the existing system of IODE data centres and WDCs. If no suitable data centre exists for a specific set of data, such centres should be established.
- As part of the end-to-end data and information framework, all coastal GOOS data sets should have one or more designated custodians, who have the capacity and responsibility for long-term data archival, and provision of data access as required, as well as for generating selected sets of standard products.
- Where appropriate, real time data management at the local and regional scales can be provided by government agencies with statutory responsibility for the maintenance of coastal safety, fisheries, and the control of pollution. Data procedures to be established by JCOMM, with data then transferred to the global archive system.

The coastal GOOS data management and communications system will be implemented in a manner consistent with that of GOOS (IOC, 2001). Clearly, development of the global coastal network of GOOS depends on the coordinated development of GRAs and the establishment of data management procedures consistent with the GOOS data policy.

6.4 Organization

The initial data management and communication system will grow in an incremental way by linking and integrating existing national and international communication networks and data management programmes. Several end-to-end systems may develop, each contributing one or more data types and providing data to other parts of the global system as required. Each of these systems is likely to involve several organizations with varying expertise and emphasis. The great challenge will be to achieve a constructive balance between bottom-up and top-down development on a global scale. The development of the coastal module faces many challenges that are not addressed by existing bodies, but for which existing practices may apply.

6.4.1 Existing Infrastructure and Expertise

Implementing and improving an integrated DMAC system for the coastal module will depend on the involvement of existing data management components and the development of new ones. Two existing organizations have the potential to give significant support to coastal GOOS, the IOC Committee on IODE and the programme area on data management of JCOMM. In addition, there are many regional programmes with well-established data management activities that could be of considerable benefit to coastal GOOS (Figure 6.3). However, international (and often national) mechanisms are generally lacking for most types of geological, chemical, biological and ecological data. An appropriate mechanism must be established that will enable coordination and collaboration among these programmes to achieve the goal of an integrated DMAC system that manages both real-time and delayed mode data streams.

Scheme of the Info-BOOS - the BOOS's information system.

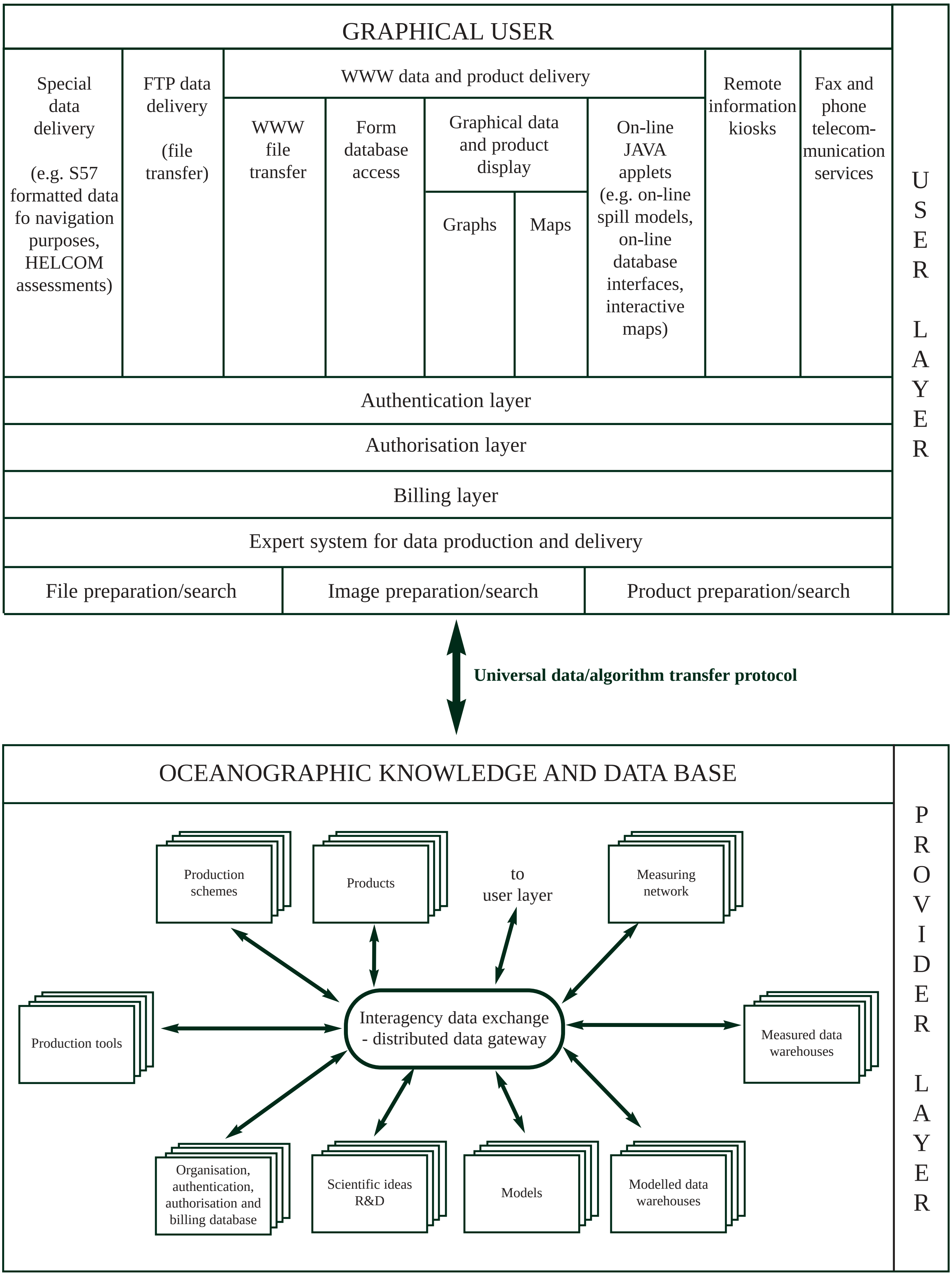

Figure 6.3. Example of a regional data management system for a GRA that is entirely within the coastal domain, The Baltic Operational Oceanographic System (Buch and Dahlin, 2000).

Box 6.1. IODE

The International Oceanographic Data and Information Exchange (IODE) System was established in 1961 to "enhance marine research, exploration and development by facilitating the exchange of oceanographic data and information between participating Member States". Recognizing that the best approach to achieving this objective is through a network of data centres distributed among the member countries, the IODE programme is built on (1) Designated National Agencies (DNAs) that assist with data exchange; (2) National Oceanographic Data Centres (NODCs) that interface with data providers within their respective countries, archive data and provide access to data; and (3) Responsible NODCs (RNODCs), that, in addition to their NODC functions, provide specialised services for specific data types. Successful implementation of the coastal module of GOOS would require enhancing this network through a variety of mechanisms such as: (a) establishing NODCs in countries that do not have one and will be acquiring large volumes of data, (b) through modernisation to facilitate more timely access to integrated data sets and products, and (c) through provision of NODC services to other countries that do not have and have no plans to establish NODCs.

Joint Technical Commission for Oceanography and Marine Meterorology

From the JCOMM Terms of Reference:

Implementation of data management systems
Development and implementation, in cooperation with the Commission for Basic Systems (CBS), the Committee for International Oceanographic Data and Information Exchange (IODE), the International Council of Scientific Unions (ICSU), and other appropriate data management bodies, end-to-end data management systems to meet the real-time operational needs of the present operational systems and the global observing systems; cooperation with these bodies in seeking commitments for operation of the necessary national compilation, quality control, and analysis centres to implement data flows necessary for users at time scales appropriate to their needs.

Delivery of products and services
Provision of guidance, assistance and encouragement for the national and international analysis centres, in cooperation with other appropriate bodies, to prepare and deliver data products and services needed by the international science and operational programmes, Members of WMO, and Members States of IOC. Monitoring of the use of observations and derived products and suggesting changes to improve quality. Coordination of the safety-related marine meteorological and associated oceanographic services as an integral part of the Global Maritime Distress and Safety System of the International Convention for the Safety of Life at Sea (SOLAS).

Assistance in the documentation and management of the data in international systems
Development of co-operative arrangements with the data management bodies of IOC, ICSU, and WMO, such as IODE, the Commission of Climatology (CCI) and the ICSU World Data Centres to provide for comprehensive data sets (comprising both real-time and delayed mode data) with a high level of quality control, long term documentation and archival of the data, as required to meet the needs of secondary users of the data for future long term studies.

For a significant range of data sets related to the fields of meteorology and physical oceanography, the existing data management and communication structures of the World Weather Watch of the WMO, the JCOMM, and the IOC Committee on IODE could be adapted to include the requirements of coastal GOOS. However, there are problems arising from the present terms of reference and existing expertise in IODE and JCOMM. IODE has extensive experience with all data types (physical, chemical, geological, biological, and ecological) but is primarily concerned with data archival and delayed mode dissemination. IODE data typically take several months to several years to reach archival centres. In addition, data obtained by governmental pollution management agencies, fisheries agencies, navigational authorities, coastal defence agencies, and meteorological offices are not usually handled by IODE.

IODE possesses the expertise to manage many of the non-physical data types, but captures only a limited proportion of the data generated and manages those data in delayed mode. The marine components of the national meteorological offices represented in JCOMM have extremely sophisticated methodologies for obtaining and processing meteorological and physical variables in real time, but have very little experience with non-physical variables. Furthermore, the combined skills of the international meteorological and oceanographic communities working jointly in JCOMM functions well in the open ocean where the required spatial scales of resolution are coarse (> 10 km) relative to coastal waters (< 1 km). In coastal waters a much broader spectrum of variability must be captured and the relevant scales differ depending on both location and the phenomena of interest. Thus, there are serious challenges and gaps in the international institutional structures for data management for coastal waters that must be overcome in the design and implementation of the coastal module.

In some regions these institutional problems have been partially solved at national and local levels, since government agencies have statutory obligations to process data from multiple sources to meet practical operational goals such as water quality management, or control of coastal erosion (e.g., Buch and Dahlin, 2000; Droppert et al., 2001). Nevertheless, this process of piece-meal local development will lead to a non-standard mosaic of mini-systems that will prohibit rapid data and information exchange. This is precisely what coastal GOOS seeks to avoid. Although the goals of coastal GOOS data management are clear, the institutional and organizational structure at the international level is still not well suited for coastal observations of non-physical variables. These problems should be analysed and prepared carefully for presentation to the second meeting of JCOMM, with the objective of agreeing on solutions.

New approaches and technologies will be needed because of the multiplicity of data sources and data types, the multiplicity of users and their varying needs, and the overarching concerns of quality assurance, timeliness, and ease of access to data and data products. Historically programmes were developed independently by different groups to address specific issues and mission-based goals. Most of the global databases have been developed for physical data, but global databases for non-physical variables are beginning to emerge. The Ocean Biogeographic Information System (OBIS) of the Census of Marine Life (CoML) is an important example. CoML is an international science programme to assess and explain the diversity, distribution, and abundance of life in the oceans. OBIS will provide a global information portal where systematic, genetic, ecological and environmental information on marine species can be cross-searched, and where these interconnected sources of information can be integrated into value-added products such as derived data, maps and models. The goals of OBIS are to:

- Energize regional, national and international scale development of ocean biogeographic and systematic databases;
- Foster collaboration and interoperability by promoting standards for technology, storage, documentation, and transfers;
- Advance integrated biological and oceanographic research by supporting a multidisciplinary ocean information portal; and
- Speed the dissemination of and public access to ocean biogeographic information while appropriately addressing the issue of intellectual property rights.

OBIS will be a global network of databases of ocean geospatial survey data, synoptic ocean environmental data, and species-specific data (taxonomy, specimen, DNA sequences, etc.). The distributed system of data will be accessible through the OBIS information portal and software tools for searching, data acquisition, mapping and analysis will be built and made available to the whole community. OBIS will develop and promote technology standards to achieve an optimal level of interoperability among its members. OBIS will seek to grow in concert with GBIF and become a major tool for ocean biogeography and systematics. OBIS databases include the following:

- Fishnet distributed biodiversity information system,
- Development of a dynamic BIS for the Gulf of Maine,
- Biogeoinformatics of Hexacorallia (corals, sea anemones, and their relatives),

- Expansion of CephBase as a biological prototype for OBIS,
- Biotic database of Indo-Pacific marine molluscs,
- ZooGene, a DNA sequence database for calanoid copepods and euphausids,
- Diel, seasonal, and interannual patterns in zooplankton and micronekton species composition in the subtropical Atlantic, and
- Census of marine fishes.

URLs for these databases can be found in Annex IX.

6.4.2 Data Management Clusters at Different Spatial Scales

Most users of GOOS data and information reside in the coastal zone where the effects of global climate change and land-use practices in coastal drainage basins play out on local to regional scales in terms of a broad range of phenomena. The challenge then is to develop an integrated DMAC system that acquires and serves diverse data and information on local to global scales. The proposed solution is to manage data in distributed clusters at the local, national/regional, and global levels (Figure 6.4).

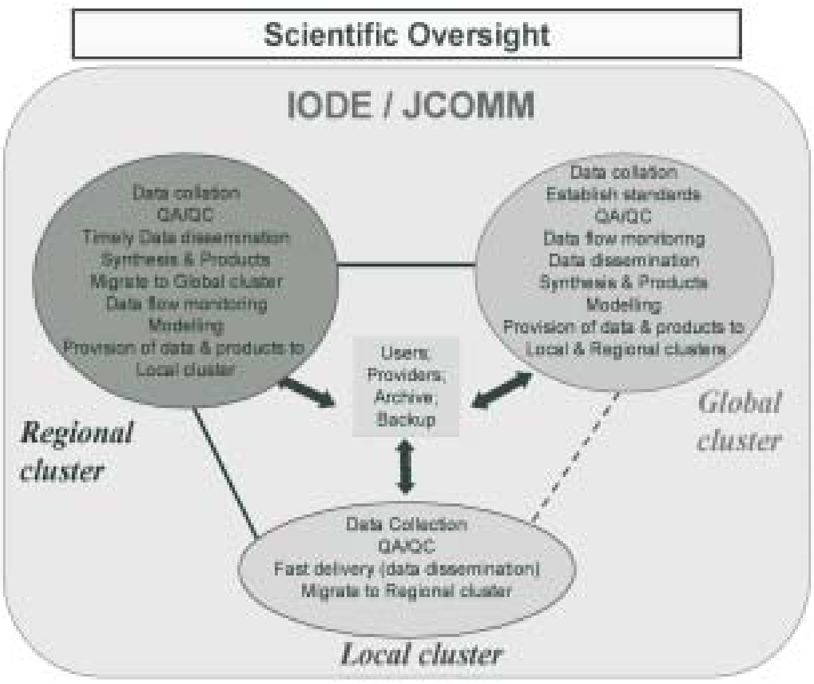

Figure 6.4. Clusters of data management

Such an approach is a pragmatic response to the scale problem. In this scheme, many components of the system (Figure 6.1) and the two data tracks (Figure 6.2) can occur at any cluster level (Table 6.1).

- Local clusters consist of organizations that collect, process, and assure the quality of the data. They will also be responsible for data dissemination and, in some cases, local data archival. The local network will provide the infrastructure for transferring data and data products via the web, or otherwise as appropriate. In the coastal context, there are a large number of such organizations, with widely differing capacities. There may be cases where an organization is collecting coastal GOOS data sets, but is not able to perform some of the functions outlined above. In such cases, mechanisms should be identified that will enable sustained participation, e.g., through capacity building or by providing the means to communicate data to a site that has the above capabilities. In all cases, quality assurance is the responsibility of the data provider.
- National and Regional clusters are the first level in which diverse data types from many different sources are collated and for which additional quality assurance and control (QA/QC) occurs. For the most part, these data management organizations will not themselves be responsible for the development of data-products. However, the data management subsystem must be designed to be responsive to user needs. This will be an evolving process in which experience and new knowledge results in more and better products. Data management at this cluster level will involve coordination of both real-time and delayed mode data tracks, and the combination of data inputs from many different research organizations and government operational agencies with statutory obligations in the coastal zone. In particular, oceanographic, meteorological, environmental and natural resource agencies will have to collaborate closely. Many products

required to meet user requirements can be generated and distributed at this level by transmitting data rapidly to appropriate analysis and service centres. For those countries that do not have NODCs, a national coordinator for coastal GOOS data management should be designated to develop procedures for performing these functions (e.g., identify Responsible Local Centres, work with existing NODCs or with global Centres). One centre in a national or regional cluster may be designated as a "lead centre" that is responsible for reporting chronic data quality problems to the Global Steering Committee as the first step in resolving problems of data quality. This function may also be performed by a global centre.

- Global Data Management and Synthesis Centres are needed to provide a global context for local and regional scale variability and change, to serve key regions, and to address key issues. Such centres would become the building blocks of a global network of data management and synthesis centres, the functions of which would be coordinated by a Global Steering Committee. The World Oceanographic Data Centres (WDCs) established by ICSU provide one model that could be used to guide the development of infrastructure, policies and procedures for the dissemination and management of coastal GOOS data. Additional systems, perhaps developed under the auspices of JCOMM, are needed to manage real-time global data sets and the distribution of global coastal data products. The responsibilities of the existing centres (Figure 6.5) may have to be expanded and additional centres developed to cover the full range of variables under coastal GOOS.

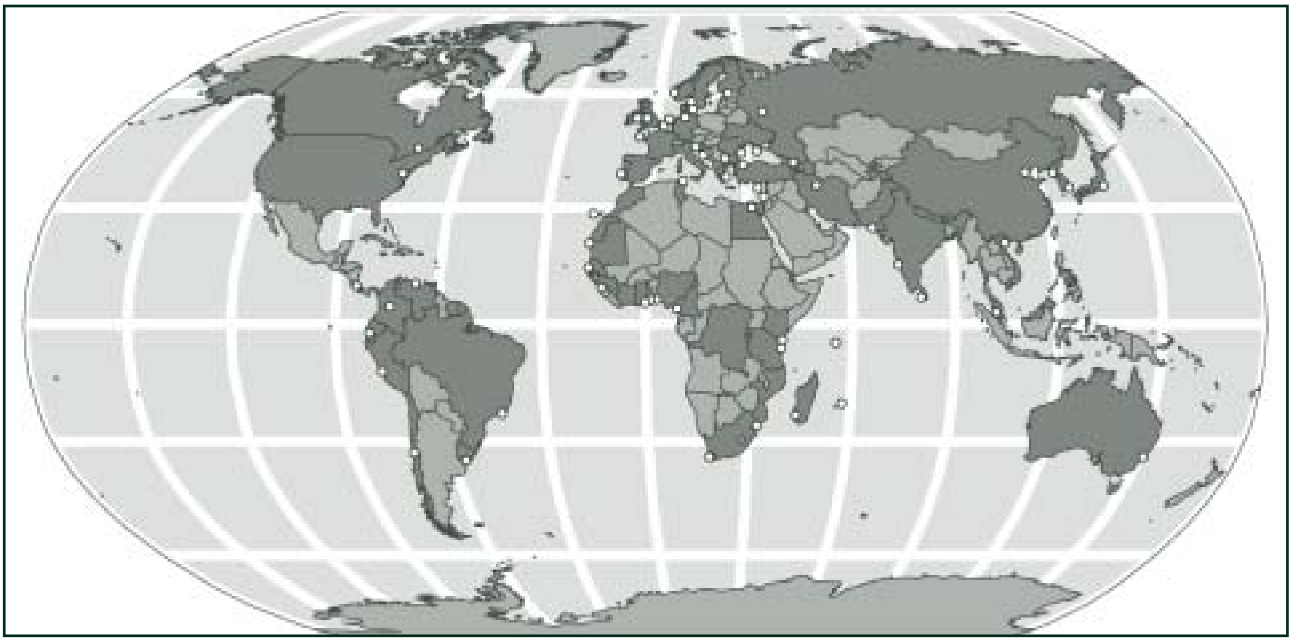

Figure 6.5. Existing data centres under IOC/ICSU.

Table 6.1. Functions performed by the organizations in each cluster

LOCAL CLUSTER	NATIONAL/REGIONAL CLUSTER	GLOBAL CLUSTER
• sustained collection of data on one or more common variables and variables measured as part of regional enhancements; • quality assurance and quality control of the data; • provision of network access to data sets in a time frame that is appropriate to the application, real-time and delayed mode; • provision of network access to comprehensive meta-data for all data sets collected by participating organizations; and • timely delivery of data sets, and associated meta-data, to designated national/regional centres in the data management structure.	• actively seek and acquire quality controlled data from local and national sources; • develop and implement QA/QC procedures based on international standards; • effect the exchange of data of known quality in real-time and delayed mode; • inventory and archive quality controlled data in accordance with international standards and protocols; and • timely dissemination of data, data products and information as appropriate	• collate data from National/Regional Centres and directly from marine and coastal science organizations and individual scientists; • establish international data standards and exchange protocols for real-time and delayed mode; • monitor the performance of the international data exchange system and report their findings to the Global Steering Committee and the IOC Secretariat; • establish global databases; • enable problem-specific data synthesis; • establish online services to provide data and data-products to users; and • provide an information directory of products and services.

At all stages of data management there should be strong scientific oversight to advise on the following:

- analysis and quality control techniques,
- meta-data requirements for understanding and interpreting the data,
- time frames for delivering the data, and
- data sets and data products required at the various stages of the data flow.

Ease of access to integrated data is important. Data, data products and information will be managed using a highly distributed system involving many organizations, databases, and clients spread globally. The coastal module of GOOS will make use of the Global Observing System Information Centre (GOSIC), designed to serve as a single entry point for users of the G3OS data and information, supplemented as necessary at local, national and global levels.

Experience with distributed data systems has demonstrated the need for strong coordination to ensure high-level performance. It would be the combined responsibility of JCOMM and IODE to provide such coordination, and particularly to:

- Monitor, analyse, and report on the data flows with the help of automated systems and data flow information in digital form provided by participating centres.
- Specify data flow monitoring products that are necessary to automate the data flow monitoring function and work with the participating centres to effect their implementation.
- Facilitate the work of science panels in developing a comprehensive set of products by identifying potential data products that are already being made available by centres and making recommendations to the appropriate panel for their consideration for GOOS products.
- Provide informational documents to be made available through GOSIC and other organizations.

6.4.3 Data Archives

Permanent archival of all data is an essential component of data management. Final archives need to be identified for all GOOS data sets as part of the implementation plan for each GOOS project. Scientific panels should identify the meta-data that is to be collected and stored with the data in the archives. As a minimum, a permanent archive generally must agree to:

- accept the data and all available supporting meta-data,
- store the data either in their original form or in a form from which all the original data and meta-data can be recovered,
- refresh or update the medium on which the data and meta-data are stored so that both are readable in the future, and
- provide the data and all supporting meta-data to users on request, free of charge, or at the cost of reproduction.

6.4.4 Data Management Infrastructure

The three-cluster, hierarchical approach to data management proposed above will require infrastructure development. At the national and regional level, good communication should be established among institutions and countries, to facilitate cooperation and to make maximum use of existing facilities. Communication channels might need to be established via a formal structure or agreement. GRAs will play an important role in liaison among interested parties.

BOX 6.2. THE INFORMATION TECHNOLOGY INFRASTRUCTURE

To detect and predict changes in coastal marine and estuarine ecosystems, there is a great need to capture in detail their baseline physical, geological, chemical, and biological properties. In these regards, three related developments now enable oceanographic research and the management of marine ecosystems and resources with an unprecedented degree of realism: enhanced observational capabilities, improved numerical models, and effective methods for linking observations to models. However, many aspects of these activities are severely limited by the information technology infrastructure (ITI). A requirement of the GOOS, is the development of fast and reliable data links to assure rapid delivery of ocean observations to operational centres and scientists. *in situ* and remote sensing have increased the volume of data required for detection and prediction by over two orders of magnitude in the last 10 years.

Physical and ecological models for coastal ecosystems have been developed and are beginning to show reasonable skill (See for example, Moll and Radach, 2001). These models in themselves are costly in terms of IT requirements (computing power, network speed, etc.). When they are linked via data assimilation to data streams for the purpose of operational, real-time forecasts, their IT requirements increase dramatically. For example, a single 4-day forecast cycle of currents, temperature and salinity at a single location using an ensemble-based assimilation technique, requires about 100 cpu hours on an advanced parallel computer and the transfer of 10 gigabytes of data. Scaling up such a system on a global scale and the incorporation of chemical and biological variables will increase IT requirements by several orders of magnitude. The ITI requirements for GOOS are expected to demand about 1,000 times the current capacity over the next 5 to 10 years. The most critical bottlenecks will be in the availability of CPU cycles, memory and mass-storage capacity, and network bandwidth. Significant challenges in software development also exist. These include re-engineering models and data assimilation packages to make more efficient use of massively parallel computers; the requirement for significant advances in visualization techniques to translate increasing volume of data and model output; and the need for well- designed, documented and tested community models of all types. Finally, exacerbating these challenges is the extreme shortage of skilled ITI technical personnel.

GRAs have already faced the necessity of providing rapid, often real-time, communications between a wide range of agencies. The GRAs which have developed most rapidly tend to be those formed around semi-enclosed seas, and therefore they have learned to process data which matches closely the requirements of COOP. The full range of agencies working in a semi-enclosed sea such as the Baltic, Mediterranean, or Japan Sea, includes the Meteorological Offices, Navies, Charting agencies, Ministries of Ports, Fisheries, Environmental Protection, Tourism, Oil and Gas exploitation, etc., and they have needs for the kind of products from numerical models described in Chapter 5. By combining access to data sets which are transmitted in real time, and by various schemes of real-time automated data exchange and data access between agencies, it has proved feasible to assemble common data sets for processing in models (Figure 6.3). Examples are the storm surge and sea level models of the North Sea (NOOS), wind wave and sea ice models in the Baltic (BOOS), and 3-dimensional predictions of temperature-salinity fields in the Mediterranean (MFS).

Redundancy should be built into the data management subsystem, e.g., by using mirror data sites and by executing the same models at different computing centres. However, it is likely that infrastructure will be deficient in many regions at the local and national level and capacity building will be required. Capacity-building initiatives must be preceded by careful planning to ensure that all elements of the subsystem are sustainable in terms of the required local human and financial resources. Some elements of planned redundancy could be used to develop capacity off site, in partnership with institutions or countries where the local circumstances do not currently favour a full membership in any of the clusters.

The primary communications tool for coastal GOOS will be the Internet. However, in many countries Internet communications are poor, or are prohibitively expensive. Until Internet communication is globally feasible for the data management and communication subsystem, provision must be made for the possibility of transferring data and information via other media.

6.5 Standards

6.5.1 QA/QC and Metadata

Ideally, observations should be unambiguous measures of the target variables. Measurements made by different laboratories, programmes, and governments must be directly comparable, irrespective of where and when they were made, and sufficiently precise and accurate to detect and predict change. Although models can integrate observations and fill gaps in time and space in principle, model outputs will be compromised by input data that are of variable quality. Differences in quality can be avoided by adopting common standards for measurements and can be accommodated for modelling if measurements of error are included with observations.

The development of QA/QC procedures for coastal GOOS must meet the following requirements:

- Measurements are made by well-trained and motivated personnel who understand how the data are to be used;
- The sampling programme is designed to provide data that are representative of the variables sampled (in both time and space) and to ensure that the appropriate meta-data accompany each sample;
- Instruments are routinely calibrated against authentic reference standards; and
- QC and recorded meta-data documentation must be applied to the successive stages of data transmission, merging, and analysis.

Meta-data should include information such as environmental conditions under which samples were collected, measurements made that are needed to interpret the data, and sampling and analysis techniques. Those responsible for making measurements should regularly participate in inter-calibration and inter-comparison exercises and should be willing to subject their sampling and measurement procedures to external vetting.

There will be a requirement for developing a variety of software to meet the required data processing and QA/QC standards. One could follow the example of GTSPP and partition this task among a group of volunteer data centres. This will reduce duplication and ensure consistency and adherence to standards. All software and procedures must be documented.

A QA/QC plan should be developed for each variable measured as part of coastal GOOS. These plans should specify standards for short-term accuracy and long-term stability. For standards to be used, there needs to be broad-based agreement on what the standards should be.

In some cases data quality might be difficult to improve in the short term and it may not be possible for standards to be followed. These data should nevertheless be included as part of the data base, but should be flagged. Manuals that describe materials and methods should be routinely published, but it should not be necessary to prescribe the precise method of measurement. This flexibility should make it possible for more countries to participate, and should encourage the development of improved methods. QA/QC plans should include inter-calibration and inter-comparison exercises for each variable as well as procedures for validation and verification. In this regard, numerical modelling can be an effective tool for quality control by providing the means to test for internal consistency of complex systems (e.g., mass balance of material flows among ecosystem components and pool size of each component). Differences between first estimate predictions and observations made at several intervals over time can also provide a sensitive test for biases, calibration drift and outliers.

6.5.2 Real-time and Delayed Modes

Atmospheric forecasters have known for many years that trade-offs must be made between timely access to data and its quality. The same will be true for marine forecasters. Some users will need to sacrifice some data quality in exchange for quicker delivery of products, whereas others can afford to wait longer for high quality data. For example, models that predict the coastal signature of ENSO events might use many sources of variable quality data to provide reliable early warnings, whereas climate research models might need high quality data, but without urgency. Different models could require the same data on the same variable (e.g. sea surface temperature), but with different constraints regarding quality and real-time versus delayed mode access.

Under current conditions, detecting and modelling changes in marine ecosystems are retrospective activities (hindcasting) that can take months or even years. Biological and chemical variables are typically variable in space and time and their measurement is often a time-consuming, labour-intensive process that requires the collection of samples and subsequent processing in the laboratory (i.e., they cannot be detected in real time). Nevertheless, while most physical variables can be regarded as "mature" in the world of data management and modelling, and most biogeochemical variables are not "mature", present research is resulting in a steady improvement in the ability to make real-time and near-real-time ecosystem forecasts and analyses. Such rapid analyses of marine biogeochemical processes are valuable in forecasting harmful algal blooms (HAB), management of fish-farms and shell-fish-farms, public health regarding bathing waters, and the management of estuarine pollution. The gradual improvement and calibration of ecosystem models through long-term trials is an exciting frontier in coastal oceanography (Moll and Radach, 2001).

Where these observations are linked to research programmes, there can also be difficulties in accessing the data in a timely fashion because of issues of ownership. However, one- or two-year lags between sample collection and nowcasts may be acceptable when ecological changes have long time scales (e.g., declines in seagrass beds caused by nutrient enrichment, decadal scale oscillations in fish populations) and mitigation measures are likely to take years to realize their effects.

6.5.3 Related Activities

Considerable effort has been invested elsewhere in defining standards and procedures. For example, WOCE and WMO standards (with recent modifications as part of Argo and other programmes) exist for physical variables, and JGOFS standards exist for certain biological variables. Standards for data, meta-data and instruments have been developed also under ICES and regional GOOS programmes. It is to be expected that much will be learned from the experiences of meteorologists in setting up the World Weather Watch and its global telecommunication system. They have already had to face the problems of timely access to data and its quality assurance and control. Pilot projects such as GODAE (the Global Ocean Data Assimilation Experiment) will be invaluable in helping to establish guidelines for making ocean monitoring and prediction a routine activity in a manner similar to weather forecasting and will help achieve the goals of GOOS.

6.6 Data Streams

The diversity of data types that will be collected and applied to the coastal zone is large. These will include, but not be limited to, observed data, derived data and data products, and predictions and modelled data, along with appropriate meta-data. Data can be acquired from a large number of different sources including many that are not a part of GOOS. In this regard, it is highly unlikely that every organization will choose to use the same database software to manage their data, so standard protocols for data exchange will be needed which can be overlaid on both existing and future software packages. Where existing standards exist, they should be used if possible.

Rapid access to data and data-products requires that data flows efficiently from instruments to end users and, concurrently, to aggregation centres, modelling centres and thence to users, as well as into distributed archives for retrospective analysis and archival (Figure 6.2). There is an immediate need to reduce the time required for these operations. Many phenomena of interest in the categories of marine services and public safety (e.g., harmful algal events, contamination of a bathing beach) must be detected in near real-time and predicted with sufficient lead time to be useful to users of the marine environment and its resources (e.g., commercial shipping, search and rescue, fishers, recreational boaters, people living close to the coast).

The data formats and transfer methods will depend on the data type(s). Furthermore, the time frame associated with 'real-time' and 'delayed mode' will depend on the data type and application. The time frame for data access will also vary. Consequently, it is imperative that coastal GOOS defines the time line for each data type and explores existing data transmission techniques, using these as possible models and building blocks for developing the fully integrated data management subsystem. GTS may be one option, but it is not an integrated system, and it may be most effective to restrict the use of GTS for data required to make weather forecasts and issue warnings.

Moored sensor arrays for monitoring water quality, nutrients, suspended sediments, chlorophyll, and some contaminants have been operated successfully in automatic mode for several years in some coastal environments, and instrument suites are being developed and tested for measuring similar variables on routine repeated sections operated by commercial vessels in coastal waters. Such data sets, combined with the output from hydrodynamic models, and supplemented by remote sensed data, provide the optimistic basis to start trials of operational ecosystem modelling and forecasting. Further research is required to extend the range of chemical variables which can be measured automatically without laboratory analysis, and to provide more rapid ways of assessing biological parameters.

An important component of the data management subsystem will be to identify, secure and provide access to historical data sets that may be in danger of loss or degradation of storage media, i.e., data archaeology and rescue. This will be particularly important for coastal GOOS as many old data sets may still be in filing cabinets or on individual PCs instead of being 'managed'.

6.7 Providing and Evaluating Data Services

The coastal module of GOOS will not be the panacea for all regional needs, and mechanisms are needed to selectively incorporate existing national and international programmes, specify and develop products and services, and to endure that the observing system improves its capacity to meet the data and information needs of users. Development of the data management and communications subsystem will be the primary integrator of the observing system, the "life blood" of the system that links all of its components. Thus, the extent to which GOOS is able meet the data and information requirements of its user community will be critically dependent on the performance of the DMAC subsystem.

Performance evaluation must be an integral part of the implementation of coastal GOOS. Two important aspects of the data management subsystem are timely access to and analysis of data. Data management must be maintained and upgraded to ensure continuity of the data streams and the routine provision of high quality data and data-products. Procedures to monitor the quality of the data must occur as close to the data source as possible to ensure precision and accuracy. The continuity of data streams and access to data must also be monitored. Evaluation, maintenance and enhancements should occur at all levels in the DMAC subsystem, and procedures must be developed to ensure that information on quality and data flow is exchanged between each cluster in the hierarchy. Finally, as the observing system develops and matures, mechanisms should be established by which end users are able to provide critical feedback on the timeliness and quality of the data and analyses provided. It will also be necessary to modify and enhance the technology behind the data subsystem as measurement programmes gain new technology, as hardware and software capabilities increase, and as demands for new products and services evolve. As the system is built and a client-base is established, additional products and services will have to be provided.

7. Preliminary Guidelines for Implementation

7.1 General Considerations

The global coastal network will develop through a combination of global, regional, and national processes. Linking operational elements that are global in scope and scaling up selected national and regional operational systems consistent with the GOOS Design Principles will not only require guidance from user groups, it will require a high level of international coordination and collaboration to ensure the emergence of a global system (from measurements to data and product management) as national, regional and global scale elements come on line. GOOS will evolve by improving access to data and information in response to user needs; by increasing the resolution, duration and spatial extent of observations; and by incorporating new technologies and models. To these ends, implementation of the coastal module must consider the following:

- Inputs of energy and matter to coastal ecosystems from atmospheric, oceanic and land-based sources must be quantified. Thus, the development of the coastal module must be coordinated with the OOPC, GCOS and GTOS.
- The integration of satellite-based and *in situ* observations must be coordinated with CEOS, the IOCCG, and other international bodies to improve remote and *in situ* sensing capabilities for detecting changes in biological and chemical properties and processes. As a part of this process, the IGOS Ocean Theme report should be up-dated and extended to include shallow, nearshore, and turbid coastal waters.
- Data management groups for the purposes of weather prediction, improved marine services and more efficient and safe marine operations have evolved two parallel and interconnected procedures for processing meteorological and physical oceanographic data. A procedure for processing real-time data with automated quality control for numerical nowcasts and forecasts of the weather and surface marine conditions (temperature, currents, waves) and a delayed mode system for the highest levels of accuracy, archival and use in off-line modes and long-term climate predictions. Both systems require major investment to increase capacity for handling much larger volumes of more diverse data (biological, chemical and geological variables), greater distribution of model outputs, and rapid exchange of large volumes of data between data centres.
- Many of the elements of a global coastal network are in place, and a user-driven (applications) process is needed to selectively identify and link existing operational systems that are global in scope and globalise (scale up) selected elements of national and regional observing systems.
- Measurements and models must become operational through mechanisms that promote and enable pre-operational testing, proof of concept pilot projects and research required to develop an integrated system. Improving the capacity for rapid detection of changes in biological and chemical variables and developing operational ecosystem-based models should be a high priority.
- Major investments in capacity building at all levels will be needed to ensure that developing nations are able to benefit from and contribute to the observing system.

All of these challenges must be addressed from the beginning and, in so doing, must involve stakeholders from research, operational and user communities. A scientifically and technically sound approach to implementation that is both feasible and effective requires an iterative process that engages all three groups in an ongoing dialogue to ensure the development of a global system that meets national and regional requirements.

7.2 ESTABLISHING THE GLOBAL COASTAL NETWORK

The global coastal network will come into being by selectively linking existing global programmes and elements, by linking existing regional and national programmes and elements, and by enhancing and supplementing these over time. These activities will be predicated on meeting user requirements for sustained data streams and products. The implementation will be phased as described in Sections 3.2 and 7.3.

7.2.1 Data Sharing, Product Development and Marketing

The design and implementation of GOOS must be guided by the identification of user groups and the data streams and products and model outputs they require (Chapters 4 and 5; Fischer and Flemming, 1999; Kite-Powell et al., 1994; NOAA-IOC, 1996; Stel and Mannix, 1997; Adams et al., 2000). Production, advertising and marketing data products are essential to the development of broad user demand and, therefore, to the development of the observing system. GRAs and national GOOS programmes provide the primary venue for product development which should begin with the exchange of existing data and information and collaborative development of operational models. Historical data and ongoing data streams exist in large numbers, but many are not now readily accessible to potential users. Current marketing and outreach tools include the GOOS Products and Services Bulletin (http://ioc.unesco.org/gpsbulletin/) and the JCOMM Bulletin. These Bulletins report products and product development activities and provide a means for user feedback on the quality and usefulness of GOOS products. As useful as these bulletins are, the establishment of user forums for product development and user feedback by GRAs should be a high priority for implementing and developing the coastal module.

Opportunities to market products and to assess user requirements also involve collaboration with specific user communities such as the International Maritime Organization (IMO), the World Health Organization (WHO), the World Tourism Organization (WTO), and the International Ocean Institute (IOI). In addition, the private sector can be expected to play an important role in product development and marketing. As is the case for atmospheric products, private firms will assess user needs and will employ the available data and information to produce value-added products for those users, thus adding economic benefit to the observing system.

BOX 7.1. DEVELOPING A USER BASE: THE CASE OF INTEGRATED COASTAL AREA MANAGEMENT

Integrated coastal area management of the environment and living resources depends on the ability to repeatedly assess and anticipate changes in the status of coastal ecosystems and living resources on national to global scales. Efforts to provide such assessments increased dramatically during the 1990s (Parris, 2000). Examples are the Global Environmental Outlook produced by UNEP (www.unep.org/unep/eia/geo1), reports of the World Resources Institute (www.wri.org/), including the Pilot Analysis of Global Ecosystems (www.wri.org/wr2000; a precursor to the Millennium Ecosystem Assessment: www.millenniumassessment.org/en/index.htm), and the State of the Nation's Ecosystems produced by the Heinz Center under the auspices of the U.S. Office of Science and Technology (O'Malley and Wing, 2000). These attempts (which are ongoing) reveal that the data required to compute quantitative indicators on national and global scales are generally difficult to acquire, inadequate, or nonexistent. Results of both PAGE and the U.S. effort lead to the following conclusion:

If assessments of the status of coastal ecosystems and resources are to be quantitative and comprehensive, and if they are to be repeated in a timely fashion for decision makers and the public at regular intervals, major improvements are needed in the kinds, quality and quantity of data collected and in the efficiency with which data are disseminated, managed, and analysed.

The most important problems that require immediate attention are as follows:

- inefficient data management systems that do not provide rapid, user-driven access to diverse data from disparate sources;
- lack of standards and protocols for measurements, data exchange, and data management;
- undersampling (insufficient resolution in time and space to estimate distributions of key properties and processes with statistical certainty);
- lack of spatially and temporally synoptic observations of key physical, chemical and biological variables;
- lack of operational models for rapidly assimilating and analysing data.

The coastal module of GOOS is being designed to address these problems. One of the more important products that the coastal module will make possible is scientifically credible, quantitative, routine and periodic assessments of the status of coastal ecosystems on regional to global scales.

Box 7.2. GOOS User Scenarios

(1) Water Levels for Coastal Managers: Water levels may vary because of tides, storm surges, wave heights, and secular changes in sea level. Each of these may act independently or in concert. All of these variables can be monitored, modelled, and predicted. To improve the control and mitigation of coastal flooding (especially from storm surges), coastal managers need to know how water levels may vary along a particular stretch of coast on seasonal and inter-annual time scales. Much of the same information will also be required by the local managers of ports and the shipping industry for controlling access to ships (loading/unloading) and estimating the maximum tonnage of cargo ships are able to load based on predictions of water depth.

(2) Surface Currents, Wave Heights and Sea Ice for Offshore Oil Exploration and Extraction: The development of oil and gas fields in deep water and under Arctic conditions within national EEZs demands increasingly accurate forecasts of surface currents, vertical current profiles, wave heights and sea ice to improve the efficiency and safety of operations. Predicting current profiles and the total impact of currents on moorings, drill strings, and submerged equipment is one of the oil industries highest priorities. Increasingly, oil production will use well-heads that are on or under the seabed, but estimates of maximum wave height will still be required where production takes place from platforms, and ice forecasts for the longer term will be essential in polar regions. Required variables for forecasting include, wave height, ice dynamics, and surface and subsurface current velocities.

(3) Dissolved Oxygen for Environmental Protection (water quality management): Increases in nutrient pollution from anthropogenic sources over the last 50 years has caused an increase in the volume of coastal bottom waters that becomes seasonally hypoxic or anoxic in coastal marine and estuarine ecosystems that are affected by river discharge. Controlling nutrient loading from land-based sources (e.g., fertilizers, animal wastes, sewage discharge) and minimizing the areal and temporal extent of bottom water oxygen depletion requires coupled drainage basin hydrolic, coastal hydrodynamic, and nutrient dynamic models that can be used to evaluate the efficacy of nutrient management decisions and predict the impacts of different scenarios of land-use practices. Required variables for prediction include fresh water and nutrient fluxes associated with river flow (surface runoff) and ground water discharge, vector winds, water level, incident radiation, water temperature, and chlorophyll concentrations.

(4) Rapid Detection and Prediction of Harmful Algal Blooms: The incidence of harmful algal blooms (HABs) appears to be increasing in coastal waters. The primary issues of concern are (1) protecting public health and water quality (paralytic shellfish poisoning, diarrhetic shellfish poisoning, amnesic shellfish poisoning, neurotoxic shellfish poisoning, and respiratory irritation and skin lesions in swimmers and beach goers), (2) effects on aquaculture production (e.g., shellfish bed closures, mass mortalities, contamination), (3) economic impacts (minimize or prevent declines in revenues from fisheries, aquaculture, tourism; decreases in property value), and (4) the dissemination of useful information to the public. The following data-products are high priorities: (1) early alerts (location, magnitude, species) that an event is in progress; (2) timely forecasts of the trajectory of the event in time and space; and (3) predictions of where and when an event is likely to occur (advance notice of the probability an event will occur). Achieving these goals depends on rapid detection of the initiation of a HAB event and coupled coastal circulation-population dynamics models to forecast where and when such an event is likely to impact human activities and living resources. The minimum set of variables to be measured are as follows: (1) real-time wind fields (updated 3-4 times/day), freshwater fluxes (rainfall, rivers, ground water) and related inputs of sediments and nutrients (daily rates updated weekly); and (2) surface currents and waves, sea surface temperature and chlorophyll distributions updated daily; vertical profiles (with measurement at surface, pycnocline, near bottom as a minimum) of temperature, salinity, dissolved oxygen, inorganic nutrients (N, P, Si), chlorophyll, coloured dissolved organic matter, and cell densities of HAB species updated at weekly (small number of stations) to monthly intervals (more stations).

7.2.2 The Importance of Regional Bodies

The Governing Council of UNEP has repeatedly endorsed the formulation and implementation of regional action plans to control marine pollution and manage coastal marine and estuarine resources. Development of the coastal module of GOOS will depend on harmonizing the need for a global network with user needs based on national and regional priorities. Thus, implementation of the coastal module will require the support and participation of at least four groups of regional bodies and activities: (1) national GOOS programmes and GOOS Regional Alliances (GRAs), (2) Regional Fishery Bodies (RFBs), (3) Regional Seas Programmes (RSPs) and (4) Large Marine Ecosystem approaches (LMEs) (Figure 7.1). These provide the primary means by which user requirements and regional priorities will be established (cf., UNEP, 2001), and their coordinated support will be needed to implement, operate and develop the coastal module (Annex VIII).

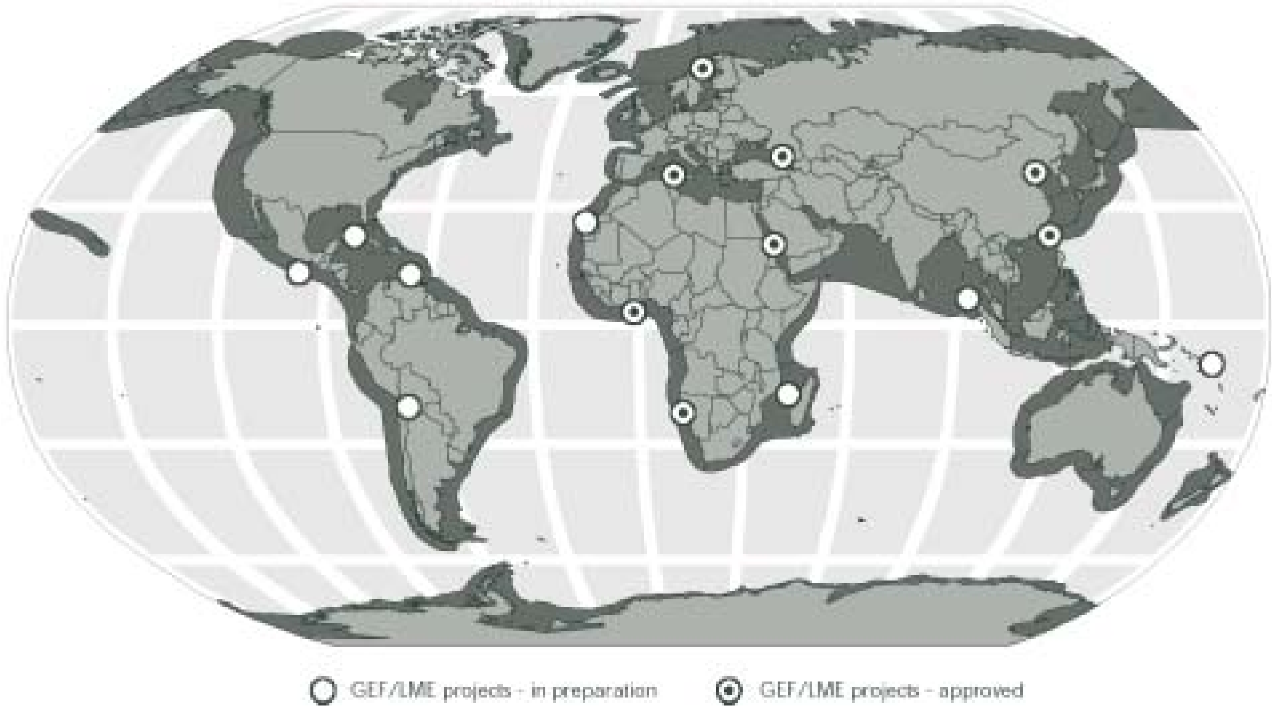

Figure 7.1. Status of the Large Marine Ecosystem programme (LMEs). Projects (○) in various stages of planning (100 - 500 thousand USDs) and projects (⊙) under implementation with funding from the Global Environmental Facility (15 - 40 million USDs). Those indicated in dark grey are potential LMEs.

There is great potential for collaboration among RFBs, RSPs, LMEs and GOOS. GOOS provides an organizational framework for the coordinated development of ecosystem based management approaches to resource management and environmental protection. Successful collaboration among RFBs, RSPs and LMEs on regional scales is critical to the timely and cost-effective implementation of the coastal module of GOOS, and there are signs that this is beginning to occur. For example, in 1997 the International Council for the Explorations of the Sea (ICES) formed a Steering Group on GOOS (SGGOOS) to draft an action plan for how ICES can play a leadership role in the establishment of GOOS in the North Atlantic with emphasis on operational fisheries oceanography in the North Sea. SGGOOS was reconstituted in 1999 as the joint ICES-IOC Steering Committee on GOOS which includes representatives from the GOOS Project Office and EuroGOOS. PICES is moving in a similar direction. In 2001, the UNEP Governing Council endorsed a resolution calling for a closer relationship between RSPs and the development of GOOS. The IOC Assembly, at its 21st session (July 2001) endorsed a similar recommendation calling for GOOS to work closely with UNEP at the regional level to assist in implementing RSPs. Shortly thereafter, the IOC, ICES, OSPAR, the North Sea Conferences and EuroGOOS sponsored a SGGOOS workshop to initiate planning for a North Sea Ecosystem GOOS pilot project. The goal of the project is to implement an ecosystem-based approach to environmental protection and fisheries management. If successful, this could provide a model for regional development of the coastal module.

7.2.3 Potential Global Building Blocks

Very few operational elements are both coastal and global in scale. Examples of global elements relevant to the development of the coastal module include (but are not limited to) the WMO data management systems, GLOSS and IODE. GLOSS, a critical component of the coastal module, consists of a global network of tide gauges providing sustained data streams that are managed and analysed globally. The IODE was established in 1961 to facilitate the exchange of oceanographic data and information among participating member states (see section 6). Most operational systems relevant to the global coastal system are regional in scope. Of these, CalCOFI, CPR, and IBTS are examples of programmes that emphasize biological observations that could be scaled up to address phenomena in the ecosystem health and living marine resources themes; BOOS is highlighted as an end-to-end system for efficient and safe marine operations that provides a physical-meteorological framework for the development of ecological capacity (which is occurring as of this writing); and GCRMN is highlighted to illustrate the importance of public awareness and involvement in developing and sustaining an observing system. Both global and regional programmes are described in more detail in Annex VII. GRAs have a great responsibility to collaborate with the COOP to coordinate the development of the Global Coastal Network, in exchanging data which are truly global in nature, and in developing those aspects of GOOS that target their respective regional needs.

Satellite data are a significant source of coastal information for GOOS, despite limitations of present sensors to provide near-shore data (e.g., altimetry breaks down within 20 km of the shoreline; algorithms that translate water leaving-radiance into chlorophyll concentrations in case II waters are in the research and development stage), to resolve gradients on scales less than 1 km, and to provide data from regions of persistent cloudiness. For the most part, the smaller the sensor footprint and the higher the spatial resolution of the product, the greater the value for coastal purposes. At present, satellite sea surface temperature, ocean colour, surface vector winds, precipitation and some components of the air-sea heat flux are available for the outer reaches of the EEZ in most coastal environments. Even when not directly applicable for coastal purposes, these data can contribute to the skill of coastal models through larger-scale products that provide offshore boundary conditions for coastal models. Calibration of satellite data with *in situ* data is very important in the highly variable coastal zone. Most of the present satellite data are now from research, not operational, missions. It is important to move these to operational status.

7.2.4 Capacity Building

Many nations do not have the resources, technologies or expertise to develop national or regional observing systems or to contribute to the global network without significant assistance. Thus, capacity building must be an early priority for the global coastal system. This is the greatest challenge to the implementation of GOOS on a global scale.

The goal of capacity building is to enable all nations to contribute to and benefit from the observing system. Achieving this goal will require partnerships between the community of donor nations and recipient nations. Capacity building will generally involve a mix of activities from technology transfer (to build the infrastructure required for observations, data communications networks and management, modelling, and product development subsystems) and training, to public outreach activities intended to educate the public, donor organizations, government ministries, and other stakeholders.

In collaboration with other capacity building activities (by WMO, IOCCG, GLOSS, GCRMN, and IPHAB), the GOOS Capacity Building Panel and the JCOMM Programme Area for Capacity Building will articulate capacity building needs and promote capacity building activities. Approaches must be tailored to regional needs and cultures and should include active community participation and awareness building (from government ministries and private enterprise to NGOs and volunteers). Above all, a sustained commitment will be required by the community of industrialized nations. Participating nations and donor organizations must recognize the need to sustain commitments beyond initial training and technology transfer programmes. Immediate priorities include the following:

- increase public and political awareness of environmental problems and the benefits of detecting and predicting changes in coastal ecosystems especially the connection to public health;
- entrain stakeholders in the design and development of the observing system on local to regional scales;
- enlist academic institutions, environmental research laboratories and government ministries to commit resources and expertise;
- incorporate existing capabilities and support and improve them according to the guidelines provided by the design plan for the coastal module (this includes incorporation of relevant existing data streams into the system);
- make use of computer-assisted and distance learning activities via the world wide web and interactive video networks; and
- develop the infrastructure for the communications network and provide the required training for data and information dissemination, QA/QC and archiving.

Initially, increasing public and political awareness in developing countries will be particularly important. In many cases, these countries will have to be convinced that more and better information on the marine environment will benefit their economies and the well being of their citizens. The focus should be on the value of information on marine ecosystems and the value-added aspect of investing in an international system. Above all, a sustained commitment will be required by the community of industrialized nations. Participating nations and donor organizations must recognize the need to maintain capacity once it has been built.

7.3 Phased Implementation

A sustained observing system, such as the World Weather Watch, is a new concept for oceanographers and marine ecologists, and there is an ongoing debate over what constitutes a system for sustained observations and what does not (Nowlin et al., 2001). Research projects intended to test hypotheses and develop new capabilities (from measurements to models) are finite in duration, and it cannot be assumed that every successful technique developed for research purposes should be incorporated into a sustained observing system. Such an approach is neither practical nor cost-effective. Thus, a mechanism is needed to select and incorporate candidate observing system elements into the sustained observing system.

In the development of current operational capabilities (e.g., ENSO forecasts), candidate systems typically pass through four stages on the path from a research project to operational modes (Nowlin et al., 2001). They are as follows:

(1) The development of observational (platforms, sensors, measurement protocols, data telemetry) and analytical (e.g., models) techniques for research purposes;

(2) Acceptance of the techniques by research and operational communities gained through repeated testing and pilot projects[11] designed to

[11] A pilot project is an organized, planned set of activities with focused objectives designed to provide an evaluation of technology, methods, or concepts the results of which are intended to advance the development of the sustained, integrated observing system. As such, pilot projects have a defined schedule of finite duration. Guidelines for reviewing an endorsing pilot and pre-operational projects are as follows: (i) Projects may be regional in scope; they may target any stage in the end-to-end system as outlined in i-iv above; and they may be enabling research or proof of concept projects. (ii) Projects must be organized and planned sets of activities with well defined objectives, a specified schedule with milestones, specified deliverables (products), and a finite lifetime. (iii) A clear statement must be made of how the project will significantly benefit the design, implementation, or development of CGOOS on regional (multi-national) to global scales. That is, the project must be justified in terms of how successful completion of its goals will improve the system's capacity to provide data and information for potential applications that are relevant to the needs of the user community. When appropriate, the project should be developed in collaboration with user groups. (iv) Projects must have funds in hand or have identified sources of funding. (v) It is expected that projects will function autonomously under the oversight of COOP or of a regional or national GOOS body as appropriate.

These criteria are intended to enable the objective selection of pilot projects that will benefit the development of GOOS and its users. They are not intended to be restrictive or exclusive if significant value can be achieved. For example, projects that address specific development needs at any stage of the end-to-end system, such as sensor development and improved assimilation techniques and models, will be eligible for endorsement providing it is clear how successful achievements of the project's goals will benefit the observing system and its users.

Finally, it must be emphasized that mechanisms for the transition of pilot and pre-operational projects to an operational mode based on accepted and objective criteria have yet to be established. This problem must be addressed immediately, for, in the absence of such a mechanism, there will be little motivation to develop the pilot projects required to build a sustained and integrated system.

demonstrate their utility and sustainability in a routine, operational mode;

(3) Pre-operational use of techniques and data by the research, operational and user communities to ensure that incorporation into the observing system leads to a value added product (is more cost-effective than functioning in isolation) and to ensure that incorporation does not compromise the integrity and continuity of data streams and product delivery; and

(4) Incorporation of techniques and data into the observing system with sustained support and sustained use. A critical aspect of incorporation into GOOS will involve the timely provision of data and metadata via an integrated data management system as described in Chapter 6.

Mechanisms must be established to promote activities in each of these stages and to selectively transition successes from stage to stage based on the requirements of user groups. Programmes such as WOCE have experience of this transition, and within the GRAs many local developments have been tested and converted successfully to operational status. These examples can be cloned between GRAs through the Regional GOOS Forum.

The private sector plays important roles in the operational meteorological community. Industry manufactures sensors and platforms. Commercial enterprises add value to the weather forecast of the National Weather Services and provide specialized forecast services to a wide range of customers. As the global and regional observing systems develop, there will be many similar opportunities for the private sector.

Technologies, understanding, requirements and applications will advance and change with time and mechanisms must be established to ensure that the observing system incorporates these changes as user needs become better defined and new technologies and models are developed. Thus, although presented as a linear sequence, in practice all four stages will develop in parallel with feedbacks among all stages. Examples of programmes and elements that are in each of the four stages are given in Annex VII.

Box 7.3. Examples of Observing System Elements the Represent Operational, Pre-Operational, and Pilot Project Stages (from Nowlin et al., 2001)

- An example of an observing system that has progressed through research, pilot project, and pre-operational stages to become operational is the ENSO observing system in the tropical Pacific (Nowlin et al., 2001). In the 1980s, the Tropical Ocean-Global Atmosphere (TOGA) research project began to develop detection capabilities, scientific understanding and models required to predict ENSO events. This developed into a multi-national pilot project during the 1980s and early 1990s. With the successful development of predictive skill based on routine observations, the pilot project became pre-operational in 1994 and in 1999 became an operational component of GOOS.
- The TOPEX/Poseidon satellite altimeter mission for precise measurements of sea surface height is an example of an observing system technology that has been proven in the research community and is now pre-operational.

The Global Ocean Data Assimilation Experiment (GODAE) is a one-time pilot project to demonstrate the feasibility and practicality of real-time global ocean data assimilation and numerical modelling for short-range open ocean forecasts, boundary conditions to extend predictability of coastal regimes, initialise climate forecast models; and research. A related sampling technology that is in the pilot project stage is the Argo project which is deploying several hundred autonomous profiling floats to measure and telemeter temperature and salinity data for the upper ocean (0 - 2000 m).

7.4 Coordination and Oversight

At present, there are no formal mechanisms in place to coordinate and link GRAs as they develop, to promote the development of the global coastal network (linking global systems and scaling up national and regional systems), to formulate and adopt common standards and protocols (measurements, data communications and management, product development), and to promote community-based modelling activities.

As many of the phenomena of interest (e.g., in the categories of human health, ecosystem health and living marine resources) transcend national borders and the EEZs of coastal states, intergovernmental mechanisms are needed to facilitate multi-lateral agreements, coordinate observing activities, and implement observing systems required to achieve the goals of international conventions. Several mechanisms are envisioned as offering avenues for coordination and oversight of the system. These include the following:

- GOOS National Programmes are basic building blocks of GOOS. Therefore they should provide the first level of coordination and oversight for the global coastal network.
- GRAs could provide the mechanism for coordinating requirements for data and products among the GRAs, LMEs, RSPs, RFBs, and IOC and WMO regional organizations. Such coordination is essential to reduce duplication of effort and to harmonize the use of observations among various regional users having distinct requirements.
- JCOMM was established by the WMO and the IOC to provide a consistent framework for the collection, archival, distribution and utilization of data for oceanographic and marine meteorological applications. The terms of reference for JCOMM allow for the inclusion of ecological and socio-economic elements of the coastal module (non-physical variables). Under the guidance of scientific and operational programmes of the IOC and WMO, JCOMM is charged with developing, maintaining, coordinating and guiding the operation of the global meteorological and oceanographic observing systems to meet the needs of member nations. This includes (1) evaluation of the effectiveness of the observing system on a continuing basis; (2) development of a data management system to meet real time operational needs (in collaboration with the CBS, IODE, ICSU and other appropriated bodies); (3) provision of guidance, assistance, and encouragement for national and international analysis centres to prepare and deliver data products and services (in collaboration with the Global Maritime Distress and Safety System of SOLAS); and (4) reviewing and enhancing the capacity of members of the IOC and WMO to benefit from and contribute to GOOS and GCOS. JCOMM is to consider (1) the extent to which efficiencies can be achieved by maximizing the types of observations obtained from various platforms (satellites, aircraft, drifters, gliders, moorings, ships, etc.) and (2) the boundary between the data and information provided by the observing system and their applications. The observing system will provide products and assessments of the state of the ocean, but will not effect specific applications, e.g., the observing system will provide descriptions of the SST, wind, and current fields required for an ENSO prediction, but will not make the actual prediction.
- GOOS Regional Alliances as a group could complement the activities of JCOMM. A group such as the Regional GOOS Forum could provide the mechanism to establish trans-regional user requirements, specify associated required products, coordinate measurements and sharing of technical information among GRAs, assess the effectiveness of the system and recommend needs to JCOMM.

Decisions regarding mechanisms for the coordination and oversight of the global coastal network are needed soon because implementation of that network is beginning. JCOMM can take on board non-physical observations, associated products, standards, etc. either directly by the formation of appropriate sub-bodies of JCOMM or through linkages to appropriate organizations that can deal with non-physical variables on behalf of JCOMM.

ANNEX I – Panel Members and Contributing Experts

COOP MEMBERS

Dagoberto Arcos
Fisheries Research Institute
Avda Cristobal Colón # 2780
P.O. Box 350
Talcahuano,
CHILE
Tel: +56 41 588886
Fax: +56 41 583939
E-mail: okean@entelchile.net
inpesca@inpesca.cl

Marcel Babin
Laboratoire d'Océanographie
de Villefranche (UMR 7093)
Université Pierre et Marie Curie/CNRS
Quai de la Darse, B.P. 8
06238 Villefranche-sur-Mer Cedex
FRANCE
Tel: +33 4 93 76 37 12
Fax: +33 4 93 76 37 39
E-mail: marcel@obs-vlfr.fr

Bodo von Bodungen
Baltic Sea Research Institute
Rostock University
Seestrasse 15
D-18119 Rostock-Warnemuende
GERMANY
Tel: +49 381 5197100
Fax: +49 381 5197 105
E-mail: bodo.bodungen@io-warnemuende.de

Alfonso Botello
UNAM-
National Autonomous University of Mexico
AP Postal 70305
Mexico 04510,
MEXICO
Tel: +52 5 622 5765
Fax: +52 5 616 0748
E-mail: alfonsov@mar.icmyl.unam.mx

Robert Bowen
Environmental, Coastal & Ocean Sciences (ECOS)
UMass Boston
100 Morrissey Blvd.
Boston, MA 02125-3393
USA
Tel: +1 617 287 7443
E-mail: bob.bowen@umb.edu

Lauro Julio Calliari
Fundação Universidade Federal
do Rio Grande (FURG)
Av. Itália km 8
Campus Carreiros
Departamento de. Geociências
Laboratório de Oceanografia Geológica
96201-900 Rio Grande, RS
BRASIL
Tel: +55 53 2336518
Fax: +55 53 2336605
E-mail: tsclauro@super.furg.br
lcalliari@geo1.log.furg.br
calliari@vetorialnet.com.br

John Cullen
Department of Oceanography
Dalhousie University
Halifax, Nova Scotia
CANADA, B3H 4J1
Tel: +1 902 494 6667
E-mail: john.cullen@dal.ca

Laura T. David
Marine Science Institute
University of Philippines
Roces Av., Diliman, Quezon City
PHILIPPINES
Tel: +63 2 922-3959
Fax: +63 2 924-7678
E-mail: ldavid@upmsi.ph

Michael Depledge
Environment Agency
Rio House
Waterside Drive, Aztec West,
Almondsbury
Bristol, BS 32 4 UD
UNITED KINGDOM
Tel: +44 (0) 1454 878828
E-mail:
michael.depledge@environment-agency.gov.uk

Eric Dewailly
WHO/PAHO Collaborating Center on
Environmental and Occupational Health
Impact assessment and Surveillance.
2400 d'Estimauville
Beauport,
CANADA, QCG1E 7G9
Tel: +1 418 666 7000 ext 222
Fax: +1 418 666 2776
E-mail: Eric.Dewailly@crchul.ulaval.ca

Michael J. Fogarty
NMFS
EASC
166 Water St
Woods Hole
MA 02543-1026,
USA
Tel: +1 508 495 2000
Fax: +1 508 495 2258
E-mail: Michael.Fogarty@noaa.gov

Juliusz Gajewski
Maritime Institute
Maritime Institute in Gdansk
Department of Operational Oceanography
Dlugi Targ 41-42 str.
80-830 Gdansk
POLAND
Tel: +48 58 3018724
Fax: +48 58 3203256
E-mail: julgaj@imorhp.im.gda.pl

Johannes Guddal
Norwegian Meteorological Institute
DNMI Region W., Allegt. 70
N-5007 Bergen
NORWAY
Tel: +47 5523 6626
Fax: +47 5523 6703
E-mail: j.guddal@met.no

Julie Anne Hall
NIWA
P.O. Box 11-115, Hamilton
NEW ZEALAND
Tel: +64 78561709
Fax: +64 78560151
E-mail: j.hall@niwa.cri.nz

Hiroshi Kawamura
Graduate School of Science
Tohoku University
Aoba, Sendai 980-8578
JAPAN
E-mail: Kamu@ocean.caos.tohoku.ac.jp

Anthony Knap (Co-chairman)
Bermuda Biological Station
for Research, Inc.
17 Biological Lane
Ferry Reach
St. George's GE 01
BERMUDA
Tel: +441 297 1880 ext. 244
Fax: +441 297 8143
E-mail: knap@bbsr.edu

Kwame Koranteng
Marine Fisheries Research Division
Ministry of Food and Agriculture
P.O. Box BT 62
Tema
GHANA
E-mail: kwamek@africaonline.com.gh

Thomas C. Malone (Co-chairman)
Horn Point Laboratory
University of Maryland Center for
Environmental Science
P.O. Box 775, Cambridge, MD 21613
USA
Tel: +1 410 221 8406
Fax: +1 410 221 8473
E-mail: malone@hpl.umces.edu

Coleen Moloney
Zoology Department
University of Cape Town
Rondebosch
7701 Cape Town
SOUTH AFRICA
Tel: +27 21 650 2681
E-mail: cmoloney@botzoo.uct.ac.za

Nadia Pinardi
Corso di Laurea in Scienze Ambientali
Bologna University
Palazzo Rasponi
Piazzale Kennedy 12
48100 Ravenna
ITALY
Tel: +39 0544 484269
Fax: +39 0544 484268
E-mail: n.pinardi@ambra.unibo.it

Jeffrey Polovina
Ecosystem & Environment Investigation
Honolulu Laboratory
NOAA,
2570 Dole St.
Honolulu, HI 96822-2396
USA
Tel: 808-983-5390
Fax: 808-983-2900
E-mail: jeffrey.polovina@noaa.gov

Hillel Shuval
Division of Environmental Sciences
The Hebrew University of Jerusalem
Jerusalem
ISRAEL
Direct Tel/Fax: +972-2-566 0429
E-mail: hshuval@vms.huji.ac.il

Vladimir Smirnov
Arctic and Antarctic Research Institute
AARI
38 Bering str.
St. Petersburg
RUSSIAN FEDERATION, 199397
Tel: +8 123521520
Fax: +8 123522688
E-mail: vgs@aari.nw.ru

Keith R. Thompson
Dept. of Oceanography
Dalhousie University
Halifax, Nova Scotia
CANADA, B3H
Tel: +1 902 494 3491
Fax: +1 902 494 2885
E-mail: keith.thompson@dal.ca

Vladimir Vladimirov
Caspian Environment Programme
Room 108, 3rd Entrance, Government House
U. Gajibeyov Str., 40
Baku-370016
AZERBAIJAN
Tel: +994 12 971785, 938003
Fax: +994 12 971786
E-mail: vlvlad@yahoo.com
Vladymyrov@caspian.in-baku.com

MVM Wafar
National Institute of Oceanography,
Dona Paula P.O. Goa 403 004
INDIA
Tel: +91 832 226253 extn. 4252
Fax: +91 832 223340
E-mail: wafar@darya.nio.org
wafar@csnio.ren.nic.in

Rudolph Wu
City University of Hong Kong
Dpt of biology and Chemistry
Tat Chee Avenue
Kowloon
Hong Kong
CHINA
Tel: +85 2 2788 7404
Fax: +85 2 2788 7406
E-mail: bhrswu@cityu.edu.hk

INVITED EXPERTS

Robert R. Christian
Biology Department
East Carolina University
Greenville, NC 27858
USA
Tel: +1 252 328 1835
Fax: +1 252 328 4178
E-mail: christianr@mail.ecu.edu

Chris Crossland
LOICZ IPO
P.O.B. 59, NL-1790AB, Den Burg
Texel
THE NETHERLANDS
Tel: +31 222 369404
E-mail: ccross@nioz.nl

Stephen J. de Mora
International Atomic Energy Agency
Marine Environment Laboratory
4, Quai Antoine 1er – B.P. 800
MC 98012
PRINCIPALITY OF MONACO
Tel: +377 97 97 72 72
E-mail: S.de_Mora@iaea.org

Roger Harris
Plymouth Marine Laboratory
Prospect Place
Plymouth, PL1 3DH
UNITED KINGDOM
Tel: + 44 (0) 1752 633100
E-mail: rph@pml.ac.uk

William Harrison
Ocean Sciences Division
Bedford Inst. of Oceanography
P.O. Box 1006
Dartmouth, Nova Scotia
CANADA B2Y 4A2
Tel: +1 902 426 3879
E-mail: harrisong@mar.dfo-mpo.gc.ca

Herman Hummel
Centre for Estuarine and Coastal Ecology
Netherlands Institute of Ecology (NIOOCEMO)
Royal Netherlands Academy of Arts and Sciences
Korringaweg 7, 4401 NT Yerseke
P.O.B. 140, 4400 AC Yerseke
THE NETHERLANDS
Tel: +31 (0) 113 577484 (577300)
E-mail: hummel@cemo.nioo.knaw.nl

Savithri Narayanan
Marine Environmental Data Service
Dept. of Fisheries and Oceans
W082, 12th Floor
200 Ken Street
Ottawa, Ontario
CANADA K1A 0E6
Tel: +1 613 990 0265
E-mail: narayanans@dfo-mpo-c.ca

Worth Nowlin
Department of Oceanography
Texas A&M University,
College Station, TX 77843,
USA
Tel: +1 979 845 3900|
Fax: +1 979 847 8879
E-mail: wnowlin@tamu.edu

Shubha Sathyendranath
POGO
Mail Stop B240
Bedford Institute of Oceanography
Dartmouth
Nova Scotia
CANADA, B2Y 4A2
Tel: +1 902 426 8044
E-mail: shubha@is.dal.ca

Neville Smith
Bureau of Meteorology Research Centre
150 Lonsdale Street
Box 1289K
Melbourne,Victoria 3001
AUSTRALIA
Tel: +61 3 9669 44 34
Fax: +61 3 9669 46 60
E-mail: nrs@bom.gov.au

IOC SECRETARIAT

Thorkild Aarup
Intergovernmental Oceanographic Commission
UNESCO
1, rue Miollis
75732 Paris Cedex 15
FRANCE
Tel: +33 (0) 145-684019
Fax: + 33 (0) 145 685812
E-mail: t.aarup@unesco.org

ANNEX II – The Phenomena of Interest: Definitions

INTRODUCTION

The phenomena of interest, grouped according to Table 1.1, are described below for consistency and as an aid to determining the variables that must be measured to detect or predict variability in them. A major goal of the coastal module of GOOS is the development of an integrated observing system for the provision of data and information required to anticipate changes and prepare for an uncertain future over a broad range of scales in time and space. In addition to improving nowcasts and forecasts of changes in the physical environment for safe and efficient marine operations and public safety (surface currents and waves, storm surges, coastal erosion, etc.), successful development of the coastal module is critical to improving the ability of governments to mitigate the effects of external forcings (climate changes and human activities) on ecosystems and people and to sustain, protect and restore marine habitats, living resources and ecosystems. Critical to improving the ability of governments to perform these functions are repeated, quantitative assessments of the state of coastal marine ecosystems in terms of their capacity to support goods and services. To this end, the integrated observing system should be designed to detect and predict changes in the broad spectrum of physical and ecological phenomena described below.

The variability exhibited by coastal environments and the organisms that inhabit them reflect the effects of external forcings (e.g., ENSO events, global warming, nutrient loading to surface waters from coastal drainage basins) and characteristics of ecosystems themselves (e.g., geomorphology, circulation and mixing regimes, physical-biological-benthic-pelagic coupling, and a diversity of biogeochemical and trophic interactions). Overfishing is among the oldest of a sequence of major anthropogenic forcings of coastal ecosystems that include nutrient enrichment, chemical contamination, physical alteration of habitats, introductions of invasive species and the production of green house gasses. The effects of any of these forcings cannot be effectively addressed independently of one another or of natural sources of variability (e.g., extreme weather events, tides, large scale currents and waves, species succession and evolution). Variations in fish stocks, biodiversity, habitats, and the resiliency of marine ecosystems to external forcings are not independent but related through complex non-linear and stochastic interactions. Consequently, the present state of the marine environment and changes in the phenomena of interest can only be predicted with acceptable skill if they are rapidly detected and quantitatively understood in terms of both the compounding effects of larger scale forcings (occurring in the oceans, on land, and in the atmosphere) and the hierarchy of interactions that define marine ecosystems.

A. MARINE SERVICES AND PUBLIC SAFETY

1. Forecasts and Changes in Sea State, Surface Currents, Current Profiles, Sea Level and Shallow Water Bathymetry[12]

Nowcasts and forecasts of sea state, sea level and coastal circulation patterns are of critical importance to safe and efficient marine operations including shipping, port operations, search and rescue operations, fishing, recreational boating and swimming,

[12] Nowcasts and forecasts of fog and sea ice are important marine services in some regions (e.g., high latitudes, coastal upwelling regions) but are not considered to be global in extent. These should be the subject of regional enhancements.

and the extraction of natural resources. Sea state describes the wave environment at the air-sea interface and is measured in terms of amplitude, frequency and direction. Wind, wave, and current data are now managed on a gridded field basis, often with directional spectra. Accurate bathymetric maps and predictions (hindcasts, nowcasts and forecasts) of sea level are also required for coastal circulation models (for research and operational purposes) and, therefore, for the coupled physical-biological models needed to predict changes in the status of marine ecosystems and the living resources they support, i.e., prediction of most of the phenomena of interest requires data (measured or calculated) on sea level, surface waves, circulation, and/or bathymetry.

2. Shoreline Changes and Coastal Flooding

Coastlines are constantly eroding and accreting from routine and episodic events associated with tides, winds, waves, storm surges, sediment resuspension and transport by rivers, tectonic processes and human modifications of the coastal zone. The latter include the construction of dams, harbours, breakwaters, and inlets; dredging to maintain shipping channels; sand mining; extraction of ground water; and modifications of biologically structured habitats (sea grass beds, kelp beds, tidal marshes, mangroves, oyster reefs, and coral reefs). These habitats help stabilize soils and sediments thereby buffering and the effects of wave action and the extent of coastal flooding. Thus, the consequences of human modifications include the mobilization of sediments and alterations of sediment transport patterns, subsidence, and increases in the susceptibility to coastal flooding.

B. Public Health

Human health risks are related to the presence and concentration of pathogens, chemical contaminants, and biotoxins produced by harmful algae. Humans are exposed to these sources of pathology via the food they eat, direct contact with seawater and inhalation of aerosols.

1. Chemical Contamination of Seafood

There is a broad spectrum of chemical contaminants that are health risks to humans via seafood consumption. Those of human origin include synthetic organic chemicals often called Persistent Organic Pollutants (POPs, e.g., PCBs, polychlorinated biphenyls and furans, DDT, chlordane, and heptachlor), Polycyclic Aromatic Hydrocarbons (PAHs, products of the thermal degradation of petroleum), and metals and organometal complexes (most notably Cd, MeHg, and TBT). Toxins produced by harmful algae are treated below. For the most part, the relative significance of these chemicals as human health risks varies regionally depending on climate and oceanographic conditions, the culture of the population (i.e., the amount and type of seafood consumed) extent and kinds of industrial development, and agricultural practices (cf., Table 5 in "A Strategic Plan for the Assessment and Prediction of the Health of the Ocean, May 1996, IOC/INF-1044, UNESCO). To the extent that circulation patterns and geomorphology influence the distribution and fate of contaminants, these factors will also be important in assessing the probability of human exposure (NRC, 1999b).

2. Human Pathogens

The primary sources of human pathogens are untreated human sewage and animal wastes (enteric bacteria). Routes of human exposure include seafood consumption (especially raw shellfish), ingestion of seawater, and direct (skin) exposure to water or sediments. To the extent that circulation patterns and geomorphology influence the distribution and concentration of pathogens, these factors will also be important in assessing the probability of human exposure. Physical and meteorologically forced models can help predict dispersion and transports.

Among the microbial agents responsible for seafood borne illnesses, viruses are the most common cause of infection, followed by bacteria and protozoa (NRC, 1999b). Shellfish are the major vectors of viral infections. Among the bacteria, *Vibrio vulnificus* has been implicated in shellfish poisoning and wound infections. *Vibrio* spp., *E. coli*, *Shigella* spp. and *Salmonella* spp. can also be contracted from ingestion of seafood or water. Less is known about protozoa induced illnesses. *Giardia* spp. and *Entamoeba gastrilis* have been epidemiologically linked to scuba diving in sewage contaminated waters. The concentration of coliform bacteria in the water column is the most commonly measured indicator of pathogen contamination. Current estimates of the cost to society of exposure to these pathogens via bathing in polluted waters and consumption of seafood are $1.6 billion and 7.2 billion USD, respectively.

C. Status (Health) of Marine and Estuarine Ecosystems

To the extent that currents, turbulent mixing and geomorphology and associated features (fronts, pycnoclines, boundary layers) influence the distribution, concentration and fate of material inputs (e.g., inorganic and organic nutrients, chemical contaminants, pathogens, non-native species) in coastal ecosystems, these factors will also be important in predicting changes in the phenomena of interest discussed below.

1. Habitat Modification and Loss[13]

The habitats targeted by the coastal module are those of the intertidal (mangrove forests, tidal marshes, mud flats, and beaches) and relatively shallow subtidal zones (kelp forests and other attached macroalgae, seagrass beds, coral and oyster reefs). These habitats are important for recreation and provide food and refuge for a high diversity of organisms, including commercial and recreational fish populations. They play major roles in sustaining living resources, providing habitat for marine organisms, maintaining shoreline stability, mitigating the effect of storm surges and coastal flooding, and controlling the fluxes of nutrients, contaminants and sediments from land to coastal ecosystem. Thus, changes in these habitats have significant affects on marine biodiversity, fisheries, recreation and tourism, the susceptibility of human populations to extreme weather, the capacity of coastal ecosystems to assimilate and recycle nutrients mobilized by human activities, and on the provision of aesthetically pleasing environments (NRC, 1994; Mitsch et al., 1994; Boehlert, 1996; Maragos et al., 1996).

The distribution and areal extent of these habitats are affected by both climatic forcings (e.g., changing patterns of heat flux and rainfall) and anthropogenic activities (e.g., excess nutrient inputs and over fishing). Coral reef bleaching and increases in the susceptibility of corals to disease are believed to be related to increases in temperature caused by ENSO events and global warming. Overfishing, nutrient enrichment and coastal erosion are also causes of coral reef loss. Mangrove forests are being cut down for firewood and to provide space for aquaculture operations (e.g., shrimp farming). Losses of sea grass beds occur as a consequence of wasting disease, nutrient enrichment, coastal erosion and sediment loading, land reclamation, harvesting bottom fish and shellfish, and dredging. Tidal marshes are susceptible to sea level rise, subsidence, canalisation, invasive species, and land use practices (e.g., coastal development and hardening the shoreline, water consumption, dams) that affect their sediment budgets and pore water chemistry.

The distribution and abundance of biologically structured habitats (mangrove forests, sea grass beds, coral reefs, etc.) vary regionally depending on water-depth, -clarity, -temperature, and salinity. For example, salt marshes are prominent features of coastal ecosystems in South Asia and the SW Atlantic but not in South Africa, the SE Pacific, or the Arctic. Coral reefs are confined to warm, clear waters of the tropics and subtropics (e.g., SW Pacific, Caribbean), and mangroves are particularly abundant in west-central Africa, the SW Atlantic, the west coast of Central America, the north coast of South America and the SE Pacific.

2. Eutrophication

The structure and function of coastal ecosystems depend on inputs of nutrients (N, P, Si, Fe, etc.) from external sources (the deep ocean, coastal drainage basins and the atmosphere). Excess inputs of nutrients (nutrient over-enrichment or nutrient pollution -- usually forms of nitrogen, phosphorus, or both) result in a phenomenon called “eutrophication”. “Excess” is typically defined in terms of outcomes. These include accumulations of organic matter (often in the form of algal biomass but also as organic detritus, dissolved organic matter, or some combination of these), increases in bacterial production, and the development of hypoxic (dissolved oxygen < 2 ppm) or anoxic (no dissolved oxygen, often associated with the production of hydrogen sulphide which is toxic to many aerobic organisms) conditions. Oxygen

13 Habitat modifications due to oxygen depletion, harmful algal events, and invasive species are treated elsewhere.

depletion of bottom waters is nearly always a consequence of excess nutrient enrichment and associated accumulations of organic matter. There is also clear and unequivocal evidence that increases in the frequency and extent (spatial and temporal) of bottom water hypoxia and anoxia are directly related to increases in diffuse and point source inputs from anthropogenic sources (Howarth et al., 2000; Kemp and Boynton, 1997; Nixon, 1995; Peierls et al., 1991). Thus, the phenomena of eutrophication will be quantified here in terms of the frequency and extent of hypoxia in coastal ecosystems.

Excess nutrient enrichment may also promote losses in biodiversity, mass mortalities, decreases in water clarity, habitat loss (e.g., coral reefs, sea grass beds), the growth of HABs and non-native species, and changes in the abundance of exploitable living marine resources. However, because these phenomena are often the consequence of other factors than nutrient enrichment and have significant implications in terms of ecosystem structure and function that are not directly related to nutrient enrichment, these phenomena are treated separately below.

For the most part, excess inputs of nutrients to semi-enclosed bodies of water and near-shore coastal ecosystems (e.g., in waters less that 50 m deep and within 50 km of the coastline) are related to human activities that mobilize nitrogen and phosphorus and increase their export from coastal drainage basins and airsheds via surface and ground water discharges and atmospheric deposition. For example, over the past 100 years, nitrate concentrations in the world's rivers have increased by as much as 20 fold, largely as a consequence of a rapid increase in the pool of fixed N (due mostly to anthropogenic fixation of N for fertilizers) and to related increases in point (sewage) and diffuse (mobilization of nitrogen by deforestation, fertilizer use, acid rain) inputs. Increases in anthropogenic inputs are reflected in the correlation between riverine N exports to coastal ecosystems and the population density of their watersheds. Evidence is growing that such increases in N loading are responsible for the loss of habitat (seagrasses, coral reefs) and for increases in the occurrence and magnitude of seasonal anoxia. Given the effects of such changes on critical fish habitat and the migrations of anadromous fish, it is likely that these effects are lowering the carrying capacity of ecosystems for exploitable fish and shellfish stocks. The effects of excess nutrient enrichment can also be exacerbated by over fishing, especially when the exploited species are filter feeders such as oysters, clams and mussels.

The measurement and control of eutrophication are often the subject of local, national, and multi-national agreements concerning coastal seas, so that matters of definition and measurement become acutely sensitive and political. Operational agencies with responsibility for this management will benefit from increased research, and improvements in operational observations and modelling.

3. Changes in Biodiversity

Of the various levels of biological diversity (from molecular to ecosystem levels of organization), the most common indices of biodiversity are based on the number of species and the distribution of abundance among species. Current estimates (which are most likely underestimates) place the number of marine species at about 200,000 with representatives from 32 phyla, 15 of which are found exclusively in the marine realm. This is in marked contrast with the terrestrial environment where there is an estimated 12 million species, over 90% of which are from two phyla: insects and flowering plants.

The rate of species extinction has been estimated to have been about 1 per year prior to the evolution of people compared to the current rate of 100-10,000 species per year (Norse, 1996). Changes in species diversity are related to large scale changes in the ocean-climate system (e.g., ENSO, PDO, NAO) and to more local scale changes such as habitat loss or modification (e.g., coral reef bleaching, declines in mangrove forests due to shrimp farming, loss of seagrasses due to nutrient enrichment), oxygen depletion, invasions of non-native species, fishing, mass mortalities of marine organisms, and harmful algal events.

4. Harmful Algal Events

There is growing evidence that coastal ecosystems are experiencing an escalating and disturbing trend in the incidence of problems associated with harmful algae, including human illness from contaminated shellfish or fish, the closure of shellfish beds, mass mortality of cultured finfish, and the death of marine mammals and seabirds (Anderson et al., 2002 and references therein; http://ioc.unesco.org/hab). Increases in harmful algal events may also be associated with the loss of biodiversity in some regions. As a result, government ministries responsible for public health and industries involved in the harvesting and marketing of sea food (wild and farmed) are recognizing the need for more timely detection of HAB events and for the development of a predictive understanding of when and where such events are most likely to occur. Timely access to such information is required to (1) protect public health, (2) control and mitigate ecological and economic impacts, and (3) disseminate relevant, accurate and useful information in a timely fashion to coastal communities and industries that are impacted or likely to be affected by such events.

Although harmful algal events are often referred to as harmful algal blooms (HABs) or "red tides", it must be recognized that: (1) HAB species represent a broad spectrum of taxa (dinoflagellates, diatoms, cyanobacteria, raphidophytes, prymnesiophytes, and pelagophytes) and trophic levels (e.g., autotrophic, heterotrophic, mixotrophic) that are referred to collectively as "algae"; and (2) many HAB species cause problems at low cell densities, i.e., a bloom is not necessarily required for a HAB event to occur. There are two general groups of HABs: (1) those that produce toxins that contaminate seafood, increase the susceptibility to disease, and kill marine animals; and (2) those that cause problems by virtue of their high abundance or biomass (oxygen depletion, habitat loss, and starvation, respiratory or reproductive failure in marine animals). The latter are discussed in the context of coastal eutrophication.

For the purposes of the design plan, a harmful algal event may be one or more of the following: (1) a bloom of a HAB species that is known to produce toxins harmful to marine life or to humans; (2) mass mortalities of marine organisms caused by HAB species; (3) non-lethal manifestations such as lesions, increased parasite load, or decreased reproductive capacity caused by HAB species; or (4) the occurrence of human illness caused by a HAB species. There are approximately 5,000 species of microalgae in the world. Of these, about 100 fall into one or more of these categories. These species produce a spectrum of toxins that typically fall into one of the following categories: paralytic shellfish poisoning, diarrhetic shellfish poisoning, amnesic shellfish poisoning, neurotoxic shellfish poisoning, and Ciguatera fish poisoning. Lesions, respiratory irritation, and memory loss may also occur via contact with water or exposure to aerosolised toxins or irritants. For the most part, the relative significance of toxic species varies regionally depending on environmental conditions conducive to growth and to the production of toxins by microalgae (Smayda and Shimizu, 1993; http://ioc.unesco.org/hab).

5. Invasive Species

As the global movement of ships, people and commodities has increased, the number of introductions of non-native species has also increased (global dispersal). The number of successful new invasions (invasive species) appears to have increased dramatically during the 1970s and 1980s, perhaps as a consequence of the combined effects of global dispersal, habitat loss and modification, nutrient enrichment and over fishing in coastal ecosystems (Carlton, 1996). Increases in the occurrence of invasive species may be a factor in the loss of biodiversity in some regions. The list of recent invaders includes several species of benthic algae, SAV, toxic dinoflagellates (e.g., *Alexandrium catenella* in Australia), bivalves (e.g., the zebra mussel in the Great Lakes and the Chinese clam in San Francisco Bay), polychaetes, ctenophores, copepods, crabs and fish. Such invasions can profoundly alter the population and trophic dynamics of coastal ecosystems. For example, the introduction of the ctenophore *Mnemiopsis leidyi* caused the collapse of the anchovy fishery in the Black Sea by preying on the anchovy's preferred food, copepods; the introduction of the macrobenthic green algae, *Caulerpa taxifolia*, displaced a diverse community of sponges, gorgonians, and other seaweeds over thousands of square meters in the northern Mediterranean; and the introduction of the Chinese clam (*Potamocorbula amurensis*) has severely limited phytoplankton production in San Francisco Bay.

6. Water Clarity

Reductions in water clarity can occur as a consequence of numerous factors including coastal erosion and sediment transport, sediment resuspension, phytoplankton growth, overfishing of filter feeding bivalves, and inputs of nutrients and organic matter from point (e.g., sewage discharges) and diffuse sources (surface and ground water flows, atmospheric deposition). Underwater light is essential for photosynthesis, the growth and maintenance of many habitats (e.g., coral reefs, seagrasses, benthic macroalgae) and vision. Photosynthesis supports most biological production in the ocean; habitats such as coral reefs, kelp beds, and sea grasses are important habitats for living resources and biodiversity; and vision is an important parameter of reproduction and feeding (trophic interactions and the transfer of phytoplankton production to higher trophic levels, including commercially important fisheries). Consequently, changes in water clarity can have profound influences on coastal ecosystems.

Solar radiation is attenuated rapidly in most coastal waters influenced by land-runoff (inputs of sediments, coloured dissolved organic matter, particulate organic matter and nutrients associated with surface water runoff), high phytoplankton productivity, and sediment resuspension. Measurements of attenuation in several wave bands can resolve the effects of sediments, coloured dissolved organic matter, and phytoplankton. Thus, in addition to being an important determinant of primary productivity, the attenuation of solar radiation can be an important tracer of phytoplankton, sediment transport, coastal erosion, areal extent and location of buoyant plumes and effluent discharges, nutrient supply, and the environmental mobility of inorganic and organic pollutants, inorganic particles, and detritus and living particulate matter.

7. Disease and Mass Mortalities in Marine Organisms

Fish, shellfish, marine mammals, turtles and sea birds experience mass mortalities and strandings (that typically lead to death) that have been related to disease, parasitism, harmful algal blooms, hypoxia, oil spills, diversions of freshwater, and climate change. The number of such events and assessments of their causes can be considered indicators of the health of marine ecosystems and their capacity to support living resources.

D. Status of Living Marine Resources

1. Changes in Harvest (both Capture Fisheries and Aquaculture)

More than 90% of the marine fish catch comes from coastal ecosystems and, in 1997, fish provided about 6% of the total protein consumed by humans. The species composition of fish landings varies among regions and is changing through time as landings of the larger, more valued species (e.g., salmon, tuna, sword fish, haddock, cod, hakes, redfish, flounders) decline. About 1 billion people, mostly in developing countries, rely on fish as their primary source of animal protein. Global fish and shellfish landings from both capture fisheries and aquaculture increased from less than 20 million metric tons in the early 1950s to more than 100 m-tons in the late 1990s. The rate of increase has decreased from about 6% per year during the 1950s and 1960s to 1.5% during the 1980s and 1990s. The FAO estimates that by 2010 fish landings will drop to about 75 million tons unless aquaculture production doubles and fishing pressure is reduced to sustainable levels.

During the late 1980s and early 1990s, seafood production (capture fisheries and aquaculture) increased from 89 million tons to 120 million tons. Capture fisheries increased by only 17% during this period and has levelled off in recent years. In contrast, aquaculture production expanded by 170% accounting for 60% of the total 31 million ton increase during this period (FAO, 2000). Aquaculture currently accounts for 30% of seafood consumption worldwide (FAO, 2000). In developed countries, aquaculture production increased by 25% (2.8 million tons in 1984 to 3.5 million tons in 1994) while capture fishery landings declined by 26% (42 million tons in 1984 to 31 million tons in 1994). In contrast, the production of both capture fisheries and aquaculture increased in developing countries by 340% and 68% respectively (FAO, 2000).

The FAO has developed three indicators that would help assess the condition of global fisheries: (1) total landing by year for each fishery region; (2) the ratio of piscivore to zooplanktivore biomass based on annual landings; and (3) percent catch by trophic level. With the exception of the eastern Indian

Ocean, piscivore landings have either peaked (NE Pacific, NE Atlantic, western Indian Ocean, western central Pacific) or declined (eastern central Pacific, NW Atlantic, NW Pacific).

It should be emphasized that aquaculture practices can have significant environmental impacts including the degradation of water quality due to the concentrated production of wastes, alteration of marine food webs due to the introduction of non-native or genetically altered species and to the removal of forage fish to use as food (e.g., salmon net pen aquaculture), habitat loss or modification (e.g., removal of mangrove stands for shrimp mariculture), the spread of disease, and increases in the incidence of harmful algal blooms (NRC, 1992, 1996a, 1996b; Chamberlain, 1997; Folke and Kautsky, 1992).

2. Changes in the Abundance of Exploitable Living Marine Resources

Sustained declines in the spawning stocks of marine fish, measured in term of total biomass and abundance, result in the loss of commercial fisheries, changes in the trophic structure and nutrient dynamics, and, in extreme cases, extinction. Such declines may also contribute to habitat loss (e.g., coral reefs), the development of invasive species and harmful algal blooms. Ecosystem level effects such as these tend to be species specific or trophic level specific (e.g., filter feeding bivalves versus piscivores). Early detection of trends in the abundance of spawning stocks of exploitable marine resources is critical to ecosystem-based fisheries management.

ANNEX III – Design Principles

There are two common misconceptions concerning the concept of an "operational" observing system (Nowlin et al., 2001). The first is that there is a clear distinction between research and operational programmes. There is not. The second is that data streams and applications do not have to be closely linked. They do. As is the case in meteorology, operational activities grow out of a rich foundation of scientific research. Using a tree as a metaphor, operational programmes are like the branches of a tree that grow from the trunk and roots, the research base. Both will prosper and grow as the strength of one enhances the strength of the other. The development of the ENSO observing system is a good example of this type of synergy. A related and important requirement is that the credit for building and sustaining GOOS must not be limited to the end members of the end-to-end system alone (the data gatherers and users). All of those involved, from measurements and data acquisition to data management, analysis and applications must be acknowledged and receive credit for their contributions to the system.

The development of the coastal module of GOOS will be guided by the GOOS Design Principles (IOC, 1998b) that have been tailored for the purposes of the coastal component. The users of the data and data-products will interact with both technical experts and scientists to drive the processes of designing, operating and improving the system in response to the evolving needs of user groups. As the coastal module develops, it must become more than the sum of its parts. The system will not be an opportunistic assembly of whatever might be available. It will develop by selectively incorporating, enhancing and supplementing existing programmes consistent with the needs of participating nations. To these ends, the design of the coastal module of GOOS will be guided by the following principles:

- **Operational**

For the purposes of GOOS, an operational observing system is one in which data streams and products are sustained into the foreseeable future and are provided routinely and systematically as specified by the users (uninterrupted, timely delivery of data and information with sufficient precision and accuracy). The successful achievement of the goals of the coastal module of GOOS requires that it be designed to capture the spectrum of environmental responses (the temporal and spatial dimensions of variability) to external forcings that are relevant to the phenomena of interest (Table 1.1). Observations must be sustained in perpetuity to capture episodic events and long-term trends (document both high and low frequency variability), enhance scientific analysis, and support model predictions.

- **Integrated**

The observing system must not only be sustained, it must be integrated (Figure III.1). The observing system will be integrated from measurements (remote and *in situ* sensing; synoptic measurements of physical, biological and chemical properties over a broad range of time and space scales) to data management (multiple data types from disparate sources) and analyses that are responsive to the needs of multiple end-users.

In addition, the observing system will provide data and information for marine operations and on changes in coastal ecosystems that require regional to global (international) approaches for rapid detection and timely prediction (e.g., local expressions of larger scale changes).

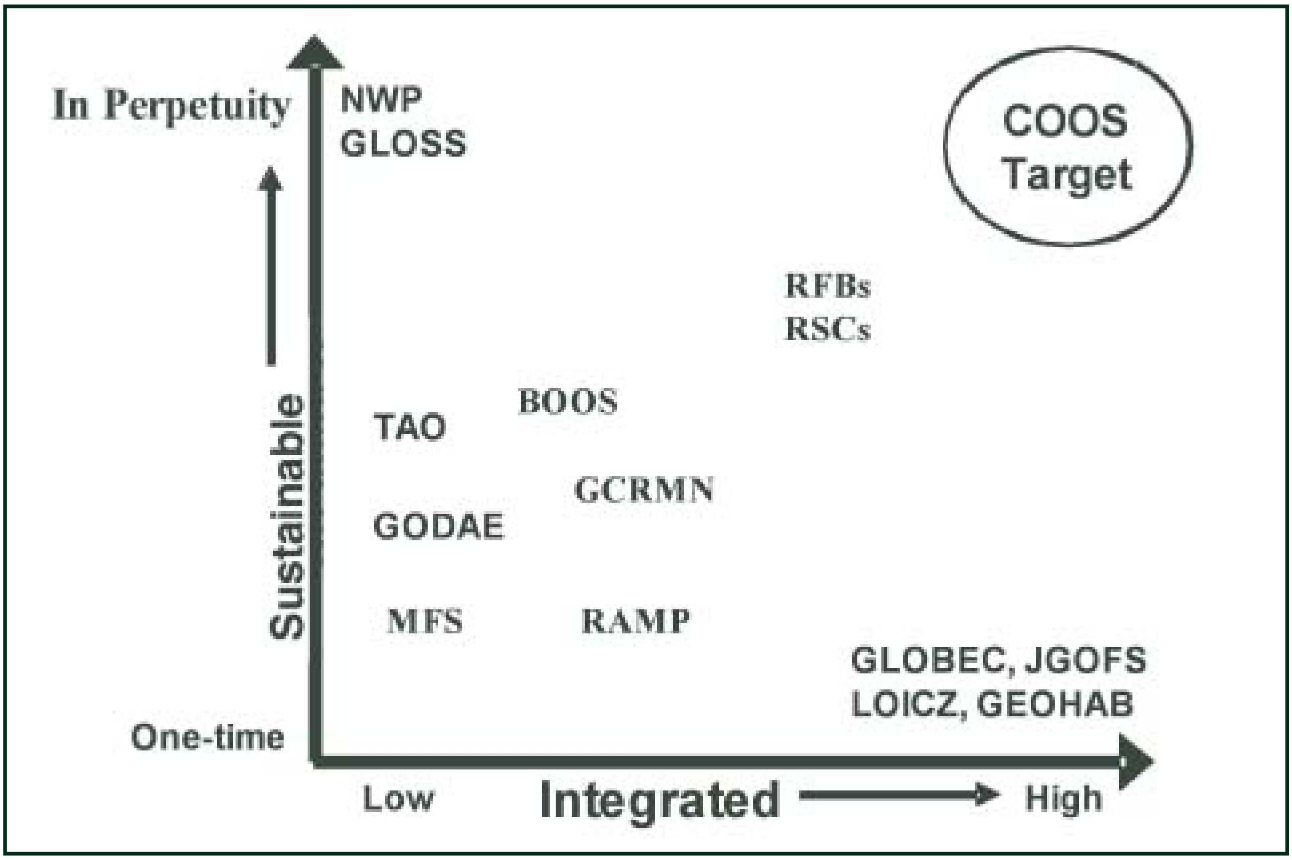

Figure III.1. The extent to which programmes are sustained and integrated. "Sustained" is the assurance that observations will be continued in perpetuity. An observing system is "integrated" to the extent that the measurement programme is multi-disciplinary (physical, chemical and biological variables measured synoptically in time and space) and the observing system is designed to address the needs of multiple user groups. Most programmes are either sustained or integrated. Very few are both. For example, Numerical Weather Predictions (NWP) and the Global Sea Level Observing System (GLOSS) are sustained, but not integrated. Likewise, research programmes such as the Land-Ocean Interactions in the Coastal Zone (LOICZ), Global Ocean Ecosystem Dynamics (GLOBEC), Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB), and the Joint Global Ocean Flux (JGOFS) programmes are integrated but not sustained. Of the examples given here, taken together, the monitoring programmes of the Regional Fishery Bodies (RFBs such as ICES and the IBSFC) and Regional Seas Conventions (RSCs such as the Barcelona Convention) come closest to the vision of the coastal module of GOOS in terms of being multi-disciplinary and sustained (MFS - Mediterranean Forecasting System, BOOS - Baltic Operational Observing System, GODAE - Global Data Assimilation Experiment).

The coastal module of GOOS is being designed and implemented as a component of GOOS and in collaboration with GCOS and GTOS. To date, few, if any, programmes are both integrated and sustained. A sustained commitment will be required of GOOS partners to establish, maintain, validate, make accessible, and distribute high quality data that meet internationally agreed upon standards.

- **Data Management**

An integrated data and information management system will be developed that ensures rapid access to diverse data and information of known quality from many sources by all users.

- **Users**

The observing system will provide data and derived data-products that address a broad spectrum of user needs[14]. This Design Plan identifies observations required to achieve defined objectives and, where possible, describes how they will be applied to the needs of users. Examples of objectives and products for the category of ecosystem health are given in Table III.1

14 The products of the coastal module of GOOS will depend on the level of data analysis required by user groups ranging from "raw" (unprocessed) data and calibrated data for scientists to near-real time predictions and more highly processed data for education and commercial use. At the present time, it is not clear where in the continuum from data to derived products the non-commercial role of GOOS ends and the commercial development of products begins.

Table III.1. Examples of objectives and associated products corresponding to the phenomena of interest in the Ecosystem Health category of Table 1.1.

OBJECTIVE	PRODUCT
More timely detection and prediction of changes in the areal extent of biologically structured habitats.	Annual report of the spatial distribution (GIS) of biologically structured habitats by region and globally (specified as tidal marsh, mangrove stands, seagrasses, macrobenthic algae, coral reefs and shellfish beds).
More timely detection of changes in species diversity of benthic, pelagic, and planktonic flora a fauna.	Annual report of the number of marine and estuarine at risk species that are increasing, decreasing or stable by region and globally.
More timely detection and improved prediction of coastal eutrophication on regional and global scales for coastal marine and estuarine ecosystems.	Weekly hindcasts of the sea surface chlorophyll-a field (mean for past week) for coastal waters < 200 m in depth by region. Annual report of the proportion of brackish water (< 32 psi) that experiences hypoxia for periods of 1 month or more by region and globally (in terms of surface area).
More timely detection and improved prediction of the presence, growth, movement, and toxicity of toxic algal species.	Annual report of the frequency of harmful algal events that have high, medium, and low intensity in terms of both spatial and temporal extent for each region and U.S. coastal waters. For hot spots (areas and seasons that have a history of HAB events), weekly reports on the distribution and abundance of selected HAB species. For hot spots, weekly forecasts (updated daily) of the trajectory of HABs and where and when blooms are likely to affect beaches, shellfish beds and aquaculture operations.
More timely detection of non-native species and improved predictions of the probability they will become invasive species.	Annual report on the occurrence of non-native species in semi-enclosed bodies of water for each region where occurrence is measured in terms of both surface area affected and number of species.
More timely detection and improved predictions of mass mortalities of fish, marine mammals and birds.	Annual report on the frequency of strandings and mass mortalities of marine organisms for each region and U.S. coastal waters. For hot spots (areas and seasons with a history of mortality events), weekly updates on the occurrence of standings and mortality events.
Improved predictions of the effects of habitat modification and loss on species diversity.	Annual report of the distribution and abundance of marine and estuarine at risk species relative to the distribution of biologically structured and abiotic (hard and soft bottom substrates, mud flats) habitats.

- **Cost-Effective**

The development of the coastal module of GOOS involves more cost-effective use of existing data, expertise and infrastructure than is currently realized, i.e., the entire process from measurements to products will be cost-effective. The coastal module of GOOS can come into being by selectively incorporating, enhancing and supplementing existing programmes based on regional priorities and user needs. It will become a comprehensive system of observations through shared use of infrastructure from measurement systems and platforms to communication networks, data management systems, assimilation techniques, and modelling. This will require national, regional and global coordination to minimize duplication and costs, optimise the temporal-spatial scales of observation, and maximize the availability data and information to participating nations.

- **System Performance and Evolution**

Products must ensure social and economic benefits that justify the operational costs of the observation system. If the coastal module is to develop and evolve as patterns of use change (as they surely will) and as the capacity to observe and analyse changes improves, there must be an ongoing constructive feedback between those groups that make measurements and provide the data and those that use the resultant data and information for their own purposes. Mechanisms will be established to (1) evaluate the functioning of the system, (2) assess the value of the information produced, and (3) improve the system as new capabilities become available and user requirements evolve.

- **Capacity Building**

A substantial investment in capacity building by the community of industrialized nations is essential to achieve the goals of the coastal module. Capacity building programmes and mechanisms for sharing knowledge, expertise and technologies must be institutionalised to enable all nations to contribute to and benefit from the development of the coastal module of GOOS. In this regard, the community of nations must reject the notion of poverty as a human condition if effective management and sustainable utilization of the marine environment and its natural resources are to be achieved on a global scale (Kim Hak-su, 2002 Asia-Pacific Forum on Environment and Development).

- **Research**

It must be recognized at the onset that many of the measurements, data management protocols, and models required for a comprehensive, fully integrated, multi-disciplinary observing system are not operational, that much work is needed to develop and determine those products that are most useful, and that capabilities and resources vary enormously among nations. Hypothesis-driven research that results in new knowledge, improved technologies, and more powerful models is of critical importance to the development of the coastal module of GOOS. Implementation of the coastal module of GOOS must create a more constructive and timely synergy between hypothesis-driven research, the detection of patterns of variability, and the generation of information in response to user needs.

ANNEX IV – Procedures for Selecting Common Variables

This Design Plan for the Coastal Module includes selection of common variables for a global system of observations in coastal environments. The goal is to identify the minimum number of variables that must be measured to detect and predict changes that are important to the maximum number of user groups. The selection process was based on a ranking procedure that addresses the needs of users, followed by a consensus-based review derived from the expertise and experience of a broad range of scientists (Chapter 4). Processes based on this model should also be useful for identifying the variables that will be measured as part of national and regional observing systems. The approaches could be modified to identify appropriate socio-economic and public health indicators; these will be included in the Coastal Module, but are not considered here.

A. Initialising the process

An objective and transparent procedure for identifying common variables was developed as follows: variables are ranked according to the number of phenomena they can help to detect and/or predict, with each phenomenon weighted by the number of user groups interested in it. The selection process begins with lists that represent the scope of the coastal module of GOOS and the variables that might be measured in a global system. Four lists were constructed through an iterative consultation with COOP members:

- *User groups*. The Coastal Module is intended to serve the needs of many user groups including industries, government agencies and ministries, teaching institutions, the public, nongovernmental organizations, and the community of research scientists. User groups provide or depend upon a broad range of services or products. These include: the management of coastal ecosystems and living resources; protection of public health; safeguards for marine operations; and prediction of the effects of anthropogenic influences or climate change. A list of user groups (Table IV.1) guides the selection of common variables; it is not intended to be exhaustive, but rather a reasonable sampling of the spectrum of user groups that are likely to benefit from the Coastal Module.
- *Phenomena of interest* include properties and processes such as sea-state, coastal erosion or accretion, changes of living resources or their habitats, and chemical contamination of seafood, all of which are detectable and potentially predictable (Table IV.2; Annex II). Users of the Coastal Module will be interested in the occurrence of or changes in the phenomena of interest.
- *Variables for detecting and predicting change* are properties or rates that can be measured with known precision or accuracy (e.g., temperature, bathymetry, and total suspended solids), and which could potentially be included in the global system of the coastal module of GOOS (Table IV.3a). The list is not intended to be exhaustive. Rather, it is intended to include variables that could, in principle, be measured as part of a global infrastructure of sustained, routine, and robustly calibrated observations. These variables are ranked as described below and then evaluated for selection as common variables for the coastal module of GOOS. Many variables were exempted from the process for selecting common variables, either because they will be measured as part of other global observing systems

and will be incorporated from them into the global coastal system, or because they require regional approaches and will be considered in the design of national and regional observing systems (Box IV.1; Table IV.3b).

- *Predictive models*. Many coastal phenomena can be predicted with models, ranging from rules of thumb, through statistical models, to sophisticated coupled atmosphere-ocean simulations based on first principles (Chapter 5). Predictive models include nowcasts (modelled fields of properties based on limited observations), to forecasts on scales from hours to decades or longer. All of these models must be driven by observations which are not necessarily the same as those required to detect the phenomena (e.g., winds need not be measured to detect coastal flooding, but they must be measured to predict it). A representative list of models is presented in Table IV.4.

B. Procedure for ranking the variables

Ranking for identification of common variables is achieved by weighting the variables according to the number of phenomena of interest that they can help to detect and predict, with each phenomenon weighted by the number of user groups interested in it. Decisions are made through an objective and transparent ranking procedure, based on the lists of user groups, phenomena of interest, variables to detect and predict change, and predictive models.

After the lists were carefully reviewed, four matrices (Tables IV.5 – IV.8) were prepared for use in the ranking exercise. Ranks of the variables are obtained by the following steps (see Figure IV.1):

(1) Each phenomenon of interest is scored according to the number of user groups interested in detecting the occurrence of or change in it (Table IV.5).

(2) Variables are scored by counting the number of phenomena that each variable can detect change in (Table IV.6).

(3) These *variables to detect change* are ranked (Table IV.6) according to their scores from step (2), with each phenomenon weighted by the number of user groups interested in it.

(4) Models to predict change are weighted by counting the number of user groups interested in each prediction (Table IV.7).

(5) Each variable is scored according to the number of models that require it for input (Table IV.8).

(6) These *variables to predict change* are ranked (Table IV.8) according to their scores from step (5), with models weighted by the number of user groups interested in the predictions, from step (4).

In the ranking exercise, when phenomena of interest, variables, and models were scored, three entries were allowed: 0 (no or insignificant relevance), 1 (significant, but partial or indirect relevance), and 2 (direct relevance). The middle category is not a catch-all; a relationship was scored only if it is significant.

Box IV.1. Variables Measured as Part of Other Integrated Global Observing Systems And Shared by the Coastal Module of GOOS

Many variables that will be measured as part of the global coastal system were not considered in the selection of common variables for one of two reasons: (1) they are or will be measured as part of other global observing systems; or (2) the variable is better considered regionally, either because it is not global in extent or because the measurement depends on geographic location.

Some observing system variables will be measured by other observing systems, but not necessarily on the scales required by the global coastal system or regional systems. They include meteorological variables (GCOS, OOPC), pCO2 (OOPC/GCOS); surface and groundwater transports of water, nutrients, sediments and contaminants (GTOS) and remotely sensed properties of surface waters, including ocean colour (CEOS and IGOS). For many of the same reasons that they were included in their respective observing systems, they are also needed to describe and predict change in coastal environments. Observations of these variables are thus essential to the Coastal Module of GOOS, and these shared variables will be included in the design of the global coastal system. The COOP, working in collaboration with GRAs, must specify observing requirements (spatial and temporal resolution, precision and accuracy) for coastal ecosystems. For example, the IGOS Ocean Theme (2000) describes current remote sensing capabilities (research and operational) and requirements for the global ocean (open ocean case I waters for the most part). The next step is to extend this analysis into the coastal environment (shallow, closer to the land margin, higher frequency variability — case 2 waters for the most part) and to specify requirements for *in situ* measurements for both validation of remotely sensed data products and the detection of changes in 4 dimensions. These issues will be addressed in the COOP implementation plan.

Variables to be considered by GOOS Regional Alliances (GRAs)

Many variables are demonstrably important for detecting and predicting change in coastal systems, but they are not appropriate for global implementation. They are:

Variables of regional significance that are not global in extent (e.g., sea ice).
Categories of variables that would be defined or measured differently depending on geographic location (e.g., extent of biologically structured habitat; including coral reefs, oyster reefs, mangrove forests, seagrass beds, and kelp beds).

Although these categories of variables were not considered for the global coastal system, they are essential to describing change in coastal regions, and it is expected that they will be considered for implementation by GRAs. Some examples are presented in Table IV.3b.

Table IV.1. User groups. This list is intended to be a reasonable sampling of the spectrum of user groups that are likely to benefit from the Coastal Module. The relative number of users from each sector influences the result; users are listed by sector to illustrate the balance that was chosen for this ranking.

Issue of Importance	Code	Phenomenon of Interest
Commercial	U1	Shipping
	U2	Marine energy and mineral extraction
	U3	Insurance and re-insurance
	U4	Coastal engineers
	U5	Fishers (commercial, recreational, artisanal)
	U6	Agriculture
	U7	Aquaculture
	U8	Hotel - restaurant industry
	U9	Consulting companies
Government	U10	Fisheries management
	U11	Search and rescue
	U12	Port authorities and services
	U13	Weather services
	U14	Government agencies responsible for environmental regulation (pollution issues)
	U15	Freshwater management/damming
	U16	Public health authorities
	U17	National security (including navies)
	U18	Wastewater management
	U19	Integrated coastal management
Public / NGO	U20	Emergency response agencies
	U21	Ecotourism, Tourism
	U22	Conservation and amenity (including environmental NGOs)
	U23	Consumers of seafood
	U24	Recreational swimming
	U25	Recreational boating
Research & Education	U26	News media
	U27	Educators
	U28	Scientific community

Table IV.2 Phenomena of interest (see Annex II). The Coastal Module should provide observations that can be used to detect or predict the occurrence of or changes in these phenomena.

Issue of Importance	Code	Phenomenon of Interest
Marine Services and Public Safety	P1	Sea state
	P2	Coastal flooding
	P3	Surface currents
	P4	Rising sea level
	P5	Changes in shoreline and shallow water bathymetry
Public Health	P6	Chemical contamination of seafood
	P7	Human pathogens in water and shellfish
Status (Health) of Marine and Estuarine Ecosystems	P8	Habitat modification and loss
	P9	Eutrophication / oxygen depletion
	P10	Changes in species diversity
	P11	Biological responses to contaminants (pollution)
	P12	Harmful algal events
	P13	Invasive species
	P14	Water clarity
	P15	Disease and mass mortalities in marine organisms
	P16	Chemical contamination of the environment (includes oil spills)
Living Marine Resources	P17	Harvest of capture fisheries
	P18	Aquaculture harvest
	P19	Abundance of exploitable living marine resources

Table IV.3a. Variables for detecting or predicting the occurrence of or changes in the phenomena of interest. These are properties or rates that can be measured with known precision or accuracy and which could potentially be included in the global coastal system.

Code	Variable to detect or predict change	Code	Variable to detect or predict change
V1	Attenuation of solar radiation	V19	Particulate organic C and N
V2	Changes in bathymetry	V20	pH
V3	Benthic biomass	V21	Phytoplankton biomass (chlorophyll)
V4	Benthic species diversity	V22	Phytoplankton species diversity > 20 µm
V5	Biological oxygen demand	V23	Primary production
V6	Neutral red assay	V24	Salinity
V7	Cytochrome p450 (biomarker; e.g., oil)	V25	Sea level
V8	Cholinesterase (biomarker; pesticides)	V26	Sediment grain size, organic content
V9	Metallothionein (biomarker; trace metals)	V27	Changes in shoreline position
V10	Currents, and current profiles	V28	Surface waves, direction, spectrum
V11	Dissolved inorganic nutrients (N, P, Si)	V29	Total organic C and N
V12	Dissolved oxygen	V30	Total suspended solids
V13	Eh in sediment	V31	Water temperature
V14	Faecal indicators	V32	Zooplankton biomass
V15	Fisheries: landings and effort	V33	Zooplankton species diversity
V16	Nekton biomass	V34	Coloured dissolved organic matter - CDOM
V17	Incident solar radiation	V35	Seabird abundance
V18	Nekton species diversity	V36	Seabird diversity

Table IV.3b. Examples of variables for regional and national systems. These variables are essential to detecting and predicting change, but they would not be defined in the same way throughout the global system and might not be relevant globally (e.g., sea ice). Lists of variables such as this could be reviewed and considered in the design of regional elements of the Coastal Module. Socio-economic and public health indicators will also be reviewed for the design of regional elements. The GOOS Regional Alliances are expected to take responsibility for many of these factors.

Artificial radionuclides	Metal toxins in sea food
Bio-assays of contaminant effects	Metals/organometals
Biogenic toxins in sea food	Nekton species
Coastline geomorphology	Optical properties of surface waters
Extent of biologically structured habitat	PAHs
Fisheries: Recruitment rates for exploitable species	Petroleum hydrocarbons
Fisheries: By-catch	Pharmaceuticals
Fisheries: Diet of exploitable fish species	Phytoplankton species
Fisheries: Fishing effort	POPs
Fisheries: Landings by species	Sea ice
Fisheries: Locations and frequency of habitat disturbance	Sediment chemical composition
Fisheries: Size spectrum of exploitable populations	Strandings and mass mortalities
Fisheries: Spawning stock biomass of exploitable populations	Suspended plastics and plastics/liter on seashore
Human pathogens	Tar balls on the seashore
Macrobenthic species	Toxins in humans
Marine mammals/birds species	Zooplankton species
Meiobenthic species	Zooplankton biomass

Table IV.4. The representative list of predictive models that was used in the ranking procedure.

Category	Code	Prediction
Coastal marine services	M1	Storm surges
	M2	Waves
	M3	Currents
	M4	Coastal erosion
Ecosystem health & relation to human health	M5	Risk assessment: seafood consumption
	M6	Risk assessment: direct contact
	M7	Chemical contamination of seafood
	M8	Habitat modification / loss
	M9	HABs - population dynamics
	M10	Anoxia / hypoxia
	M11	Invasive species
	M12	Pollution effects - population
	M13	Water quality model
Living marine resources	M14	Capture fishery production/sustainability
	M15	Aquaculture production/sustainability - finfish
	M16	Aquaculture production/sustainability - shellfish
	M17	Fisheries: Sequential population analysis
	M18	Fisheries: Community dynamics
	M19	Fisheries: Ecosystem dynamics

Although the needs of users figured heavily in the ranking, scientists, rather than users, provided primary input for the exercise. Scientific expertise is needed to fill in the matrices because many of the questions require technical knowledge: for example, a resort owner is not likely to know what variables should be measured to predict beach erosion, and the operator of a fish farm may not be aware that many harmful algal blooms can be detected by measuring the attenuation of solar radiation. As the Coastal Module is implemented and regional systems are developed, it will be important to involve the user community in this type of process; it will improve the representation of user interests and educate all stakeholders about the benefits of GOOS in the process.

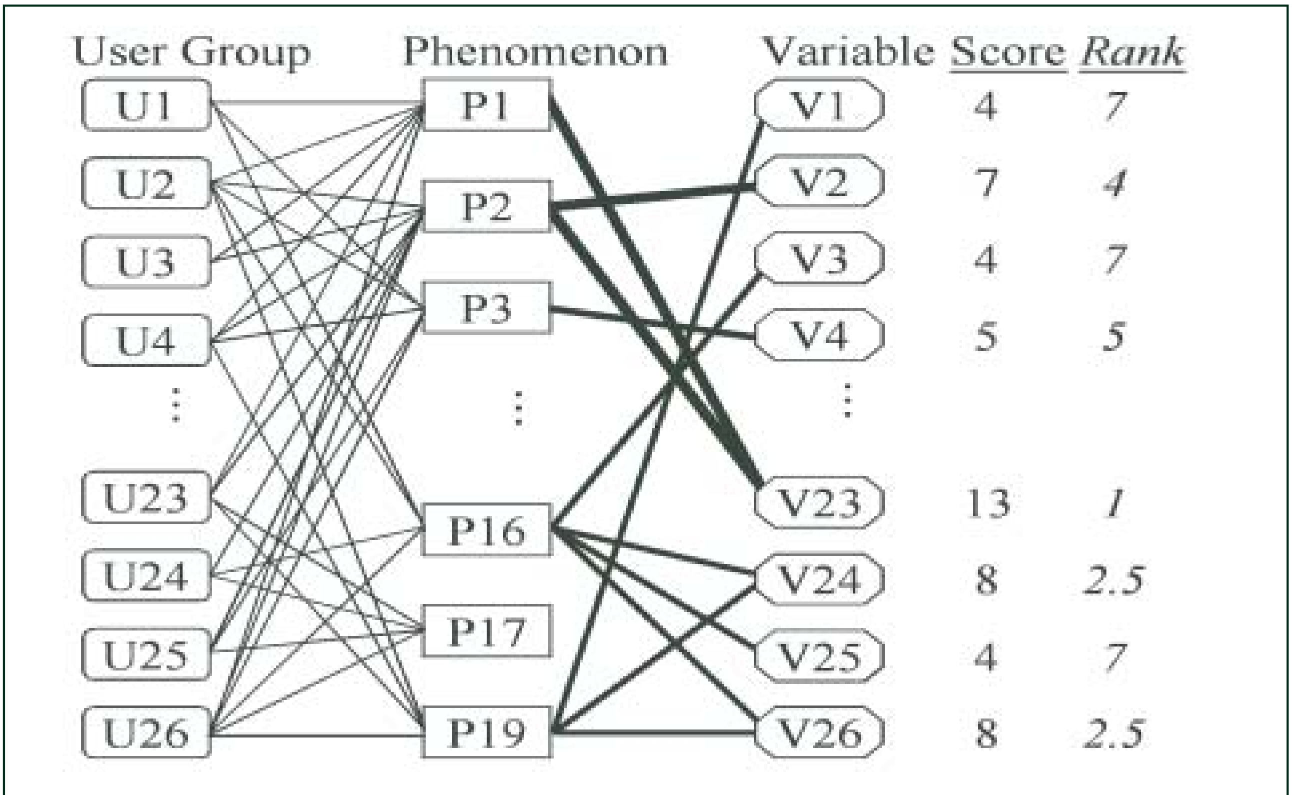

Figure IV.1. Procedure for ranking variables to detect change. Each phenomenon of interest from Table IV.2 is scored (indicated here with lines) for the number of user groups (from Table IV.1) interested in it. Then, each variable to detect or predict change (Table IV.3) is scored for a phenomenon if it can detect the occurrence of or a change in it. The thickness of lines shows how the phenomena are weighted according to the number of interested user groups. Scores for the variables are then ranked. Predictive models (Table IV.4) replace phenomena of interest in the ranking of variables to predict change. For clarity, only positive scores are represented; during the ranking procedure, scores of 0, 1, or 2 (not relevant, significant, but indirect or partial relevance, directly relevant) were allowed. The scores presented here are for illustration and do not represent the results of the exercise.

Table IV.5. Weighting of phenomena of interest by user group. This truncated example (see Tables IV.1 and IV.2 for full listings) shows how phenomena of interest are scored according to user groups interested in them (2 for direct interest, 1 for significant but indirect or partial interest). The scores presented here and in the following three matrices are for illustration and are somewhat arbitrary. Responses of panellists were used to generate rankings.

Phenomenon of Interest (occurrence or change)		Sea state	Coastal flooding	Surface currents	…	Chemical contamination (environment)	Fisheries harvest	Abundance of living marine resources
User Group		P1	P2	P3	…	P16	P17	P19
Shipping	U1	2	0	2		1	0	0
Energy	U2	2	1	2		2	0	1
Insurance	U3	2	2	0		0	0	0
Coastal engineers	U4	2	2	1		0	0	1
• • •	• • •							
Boating	U25	2	2	0		0	1	2
News media	U26	0	2	0		2	1	0
Educators	U27	0	2	1		1	2	0.5
Scientists	U28	2	2	2		2	2	2
Total Score		12	13	8		8	6	9

Table IV.6. Procedure for ranking variables to detect change. Variables (fully listed in Table IV.3) are scored (2 for direct relevance, 1 for significant but indirect or partial relevance) if they can be measured to detect the occurrence of or change in a phenomenon of interest. Otherwise, the score is 0. Each phenomenon is weighted for user groups (bottom row: from Table IV.5) and the weighted variables are ranked in the final column (rankings among only 8 variables are shown).

Phenomenon of Interest (occurrence or change)		Sea state	Coastal flooding	Surface currents	…	Chemical contamination (environment)	Fisheries harvest	Abundance of living marine resources	Variable weighted by Phenomena	Rank of Variable to Detect Change
Variable to detect occurrence or change in the phenomenon		P1	P2	P3	…	P16	P17	P19		
Attenuation of Solar Radiation	V1	0	0	0		0	0	2	18	6
Changes in Bathymetry	V2	1	2	1		0	0	0	46	2
Biological Oxygen Demand	V5	0	0	0		2	0	0	16	7.5
Currents	V10	0	0	2		0	0	0	16	7.5
• • •										
Surface Waves	V28	2	2	0		0	0	0	50	1
Total Organic C and N	V29	0	0	0		2	0	2	17	4
Total Suspended Solids	V30	0	0	0		2	0	1	25	5
Zooplankton Biomass	V32	0	0	0		2	1	2	40	3
Weighting of Phenomenon for User Group		12	13	8		8	6	9		

Table IV.7. Weighting of predictive models by user group. The procedure is directly comparable to that described for weighting phenomena of interest (Table IV.5), but here, models to predict change are scored according to the user groups interested in the prediction. As with the other tables, this truncated example is for illustration; scores of panellists were compiled for the rankings.

Predictive Model		Storm surges	Waves	Coastal erosion	…	Invasive species	Water quality model	Fisheries: Sequential population analysis
User Group		M1	M2	M3	…	M16	M17	M19
Shipping	U1	2	2	0		1	1	0
Energy	U2	2	2	1		0	1	0
Insurance	U3	2	2	2		0	0	0
Coastal engineers	U4	2	1	2		1	2	0
• • •	• • •							
Boating	U25	2	2	1		1	0	0
News media	U26	2	2	1		1	1	1
Educators	U27	0	0	1		1	1	1
Scientists	U28	2	1	2		2	1	2
Total Score		**14**	**12**	**10**		**7**	**7**	**4**

Table IV.8. Procedure for ranking variables to predict change. The table is directly comparable to that for weighting of variables by phenomena of interest (Table IV.6), but here, variables for predicting change are scored for each model that needs measurement of that variable for input (Table IV.2). Prior to ranking of weighted variables in the final column, each predictive model score is weighted for user groups (bottom row: from Table IV.7).

Predictive model		Storm surges	Waves	Coastal erosion	…	Invasive species	Water quality model	Fisheries: Sequential population analysis	Variable weighted by Model	Rank of Variable to Predict Change
Variable to predict change		M1	M2	M3	…	M16	M17	M19		
Attenuation of Solar Radiation	V1	0	0	0		1	1	1	18	8
Changes in Bathymetry	V2	2	1	2		0	0	1	64	3
Biological Oxygen Demand	V5	0	0	0		2	2	2	36	5.5
Currents	V10	2	2	2		1	2	2	101	1
• • •	• • •									
Surface Waves	V28	2	2	2		0	0	0	72	2
Total Organic C and N	V29	0	0	0		2	0	2	22	7
Total Suspended Solids	V30	0	0	2		2	0	2	42	4
Zooplankton Biomass	V32	0	0	0		2	2	2	36	5.5
Weighting of Model for User Group		**14**	**12**	**10**		**7**	**7**	**4**		

C. Implementation of the ranking exercise

The ranking procedure requires individual responses for 2,432 relationships between users, phenomena, variables and models. Few if any experts or users could score each with confidence, yet the process requires information on each relationship in order to generate the ranking. The challenge is to obtain expert guidance from many respondents without burdening individuals with the need to provide 2,432 responses, many of which might be to questions beyond their expertise or interests. The following procedure was used to facilitate the ranking process:

(1) A group of six COOP panel members met to fill out the four matrices by consensus. Discussions led to minor modifications of the lists, which were altered after consultation with COOP panellists. The results served as provisional scores for each matrix element.

(2) The matrices were distributed to all panel members, who were encouraged to fill them out individually or in small groups, including colleagues and potential users if possible. Special software was developed to facilitate filling in the matrices. Provisional scores were shown in the matrices for initial guidance; respondents were asked to endorse or change any or all of the scores. Only these endorsements or changes were retained for the final ranking. Provisional scores were provided so each respondent could generate a complete set of scores for ranking without being forced to focus on questions that he or she did not wish to answer.

(3) For each element of the four matrices, the endorsements and changes of scores were averaged and compiled as illustrated in Tables IV.5 to IV.8 to generate two ranked lists: *variables to detect change (and assess current state) and variables to predict change (Figure IV.2)*.

(4) The final rankings for the selection process for common variables was determined by the better rank for detection or prediction (Table IV.9). In this way, a variable that is particularly important in either role is favoured. Since one or more respondent either endorsed or changed each element of the matrices, the provisional scores carried no weight in the final tabulation.

The combined rankings in Table IV.9 provide a basis for selecting the common variables, but they do not reveal exactly how many variables should be retained in the final list. Plots of the scores for both detection and prediction show patterns in the ranked variables that can be used for this purpose (Figure IV.2). Variables can be grouped in four categories (A, highest ranking to D, lowest ranking) according to discontinuities in the distributions of scores for both detection and prediction. Ten variables for detection and 13 for prediction fell within the first two groups. The two lists combined comprise the 14 top-ranked variables in Table IV.9.

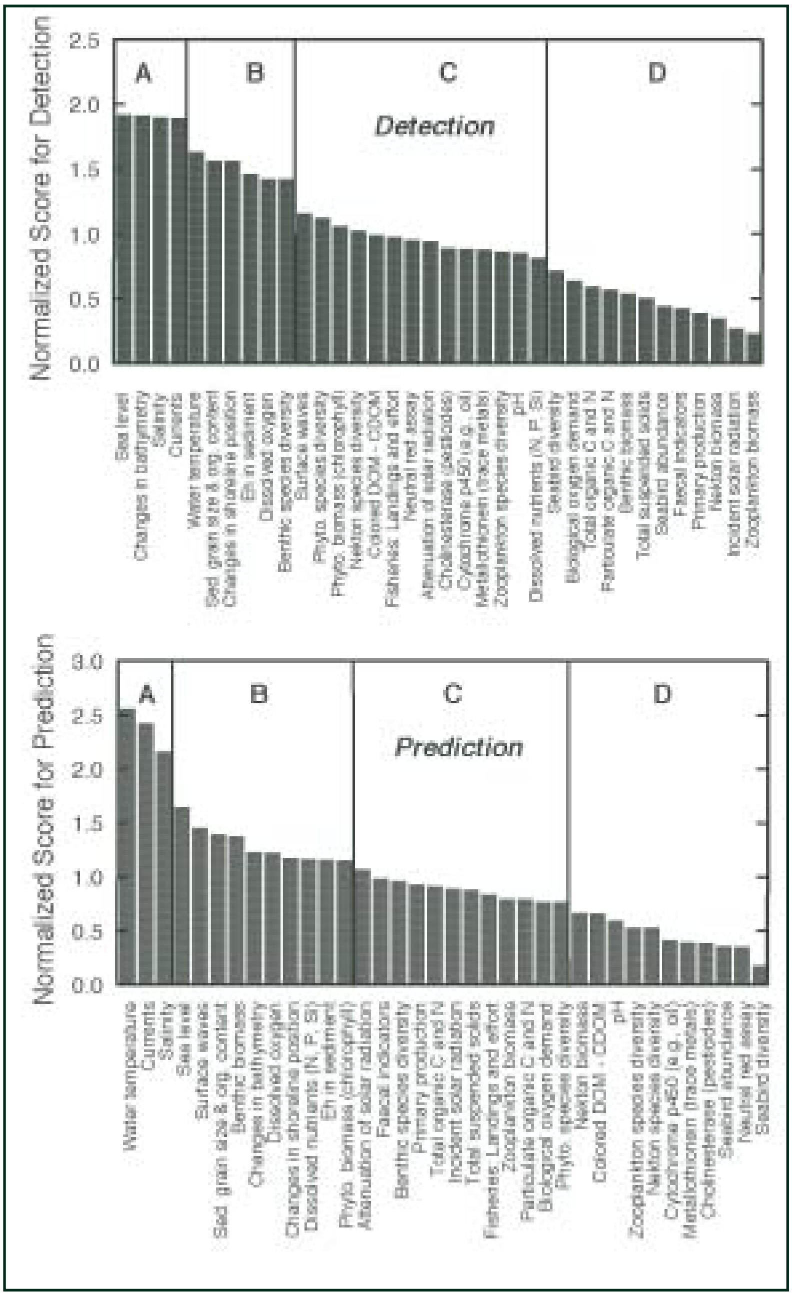

Figure IV.2. Variables for detection and prediction of change, in ranked order, with their scores from the ranking exercise normalized to the average for either detection or prediction. The variables are grouped in four categories (A, highest ranking to D, lowest ranking) according to discontinuities in the distributions of scores for both detection and prediction.

Table IV.9. Ranks of the common variables after the first complete ranking exercise. The variables are ranked according to the number of phenomena of interest that they can help to detect and predict, with each phenomenon weighted by the number of user groups interested in it. Final ranks are consistent with the better rank for detection or prediction.

Rank	Variable	Rank	Variable
1	Sea level	19	Coloured dissolved organic matter - CDOM
2	Water temperature	20	Fisheries: Landings and effort
3	Currents	21	Primary production
4	Changes in bathymetry	22	Total organic C and N
5	Salinity	23	Neutral red assay
6	Surface waves	24	Incident solar radiation
7	Sediment grain size, organic content	25	Total suspended solids
8	Benthic biomass	26	Cholinesterase (pesticides)
9	Changes in shoreline position	27	Cytochrome p450 (e.g., oil)
10	Dissolved oxygen	28	Metallothionein (trace metals)
11	Eh in sediment	29	Zooplankton biomass
12	Benthic species diversity	30	Particulate organic C and N
13	Dissolved inorganic nutrients (N, P, Si)	31	Zooplankton species diversity
14	Phytoplankton biomass (chlorophyll)	32	Biological oxygen demand
15	Phytoplankton species diversity > 20 µm	33	PH
16	Attenuation of solar radiation	34	Seabird diversity
17	Nekton species diversity	35	Nekton biomass
18	Faecal indicators	36	Seabird abundance

D. Review of Results and Selection of the Common Variables

Results of the matrix process are the first step toward and a principal guide for identifying the common variables for the global coastal system. The next step was to review the preliminary list of 14 variables to ensure that selection of common variables based on the rankings was acceptable to all Panel members based on their expertise and experience. Variables were retained if it was felt they could be measured with sufficient resolution to provide the information required to detect or predict changes in a timely fashion. Compelling reasons for adding variables to the list also were considered. Reasons would include large benefit relative to the cost for making the measurement and strong complementarity with measurements already on the list.

Upon review, the decision was made to include faecal indicators (rank 19) and the attenuation of solar radiation (rank 16) and to drop benthic diversity and sediment Eh. The rationale for making these changes are as follows:

- As documented in Chapter 2, the economic and public health impacts of contamination by sewage are severe. This contamination is tracked by routine measurements of faecal indicators. The benefit of including faecal indicators in the list of common variables, and the relative ease and low cost of implementation, justifies inclusion of faecal indicators in the list of common variables.
- Observations of the attenuation of solar radiation reveal much more than the light available for water column or benthic photosynthesis - they reflect changes in the constituents of the water column as influenced by eutrophication and sediment load. Secchi depth, a simple measure of attenuation, has been measured routinely for many decades and is demonstrably useful for documenting change in coastal environments. Requirements for capacity building are minimal and cost is almost nothing. In regions of the developing world influenced by changes in land use, this may be one of the only quantitative measures of water quality that could be made with adequate resolution to document change. Comparison with more discriminating radio-

metric measures of attenuation can be made routinely. Thus, the attenuation of solar radiation is included in the list of common variables.

- Although biological diversity is clearly an important parameter of ecosystem health and the carrying capacity of ecosystems for living resources, the identification and enumeration of species globally is a major challenge: target species groups will vary from region to region and the methods and expertise required are not suitable at this time for incorporation into a global system of routine observations using time-tested, standard techniques.
- The routine measurement of sediment Eh in a global system may be problematic due to problems with instrument reliability and the need for vertically resolved measurements. This, and the fact that the measurement is somewhat redundant with dissolved oxygen, led to the decision to drop Eh from the list of common variables, with the recognition that this and other variables may be added to the system as technology advances.

The Panel also decided to list sediment grain size and organic content as two separate variables, bringing the number of recommended common variables to 15 (Table IV.10). This list of variables for the global coastal system is supplemented by the shared variables from other observing systems (Box IV.1; Table IV.10).

This procedure for selecting common variables is only a first step in deciding which measurements will be included in the global coastal system. The purpose of this exercise was to determine at the outset the most useful variables to observe without considering in detail the methods of measurement, their feasibility, or their impact on the ability to detect or predict changes in a timely fashion. These issues will be addressed in the implementation plan.

This list of variables for the global coastal system will be finalized in the implementation plan through an impact versus feasibility (I-F) analysis of potential techniques for each variable. Impact is a subjective assessment of the relative value of the technique for making quality measurements of the variable in question with adequate resolution on the required time-space scales. Feasibility is an appraisal of the degree to which observational techniques can be used in a routine, sustained and cost-effective fashion, i.e., the extent to which they are operational. For many common variables, more than one measurement technique will be identified depending on regional capacities and the applications for which the variable is used. Once the I-F analysis is completed for each variable, techniques will be categorized in one of the following four categories: suitable for incorporating into the observing system now (operational), suitable for pre-operational testing, ready for evaluating as part of a pilot project, or requires additional research and development. When different measurement systems are employed, comparability of measurements must be assured. The same I-F analysis will be applied to the variables measured as part of other integrated global observing systems and recommended to be shared by the Coastal Module. Additional common variables may be added as they are needed and routine measurements become feasible.

Table IV.10. Common variables recommended by the Panel to be measured as part of the global coastal system (Annex IV). Additional variables, shared with other observing systems, are also recommended for inclusion in the global coastal system.

PHYSICAL	CHEMICAL	BIOLOGICAL
Sea level Temperature Salinity Currents Surface waves Bathymetry Shoreline position Sediment grain size Attenuation of solar radiation	Sediment organic content Dissolved inorganic nitrogen, phosphorus, silicon Dissolved oxygen	Benthic biomass Phytoplankton biomass Faecal indicators

Variables Measured as Part of Other Integrated Global Observing Systems and Recommended to be Shared by the Coastal Module

Meteorological Variables (GCOS, OOPC)	**Chemical Variable (*Atmosphere / Ocean*) (OOPC / GCOS)**	**Remotely Sensed Variables at the Sea Surface (CEOS and IGOS)**	**Land Margin Variables (GTOS)**
Air temperature Vector winds Humidity Wet and dry precipitation Incident solar radiation	pCO_2	Temperature Salinity Elevation (currents) Roughness (winds) Ocean colour (chlorophyll, attenuation of solar radiation)	Surface and Groundwater Transports of: • Water • Nutrients • Sediments • Contaminants

ANNEX V – Description of the Common Variables

In many cases the references for the specific methods are annotated. However, many of the detailed methods can be found in three specific reference areas. The Protocols for the Joint Global Flux Study (JGOFS) Core Measurements, (IOC, 1994); Biological Oceanographic Processes (Parsons et al., 1984a); A Practical Handbook of Seawater Analysis (Strickland and Parsons, 1972) and A Manual of Chemical and Biological Methods for Seawater Analysis (Parsons et al., 1984b).

Physical variables

Bathymetry

Water depth affects, directly or indirectly, virtually every indicator of change in coastal ecosystems (Mann, 1976; Petersen et al., 1997; IOC/SCOR 2002). The response of marine ecosystems to meteorological forcing and inputs of water, sediments, nutrients and contaminants are, to a great extent, governed by water depth and the proximity of the benthos to the air-sea interface. The near-shore zone is particularly energetic region where waves shoal and interact with the shape of the seabed. In addition to navigational needs, an accurate knowledge of bathymetry is essential to further the understanding and prediction of coastal processes and predict long-term trends in shoreline evolution. Overall a good knowledge of bathymetry is critical for the coastal ocean observing system.

A number of methods are available to survey bathymetry across the coastal ocean. In deeper water, single beam echosounders have been used to map the seafloor. Although this method is inexpensive, the temporal and spatial resolution are relatively poor. Multi-beam acoustic swath mapping systems have been used to map large areas of the seafloor with accuracy on the order of 1 m. Although they offer excellent spatial resolution, these systems are very expensive and the swath width decreases considerably in shallow water. Moving closer to shore, near-shore bathymetry can be measured through direct contact with the bed or it can be inferred by measuring water depth. Methods of direct measurement include the traditional hand-held rod and transit, amphibious vehicles, and survey sleds. These techniques can provide accurate results but have limited spatial and temporal resolution. A single beam echosounder mounted on a jet ski provides a quick, inexpensive, portable survey method that can operate in moderate sea states, shallow water (1 m), and vegetated environments (Dugan et al., 1999). A motion sensor and GPS receiver must be mounted on the jet ski to determine position and orientation. Airborne scanning LIDAR allows seamless surveying across the air-sea interface, providing fast, rapid-response surveying of large coastal areas with high spatial and temporal resolution (Lillycrop et al., 1997). Although airborne LIDAR allows access to hazardous and remote regions the accuracy is limited by vegetation and a penetration depth of less than 50 m. The penetration depth may be further limited by turbidity. Video imagery analysis is a developing technique whereby video images of the near-shore region are collected from elevated land-based or airborne camera platforms. Recently, video image analysis employed advanced photogrammetric techniques and linear wave theory to estimate water depth from wave celerity (Stockdon and Holman, 2000). Although this method offers relatively poor accuracy, it provides an inexpensive means of making long-term measurements of nearshore bathymetry without deploying instruments into a damaging environment. Standardised gridded bathymetric data sets are needed to provide the boundary conditions for all types of hydrodynamic and ecosystem models. The compilation of these gridded arrays is a major undertaking, using archived and modern data.

Sea Level

Rapid increases of sea level on time scales of hours can cause severe flooding of low lying coastal regions and dramatic loss of life. Rapid decreases in sea level can cause problems in the safe navigation of large vessels in shallow water. Sea level is a basic state variable of the coastal ocean and is closely related to surface currents and the density field. It should therefore not be surprising that tide gauges can provide a cost-effective way of monitoring variations in the surface flow, particularly flows through straits, and the flushing rates of coastal embayments. Sea level observations can also be assimilated into shelf models to help define important quantities that are not observed directly such as open boundary and initial conditions. On time scales of decades and longer, measurements of sea level with respect to stable fixed points on land can provide an indirect measure of vertical crustal movement, global warming of the world's ocean, melting of Antarctic ice sheets, and deep-sea circulation.

The most direct way of measuring sea level is with coastal tide gauges. Many of these gauges were installed in harbours for navigation purposes and a large database is now available for analysis. (The database managed by the Permanent Service for Mean Sea Level contains almost 49,000 station-years of monthly and annual mean from over 1,800 tide gauge stations around the world. Approximately 2,000 station-years of data are added each year.). There is considerable interest at the present time in using Global Positioning System measurements at tide gauge sites to measure directly the rate of vertical land movements with the goal of removing it from the observed sea level record (see http://www.nbi.ac.uk/psmsl/landmove.html for recent references.) It is possible to make indirect measurements of sea level variability about an unknown mean in offshore regions using bottom pressure gauges. If the water density is reasonably constant then bottom pressure generally agrees with sea level to better than one centimetre. Sensor drift can become a problem for deployments approaching a year in length. Satellite altimeters (e.g. TOPEX/Poseidon, Jason) are providing extremely valuable information on the global distribution of sea level and these data are being assimilated into operational models of the deep ocean. The coastal sea level distributions are more difficult to monitor with altimeters; the high spatial and temporal (e.g. tidal) variability require particular case must be exercised to avoid aliasing sea level and bathymetry.

Currents

This is one of the basic state variables of the coastal ocean. Along with the wind, currents control the transport and distribution of water masses, nutrients, plankton, suspended sediments, point source discharges, river plumes, life rafts, oil slicks, sea ice and icebergs, etc. Current patterns are important for navigation; the location and design of bridges, piers, offshore platforms and mariculture operations; and the development and location of fronts, eddies, and multi-layered circulation patterns that influence the abundance and distribution of marine organisms through their effects on reproduction, feeding, and recruitment (Powell, 1989; Levin, 1992; Hood et al., 1999).

The coastal velocity field varies on time scales of seconds (surface waves) through hours (tides), days (meteorological events) to seasons and years, over horizontal space scales of 10s of metres to 10s of kilometres and vertical scales of 0.1 to 200 metres. It is a challenge to select the appropriate instrument to observe the appropriate velocity statistics for a particular application. In many short to medium time scale biological or pollution process studies, it is important to track a patch of water in which a process is taking place. Here currents can be observed with surface and sub-surface drifters that are carried by the current and are positioned visually, by ship radars, or by radio, acoustic or satellite positioning systems. For many other applications one needs to measure currents in a fixed reference frame. This is usually accomplished by mooring current meters for periods of weeks to months. Older current meters use rotors or propellers to measure speed; some more recent models use electromagnetic flow or travel time acoustic sensors. Each has advantages and disadvantages with regard to resolution, accuracy, sensor stability and power requirements. A more recent instrument, the Acoustic Doppler Current Profiler (ADCP) measures the Doppler shift in back scattered acoustic signals to estimate both the horizontal and vertical current components at selected distances from the instrument. Instead of a single velocity value, these instruments observe the velocity profile over depth ranges of up to 400 metres. ADCPs have solved the problem of observing changes in velocity with depth; however, describing the structure of the current field in the horizontal remains a challenge. Current meters and their moorings are expensive and it is difficult to fund an array that covers sufficient area with a sufficiently fine resolution to resolve all of the features of interest. ADCPs are also mounted on research vessels and these can be used to explore the horizontal structure of a current field. Surface current patterns can be observed by measuring the frequency-dependent Bragg back scattering of an HF radio signal by surface waves. The Doppler shift of the back-scattered signal is analysed to infer the axial component of the surface current. By using two or more transceiver stations one can estimate the horizontal surface current over a selected shelf region. These systems, called CODAR, have ranges of 100-150 km, with horizontal resolution of order 3 km. Combinations of CODAR systems and moored ADCPs can describe the 3D structure of current fields in shelf and coastal regions.

Surface Waves

Waves and associated turbulence have significant effects on a wide range of processes from coastal erosion and sediment transport to species composition of littoral communities, habitat loss or modification, extent of anoxia and the dispersal of oil slicks. The importance of waves to safe navigation is undeniable and is reflected in the operational wave forecasting systems that are run by meteorological centres in many nations. Coastal flooding is often the result of a combination of high tide, surge and waves. They are a major determinant of beach dynamics and can generate mean alongshore currents. Ocean surface waves are one of the most important mechanisms for two-way coupling of the atmosphere and ocean: when waves are generated by winds, some of the atmospheric momentum that would otherwise pass directly into currents is radiated away from the generation area. Waves are also responsible for a feedback of the ocean surface to the atmosphere through their modifications of the wind stress that drives them.

Systematic wave measurements have been made for the last several decades. During the early half of the twentieth century visual observations from transport and passenger ships constituted the bulk of the available wave data. These were referenced to the well-known Beaufort scale, relating wave heights and wind speeds to features on the sea surface, such as the prevalence of whitecaps, spray, streaks and foam (http://lavoieverte.qc.ec.gc.ca/meteo/secrets_stlaurent/beaufort_scale_e.htm). Although the Beaufort scale is still used, instrumented measurements have since replaced it in all scientific field experiments. *in situ* instruments are usually buoys. Operational buoys such as archived by national governments, usually measure only wave heights, obtained from accelerometers. These instruments have been deployed for the last two decades, off N. America, Europe, Japan and other areas.

For dedicated field experiments, during this time, directional buoys are used. These measure the three basic components of pitch and roll. Modern directional waveriders are about a meter in diameter, allowing easy deployment, are powered by batteries or by solar panels. Wave height data can be transmitted via satellite for assimilation into real-time marine forecasts. More intensive experiments in coastal waters may involve wave staff arrays, as deployed via a spar buoy, for example as in the recent Sandy-Duck campaign (http://anole.rsmas.miami.edu/people/mdonelan.html) off North Carolina. Comparable directional measurements (to directional waverider buoy) are also being made from bottom ADCP current-profiling instruments http://www.adcp.com/waves.html particularly for shallow and coastal waters. Remotely sensed data from satellites involves images from altimeters and SAR (synthetic aperture radar) instruments. The basic physical mechanisms are reasonably well understood (Hasselmann et al., 1985), and have been reviewed recently by Dowd et al., (2001). Recently the state-of-the-art for airborne remote sensing has moved to SRA (Surface Contour Radar) which is a scanning radar that images the wave topography and the resultant data is transformed into directional wave spectra (Walsh et al., 1996).

Temperature

Temperature is one of the key state variables of physical oceanography and directly affects circulation and mixing. It is an indicator of both short and long time scale changes in thermodynamic conditions. Temperature and salinity data can also be used together for water mass tracing and for water mass mixing estimates. They are also used for computing dynamic height, which can be used for determining horizontal geostrophic currents with respect to a reference level at depth. By using temperature along with salinity and pressure measurements, water density can be easily determined using a well-known equation of state. Stratification, or a gradient in density in the vertical dimension, is one of the important parameters relevant to mixing. Two common forms of mixing processes involve (1) gravitational instability: denser water temporarily overlying less dense water and (2) shear instability. Chemical and biological species are transported and mixed as a result of density and thus temperature variability on a range of time and space scales. In particular, many chemical and biological processes are affected by and often correlated with temperature on time scales of a day, the annual cycle, and on to the interannual (e.g., El Niño-Southern Oscillation) and decadal (North Atlantic Oscillation and Pacific Decadal Oscillation) scales. Long-term changes in temperature may affect the health of kelp, coral reefs, and generally ecosystem structures (e.g., frequency of harmful algal blooms) and population dynamics and fisheries.

Measurements of temperature are now most commonly measured *in situ* electronically using thermistors (reviews by Dickey et al., 1998; Dickey, 2002). These are used as part of shipboard profiling conductivity-temperature-pressure (CTD) systems as well as autonomous sampling platforms including moorings, drifters, profiling floats, autonomous underwater vehicles (AUVs), and gliders. They can also be deployed ship-based or airborne expendable bathythermographs (XBTs and AXBTs, respectively). Aircraft and satellite platforms can provide sea surface temperature measurements regionally and globally. Each platform has specific advantages in terms of temporal and spatial resolution and coverage (e.g., Dickey, 2002).

Salinity

Salinity, like temperature, is a key variable of physical oceanography. Many of the points made concerning temperature above are relevant for salinity and measurements of the two are frequently done concurrently when possible in order to maximize informational content in regard to circulation and mixing. In coastal regions, variability in salinity often dominates temperature in terms of importance for stratification, mixing, and water movement because of freshwater input through rivers and groundwater (e.g., buoyancy driven flows), especially during storm events. Horizontal fronts in salinity are common features. Salinity is often well correlated with coloured dissolved organic matter (CDOM) concentrations. Salinity changes, like temperature, are important for many marine organisms and the coastal ecosystem in general.

Salinity is typically measured using concurrent conductivity and temperature (e.g., CTD) measurements deployed from the platforms described in the temperature subsection (reviews by Dickey et al., 1998; Dickey, 2002). Special expendable devices (XBTs with added conductivity sensor) are available. Remote sensing of salinity using aircraft is being developed for coastal applications and some demonstration experiments have been successfully executed. Extension to satellite-based measurements is in the research and development stage at present. Two salinity remote sensing satellites are currently under development by ESA and NASA with launches scheduled for 2006-07. These satellites are expected to have sensor accuracy and precision and spatial resolution suitable for open ocean and coastal applications.

Shore Line Position

The present position of the coastline is affected by a great number of factors some linked to natural causes (dynamic coastal processes) and others to human influence in the coastal zone. As a result of the interaction of these factors the coastline can become stable, accrete (deposition) or recede (erosion). Two of the main problems related to erosion are related to human occupation of the coastline (urbanization), and loss of natural habitats.

For purposes of coastline management and land-use planning, records of coastline changes over the last hundred years or at least several decades, provides evidence of medium-term erosion rates. Certain coastal locations have experienced drastic shoreline displacement (on the order of 3 to 10 m/year) due entirely to natural processes over scales of decades. If we add the effect of extreme events like hurricanes, this rate can be even higher.

The historic evolution of the coastline should be determined using selected methods according the regional capabilities and resources. In the more simple case, all the overlapping aerial photographic coverage available should be obtained. For best results, a spacing of 5 to 10-year intervals is required. In order to be able to obtain good results, distortions in the photographs must be corrected. The best scales for comparison are under 1:20,000. In areas where the erosion problems are accentuated, satellite photos can be used for the same purpose. During the last five years, DGPS (Digital Global Positioning System) surveys have been completed more frequently (monthly or yearly) to monitor the coastline.

Once the “critical areas” to be monitored are determined, a programme of benchmarked beach profile monitoring should be planned. Beach profiles survey should be conducted frequently (weekly or monthly) and extreme events monitored. Repeat DGPS surveys can also be used as a powerful tool to monitor zone of coastal retreat or areas of “habitat loss.”

Attenuation of Solar Radiation

Light is the critically important factor for photosynthesis, and photosynthesis supports most biological production in the ocean; in turn, light is required for vision, and vision is essential to many trophic interactions and reproductive behaviours which structure marine ecosystems. Consequently, variations in underwater light due to the attenuation of solar radiation with depth strongly influence primary production and food web dynamics, and they play a key role in determining the extent of habitats such as coral reefs, seagrass beds and kelp forests.

The attenuation of solar radiation in the water is determined by constituents that absorb and scatter light. These include phytoplankton, suspended sediment, and coloured dissolved organic matter (CDOM or gelbstoff). Thus, observations of the attenuation of solar radiation reveal much more than the light available for photosynthesis or vision — they reflect changes in the constituents of the water column as influenced by eutrophication, sediment load and runoff from land.

The attenuation of solar radiation can be measured or estimated using several approaches:

- The Secchi Disk, a 30-cm white plate, is lowered into the water until it is no longer visible (the Secchi depth). Easily and inexpensively, Secchi depth provides a quantitative, though imprecise record of water clarity. It has been measured routinely for many decades and is demonstrably useful for documenting change in coastal environments. Requirements for training are minimal and cost is almost nothing. In regions of the world with limited resources for ocean observation, this may be one of the only quantitative measures of water quality that could be made with adequate resolution to document change.
- Attenuation of photosynthetically active radiation (PAR; 400 - 700 nm) is estimated with profiling instruments. The depth of 1% surface PAR is a useful and readily interpretable variable that can be measured routinely in a consistent way in waters of sufficient depth. The measurement of PAR attenuation in a global system could be problematic because routine procedures do not exist for calibrating sensor response to subsurface irradiance spectra.

- Penetration of sunlight in one narrow waveband (e.g., 490 nm) is readily measured with sensors that can be rigorously calibrated. Subsurface layers of absorbing material can be detected with profiling instruments or with chains of sensors on moorings, but the nature of the absorbing material cannot be inferred.
- Attenuation at several wavelengths can be measured with radiometers on profiling instruments or moorings. Concentrations of chlorophyll a, CDOM and suspended sediment can be estimated in much the same way as for ocean colour, except that subsurface features such as layers can be resolved. The approach is not as well developed as for ocean colour, however.
- Measurements of water leaving radiance (ocean colour) from radiometers on ships, aircraft and

satellites can be used to estimate the attenuation of sunlight in surface waters. When suspended sediment is a dominant influence, sensors designed to measure sea surface temperature can also be used to derive estimates of water clarity.

Sediment Grain Size

Sediment type and composition (including grain size distribution) are major factors governing the distribution of benthic organisms, sediment transport and bottom friction. Sediment transport has a direct effect on the bathymetry of coastal regions, including relatively rapid changes in coastline associated with the in filling of jetties, beach loss, and migration of manmade and natural channels. Other bathymetric effects include the migration and growth of sand ridges (with length scales on the order of a tidal excursion), wave energy refraction, reflection and dissipation over sand bars, and the evolution and growth of ebb-tidal deltas. Bottom sediment type and composition exert strong control over local sediment resuspension. High concentrations of suspended sediment can generate sediment size-dependent, apparent density stratification near the bed. This stratification feeds back into the estimation of bottom shear stress and friction.

The techniques commonly used for granulometric analysis are: (1) sieving and pipetting, and (2) settling. Sieving is effective for grains that are sand size and coarser (> 0.062 mm.). For mud which is composed of silt (< 0.062 mm and > 0.0039 mm) and clay (< 0.0039 mm) the grain size is determined by sedimentation, settling in water filled tube. In the sieving method, the sample (generally more than 20 grams) is shaken through a series of screen, and the particles retained on each screen are weighed to obtain the weight frequency distribution of the sample. The finer material (silt and clay) are analysed by settling method using a simple pipette or a sedimentation balance. The settling velocities of the grains are converted to sizes with the help of Stokes´s Law ($W_s = Cd^2$) where: W_s is settling velocity; d is grain diameter and C includes the various constants represented by: particle density, fluid density, acceleration of gravity and fluid viscosity. Both the sieved and the pipetted data are merged to determine grain size distribution.

In a settling tube, the sand material (0.50 to 0.75 grams) is allowed to settle through a long column of water, and the amount of sediments settled are automatically recorded against time with the help of an analytical balance. Gibbs et al. (1971) developed an empirical equation to predict fall velocities for different particle sizes and water temperatures. Most modern equipment yields continuous records of settling times. Whereas Stokes´s Law is not valid for sizes greater than 0.1 mm but the Impact Law ($W_s = C^2d$) is, the settling times are converted to grain sizes with the help of experimentally determined curves for single, spherical quartz grains. Corrections for grain shape and density are necessary because both have a great influence on settling velocity. These corrections can be made by conversion of sphere diameters produced with Gibbs equation to that of natural grains using the equation of Baba and Komar (1981). There exists no known method of measuring settling velocity of gravel and coarser grained sediments in the laboratory. This forces the merging of data derived by settling velocities with sieve data as a reasonable alternative to account for all size classes. Once the raw data on the "size" distribution of samples, various means to obtain summary statistical parameters that represent characteristics of these distribution exists.

CHEMICAL VARIABLES

Organic Matter in Sediments

Most sediments contain some remains of the organisms that were deposited with the sediment. In many sediments, these remains are no longer recognizable, but occur as widely disseminated decomposition products of cellular material or skeletal units. The abundance of organic material can provide information about the sediment source, as well as, the depositional environment, such as productivity of the overlying waters (upwelling areas), dissolved oxygen, and at least indirectly, the activity of bottom currents at the boundary layer sediment-water. Generally, in marine and estuarine sediments the total content of organic matter increases directly with the amount of fine sediments, specifically mud (silt+clay).

Carbon, the most abundant element, constitutes about half of the tissue on an ash-free basis. Thus organic carbon analysis provides the most sensitive and reliable way for the abundance of biogeneous material in the sediment. Nitrogen and phosphorus are much less abundant than carbon and exhibit much greater variation. Sulphur also occurs as a constituent of certain organic compounds, but its abundance in sediments is not a useful indicator of the abundance of organic matter. Although we are considering organic matter in terms of carbon, nitrogen, phosphorus, and other elements, it actually consists of a complex mixture of high molecular weight compounds including, lipids, carbohydrates, proteins, pigments and cellulose.

A complete analysis of the organic matter in sediments would ideally include the abundance of all compounds.

There are three main approaches to analyse organic matter:

- Weight loss by ignition or oxidation by H_2O_2. Weight loss on ignition is based on weight loss of sample heated to 550 ^{0}C for four hours. It is a simple and rapid technique. Minimal equipment is required. Such methodology, however, have a poor reproducibility and is not useful in clay-rich sediments. The oxidation by H_2O_2 has the same issues as loss on ignition, however the reproducibility may be fair to poor and detects only easily oxidized components.
- Wet-oxidation techniques. Basically these techniques involve using a strong oxidizing agent such as chromic acid or potassium permanganate in an acid, (usually sulphur acid) to oxidize organic matter.
- Elemental analysis. This is the preferred methodology. This analytical procedure selectively oxidizes or breaks down the carbon compounds and measures the gases released. For total carbon determination it is essential that all carbon compounds are broken down or oxidized. The higher the temperature the more reproducible the results. This analysis uses a combustion method in a pure oxygen environment to convert the accurately weighed sample into the simple gases CO_2, H_2O, and N_2. This is the preferred method but initial purchase to the CHN analyser and consumables are expensive.

Dissolved Inorganic Nitrogen, Phosphorus and Silica

External loads and internal stocks of nutrient (inorganic and organic) drive the supply of organic matter in marine ecosystems, thus the concentrations of nutrients provide indirect information on the general trophic status from oligotrophy to hypertrophy. Nutrients of interest are nitrogen, phosphorus and silica. Concentrations in the euphotic zone are often low in the presence of phytoplankton growth. During non-growth periods dissolved inorganic nutrient concentrations are much higher and yield information about the carrying capacity of the coastal ecosystems and on decadal scale changes in nutrient availability. Below the euphotic zone and/or pycnoclines, higher nutrient concentrations are the result of remineralisation in the water column and reflux from the sediments. Highest concentrations are encountered at the river mouths where changes in concentrations indicate varying precipitation patterns and changes in human land use. Variations in concentrations available for the primary production of organic matter depend on physical, chemical and biological processes that govern external loads, uptake, recycling, export to aphotic depths and sediments, as well as burial in and reflux from the sediments. As there is no linear relationship between human mediated external loads and concentrations of dissolved inorganic nutrients in the system; long term measurements of nutrients are needed in concert with measurements of related environmental variables (temperature, salinity, dissolved oxygen) for the detection of decadal and secular trends in the effects of anthropogenic nutrient loading on water quality and living marine resources. Besides the impacts of changes in total amount, major deviations in the ratios of dissolved inorganic nutrient concentrations (N:P:Si) from that of the requirements of primary producers can have profound consequences in terms of species succession and the occurrence of HABs. Such deviations may also indicate changes in nitrogen fixation and denitrification.

When drawn from water bottles samples for nutrient analysis should be taken immediately after those for dissolved oxygen from the water bottle. Sample may be frozen at -20 ^{0}C. Prolonged storage of samples is not advisable, even if deep-frozen. Besides sampling from discrete depth (water bottles) continuous flow analyses is recommended for high spatial resolution, particularly when combined with an auto-analyser. The principle of the nutrient analysis, automated and manual, is a quantitative chemical conversion of the nutrient in question into a coloured substances, the extinctions of which can be measured spectrophotometrically. For dissolved inorganic nitrogen the reactive species nitrate, nitrite and ammonia should be measured. Absolutely clean procedures are needed, as particularly ammonia and phosphate are sensitive to contamination. Concentrations should be given in molar units (μmol kg^{-1}). A detailed description of the methods including detection limits, reagents and quality assurance procedures is given in the JGOFS Protocols (1996, JGOFS Report No. 19, 170 pp.).

Dissolved Oxygen

Dissolved oxygen (DO) is an important habitat parameter for both aerobic and anaerobic heterotrophic organisms. The distribution of dissolved oxygen is an integrative measure of the dynamic balance between photosynthetic oxygen production, biological and chemical consumption, physical transport and exchange processes across the air-sea interface. Changes in dissolved oxygen provide a means to assess (1) the trophic status (oligotrophic to hypertrophic) and (2) the alteration of habitats (e.g., development of anoxia). The calculated percent saturation of oxygen is also a measure to differentiate between situations of excess autotrophic production (and thus export of organic matter/nutrients from the euphotic zone) and those of a balance between autotrophy and heterotrophy (conservation of organic carbon nutrients within the euphotic zone). Oxygen concentrations indicate the extent to which coastal ecosystems are sources or sinks of organic carbon and changes in the biogeochemical cycles of biologically important elements including nitrogen, phosphorus, and iron. Thus, changes in dissolved oxygen are related to many indicators of environmental change including accumulations of organic matter, harmful algal blooms (HABs), carbon storage and export, habitat loss, changes in biodiversity, and fish recruitment. Long-term measurements of DO (together with related variables such as temperature, salinity, nutrients and phytoplankton biomass) are needed to detect and predict the temporal and spatial extent of changes in coastal ecosystems that are caused by natural variability and anthropogenic activities (nutrient inputs and exploitation of living resources).

When using water bottles samples for oxygen are the first to be drawn from a water bottle to avoid contamination from atmospheric oxygen. This must also be avoided when filling the sample flask, particularly when the water is undersaturated with oxygen. The analysis follows the Winkler procedure, which through several reagents forms an amount of iodine equivalent to the oxygen content of the sample. This is titrated then with a thiosulfate. The endpoint may determine either visually or by a detector for UV-transmission, or potentiometric. These different assessments of the endpoint give comparable precision. Oxygen may also be measured by probes connected to the CTD system as well as moorings, platforms and autonomous vehicles to increase spatial or temporal resolution, however, these results have to be calibrated frequently by a Winkler procedure. Concentrations should be given as number of micromoles of the gas O_2 in seawater (μmol kg^{-1}). A detailed description of the method and of quality assurance procedures is given in the JGOFS Protocols (1996, JGOFS report No. 19, 170 pp.).

BIOLOGICAL VARIABLES

Benthic Biomass

Benthic organisms are animals living on the seabed. Some of them (e.g. sea cucumbers, crabs, shrimps, urchins and sea stars) may dwell on the surface of the seabed, and they are called epifaunal benthos. Those burrow into sediment (e.g. worms, clams and burrowing anemones) are called infaunal benthos. Marine benthos play an important role in marine food chain, and provide important food sources for fisheries. They also play an important role in decomposition of organic matters and nutrient recycling. Since most benthic animals have limited range and are relative long lived, conditions of benthic communities are often indicative of environmental changes and pollution occurring in the area.

Benthic biomass refers to the biomass of benthic animals. Total benthic biomass may provide useful information on the general condition of benthic communities. Increase in organic/nutrient input often result in changes in benthic biomass, and changes in species number, abundance and benthic biomass (SAB) along pollution gradient have been well documented. As a general rule, as organic matter increases slightly, there will be an increase in number of species. Further increase in organic matter createsan increase in benthic biomass, until a point (the "ecotone point") is reached, species, abundance and biomass will all decrease sharply. Provided the Productivity/Biomass (P/B ratio) is known, benthic biomass may be used to extrapolate secondary productivity of benthic animals. In an unstressed environment, the biomass curve is always above the abundance curve whereas in severely stressed environment the abundance curve is above the biomass curve. Under an intermediate level of stress, the two curves will cross each other.

Benthic biomass is easy to measure. Infaunal benthos is often sampled by grabs (e.g. van Veen grab, Smith McIntyre grab or Petersen grab, depends on sediment type and sea conditions). The sediment samples are normally sieved in running seawater (using a 0.5 mm or 1 mm mesh), and animals retained on the mesh are collected, preserved (in 4% buffered formalin), identified and their biomass measured. Because of their small size, 0.1% rose Bengal in seawater may be used to stain the animals in order to facilitate sorting. Sugar flotation method may also be used to extract small size animals from sediment. Epifaunal benthos may be sampled using a variety of sampling gear such as rock dredge, oyster dredge, anchor dredge, Agasssiz trawl, beam trawl or shrimp trawl, depending upon the type of seabed and water depth. Unlike sampling by grab (which is generally accepted as quantitative sampling), sampling efficiency of dredging and trawling are normally <50% and samples obtained by dredging and trawling are, at the best, semi-quantitative. As such, care should be taken when comparing data derived from different studies and different sampling equipment. Benthic biomass may be expressed as g wet weight, g dry weight, g ash-free weight, or mg-carbon per unit area (usually m^{-2}).

Phytoplankton Biomass

Phytoplankton are critically important to life in the sea, and their dynamics must be assessed to understand the ecological effects of human activities in the coastal zone, the influences of climate variability on coastal ecosystems, and the possible causes of variability in fisheries and other living marine resources. Harmful algal events have significant impacts on aquaculture, human health and coastal ecosystems and these impacts are increasing in many regions; it is therefore very important to describe the occurrence of harmful species in the context of phytoplankton dynamics worldwide. The contributions of phytoplankton to food webs and biogeochemical cycling depend on their concentration, morphological/biochemical characteristics, and growth rates. At a minimum therefore, effective assessment of phytoplankton in coastal ecosystems requires measurements of phytoplankton biomass.

Chlorophyll *a* (Chl *a*) is the most common proxy for phytoplankton biomass. Of the plant pigments found in phytoplankton, Chl *a* (or its variant di-vinyl chlorophyll *a*) is the only one that is present in all species of phytoplankton. Consequently, the concentration of chlorophyll is a key biological variable in coupled physical/biological models, though caution is required because the relationship between Chl *a* and biomass (measured in terms of carbon, nitrogen or dry weight) can vary by over an order of magnitude due to changes in species composition and physiological state. Chlorophyll a can be measured directly on discrete samples using standard extraction and fluorometric or spectrophotometric methods. High performance liquid chromatography yields more accurate results and measurements of co-occurring pigments. However, the method is slow and expensive. Microscopic examination of preserved samples is the most direct method for determining the abundance and estimated biomass of phytoplankton species; automated methods using either flow cytometry or image recognition are being developed and tested.

Measurements of ocean colour and chlorophyll fluorescence are much better suited for continuous or synoptic observations of variations in Chl a. Near-surface Chl a is estimated from ocean colour detected by sensors on satellites, aircraft, ships, fixed platforms and sensors floating at the surface. Assessment in coastal waters is complicated by co-occurring substances, so direct sampling of surface waters with concurrent radiometric measurements is used to develop and validate models for estimating Chl *a* from ocean colour.

Chlorophyll a fluorescence is also measured routinely in research and monitoring. Fluorometers on moorings, autonomous vehicles and ships can provide continuous records related to the variability of chlorophyll a. Frequent calibration is required because the relationship between fluorescence and chlorophyll a is strongly influenced by ambient light, species composition and physiological condition of phytoplankton in ways that are somewhat dependent on the instrument.

Faecal Indicators

A significant portion of the human body wastes and wastewater flows of the populations living in areas contiguous to the sea, laden with pathogenic microorganisms, find their way into the world's coastal waters. The coastal waters of the world, contiguous to and in the vicinity of human habitations, are more often than not, polluted with a constant daily flux of fresh human faecal pathogens.

There is epidemiological evidence that enteric/gastrointestinal and respiratory diseases can be associated with, and are caused by bathing/swimming in marine coastal waters contaminated with pathogenic microorganisms from domestic wastewater sources. The evidence from 22 highly credible epidemiological studies, which have been analysed by the WHO, clearly supports the conclusion that the rate of certain enteric and respiratory infections and disease among bathers compared to unexposed non-bathers, increases steadily with increasing concentrations of faecal indicator organisms and have been described by a series of dose-response relationships. The dose-response relationships presented in these studies provide a sound scientific basis for estimating the risk of infection and disease among marine bathers as a function of the concentration of faecal indicator organisms in the seawater.

Seafood, particularly filter-feeding bivalves normally eaten uncooked, is a commonly implicated vehicle for the transmission of infectious diseases caused by enteric microorganisms, including bacteria and viruses, that enter the coastal marine environment through the disposal of urban/domestic wastewater from land based sources or ships to the sea.

Filter feeding bivalve shellfish/molluscs such as oysters, mussels, clams and cockles are particular susceptible to bacterial and viral contamination since they feed by sieving large volumes of seawater, many times their own weight, and concentrate and retain food particles, including faecal particles containing pathogenic microorganism. Thus, such shellfish, filter-feeders, whose breeding areas are often placed near sources of nutrients such as wastewater outfalls or polluted estuaries are particularly prone to concentrate high levels of pathogens.

The hygienic/sanitary quality standards for drinking water, recreational waters and shellfish harvesting waters for the past 100 years have been based on determining the concentration of faecal indicator organisms such as Esherichia coli, coliform bacteria or faecal coliform bacteria. The public health rational for this has been that these easily detectible, non-pathogenic bacteria, which are ubiquities in normal faces and domestic wastewater serve as universal surrogates for the broad spectrum of dozens or even hundreds of potential water-borne pathogenic bacteria, viruses and protozoans. In recent years bacteriophages have become more accepted as possible indicators of viral pollution. However, the only truly accurate method of determining the degree of contamination of the shellfish harvested in the field or in the market is to assay them for enteroviruses.

The most authoritative and widely accepted publication with laboratory methods for the detection and quantitative measurement of the concentration of bacterial faecal indicator organisms, enteroviruses and coliphages are those contained in the latest edition of *Standard Methods for the Analysis of Water and Wastewater* published by the APHA/AWWA/WEF (1998) (American Public Health Association/American Water Works Association and the Water Environment Federation).

ANNEX VI – Linking the Coastal Modules of GOOS and GTOS

The effects of land-based human activities on the oceans are especially pronounced in coastal marine and estuarine ecosystems (Chapters 1 and 2) and GOOS must rely on GTOS to quantify surface and groundwater discharges and associated inputs of sediments, contaminants, and nutrients. Consequent changes in coastal waters that impact human health and safety and their capacity to support goods and services also affect the socio-economics of coastal States. For example, freshwater (buoyancy) and nutrients (phytoplankton production) from terrestrial ecosystems are inputs to coastal water quality models that are used to predict and control human activities on land (e.g., sewage treatment and discharge, agriculture); data on human labour pools can be input for fishery models; and coastal storm surge models provide predictions of flood risks that impact insurance rates and are used for evacuating coastal populations. In short, land- and water-based changes in the coastal zone are intertwined by purpose, geographic position, user groups, variables, and products. These realities underscore the importance of coordinating the development of the coastal modules of GOOS and the Global Terrestrial Observing System (C-GTOS), and it highlights the need for an integrated approach to the coastal zone within the framework of the IGOS. Planning for the coastal module of GOOS is much farther along than that for GTOS. Thus, GTOS can and should build heavily on the design of the coastal module of GOOS.

Boundaries between the Coastal Modules of GOOS and GTOS

The boundaries of the two coastal modules overlap in many respects. For the purposes of the coastal module of GOOS, "coastal" refers to regional mosaics of habitats including intertidal habitats (mangroves, marshes, mud flats, rocky shores, sandy beaches), semi-enclosed bodies of water (estuaries, sounds, bays, fjords, gulfs, seas), benthic habitats (coral reefs, seagrass beds, kelp forests, hard and soft bottoms) and the open waters of the coastal ocean to the seaward limits of the Exclusive Economic Zone (EEZ). GTOS is responsible for freshwater (rivers, streams, lakes and ground water) and terrestrial systems, including coastal drainage basins, barrier islands, and land "reclamation" (land fills). In this context, many of the phenomena of interest for the coastal module of GOOS (Chapter 1) are also of interest to C-GTOS. These include coastal flooding, extreme weather, coastal erosion, trajectories of oil spills and harmful algal blooms, sea-level rise, changes in shoreline, habitat loss, spread of water-borne disease, and aquaculture. Thus, the two systems overlap geographically in the intertidal and this overlap is reflected in the kinds of phenomena the two systems should be responsible for detecting and predicting.

The two systems also overlap in terms of the human dimension on at least three fronts. First, human activities are major drivers of environmental changes in both terrestrial and marine systems and these changes have socio-economic consequences that affect human behaviour. People and their environment interact through complex feedback loops that may have destabilizing or stabilizing influences. Understanding the nature of these feedbacks should be a high priority for both coastal modules. One challenge to addressing these feedbacks within the observing system framework are the different scales of variability that characterize changes in terrestrial and coastal marine and estuarine ecosystems and the relationship of these changes to the scales on which humans alter these environments, i.e., primary producers and habitats in coastal marine and estuarine ecosystems tend to be more variable on shorter time scales than is typical of terrestrial ecosystems (Chapter 1). Thus, while the coastal module of GOOS emphasizes the importance of high-resolution time series observations, observations of the dynamics of terrestrial ecosystems and human activities tend to focus on larger time scales. Thus, coordination of the two coastal programmes requires agreements on the scales of observation that benefit both.

Second, there is much overlap in potential user groups. Common user groups include coastal engineers, agriculture, mining, aquaculture, port authorities and services, national weather services and private sector weather services, land-use planners and developers, government agencies for environmental protection, public health authorities, coastal management, emergency management agencies, coastal communities, tourism, conservation groups, recreation, news media, educators, and the scientific community. Users that have been previously identified for C-GTOS include the following:

- GTOS and other observing system programmes and in particular those associated with coastal waters (e.g., COOP, Baltic Operational Oceanographic System, BOOS; Global Sea Level Observing System, GLOSS);
- The research community, including individual scientists and programmes such as the European Land-Ocean Interaction Studies (ELOISE), Land-Ocean Interactions in the Coastal Zone (LOICZ), and I-LTER;
- Programmes associated with global change or global issues (e.g., IGBP, GPA, Coastal Zone Management Centre);
- Conventions, including the UN Framework Convention on Climate Change, the Ramsar Convention on Wetlands, Convention on Biological Diversity, and Regional Seas Conventions;
- Policy makers and environmental managers (e.g., European Environment Agency, National Oceanic and Atmospheric Administration of the USA);
- Modellers working the range in scale from particular species populations of economic or social value to global climate change and biosphere response (e.g., Tool to Assess Regional and Global Environmental and health Targets for Sustainability [TARGETS, Rotmans and de Vries 1997]);
- Non-governmental organizations for industry, transportation, tourism, agriculture, fisheries and environmentalism (e.g. European Chemical Industry Council, Wetlands international, Birdlife international).

Thus, the "scales" of user may also have to be coordinated between the two programmes as well as the "scales" of measurement.

Third, largely as a consequence of one and two, integration of observing elements and regional enhancements will involve government agencies that contribute to and benefit from both GOOS and GTOS.

Design of the Coastal Module

An important element of the observing subsystem for the coastal module of GOOS is the Network of Coastal Observations (Chapter 4). Many of the coastal laboratories that will constitute this Network have been identified as part of the Terrestrial Ecosystem Monitoring Sites (TEMS) network within GTOS. In addition, Long-Term Ecological Research (LTER) sites, including coastal sites, are part of the GTOS design and are included in the GTOS Global Hierarchical Observing Strategy (GHOST). The latter will play an important role in data acquisition and processing for the GTOS, and regional synthesis centres (Chapter 6) may serve both GOOS and GTOS.

Remote sensing is critical to both GOOS and GTOS. It provides spatial coverage unavailable by any other means. Thus, it is an integral part of GOOS and GTOS and explicitly a hierarchical level within GHOST. Common modes of remote sensing (especially land-based platforms, satellites and aircraft) will bridge the two coastal programmes. Some sensors will be unique to each programme, but some are common. It will improve the effectiveness and efficiency of both programmes if the commonalities can be identified. Images may be able to be gotten, stored, analysed and managed with cost savings and efficacy.

The linkages between land and sea and between environmental changes and socio-economics are highly national and regional in character. Consequently, coordinated development of the coastal module of GOOS and C-GTOS will be most important on the regional scale – especially in terms of the acquisition and processing of *in situ* observations. Overlap of products and user groups may promote duplication in observing and data management subsystems. As the design plan for C-GTOS has not been developed, it is not known how the need for both regional and global approaches will be addressed. As the plan begins to form and be implemented, the need may first be to ensure collection of information and then to avoid duplication with the coastal module of GOOS. If duplication is to be avoided during the implementation of the programmes, considerable coordination will be needed, especially for data communications and management. The respective implementation plans must address this issue.

In terms of modelling, GTOS has not begun to identify models, but interaction at this level is highly likely and will need coordination. Coordination may involve (1) joint use of same models (e.g., sediment transport, coastal erosion) and (2) use of separate models that can be linked (e.g., Storm surge models linked to evacuation plan models, and ecosystem models). Two modelling areas in which interaction is quite obvious are public health and effects of anthropogenic activity on ecosystems. But others also exist. Furthermore, some issues of modelling are universal. There will be a need for quality observations and assimilation processes in both programmes. There is also a need for transparent decision making for model construction, verification, validation and analysis. Again, the two programmes must maintain communication among those responsible for modelling.

The data management and communication subsystem of the coastal module of GOOS builds on existing systems. GTOS should begin a programme to assess the applicability of these existing systems. Much of the data management and communication subsystem will have to conform to the agencies responsible for the data. Where the agencies are the same for both the coastal module of GOOS and C-GTOS, the rules and processes should be the same. Also, some issues are universal (e.g., QA/QC) and therefore should be similar for both programmes. But details within existing agencies and development of procedures for newly formed networks need special attention. Both observing systems have guidelines, and these guidelines need to be coordinated. The hierarchical design of the coastal module of GOOS may be considered by GTOS or compatibility of GTOS systems to this is needed.

CONCLUSIONS

The coastal module of GTOS is in the early stages of design. It is clear that linkages with the coastal module of GOOS are not only warranted, but also necessary for a successful observing system for the coastal zone. The opportunities for linkage are at all levels of system design from user groups and the phenomena of interest to observations and data management. There are many opportunities to make more effective use of resources and to achieve economies of scale. But for these to be realized, considerable coordination and collaboration will be necessary. As a first step, GTOS has been represented in the development of the design plan for the coastal module of GOOS. The next step is to establish a joint committee charged with ensuring the two systems are integrated and develop to the benefit of both.

ANNEX VII – Examples of Potential Building Blocks of the Coastal Module

Examples of operational systems, pre-operational and pilot projects, and research programmes that the design and implementation of the coastal module depend on are listed below. Selectively linking operational systems based on user needs (which includes meeting the terms and conditions of international conventions and agreements) and enhancing those projects and programmes that are likely to improve operational capabilities is the highest priority for initiating the global component of the coastal module. The summaries of programmes and projects that follow are not intended to be a comprehensive listing of candidate programmes. They are intended to illustrate the kinds of programmes that should be considered. For those programmes that are considered to be operational, guidelines are needed to officially recognize them as an element of GOOS and for their incorporation into the coastal module.

Although sustained operational remote sensing of the oceans is clearly of fundamental importance to achieving the goals of GOOS, this subject is not addressed here. Operational satellite capabilities with sufficient redundancy to ensure continuity and consistency among different sensors and missions (sea surface temperature from infrared imagery; global scale sea level, large scale surface currents and wave height, and wind speed from altimetry; ocean vector winds from scatterometry; sea ice, surface wave spectra, and oil slicks from synthetic aperture radar; sea surface chlorophyll from ocean colour) have focused on open ocean environments and case I waters (ocean colour) and generally lack the spatial resolution required for coastal systems (< 500 m), especially for shallow inshore waters and estuaries. Remote sensing of coastal ecosystems will be addressed in detail by the implementation plan for the coastal module.

Operational Systems

- The CalCOFI is a regional programme that was established by the United States in 1950 in response to the collapse of the California sardine fishery. Its goal is to document long-term ecological changes in the marine environment (temperature, salinity, nutrient concentrations, and the biomass and taxonomic composition of phytoplankton, zooplankton, and forage fish) that influence the capacity of the California Current system to support marine fisheries. It is a collaboration between academic institutions and government agencies (University of California, U.S. National Marine Fisheries Service, and the California Department of Fish and Game). The initial programme extended from northern California to mid-Baja California with a large array of stations (> 600 stations along 36 inshore-offshore transects roughly normal to the California Current) sampled at monthly intervals (hydrocasts, plankton tows). Although the programme was reduced in scope in 1984, (< 70 stations sampled are quarterly intervals along transects between San Diego and San Luis Obispo), it is among the longest continuous, systematic, interdisciplinary monitoring programmes of an open coastal ecosystem in the world which measures many of the core variables identified above (temperature, salinity, nutrients, attenuation coefficient, turbidity, phytoplankton biomass and floristic composition).
- The CPR survey of the North Atlantic and North Sea, which has been conducted monthly

since 1946, provides data on seasonal, annual and interannual variations in the abundance and composition of phytoplankton and zooplankton (Warner and Hays, 1994). These data have been used to develop plankton "climatologies" for the region. They also reveal the effects of basin scale climatic variability on the structure and function of the North Atlantic ecosystem (Fromentin and Planque, 1996; Beaugrand et al., 2002). This programme is expanding into the Pacific Ocean and is being incorporated into some LMEs.

- The IBTS of the North Sea has been conducted quarterly since 1970 to assess the distribution and abundance of herring, sprat, mackerel, cod, haddock, whiting, saithe, and Norwegian pout in the context of distributions of temperature, salinity and nutrient concentrations. This has allowed the development of "climatologies" for these species and provides data needed for ecosystem-based fishery management.
- BOOS is a collaboration between government agencies of the countries surrounding the Baltic Sea (Germany, Poland, Lithuania, Latvia, Estonia, Russia, Finland, Sweden, and Denmark) that are responsible for monitoring and modelling the Baltic and for providing marine forecasts and other services for the marine industry, environmental organizations, and other end users. Through the shared use of infrastructure, expertise and data, the goals of BOOS are to: (1) improve services to meet the requirements of environmental and maritime user groups; (2) increase the cost-effectiveness of investments in ocean observations; (3) further develop the market for operational oceanographic products by identify new customers; (4) provide high quality data and long time series required to advance the scientific understanding of the Baltic Sea; and (5) provide data and forecasts to protect the marine environment, conserve biodiversity, and monitor climate change and variability.
- The GCRMN is an international programme that was established in 1997 in response to a global scale degradation of coral reefs in the tropics from East Africa and Southeast Asia to the Caribbean. It is sponsored by the IOC, UNEP and IUCN. The goals of the GCRMN are to: (1) improve the conservation, management and sustainable use of coral reefs and related coastal ecosystems by providing data and information on the trends in biophysical status and social, cultural and economic values of these ecosystems; and (2) provide individuals, organizations and governments with the capacity to assess the resources of coral reefs and related ecosystems and collaborate within a global network to document and disseminate data and information on their status and trends. The collection of data and information on reef status and trends began in 1997. Regional nodes have been created within participating countries to coordinate training, monitoring, and data management in regions based on the UNEP Regional Seas Programme: Middle East, western Indian Ocean and east Africa, south Asia, east Asia, the Pacific, and the Caribbean and tropical Americas. The first report on the status of coral reefs was published in 1998 (Wilkinson, 1998). There are at least two important features of the GCRMN that are relevant to coastal module beyond the degradation of coral reefs and the living resources and recreational activities they support: (1) its emphasis on community awareness through the involvement of all users in the collection of data on status and trends and (2) the significance of coral reef bleaching as an early warning and potential effects of global climate change (Wilkinson et al., 1999).

PRE-OPERATIONAL PROJECTS

Two pre-operational projects are highlighted that illustrate the advanced state of the art of forecasting systems that are based on observations of physical and meteorological variables and numerical models of physical processes.

- The Mediterranean Forecasting System (MFS) is a collaboration between environmental agencies of Cyprus, Egypt, France, Greece, Italy, Israel, Malta, Spain, Norway and the United Kingdom. The overarching goal is the prediction of marine ecosystem variability from sea surface temperature and salinity and currents to primary production on time scales of days to months. The scientific rationale for the system is based on the hypothesis that coastal hydrodynamics and ecosystem fluctuations are intimately connected to the large-scale general circulation. The emphasis to date has been on demonstrating the utility of near real time (NRT) forecasts of basin scale currents. NRT data from networks of voluntary observing ships (SST, SSS), moored autonomous *in situ* sensors (temperature, salinity, currents), and satellites (sea surface height, SST) and data assimilation techniques are used to produce 3-, 5- and 10-day forecasts for 3-month periods for the entire basin.

- An interim partnership of 10 countries in the South China Sea region aims to facilitate operational coastal wave and storm surge forecasting for all of the partners. Based on a previous national project in Vietnam, a more structured, multi-national, regional project has been implemented. A survey of the needs and priorities for operational forecasting has been conducted to identify gaps in ocean monitoring networks and numerical forecasting capabilities. The area is prone to strong winds, waves and storm surges in connection with tropical cyclones, and consequently this project benefits from the support and contribution by the IOC/WMO Tropical Cyclone Programme. The interim partners have met once for a workshop on operational systems in Hanoi (2002) and will meet again for a follow-up workshop in Malaysia in July, 2003. The goals of the second workshop are: (1) to agree on common, regional priorities of ocean monitoring; (2) to enable all partners to utilize and apply a standard suite of numerical wave/storm surge forecasting models; (3) to develop forecasting and hindcasting scenarios from tropical cyclone forcings; (4) to learn by means of inverse modelling to define requirements for an ocean monitoring network in support of forecasting; and, ultimately, (5) to strengthen the interaction with end users. This project will help to crystallize the development of the coastal module of GOOS and of linkages between the open ocean and coastal modules of GOOS in the region. Consequently, the project enjoys the support of the IOC Perth Office, the IOC/WESTPAC secretariat in Bangkok, the WMO and the Norwegian Meteorological Institute. Although the project is focused on physical and meteorological processes at present, its success is facilitating international collaboration in the region and catching the interest of marine biologists in Indonesia and the Philippines.

Pilot Projects

Six pilot projects (GOTOS, GHRSST, NSEAM, RAMP, SeagrassNet, and OBIS) are highlighted below because they illustrate the broad spectrum of phenomena of interest that the coastal module is intended to address, and they represent projects that were established with the goal of establishing or becoming part of an operational observing system.

- The Global Ocean Time Series Observatory System (GOTOS) will provide high resolution time series of vertical distributions of ocean-climate related properties at fixed locations in both oceanic and coastal environments. In addition to data from profiling floats and satellites, these data are critical to improving estimates of ocean-atmosphere gas fluxes, phytoplankton productivity, and bottom processes (geophysical and biological) on regional to global scales. Although shipboard sampling at fixed sites is part of the mix of platforms, autonomous, moored sensors for real time telemetry of meteorological, physical, biological, chemical and geological data is emphasized. Coastal sites are located in regions where basin scale ocean variability is likely to be expressed locally. Sentinel sites are selected to be representative of meteorological, physical, chemical, biological or geological provinces and to provide data required to quantify important processes and validate models.
- The Global Ocean Data Assimilation Experiment (GODAE) High Resolution Sea Surface Temperature (GHRSST) pilot project has been established to give international focus and coordination to the development of a new generation of global, multi-sensor, high-resolution, SST products. In this decade (2003 - 2013), enhanced ocean sampling from satellites (e.g., ENVISAT, EOS, ADEOS, MSG) and *in situ* platforms (e.g., Argo and GOTOS) is expected. GHRSST will capitalize on these developments to demonstrate the benefits of integrated global ocean SST products. The goal is to rapidly and periodically provide high resolution (time and space) SST products that meet the needs of GODAE, the scientific community, operational users and climate applications at a global scale.
- The North Sea Ecosystem Assessment and Management (NSEAM) is a joint project of ICES,

EuroGOOS, the IOC, and OSPAR (EuroGOOS Publication 15, October 2000) to assist in the development of an ecosystem-based approach to fisheries management. As articulated at the September, 2001 workshop, the goal of this pilot project is to develop an ecosystem approach to North Sea management that is more cost-effective and to establish an integrated approach to the management of fisheries and oceanographic data.

- The Rapid Assessment of Marine Pollution (RAMP) pilot project is intended to provide sensitive rapid assessments of contamination from discharges of sewage and chemical pollutants, as well as of physical stresses associated with land reclamation and development of coastal areas for tourism and industrial activities. RAMP has been designed to test and provide easy-to-use, inexpensive chemical and biological markers that can be used to assess pollution and improve environmental management. A RAMP pilot project was initiated in Brazil in 1997. RAMP's immunoassay-based tests provide an inexpensive, rapid and highly selective means of measuring specific chemical compounds and have been used to diagnose medical conditions for many years. Recently the technology has been directed towards environmental contaminants in water, food and soil samples. The analyses can be run by relatively unskilled personnel in the field and provide obvious advantages for developing countries. Limited trials have proved of great interest and some environmental agencies are discussing incorporation of such techniques for screening. The choice of determinants amenable to detection by the rapid chemical analyses procedures is broad and thus the most relevant contaminants were selected following surveys and discussions with the Brazilian partners. PAH, PCB's, organochlorine and organophosphorous pesticides, selected herbicides and fungicides have all been identified as relevant environmental contaminants/pollutants. Biomarkers used in the RAMP programme are simple to use, inexpensive and reliable. They provide a means of detecting deterioration in the condition of biota from contaminated sites. Progress to date in Brazil has been excellent. Based on the early success of the work, plans have developed to establish RAMP programmes in the Caribbean, the Black Sea, and Vietnam.
- The global Sea Grass Monitoring Network (SeagrassNet) was established during the 3rd International Seagrass Biology Workshop in 1998 (Manila, Philippines) to function as the primary mechanism for serving the data and information needed by the World Seagrass Association (WSA) to promote research and provide advice to management agencies and the public on the protection and restoration of sea grass communities. Objectives are: to (1) develop an observing system to assess the status (areal extent and health) of seagrass ecosystems worldwide; (2) facilitate data and information exchange among scientists; (3) develop models to predict the effects of global climate change and human activities on seagrass ecosystems; and (4) enhance training and education and disseminate information on seagrass beds, their importance as essential fish habitat, their ecological significance, and their contribution to the well-being of human coastal populations.
- The Ocean Biogeographical Information System (OBIS), part of the Census of Marine Life, is an effort to create and maintain a dynamic global data system for marine biological and environmental data. The initial vision and strategy of OBIS, formulated at the 1st International OBIS Workshop in 1999 (Washington, D.C.), is that of "an on-line, world-wide marine atlas infrastructure providing scientists with the capability of operating in a 4-dimensional environment so that analysis, modelling, and mapping can be accomplished in response to user demand through accessing and providing relevant data." The system will provide a global information portal where systematic, genetic, ecological, and environmental information on marine species can be cross-searched and where information can be integrated into value added products such as derived data, maps, and models. OBIS is to be managed as a federation of database sources that allows interoperability among autonomous data systems. OBIS is an Associate member of the Global Biodiversity Information Facility (GBIF).

Enabling Research

Achieving the goals of the coastal module will depend to a great extent on the establishment of synergistic relations with hypothesis driven research programmes. The knowledge and technologies generated by these programmes will improve the observing system through: (1) the development of a more comprehensive quantitative understanding of the causes and consequences of environmental change; (2) more effective and less expensive technologies for real time monitoring and data telemetry; (3) improved capabilities to visualize and analyse change in near real-time; and (4) the development of models for improved prediction of current conditions, future events and environmental changes.

The coastal module of GOOS will provide the spatial and temporal framework of observations required to understand the global and long-term significance of results from research on targeted ecosystems. A high priority will be coordination and collaboration among related programmes to enable timely access to and analysis of the diverse data required to detect changes in coastal indicators and to develop predictive capabilities. Programmes such as LOICZ, GLOBEC, GEOHAB, SIMBIOS, and LMEs are critical to the development of the coastal module.

- The broad goal of Land-Ocean Interaction in the Coastal Zone (LOICZ) is to determine the fluxes of materials (emphasis on water, sediments, and carbon, nitrogen, and phosphorus compounds) into, within, and from coastal ecosystems. LOICZ activities are organized into four focus areas: (1) The effects of changes in external forcings on coastal fluxes; (2) Coastal biogeochemistry and global change; (3) Carbon fluxes and trace gas emissions; and (4) Economic and social impacts of global change in coastal systems. Two major goals to be achieved by the end of this 10-year programme are global estimates of C, N and P budgets for the coastal ocean and an assessment of specific data and techniques needed to improve and track changes in these budgets in local ecosystems and on regional to global scales.

Recognizing that LOICZ has a finite “life” (1992-2002, subject to current negotiations in IGBP), mechanisms are needed to ensure that the data, knowledge, tools, and networks developed by LOICZ are incorporated as appropriate. It is expected that the coastal module will encourage the development of observing system elements required to document and predict the consequences of changes in biogeochemical cycles and fluxes to, within and from coastal ecosystems; and will promote the use of new knowledge and technological advances (sensors, models, data management) generated by LOICZ for applied purposes and provide the framework of observations required to extrapolate research results to coastal systems that have not been the subject of an in-depth LOICZ study. There are two areas where collaboration between the coastal module and LOICZ could begin immediately: data management and applications of the LOICZ coastal typology.

The work of the joint JGOFS/LOICZ Continental Margins Task Team will be important in this regard. The major goal of the task team is to determine the role of the continental margins in the fluxes of carbon, nitrogen and phosphorus. Close collaboration between this effort and future development of GOOS will be required to enable GOOS to effectively utilize the scientific knowledge generated by the continental margins studies. This will enable research results from research programmes to be extrapolated to coastal ecosystems on a global scale using data from the GOOS.

- The Large Marine Ecosystem (LME) Programme is developing procedures for assessing and managing the effects of human activities in an ecosystem context. This approach uses a “modular strategy” for linking science-based assessments of changing states of marine ecosystems to the socio-economic benefits of sustaining ecosystems goods and services, (Sherman, 1994; Sherman and Duda, 1999). LMEs include coastal drainage basins and the coastal ocean (estuaries to the edge of the continental shelf or the outer margins of coastal current systems). Most of the world’s coastal zone is divided into 50 regional LMEs (the modules) that support about 95% of the world’s fisheries.
- The Global Ocean Ecosystem Dynamics (GLOBEC) project was initiated in 1991 to understand and model the effects of physical forcings on the distribution, diversity and productivity of animal populations (zooplankton in particular) in marine ecosystems. Emphasis is on (1) the dynamics of zooplankton populations relative to phytoplankton and fish predators, and

(2) the influence of physical processes on zooplankton dynamics. Research projects are organized around 4 themes: (1) building a foundation for the development of ecosystem models through retrospective analysis of historical databases; (2) conducting process studies; (3) developing predictive models through interdisciplinary, coupled modelling-observational systems; and (4) cooperating with other research programmes to understand interactions among marine, terrestrial and atmospheric systems.

- The Global Ecology of Harmful Algal Blooms (GEOHAB) programme was established in 1998 (sponsored by SCOR and the IOC) to provide a framework for research designed to improve the prediction of harmful algal events by determining the mechanisms underlying their population dynamics through interdisciplinary research, modelling, and an enhanced observational network. Three major questions will be addressed: (1) What are the environmental factors that determine the changing distribution of HAB species, their genetic variability and the biodiversity of associated communities? (2) What are the unique adaptations of HAB species that determine when and where they occur and the extent to which they produce harmful effects? (3) What are the effects of human activities (e.g., nutrient enrichment) on the occurrence of HABs? How do HAB species, their population dynamics and community interactions respond to changes in their environment?

GEOHAB will foster scientific advancement in the understanding of HABs by encouraging and coordinating basic research. International cooperation to conduct research in comparable ecosystems is encouraged. Improved global observing systems will be required to resolve influences of natural environmental factors and anthropogenic effects on distributions and trends in HAB occurrence. This will be greatly facilitated through strong links between GEOHAB and GOOS.

- The Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) was initiated by NASA in 1994 to foster information exchange and collaboration between satellite missions for the remote sensing of ocean colour. Remote sensing of ocean colour is a high priority for the development of the coastal module. Given that ocean colour provides the only global scale window into marine ecosystems on synoptic scales, it would be unthinkable to develop plans for monitoring marine ecosystems without the benefit of satellite data on ocean colour. Ongoing and projected ocean-colour missions are highly complementary in many important respects, but the sensors employed differ in design and capabilities. The goal is to develop methods to combine data on ocean colour from an array of independent satellite systems (e.g., SeaWiFS, MOS, MODIS, OCTS, POLDER) to ensure consistency and provide data products based on accurate and integrated spatial and temporal patterns of ocean colour. The strategy to achieve this targets three goals: (1) quantify the relative accuracies of products from international ocean-colour missions; (2) improve the compatibility among products; and (3) develop methods for generating merged global products for more comprehensive and detailed spatial and temporal coverage. Of particular importance to the coastal module is the development of algorithms for case 2 waters.

Table VII.1. Examples of projects and programmes that provide the scientific and operational basis for the coastal module of GOOS. For more information, see Annex IX for a list of corresponding URLs.

STAGE	SCALE	PROGRAMME
Enabling Research	Global	Climate Variability and Predictability (CLIVAR) Programme Sensor Intercomparisons and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) World Climate Research Programme (WCRP) Large Marine Ecosystems (LMEs) Census of Marine Life (CoML)
	Regional	Land-Ocean Interactions in the Coastal Zone (LOICZ) Global Ecology and Oceanography of Harmful Algal Blooms (GEOHAB) Global International Waters Assessment (GIWA) Global Ocean Ecosystem Dynamics (GLOBEC) Large Marine Ecosystems (LMEs)
Pilot Projects	Global	Global Ocean Data Assimilation Experiment (GODAE), Argo, & GHRSST Global Time Series Observatory System Global Sea Grass Network (SeagrassNet) Ocean Biogeographical Information System (OBIS)
	Regional	Adriatic Sea Integrated Coastal Areas and River Basin Management System (ADRICOSM) Caribbean Coastal Marine Productivity (CARICOMP) Mediterranean Network to Assess and Upgrade Monitoring and Forecasting Activity (MAMA) Quickly Integrated Joint Observing Team (QUIJOTE) Rapid Assessment of Marine Pollution (RAMP)
Pre-Operational Elements	Global	TOPEX/Poseidon Satellite Altimeter Mission
	Regional	Mediterranean Forecasting System (MFS) Vietnamese Forecasting System (VFS)
Operational Elements	Global	Global Sea Level Observing System (GLOSS) Global Investigation of Pollution in the Marine Environment (GIPME) International Oceanographic Data and Information Exchange (IODE) International Panel on Harmful Algal Blooms (IPHAB)
	Regional	Arctic Monitoring and Assessment Programme (AMAP) California Cooperative Fisheries Investigations (CalCOFI) Continuous Plankton Recorder (CPR) Survey Baltic Operational Observing System Global Coral Reef Monitoring Network (GCRMN) ICES Bottom Trawl Survey (IBTS) International Tsunami Warning System in the Pacific (ITSU) Regional Fishery Bodies (with conventions) Regional Seas Programmes (with conventions)

ANNEX VIII – Regional Bodies

GOOS Regional Alliances: The GOOS Steering Committee has established policies to guide the development of GRAs that focus on sustained ocean observations and the associated development of product and services (http://ioc.unesco.org/gpsbulletin/). GRAs are formed to implement activities that require multinational coordination to meet national priorities for detecting and predicting changes in coastal marine environments and resources. As such, GRAs should provide the framework for coordinating the synergistic development of RFBs, RSPs, and LMEs.

To be recognized as a regional alliance, a GRA must include definable elements that contribute to the GOOS in accordance with the GOOS Principles. Based on reviews by GOOS executive bodies and the GSC, a GRA will receive recognition through endorsement by the I-GOOS followed by approval of the Assembly of the IOC. Together with national GOOS Programmes, GRAs (including national GOOS programmes) are seen as the primary mechanism for implementing the integrated design plan for the coastal module of GOOS. Existing national GOOS programmes and GRAs are shown in Table VIII.1.

Regional Fishery Bodies: RFBs have been established as a mechanism for multilateral management of fisheries within regions that extend beyond national jurisdictions. The first, the International Council for the Exploration of the Sea (ICES), was established in 1902 for cooperative research and monitoring of the NE Atlantic (including the North Sea and the Baltic) and its resources. Since the formation of ICES, over 30 regional fisheries bodies have been established with missions that range from promoting scientific collaboration and providing advice to government ministries to regulatory authority for fisheries management (Table VIII.2).

Some RFBs have mandates based on geographic areas while others target specific species within a geographic area. In general, the activities of RFBs relate to the impact of fishing on fisheries and ecosystems, the impact of land-based activities on fisheries, the impact of climate on fisheries, and ecosystem monitoring. A few RFBs (CCAMLR, GFCM, IATTC, IBSFC, ICES, IPHC, IWC, NASCO, NPAFC, PICES and SPC) explicitly incorporate the concept of ecosystem-based management, but most have not formally adopted this approach.

Regional Seas Programme, Conventions and Action Plans: Beginning in the late 1960s, it was recognized that controlling marine pollution would be most effective through region-specific agreements. The first agreement of this type was adopted in 1972 (Oslo Convention, which has been superseded by the OSPAR Convention), and subsequently (1974) UNEP initiated the Regional Seas Programme. The UNEP Regional Seas Programme presently includes 14 regions (Table VIII.1) with over 140 coastal States and territories participating in it. There are also two non-UNEP Regional Seas programmes, OSPAR for the Arctic and NE Atlantic and HELCOM for the Baltic.

Regional Seas Conventions (RSCs) and action plans are the responsibility of the Division of Environmental Conventions and provide the primary mechanism for UNEP to respond to chapter 17 of Agenda 21 (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 their living resources).

Table VIII.1. Table VIII.1. National GOOS Programmes (having provided national reports to the GOOS Project Office as of January 2003) and GOOS Regional Alliances (GRAs), Regional Seas Conventions and Action Plans (RSCs), and Regional Fisheries Bodies (RFBs).

Region	National GOOS	GRAs	RSCs	RFBs
NW Pac.	1)	NEAR-GOOS	NW Pacific	N. Pacific Marine Science Organization (PICES) Pacific Salmon Commission
NE Pac.	2)		NE Pacific	PICES North Pacific Anadromous Fish Commission International Pacific Halibut Commission
SW Pac.	3)	Pacific Islands GOOS	East Asian South Pacific	Asian-Pacific Fisheries Commission (APFIC) Inter-American Tropical Tuna Commission Secretariat of the Pacific Community (SPC) South Pacific Forum Fisheries Agency (FFA)
SE Pac.	4)	Under development	SE Pacific	South Pacific Permanent Commission (CPPS)
NW Atl.	5)			NW Atlantic Fisheries Organization
NE Atl.	6)	BOOS NOOS EuroGOOS	Baltic North Sea NE Atlantic	International Baltic Sea Fishery Commission International Council for the Exploration of the Sea (ICES) North Atlantic Salmon Conservation Organization NE Atlantic Fisheries Commission
W Asia	7)	Black Sea GOOS	Black Sea	
SE Asia	8)	Under development	Reg. Coordination Unit for East Asian Seas	Asia-Pacific Fisheries Commission
Carib.	9)	IOCARIBE GOOS	Caribbean	Western Central Atlantic Fishery Commission
Med.	10)	EuroGOOS MedGOOS	Mediterranean	General Fisheries Commission for the Mediterranean
SW Atl.	11)		SW Atlantic	Joint Technical Commission for Argentina/Uruguay Maritime Front International Commission for the Conservation of Atlantic Tuna
SE Atl.	12)	GOOS Africa	West & Central Africa	International Commission for SE Atlantic Fisheries Fisher Commission for the Eastern Central Atlantic
Indian Ocean	13)	IOGOOS	Eastern Africa Red Sea & Gulf of Aden South Asian	Indian Ocean Tuna Commission Regional Commission for Fisheries (Arabian Sea) SW Indian Ocean Fishery Commission
Arctic	14)	EuroGOOS		North Atlantic Marine Mammal Commission
Antarctic				Commission for the Conservation of Antarctic Marine Living Resources

1) China, Japan, Republic of Korea, and Russian Federation; 2) Canada and U.S.A.; 3) Australia, New Zealand and South Pacific Applied Geoscience Commission (on behalf of island nations in the region); 4) Chile, Colombia, Ecuador and Peru; 5) Canada and U.S.A.; 6) Belgium, Finland, France, Germany, Holland, Iceland, Norway, Poland, Russian Federation, Spain and UK; 7) Georgia, Russian Federation and Ukraine; 8) Australia, China, Malaysia and Vietnam; 9) Colombia, Cuba and U.S.A.; 10) Croatia, Cyprus, France, Italy, Malta, Slovenia and Spain; 11) Argentina and Brazil; 12) Gambia, Guinea, Nigeria and South Africa; 13) Australia, India, Kenya, Mauritius, South Africa, Tanzania and U.S.A; 14) Canada, Norway, Russian Federation and U.S.A.

Regional Seas Programmes are implemented, in most cases, through legally binding conventions under the authority of the contracting parties or intergovernmental bodies. RSCs generally include five components: environmental assessment, environmental management (including the control of land-based sources of pollution), environmental legislation, institutional arrangements and financial arrangements. The more mature RSCs have developed protocols for implementing global conventions and agreements such as the Convention on Biological Diversity (CBD), the Convention on International Trade in Endangered Species (CITES), the Basel Convention, and the Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA)[15] .

The Large Marine Ecosystem Approach: Large marine ecosystems (LMEs) define a scale of observation and research based on the spatial and temporal scales of fish population dynamics and trophic interactions upon which fish production depends. During the 1990s, the coastal ocean was divided into LMEs in order to promote ecosystem-based management of fisheries. The regions encompassed by LMEs are large (typically in excess of 200,000 km^2) and are characterized by distinctive hydrographic regimes, geomorphology, productivity, and the trophic levels of the predominant fisheries (Sherman, 1991). The legal framework for ecosystem-based management of living marine resources was set forth in the United Nations Convention for the Law of the Sea.

The approach is based on the implementation of five related modules: (1) productivity (primary productivity, diversity and production of zooplankton, hydrographic variability), (2) fishery resources (species diversity, abundance and distribution of species), (3) ecosystem health (extent and quality of habitat, bottom water oxygen depletion, harmful algal blooms, diseases in marine organisms, etc.), (4) socio-economics (effects of human activities on the sustainability of ecosystem goods and services, http://ioc.unesco.org/gpsbulletin/), and (5) governance (adaptive management, stakeholder participation). Recently, international donor agencies (e.g., the Global Environmental Fund and The World Bank) have shown interest in funding regional programmes based on the LME approach. To date, 30 countries in Asia, Africa, and Eastern Europe have made commitments to ecosystem-based assessment and management practices in support of Chapter 17 in Agenda 21 with the initiation of LME projects.

15 Recognizing that 80% of pollution in the oceans comes from land-based sources, the international community in 1995 agreed to initiate the Global Programme of Action (GPA) for the Protection of the Marine Environment from Land-Based Activities. The GPA seeks to establish an integrated approach to management and to mobilize support for developing countries to participate. The Regional Seas Programme was identified as key mechanism for implementation of the GPA. The goal is to establish an ecosystem-based approach on a regional scale to ensure integrated and sustained management of the marine environment and its living resources. The Montreal Declaration (from the intergovernmental review of the GPA, 30 November, 2001) commits participating nations to improve and accelerate the implementation of the GPA by "(a) taking appropriate action at national and regional levels to strengthen institutional cooperation among, inter alia, river-basin authorities, port authorities and coastal zone managers; and to incorporate coastal management considerations into relevant legislation and regulations pertaining to watershed management; (b) strengthening the capacity of local and national authorities to obtain and utilize sound scientific information to engage in integrated decision making, with stakeholder participation, and to apply effective institutional and legal frameworks for sustainable coastal management; (c) strengthening the Regional Seas Programme to play a role in, as appropriate, coordination and cooperation (i) in the implementation of the GPA, (ii) with other relevant regional organizations, (iii) in regional development and watershed management plans, and (iv) with global organizations and programmes relating to implementation of global and regional conventions; (d) improving scientific assessment of the anthropogenic impacts on the marine environment, including, *inter alia*, the socio-economic impacts; (e) enhancing state of the oceans reporting to better measure progress toward sustainable development goals, informing decision making (such as setting management objectives), and improving public awareness and helping assess performance; and (g) improving technology development and transfer, in accordance with the recommendations of the United Nations General Assembly.

Table VIII.2. Regions and countries where marine resource ministries (fisheries, environment, finance) are supportive of ecosystem-based resource assessment and management.

LME	PARTICIPATING COUNTRIES	STATUS
Bay of Bengal	Bangladesh, India, Indonesia, Malaysia, Maldives Myanmar, Sri Lanka, Thailand	PDF Block B funding approved; executing agency - FAO
South China Sea	Cambodia, China, Indonesia, Malaysia, Philippines, Sumatra, Thailand, Vietnam	Implementation funding approved; executing agency - UNEP
Yellow Sea	China, Republic of Korea	Implementation funding approved; executing agency - UNDP
Agulhas Current	Madagascar, Mozambique, South Africa	PDF Block B funding approved; executing agency - UNEP
Benguela Current	Angola, Namibia, South Africa	Funding approved; executing agency UNDP
Canary Current	Cape Verde, Gambia, Guinea, Guinea Bissau, Mauritania, Morocco, Senegal	PDF Block funding approved; executing agency - UNEP
Guinea Current	Angola, Benin, Cameroon, Congo, Côte d'Ivoire, Gabon, Ghana, Guinea, Liberia, Nigeria, Sao Tome & Principe, Sierra Leone, Togo	Project in phase 2; executing agency - UNIDO
Somali Current	Kenya, Tanzania	PDF Block B funding approved - executing agency UNEP
Caribbean Sea	Bahamas, Barbados, Belize, Brazil, Colombia, Costa Rica, Cuba, Jamaica, Mexico, Panama, St. Lucia, Trinidad & Tobago, Venezuela (IOCARIBE members)	PDF Block A funding approved; executing agency - UNESCO/IOC
Humboldt Current	Chile, Ecuador, Peru	In planning phase
Pacific Central America	Columbia, Costa Rica, Ecuador, El Salvador, Guatemala, Mexico, Nicaragua, Panama	In planning phase
Baltic Sea	Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia, Sweden	Implementation funding approved; executing agency - World Bank

ANNEX IX – URLs of Programmes and Projects Relevant to the Coastal Module of GOOS

Argo - http://www-argo.ucsd.edu/
Biodiversity/BIOMAR – http://www.biomareweb.org
CalCOFI – http://www-mlrg.ucsd.edu/calcofi.html
CLIVAR – http://www.clivar.ucar.edu/hp.html
C-GOOS Strategic Design Plan – http://ioc.unesco.org/iocweb/iocpub/iocpdf/i1146.pdf
Chesapeake Bay Monitoring Programme – http://www.chesapeakebay.net/Program.htm
Coastal population – http://www.LDEO.columbia.edu/~small/CoastalPop.html
CODAR – http://marine.rutgers.edu/cool/coolresults/papers/oi_london_kohut.pdf
COOP – http://ioc.unesco.org/goos/coop_co.htm
Economic Valuation of Wetlands, Ramsar Convention Bureau, Gland, Switzerland – http://www.ramsar.org/lib_val_e_index.htm.
Ecosystem Models – http://www.ecopath.org
Environmental Indicators, European System – http://www.e-m-a-i-l.nu/tepi/firstpub.htm
EuroGOOS – http://www.soc.soton.ac.uk/OTHERS/EUROGOOS/eurogoosindex.html
GCOS – http://193.135.216.2/web/gcos/gcoshome.html
GEBCO – http://www.ngdc.noaa.gov/mgg/gebco/
GEOHAB – http://ioc.unesco.org/hab/GEOHAB.htm
GESAMP – http://gesamp.imo.org
GLCCS (Global Land Cover Characteristics Database) – http://edcdaac.usgs.gov/glcc/glcc.html
Global distribution of people – http://www.ldeo.columbia.edu/~small/ContPhys.html
Global Monitoring for Environment and Security – http://gmes.jrc.it/
Global observing systems information centre – http://www.gos.udel.edu
Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) – http://www.gpa.unep.org
GLOBEC – http://www.pml.ac.uk/globec/main.htm
GODAE – http://www.bom.gov.au/bmrc/ocean/GODAE/
GOOS – http://ioc.unesco.org/goos/
GOOS Capacity Building Strategy – http://ioc.unesco.org/goos/key5.htm#cap
GOOS 1998 Prospectus, -- http://ioc.unesco.org/goos/Prospe98/Contents.html
GOOS Products and Services Bulletin – http://ioc.unesco.org/gpsbulletin/
GTOS – http://www.fao.org/gtos
GTOS Carbon Observation (TCO) data warehouse – http://www.fao.org/gtos/TCO.html
HOTO – http://ioc.unesco.org/goos/hoto.htm
IBOY – http://www.nrel.colostate.edu/IBOY/index2.html
ICES – http://www.ices.dk/
IGBP – http://www.igbp.kva.se
IGBP/OCEANS – http://www.igbp.kva.se/obe/
Invasive Species – http://www.invasivespecies.gov
IOCCG – http://www.ioccg.org

IOC-IODE Ocean Portal – http://oceanportal.org

IODE – http://ioc.unesco.org/iode/

JCOMM – http://www.wmo.ch/web/aom/marprog/index.htm

LMR – http://ioc.unesco.org/goos/lmr.htm

LOICZ – http://www.nioz.nl/loicz/welcome.html

MFS – http://www.cineca.it/~mfspp000

NEARGOOS – http://ioc.unesco.org/goos/NearGOOS/neargoos.htm

Non-indigenous species, environmental and economic costs in the United States – http://www.invasivespecies.gov

OBIS Databases

- http://habanero.nhm.ukans.edu/FISHNET/
- http://netviewer.usc.edu/web/index2.html
- http://www.kgs.ukans.edu/Hexacoral/index.html
- http://www.cephbase.utmb.edu/
- http://www.zoogene.org/

OOPC – http://ioc.unesco.org/goos/oopc.pdf

OOSDP – http://www-ocean.tamu.edu/OOSDP/FinalRept/t_of_c.html

QUIJOTE – http://www.cem.ufpr.br/fisica/quijote.htm

RAMSAR (Background Papers on Wetland Values and Functions) – http://www.ramsar.org/values_intro_e.htm

SAHFOS – http://www.sahfos.org

SIMBIOS – http://simbios.gsfc.nasa.gov

State of the Environment Reports

- GEO 2000 - http://www.unep.org/geo2000/
- Millennium Ecosystem Assessment - www.millenniumassessment.org
- Pilot Analysis of Global Ecosystems - www.wri.org/wr2000/coast_page.html
- World Resources - http://www.wri.org/wr-96-97/96tocful.html
  - http://www.wri.org/wri/wr-98-99/index.html
  - http://www.wri.org/wri/wr2000/index.html
- State of the Coast - http://state-of-coast.noaa.gov/
- State of the Nation's Ecosystems - http://www.heinzctr.org/ecosystems/index.htm
- Chesapeake Bay - http://www.chesapeakebay.net/pubs/sob/index.html
- Gulf of Finland - http://meri.fimr.fi
- Puget Sound - http://www.wa.gov/puget_sound
- Wadden Sea - http://cwss.www.de/TMAP/QSR.html

Sustainable Development Indicators – www.undp.org/devwatch/indicatr.htm

U.S. GOOS

- Ocean.US – http://www.ocean.us.net
- Ocean.US Integrated Ocean Observing System Plan – http://www.ocean.us.net/projects/papers/post/FINAL-ImpPlan-NORLC.pdf
- US GOOS Steering Committee – http://ocean.tamu.edu/GOOS/usgsc.html
- US GOOS Publications – http://ocean.tamu.edu/GOOS/publications.html

World Resources Institute, Wastewater Treatment, 1996-97 – http://data.wri.org:1996/cgi-bin/charlotte

ANNEX X – Linking Socio-economic Factors and Environmental Dynamics

During the past decade various efforts have attempted to develop organizing frameworks that conceptually link human and environmental dynamics. Perhaps, most notably has been the evolution of thought on the Pressure-State-Response (PSR) framework. Within the Pressure-State-Response (PSR) model, popularised by the OECD (OECD, 1993), environmental problems and solutions are simplified into variables that stress the cause and effect relationships between human activities that exert influence on the environment (pressure), the condition of the environment (state), and society's policy and regulatory reaction to the condition (response). The original P-S-R descriptions focused on anthropogenic pressures and responses. One of several problems was that the original definitions did not effectively factor natural causes into the pressure category. Therefore, natural variability and episodic events had no real place in the model. While anthropogenic forcing is often an important, if not dominant, factor in environmental change, efforts that ignore other influences may lead to the imposition of unwarranted regulatory constraints that hold little, if any, promise to improve environmental quality.

In part, this challenge led some, most notably the United Nations Commission on Sustainable Development to describe a Driving Force-State-Response model. A primary modification here was to expand the concept of "pressure" to incorporate, social, economic, institutional and natural system pressures (UNEP, 2000). However, even when "driving force" replaces "pressure", the model does not explicate a category to account for the underlying reasons for the pressures. To analyse policy options and resource allocation in environmental management, it is essential to have a grasp of the root causes of the problems being addressed (GIWA, 2002). A model that measures pollutants but gives no information about the social conditions surrounding driving pollutant introduction (e.g., changes in the organization of watershed agriculture or coastal industrial production) is not providing the data needed to inspire meaningful change.

Another element missing from the P-S-R model is an examination of human motivation responding to the state of environmental conditions. While social stewardship of the environment should be an essential component of environmental policy, it is not the sole motivation. Social resources are not infinite. Expenditures of time, energy and effort are prioritised according to a rich and often conflicting suite of factors. Certainly, one of those factors should be the social costs imposed or benefits gained through changes in the quality of supporting environments. The social impact of environmental change is an essential factor in influencing policy. An indicator system that records the state but not the impact essentially assumes that every change in the pressure, state, or response should be given the same amount of attention or resources. Realistically, all ICM efforts are a careful balancing of priorities. Including indicators that measure impacts to humans and the ecosystem makes the model a more useful management tool.

Thus, challenges to the initial P-S-R model have contributed to the refined and expanded approach described as the Driver-Pressure-State-Impact-Response Model by, among others, the European Commission (2000). Within this model:

Drivers describe large-scale socio-economic conditions and sectoral trends such as patterns in coastal land use and land cover, and growth and development in coastal industry sectors.

Pressures such as patterns of coastal wetland alteration, the introduction of industrial POPs/metals and fertilizer use in the coastal watershed hold the ability to directly affect the quality of coastal environments.

State indicators describe observable changes in coastal environmental dynamics and in functions describing sustainable development.

Impacts are the discrete measured changes in social benefit values linked to environmental condition such as the cost of marine-vectored disease, loss of recreational bathing beach value, or losses to commercial fishing value due to contaminant burdens; and,

Response indicators are described as the institutional response to changes in the system (primarily driven by changes in state and impact indicators).

Figure 5.3 represents the D-P-S-I-R approach and includes illustrative examples of indicators and indicator classes that could contribute to refinements of the framework within a coastal context.

ANNEX XI – References

Adams, R., Brown, M., Colgan, C., Flemming, N., Kite-Powell, H., McCarl, B., Mjelde, J., Solow, A., Teisberg, T. and Weiher, R., 2000. *The economics of sustained ocean observations: benefits and rationale for public funding.* NOAA and ONR, 53 pp.

Anderson, D.M., Glibert, P.M. and Burkholder, J.M., 2002. Harmful algal blooms and eutrophication: nutrient sources, composition and consequences. Estuaries, 25, 704-727.

APHA/AWWA/WEF, 1998. *Standard Methods for the Examination of Water and Wastewater*, 20th ed., edited by L.S. Clesceri, A.E. Greenberg and A.D. Eaton: Prepared and published by APHA, AWWA & WEF.

Arcos, D.F., Cubillos, L.A. and Núñez, S.P., 2001. The Jack mackerel fishery and El Niño 1997-98 effects off Chile. *Progress in Oceanography*, 49, 597-617.

Baba, J. and P.D. Komar, 1981. Measurements and analysis of settling velocities of natural quartz sand grains. *Journal of Sedimetary Sedimentary Petrology*, 51, 631-640.

Barber, R.T. and Chavez, F.P., 1986. Ocean variability in relation to living resources during the 1982-83 El Niño. *Nature*, 319, 279-285.

Baretta, J.W., Ebenhoh, W. and Ruardij, P., 1995. The European Regional Seas Ecosystem Model, a complex marine ecosystem model. *Netherland Journal of Sea Research*, 33, 233-246.

Barnthouse, L., 1993. Population level effects. In: G.W. Suter (ed.), *Ecological Risk Assessment*, 247-274 pp. Michigan, Lewis Publishers.

Barry, J.P., Baxter, C.H., Sagarin, R.D. and Gilman, S.E., 1995. Climate-related, long-term faunal changes in a California rocky intertidal community. *Science*, 267, 672-675.

Beaugrand, G., Reid, P.C., Ibañezs, F., Lindley, J.A. and Edwards, M., 2002. Reorganization of the North Atlantic marine copepod biodiversity and climate. *Science*, 296, 1692-1694.

Birkeland, C. (ed.), 1997. *Life and Death of Coral Reefs*. New York, Chapman and Hall, 536 pp.

Boehlert, G.W., 1996. Biodiversity and the sustainability of marine fisheries. *Oceanograhy*, 9, 28-35.

Bolin, B., Doos, B.R., Jager, J. and Warrick, R.A., 1986. *The Greenhouse Effect, Climate Change and Ecosystems*. New York John Wiley & Sons, 541 pp.

Booij, N., Ris, C. and Holthuijsen, L.H., 1999. A third generation wave model for coastal regions. Part I. Model description and validation. *Journal of Geophysical Research*, 104, 7649-7666.

Bowen, R.E. and Crumbley, C., 1999. Evolving Principals in Coastal Management: From Concept to Action. In: Dennis L Soden and Brent S. Steel (eds.), *Handbook of Global Environmental Policy and Administration*. New York: Marcel Dekker.

Brink, K. and Robinson, A.R., 1998. *The Sea. The Global Coastal Ocean I. Processes and Methods*, Vol. 10. New York, John Wiley & Sons.

Brown, D.S. and Allison, J.D., 1987. MINTEQAI *Equilibrium metal speciation model: a user's manual*. Athens, Geor., USEPA.

Brown, S.M. and Silver, A., 1986. Chemical spill exposure assessment. *Risk Analysis*, 6, 291-298.

Buch, E. and Dahlin, H., 2000. BOOS Plan: *Baltic Operational Oceanographic System 1999-2003*. Southampton, Southampton Oceanography Centre. (EuroGOOS Publication No. 14).

Buckley, R. (ed.), 1992. *The Mediterranean – Paradise Under Pressure*. Cheltenham, European Schoolbooks Publishing, p. 1-9.

Carlton, J.T., 1996. Marine bioinvasions: the alteration of marine ecosystems by nonindigenous species. *Oceanography*, 9, 36-45.

CEC, 1995. *Wise Use and Conservation of Wetlands*. Communication from the Commission to the Council and the European Parliament COM (95), Brussels.

Cerco, C.F. and Cole, T., 1993. Three-dimensional eutrophication model of Chesapeake Bay. *Journal of Environment Engineering*, 119, 1006-1025.

Cesar, H.S.J., 2000. *Collected Essays on the Economics of Coral Reefs*. Kalmar, CORIDO.

Chamberlain, G.W., 1997. Sustainability of world shrimp farming. In: E. Pikitch, D.D. Huppert and M. Sissenwine (eds.): *Global Trends in Fisheries Management. American Fisheries Society Symposium* 20, p. 195-209. Bethesda, Mar., American Fisheries Society.

Chapelle, A., Menesguen, A., DeslousPaoli, J. M., Souchu, P., Mazouni, N., Vaquer, A. and Millet, B., 2000. Modelling nitrogen, primary production and oxygen in a Mediterranean lagoon. Impact of oysters farming and inputs from the watershed. *Ecological Modelling*, 127, 161-181.

Chavez, F.P., Strutton, P.G., Friederich, G.E., Feely, R.A., Feldman, G.C., Foley, D.G. and McPhaden, M.J., 1999. Biological and chemical response of the equatorial Pacific Ocean to the 1997-98 El Niño. *Science*, 286, 2126-2131.

Chelton, D.B., Bernal, P.A. and McGowan, J.A., 1982. Large scale interannual physical and biological interactions in the California Current. *Journal of Marine Research*, 40, 1095-1125.

Clark, J, 1977. *Coastal Ecosystems Management*. New York, John Wiley.

Cloern, J.E., 1996. Phytoplankton bloom dynamics in coastal ecosystems: a review with some general lessons from sustained investigation of San Francisco Bay, California. *Reviews of Geophysics*, 34, 127-168.

Cloern, J.E., 2001. Our evolving conceptual model of the coastal eutrophication problem. *Marine Ecology Progress Series*, 210, 223-253.

Cohen, J.E. and Small, C., 1998. Hypsographic demography: the distribution of the human population by altitude. *Proceedings of the National Academy of Sciences of the USA*, 95, 14009-14014.

Costanza, R., Kemp, W.M. and Boynton, W.R., 1993. Predictability, scale and biodiversity in coastal and estuarine ecosystems: Implications for management. *Ambio*, 22, 88-96.

Costanza, R., d'Arge, R., de Groots, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P. and van den Belt, M., 1997. The value of the world's ecosystem services and natural capital. *Nature*, 387, 253-260.

CSPI, 2002. *Outbreak Allert!*, September, 2002. 64 pp. http://www.cspinet.org/reports/outbreak_report.pdf.

Daily, G.C., Soderqvist, T., Aniyar, S., Arrow., K., Dasgupta, P., Ehrlich, P.R., Folke, C., Jansson, A.M., Jansson, B-O., Kautsky, N., Levin, S.A., Lubchenco, J., Maler, K-G., Simpson, D., Starrett, D., Tilman, D., Walker, B., 2000. The value of nature and the nature of value. *Science*, 289, 395-396.

Daley, R., 1991. *Atmospheric Data Analysis, Cambridge Atmospheric and Space Science series*. Cambridge University Press, 457 pp.

Dayton, P.K. and Tegner, M.J., 1984. Catastrophic storms, El Niño, and patch stability in a southern California kelp community. *Science*, 224, 283-285.

Diamond, J. M., and R. M. May, 1976. Island biogeography and the design of natural reserves. In: R.M. May (ed.) *Theoretical Ecology*. Philadelphia, Saunders.

Dickey, T., 1991. The emergence of concurrent high-resolution physical and bio-optical measurements in the upper ocean and their application. *Reviews of Geophysics*, 29, 383-413.

Dickey, T., 2002. Emerging instrumentation and new technologies in the early 21st century. In: J.G. Field, G. Hempel and C.P. Summerhayes (eds.): *Oceans 2020: Science for Future Need*, p. 213-256. Washington, DC Island Press.

Dickey, T., Frye, D., Jannasch, H., Boyle, E., Manov, D., Sigurdson, D., McNeil, J., Stramska, M., Michaels, A., Nelson, N., Siegel, D., Chang, G., Wu, J. and Knap, A., 1998. Initial results from the Bermuda Testbed Mooring Program. *Deep-Sea Research*, 45, 771-794.

DiToro, D.M., 2001. *Sediment flux modeling*. New York, Wiley-Interscience.

Dolan, D.M. and Bierman, V.J. Jr., 1982. Mass balance modelling of heavy metals in Saginaw Bay, Lake Huron. *Journal of Great Lakes Research*, 8, 676-694.

Dowd, M., 1997. On predicting the growth of cultured bivalves. *Ecological Modelling*, 104, 113-131.

Dowd, M., Vachon, P.W., Dobson, F.W. and Olsen, R.B., 2001. Ocean wave extraction from RADARSAT synthetic aperture radar inter-look image cross-spectra. *IEEE Transactions on Geoscience and Remote Sensing*, 39, 21-37.

Droppert, L.J., Cattle, H., Stel, J.H., Behrens, H.W.A. (eds.), 2000. *The NOOS Plan: North West Shelf Operational Oceanographic System, 2002-2006*. Southampton, Southampton Oceanography Centre, 68 pp. (EuroGOOS Publication No. 18).

Duce, R.A., Liss, P.S., Merrill, J.T., Atlas, E.L., Buat-Menard, P., Hicks, B.B., Miller, J.M., Prospero, J.M., Ari-moto, R., Church, T.M., Ellis, W., Galloway, J.N., Hansen, L., Jickells, T.D., Knap, A.H., Reinhardt, K.H., Schneider, B., Soudine, A., Tokos, J.J., Tsunogai, S., Wollast, R. and Zhou, M., 1991. The atmospheric input of trace species to the world ocean. *Global Biogeochemical Cycles*, 5, 193-259.

Dufour, A.P., 1984. *Health effects criterial for fresh recreational waters*. U.S. EPA-600/1-884-004.

Dugan, J.P., Vierra, K.C., Morris, W.D., Farruggia, G.J., Campion, D.C. and H.C. Miller, 1999. Unique vehicles used for bathymetric surveys in exposed coastal regions, In. U.S. Hydrographics Conference, *Hydro '99*. Mobile AL.

European Commission, 2000. Towards Environmental Performance Indicators for the European Union (EU). A European system of environmental indicators, First Publication. Retrieved from http://www.e-m-a-i-l.nu/tepi/firstpub.htm.

Eyles, M.J., 1986. Microbiological hazards associated with fishery products. CSIRO *Food Research Quarterly*, 46, 8-16.

FAO, 2000. *The state of world fisheries and aquaculture 2000*. Rome, FAO. 142 pp.

Fasham, M., Ducklow, H. and McKelvie, S., 1990. A nitrogen-based model of plankton dynamics in the oceanic mixed layer. *Journal of Marine Research*, 48, 591-639.

Fenical, W., 1996. Marine biodiversity and the medicine cabinet: the status of new drugs from marine organisms. *Oceanography*, 9, 23-24.

Fischer, J. and Flemming, N.C., 1999. *Operational oceanography: data requirements survey*. Southampton, Southampton Oceanography Centre. (EuroGOOS Publication No. 12).

Fischer, J., Baretta, J., Colijn, F. and Flemming, N.C., 2000. *Bio-ecological observations in operational oceanography*., Southampton Oceanography Centre, Southampton. (EuroGOOS Publication No. 15).

Flather, R. A., 2002. Existing Operational Oceanography. *Coastal Engineering*, 41, 13-40.

Folke, C. and Kautsky, N., 1992. Aquaculture with its environment: prospects for sustainability. *Ocean and Coastal Management*, 17, 5-24.

Francis, R.C. and Hare, S.R., 1994. Decadal-scale regime shifts in the large marine ecosystems of the northeast Pacific: A case for historical science. *Fisheries Oceanography*, 3, 279-291.

French, D.P., 1998. *Evolution of Oil Trajectory, Fate and Impact Assessment Models. Oil Spill 98*. Southampton, Wessex Institute of Technology.

Fromentin, J-M. and Planque, B., 1996. *Calanus* and environment in the eastern North Atlantic. II. Influence of the North Atlantic Oscillation on *C. finmarchicus* and C. helgolandicus. Marine Ecology Progress Series, 134, 111-118.

Gardner, R., Kemp, W. M., Petersen, J. and Kennedy, V. (eds.), 2001. *Scaling relations in experimental ecology*. New York, Columbia University Press.

GEOHAB, 1998. *The Global Ecology and Oceanography of Harmful Algal Blooms*. Joint SCOR-IOC Workshop, Havreholm, Denmark 13-17 October 1998, 43 pp.

GESAMP, 2001a. Protecting the Oceans from Land-based Activities: Land-based Sources and Activities Affecting the Quality and Uses of the Marine, Coastal and Associated Freshwater Environments. *GESAMP Reports and Studies*, 71, 162 pp.

GESAMP, 2001b. Sea of Troubles. *GESAMP Reports and Studies*, 70, 35 pp.

Gibbs, R.J., Matthews, M.D., Link, D.A., 1971. The relationship between sphere size and settling velocity. *Journal of Sedimentary Petrology*, 41, 7-18.

Gilbert, A.J. and Janssen, R., 1998. Use of environmental functions to communicate the values of a mangrove ecosystem under different management regimes. *Ecological Economics*, 25, 323-346.

GIWA, 2002. *Methodology: Detailed Assessment, Causal Chain Analysis, Policy Option Analysis*, Kalmar, Sweden, 5 May 2002. http://www.giwa.net/methodology/the_giwa_methodology_for_remaining_stages_3rd_draft_v3p5.pdf.

Glenn, S.M., Boicourt, W., Parker, B. and Dickey, T.D., 2000a. Operational observation networks for ports, a large estuary and an open shelf. *Oceanography*, 13, 12-23.

Glenn, S.M., Boicourt, W., Parker, B. and Dickey, T.D., 2000b. Long-term, real-time coastal ocean observation networks. *Oceanography*, 13, 24-34.

Grant, J. and Bacher, C., 1998. Comparative models of mussel bioenergetics and their validation at field culture sites. *Journal of Experimental Marine Biology and Ecology*, 219, 21-44.

Haapala, J. and Leppaeranta, M., 1996. Simulating the Baltic Sea ice season with a coupled ice-ocean model. *Tellus. Series A: Dynamic Meteorology and Oceanography*, 48A, 622-643.

Haidvogel, D.B. and Beckman, A., 1998. Numerical models of the coastal ocean, Vol. 10. In: K.H. Brink and A.R. Robinson (eds): The Sea. *The global coastal ocean. Processes and methods.* New York, John Wiley & Sons,

Harbison, G.R. and Volovik, S.P., 1994. The ctenophore, *Mnemopsis leidyi*, in the Black Sea: a holoplanktonic organism transported in the ballast water of ships, 25-32 pp. In: NOAA. *Proceedings of the Conference and Workshop on Nonindigenous Estuarine and Marine Organisms (NEMO)*, Seattle, Washington. NOAA.

Hasselmann, K., Raney, R.K., Plant, W.J., Alpers, W., Shuchman, R.A., Lyzenga, D.R., Rufenach, C.L. and Tucher, M.J., 1985: Theory of synthetic aperture radar ocean imaging. *Journal of Geophysical Research*, 90, 4659-4686.

Hinrichsen, D., 1981. The Caribbean. *Ambio*, 10 special issue, No. 6.

Hinrichsen, D., 1998. *Coastal Waters of the World: Trends, Threats, and Strategies*. Washington, D.C., Island Press, 275 pp.

Hofmann, E.E. and Friedrichs, M.A.M., 2002. Predictive Modelling for Marine Ecosystems, Vol. 12. In: A.R. Robinson, J.J. McCarthy and B.J. Rothschild (eds). *The Sea. Biological-Physical Interactions in the sea*, New York, John Wiley & Sons.

Hofmann, E.E. and Lascara, C.M., 1998. Overview of interdisciplinary modeling for marine ecosystems, Vol. 10. In K.H. Brink and A.R. Robinson (eds): *The Sea. The global coastal ocean. Processes and methods*, New York, John Wiley & Sons.

Hollowed, A B., Bax, N., Beamish, R., Collie, J., Fogarty, M., Livingston, P., Pope, J. and Rice, J.C., 2000. Application of multispecies models in assessment of impacts of commercial fishing. Symposium proceedings on the ecosystem effects of fishing, *ICES Journal of Marine Science*, 57, 707-719.

Hood, R.R., Wang, H.V., Purcell, J.E., Houde, E.D. and Harding, L.V., 1999. Modeling particles and pelagic organisms in Chesapeake Bay: Convergent features control plankton distributions. *Journal of Geophysical Research*, 104, 1223-1243.

Houde, E.D. and Rutherford, E.S., 1993. Recent trends in estuarine fisheries: predictions of fish production and yield. *Estuaries*, 16, 161-176.

Howarth, R. W. 1998. An assessment of human influences on inputs of nitrogen to the estuaries and continental shelves of the North Atlantic Ocean. *Nutrient Cycling in Agroecosystems*, 52, 213-223.

Howarth, R.W., Fruci, J.R. and Sherman, D., 1991. Inputs of sediment and carbon to an estuarine ecosystem: Influence of land use. *Ecological Application*, 1, 27-39.

Howarth, R.W., Anderson, D., Cloern, J., Elfring, C., Hopkinson, C., Lapointe, B., Malone, T., Marcus, N., McGlahery, K., Sharpley, A. and Walker, D., 2000. Nutrient pollution of coastal rivers, bays and seas. Issues In *Ecology, Ecological Society of America*, 7, 15 pp.

IOC, 1994. *Protocols for the Joint Global Ocean Flux Study (JGOFS) core measurements*. Paris, UNESCO, 170 pp. (Manuals and Guides, 29)

IOC, 1996. *A strategic plan for the assessment and prediction of the health of the ocean: a module of the Global Ocean Observing System*. Paris, UNESCO (IOC/INF-1044).

IOC, 1998a. *The Global Ocean Observing System Prospectus* 1998. Paris, UNESCO, 168 pp. (GOOS Publication No. 42)

IOC, 1998b. *Strategic plan and principles for the Global Ocean Observing System (GOOS)*. Paris, UNESCO (IOC/INF-1091).

IOC, 2000. *Meeting of the Ad Hoc Working Group on Oceanographic Data Exchange Policy*, UNESCO Headquarters, Paris, France, 15-17 May, 2000. Paris, UNESCO, 53 pp. (IOC/INF-1144).

IOC, 2001. *The Final Design Plan for the HOTO Module of GOOS*. Paris, UNESCO (IOC/INF-1167).

IOC, 2002. GOOS Data and information Management Strategy and Plan. Paris, UNESCO (IOC/INF-1168).

IOC/SCOR, 2002. *Improved Global Bathymetry – Final Report of SCOR Working Group 107*. Paris, UNESCO (IOC Technical Series, 63).

IUCN, 2000. A world strategy for conservation and sustainable management of water resources in the 21st century. 69 pp.

Jackson, J.B.C., Kirby, M.X., Berger, W.H., Bjorndal, K.A., Botsford, L.W., Bourque, B.J., Bradbury, R.H., Cooke, R., Erlandson, J., Estes, J.A., Hughes, T.P., Kidwell, S., Lange, C.B., Lenihan, H.S., Pandolfi, J.M., Peterson, C.H., Steneck, R.S., Tegner, M.J., Warner, R.R., 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science*, 293, 629-643.

Jickells, T.D., 1998. Nutrient Biogeochemistry of the Coastal Zone. *Science*, 281, 217-222.

Kelleher, G., Bleakley, C. and Wells, S. (eds), 1995. *A Global Representative System of Marine Protected Areas*. Washington, D.C., World Bank, Vol. 1.

Kemp, W.M. and Bartleson, R.D., 1991. Preliminary ecosystem simulations of estuarine plankton-benthic interactions: The benthic submodel. p. 253-264. In: J.A. Mihursky, et al. (eds.): *New Perspectives in the Chesapeake Bay System*. Solomons, MD, CRC Publication.

Kemp, W.M. and Boynton, W.R., 1997. Eutrophication, habitat dynamics and trophic feedbacks: understanding and managing coastal ecosystems. In the Stockholm Water Symposium, Rivers to the Sea: Interaction of Land Activities, Fresh Water and Enclosed Coastal Seas, pp. 93-103. In: Joint Conference, 7th Water Symposium and the 3rd International Conference on the Environmental Management of Enclosed Coastal Seas, *Proceedings*. Stockholm.

Kistler, R., Kalnay, E., Collins, W., Saha, S., White, G., Woollen, J., Chelliah, M., Ebisuzaki, W., Kanamitsu, M., Kousky, V., van den Dool, H., Jenne, R. and Fiorino, M., 2001: The NCEP-NCAR 50-Year Reanalysis: Monthly Means CD-ROM and Documentation. *Bulletin of the American Meteorological Society*, 82, 247-268.

Kite-Powell, H.L., Farrow, S. and Sassone, P., 1994. *Quantitative estimation of benefits and costs of a proposed coastal forecast system*. Report NOAA's National Ocean Service. Marine Policy Center, Woods Hole, Massachusetts, Woods Hole Oceanographic Institution.

Klaasen, C.D. and Eaton, D.L., 1991. Principles of toxicology, p. 12-49. In: M.O. Amdur, J. Doull, and C. Klaasen (eds). *D Casarett and Doull's Toxicology.* New York, Pergamon Press.

Koblinsky, C.J. and Smith, N.R. (eds), 2001. *Observing the Oceans in the 21st Century.* Melbourne GODAE Project Office, Bureau of Meteorology, p. 391-418.

Komar, P.D., 1998. *Beach processes and sedimentation*. New Jersey: Prentice-Hall, 544 pp.

Kremer, J. N., Kemp, W.M., Giblin, A., Valiela, I., Seitzinger, S., Hofmann, E., 2000. p. 299-346, In: J.E. Hobbie (ed.). *Estuarine science: A synthetic approach to research and practice*. Washington D.C., Island Press

Kudela, R.M. and Chavez, F.P., 2000. Modeling the impact of the 1992 El Niño on new production in Monterey Bay, California. *Deep-Sea Research*. II, 47, 1055-1076.

Lawson, L., Hofmann, E. and Spitz, Y., 1996. Time series sampling and data assimilation in a simple marine ecosystem model. *Deep-Sea Research*, 43, 625-621.

Levin, S.A., 1992. The problem of pattern and scale in ecology. *Ecology*, 73, 1943-1967.

Levine, S.N., 1989. Theoretical and methodological reasons for variability in the responses of aquatic ecosystem processes to chemical stresses, p. 145-179. In: S.A. Levin, M.A. Harwell, J.R. Kelly and K.D. Kimball (eds.): *Ecotoxicology: problems and approaches*, Berlin, Springer-Verlag.

Lewis, T., 1989. Tragedy in Alaska. *National Wildlife Magazine*, June-July, p. 5-9.

Lillycrop, W.J., Irish, J.L. and L.E. Parson, 1997. SHOALS System. *Sea Technology*, 38(6), 17-25.

Limburg, K.E. and Schmidt, R.E., 1990. Patterns of Fish Spawning in Hudson River Tributaries: Response to an Urban Gradient? *Ecology*. 71, 1231-1245.

Linden, E., 2000. Condition critical. *Time*, 155, 18-24.

Liu, K.K., Iseki, K. and Chao, S.Y., 2000. Continental margin carbon fluxes, p. 187-239. In R.B. Hanson, H.W. Ducklow, and J.G. Field. *The Changing Ocean Carbon Cycle*, Cambridge, Cambridge University Press.

Lozano, C.J., Robinson, A.R., Arango, H.G., Gangopadhyay, A., Sloan, N.Q., Haley, P.J. and Leslie, W.G., 1996. An interdisciplinary ocean prediction system: assimilation strategies and structured data models. In: P.Malanotte-Rizzoli, ed., *Modern Approaches to data assimilation in Ocean Modeling*, Amsterdam, Elsevier Science. (Elsevier Oceanography Series).

Lung, W.-S., 1989. *Water quality modeling: III. Application to estuaries*. Boca Raton, FL, CRC Press.

MacGarvin, M., 1990. *The North Sea*. London. Collins and Brown.

Mackay, D., 1991. *Multimedia Environmental Models: the Fugacity Approach*. Chelsea, MI, Lewis Publishers.

Malone, T.C. and Cole, M., 2000. Toward a global scale coastal ocean observing system. *Oceanography*, 13 (1), 7-11.

Mann, K.H., 1976. Production on the bottom of the sea. In D.H. Cushing and J.J. Walsh (eds.): *The Ecology of the Seas,* p. 225-250. London, Blackwell Scientific Publications.

Maragos, J.E., Crosby, M.P. and McManus, J., 1996. Coral reefs and biodiversity: A critical and threatened relationship. *Oceanography*, 9, 83-99.

Mikolajewicz, U., Santer, B.D. and Maier-Reimer, E., 1990. Ocean response to greenhouse warming. *Nature*, 345, 589-593.

Mitsch, W.J., Mitsch, R.H. and Turner, R.E., 1994. *Wetlands of the old and new worlds: ecology and management*.

Moll, A. and Radach, G., 2001. *Synthesis and new conception of North Sea Reasearch. Working Group 6: Review of three-dimensional ecological modelling related to the North Sea shelf system*. Hamburg, Zentrum für Meeres- und Klimaforschung der Universität Hamburg. 225 pp.

Najjar, R.G., Walker, H.A., Anderson, P.J., Barron, E.J., Bord, R.J., Gibson, J.R., Kennedy, V.S., Knight, C.G., Megonigal, J.P., O'Connor, R.E., Polsky, C.D., Psuty, N.P., Richards, B.A., Sorenson, L.G., Steele, E.M. and Swanson, R.S., 2000. The potential impacts of climate change on the Mid-Atlantic coastal region. *Climate Research*, 14, 219-233.

Nendza, M., 1998. *Structure-Activity Relationships in Environmental Sciences*. London, Chapman and Hall, 269 pp.

Nicholls, R.J. and Leatherman, S.P. (eds.), 1995. The Potential Impacts of Accelerated Sea-Level Rise on Developing Countries. *Journal of Coastal Research*, 14 Special Issue, 323 pp.

Nicholls, R.J. and Small, C., 2002. Improved estimates of coastal population and exposure to hazards. *EOS*, 83, 301.

Nihoul, J.C.J. and Djenidi, S., 1998. Coupled physical, chemical and biological models, Vol. 10, p. 483-506. In: K.H. Brink and A.R. Robinson (eds.): *The Sea: The Global Coastal Ocean, Processes and Methods*, New York, John Wiley & Sons.

Nixon, S.W., 1996. Regional coastal research -- What is it? Why do it? What role should NAML play? *The Biological Bulletin*, 190, 252-259.

NOAA-IOC, 1996. *Workshop on Socio-Economic Aspects of the Global Ocean Observing System: Assessing benefits and costs of the climate and coastal modules*. Bethesda, Maryland.

NOAA, 1998. *Population: Distribution, Density and Growth*. In: Thomas J. Cullition. NOAA's State of the Coast Report. Silver Spring, MD. URL: state-of-coast.noaa.gov/bulletins/html/pop_01/pop.html.

Norse, E.A., 1996. A river that flows to the sea: the marine biological diversity movement. *Oceanography*, 9, 5-9.

North Sea Task Force, 1993. *North Sea Subregion 1, Assessment Report 1993, Norway and the United Kingdom*. Oslo, State Pollution Control Authority, p. 5-29.

Nowlin, W.D., Briscoe, M., Smith, N., Needler, G., McPhaden, M., Roemmich, D., Chapman, P., and Grassle, J., 2001. Evolution of a Sustained Ocean Observing System. *Bulletin of the American Meteorological Society*, 82, 1369-1376.

Nowlin, W.D., Smith, N., Needler, G., Taylor, P.K., Weller, R., Schmitt, R., Merlivat, L., Vezina, A, Alexiou, A., McPhaden, M. and Wakatsuchi, W., 1996. An ocean observing system for climate. *Bulletin of the American Meteorological Society*, 77, 2243-2273.

NRC, 1992. *Marine Aquaculture: Opportunities for Growth*. Washington, D.C., National Academy Press, 290 pp.

NRC, 1994. *Priorities for Coastal Ecosystem Science*. Washington, D.C., National Academy Press, 106 pp.

NRC, 1996a. *Upstream: Salmon and Society in the Pacific Northwest*. Washington, D.C., National Academy Press.

NRC, 1996b. *Priorities for coastal ecosystem science*. Washington, D.C., National Academy Press, 106 pp.

NRC, 1999a. *Sustaining Marine Fisheries*. Washington, D.C., National Academy Press, 164 pp.

NRC, 1999b. *From Monsoons to Microbes: Understanding the Ocean's Role in Human Health*. Washington, D.C., National Academy Press, 144 pp.

NRC, 2000. *Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution*. Washington, D.C., National Academy Press.

NRC, 2001. *Transforming Remote Sensing Data into Information and Applications*. Washington, D.C., National Academy Press, 75 pp.

NSC, 1998. *Coastal Challenges: A Guide to Coastal and Marine Issues*. Washington, D.C., National Safety Council's Environmental Health Center, 178 pp.

Ocean.US, 2002. *Building Consensus: Toward an Integrated and Sustained Ocean Observing System (IOOS)*. Arlington, VA., Ocean US, 175 pp.

Odum, E.P., 1971. *Fundamentals of Ecology*. Philadelphia, Saunders, 574 pp.

OECD, 1989. *Compendium of Environmental Exposure Assessment Methods for Chemicals*. Paris, (OECD Environment Monographs, No 27).

OECD, 1993. *OECD core set of indicators for environmental performance reviews*. Paris.

O'Malley, R. and Wing, K., 2000. Forging a new tool for ecosystem reporting. *Environment*, 42, 20-31.

Parris, T.M., 2000. Tracking down state of the environment reports. *Environment*, 42, 3-4.

Parsons, T.R., Takahashi, M. and Hargrave, B., 1984. *Biological Oceanographic Processes*, 3rd ed. Oxford, Pergamon Press, 323 pp.

Parsons, T.R., Maita, Y. and Lalli, C.M., 1984. *A Manual of Chemical and Biological Methods for Seawater Analysis*. Oxford,Pergamon Press, U.K., 172 pp.

Pastor, X. (ed.), 1991. *The Mediterranean*. London, Collins and Brown, p. 29-93.

Pastres, R., Solidoro, C., Cossarini, G., Canu, D.M. and Dejak, C., 2001. Managing the rearing of Tapes philippinarum in the lagoon of Venice: a decision support system. *Ecological Modelling*, 138, 231-245.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R. and Torres, F. Jr., 1998. Fishing down marine food webs. *Science*, 279, 860-863.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Rashid Sumaila, U., Walters, C.J., Watson, R. and Zeller, D., 2002. Towards sustainability in world fisheries. *Nature* 418, 689 - 695.

Pearce, F., 1995. Dead in the water. *New Scientist*, 145, 26-31.

Pearce, K.F. and Frid, C.L.J., 1999. Coincident changes in four components of the North Sea ecosystem. *Journal of the Marine Biological Association*, 79, 183-185.

Peierls, B.L., Caraco, N.F., Pace, M.L. and Cole, J.J., 1991. Human influences on river nitrogen. *Nature*, 350, 386-387.

Petersen, J.E., Chen, C.C. and Kemp, W.M., 1997. Spatial scaling of aquatic primary productivity: experiments under nutrient and light-limited conditions. *Ecology*, 78, 2326-2338.

Pimentel, D., Lach, L., Zuniga, R. and Morrison, D., 1999. *Environmental and Economic Costs Associated with Non-Indigenous Species in the United States*, Cornell University, College of Agriculture and Life Sciences. U.S. Department of Agriculture. 17 pp.

Pinet, P.R., 1999. *Invitation to Oceanography*, 2nd ed. Sudbury, Mass., Jones and Bartlett Publishers, 556 pp.

Powell, T., 1989. Physical and biological scales of variability in lakes, estuaries, and the coastal ocean, p. 157-180. In: J. Roughgarden, R.M. May, and S.A. Levin (eds.): *Perspectives in theoretical ecology*, Princeton, N.J., Princeton University Press.

Pugh, D.T., 1987. *Tides, Surges and Mean Sea Level*. New York, John Wiley & Sons. 472 pp.

Quinn, T.J. and Deriso, R.B. 1999. *Quantitative Fish Dynamics*. New York, Oxford University Press, 542 pp.

Ralston, S. and Polovina, J.J., 1982. A multispecies analysis of the commercial deep-sea handline fishery in Hawaii. *Fishery Bulletin*, 80, 435-448.

RAMSAR, 2001. *Background Papers on Wetland Values and Functions.* URL: www.ramsar.org/values_intro_ e.htm

Riedlinger, S.H. and Preller, R.H., 1991. The development of a coupled ice-ocean model for forecasting ice conditions in the Arctic. *Journal of Geophysical Research*, 96, 16, 955-977.

Roberts, J.R., Mitchell, M.S., Boddington, M.J. and Ridgeway, J.M., 1981. *A screen for the relative persistence of lipophilic organic chemicals in aquatic ecosystems. – an analysis of the role of a simple computer model in screening. Part 1*. Ottawa, National research Council of Canada. (Rep. No. NRCC 18570).

Robinson, A.R., 1999. Forecasting and simulating coastal ocean processes and variabilities with the Harvard ocean prediction system. *Coastal Ocean Prediction*, *AGU Coastal and Estuarine Studies*, 56, 77-99.

Robinson, A. R. and Lermusiaux, P.F., 2002. Data assimilation for modeling and predicting coupled physical-biological interactions in the sea, Vol. 12. In: A.R. Robinson, J. J. McCarthy and B. J. Rothschild (eds): *The Sea. Biological-Physical Interactions in the sea*, New York, John Wiley & Sons.

Ross, A.H., Gurney, W. and Heath, M., 1993. Ecosystem models of Scottish sea lochs for assessing the impact of nutrient enrichment. ICES. *Journal of Marine Science*, 50, 359-367.

Rothschild, B.J. and Fogarty, M.J., 1998. Recruitment and the population dynamics process, Vol. 10, p. 293-325. In: Edited by K.H. Brink and A.R. Robinson (eds.): *The Sea. The Global Coastal Ocean I. Processes and Methods.* New York, John Wiley & Sons.

Rotmans, J. and de Vries, B. (eds), 1997. *Perspectives on global change: the TARGETS approach*. Cambridge, Cambridge University Press, 463 pp.

Sarmiento, J.L., Slater, R.D., Fasham, M.J.R., Ducklow, H.W., Toggweiler, J.R. and G.T. Evans, 1993. A seasonal three-dimensional ecosystem model of nitrogen cycling in the North Atlantic euphotic zone. *Global Biogeochemical Cycles,* 7, 417-450.

Saucier, F.J. and Dionne, J., 1998. A 3-D coupled ice-ocean model applied to Hudson Bay, Canada: The seasonal cycle and time-dependent climate response to atmospheric forcing and runoff. *Journal of Geophysical Research*, 103, 27689-27705.

Sherman, K., 1991. The large marine ecosystem concept: research and management strategy for living marine resources. *Ecological Applications*, 1, 349-360.

Sherman, K., 1994. Sustainability, biomass yields, and health of coastal ecosystems: an ecological perspective. *Marine Ecology Progress Series*, 112, 277-301.

Sherman, K. and Duda, A.M., 1999. An ecosystem approach to global assessment and management of coastal waters. *Marine Ecology Progress Series,* 190, 271-287.

Shuto, N., 1991. Numerical simulation of Tsunami - Its present and near future. *Natural Hazard*, 4, 171-191.

Shuval, H., 2003. Estimating the global burden of thalassogenic disease- human infectious disease caused by wastewater pollution of the marine environment. *Journal of Water and Health*, 1, (in press).

Small, C., Gornitz, V. and Cohen, J.E., 2000. Coastal hazards and the global distribution of human population. *Environmental Geosciences*, 7, 3-12.

Small, C. and Nicholls, R.J., 2003. A global analysis of human settlement in the coastal zone. *Journal of Coastal Research* (in press).

Smayda, T.J. and Shimizu, Y. (eds.), 1993. *Toxic Phytoplankton Blooms in the Sea*, *Proceedings of the Fifth International Conference on Toxic Marine Phytoplankton*. Amsterdam, Elsevier.

Soares, M. (ed.), 1998. *The Ocean: Our Future. Report of the Independent World Commission on the Oceans*, Cambridge, Cambridge University Press, 247 pp.

Souter, D.W. and Linden, O., 2000. The health and future of coral reef systems. *Ocean and Coastal Management* 43, 657-688.

Spalding, M.D., Blasco, F. and Field, C.D., 1997. *World Mangrove Atlas*. Okinawa, The International Society for Mangrove Ecosystems, 187 pp.

Spaulding, M.L., 1988: A state-of-the art review of oil spill trajectory and fate modeling. *Oil & Chemical Pollution*, 4, 39-55.

Steele, J.H., 1985. A comparison of terrestrial and marine ecological systems. *Nature*, 313, 355-358.

Steiner, R., 1995. Probing an oil-stained legacy. *National Wildlife*, 31(3), 4-11.

Stel, J.H. and Mannix, B.F., 1997. *A benefit-cost analysis of a regional Global Ocean Observing System: Seawatch Europe.* Marine Policy.

Stockdon, H.F. and Holman, R.A., 2000. Estimation of wave phase speed and nearshore bathymetry from video imagery. *Journal of Geophysical Research*, 105, 22015-22033.

Strickland, J.D.H. and Parsons, T.R., 1972. *A Practical Handbook of Seawater Analysis.* Ottawa, Fish. Res. Bd. Can., 310 pp.

Suter, G.W., 1993. *Ecological Risk Assessment*. Michigan Lewis Publishers, 538 pp.

Sætre, R., Skjodal, M., Flemming, N.C. and van Beek, F., 2001. *Toward a North Sea ecosystem component of GOOS for assessment and management*, *Report from a strategic workshop in Bergen 5-7 September 2001*, Fisken Og Havet, No. 11.

Tiner, R.W., 1984. *Wetlands of the United States: Current Status and Trends*. Washington, D.C., U.S. Fish and Wildlife Service,

Turner, R.K. and Adger, W.N., 1995. *Coastal Zone Resources Assessment Guidelines*. LOICZ, (Reports and Studies No. 4).

Turner, R.K., van den Bergh, C.J.M., Soderqvist, T., Barendregt, A., van der Straaten, J., Maltby, E. and van Ierland, E.C., 2000. Ecological-economic analysis of wetlands: scientific integration for management and policy. *Ecological Economics*, 35, 7-23.

United Nations, 1996. *Country population statistics and projections 1950-2050*. Report. Rome, Food and Agricultural Organization of the United Nations.

United Nations, 1998. *Trends in urbanization and the components or urban growth*. In Proceedings of the Symposium on Internal Migration and Urbanization in Developing Countries, 22-24 January 1996. New York: United Nations Population Fund.

UNEP, 1992a. Assessing the Impact of the Kuwait Oil Fires. *Siren*, 47, 4.

UNEP, 1992b. Lessons of the War. *Siren*, 45, 1-4.

UNEP, 1995. *Global program of action for the protection of the marine environment from land-based activities*. UNEP ((OCA)/LBA/IG.2/7).

UNEP, 2000. *Global Change of Infoterra to UNEP-Infoterra: Enabling Countries to Build an Integrated Environmental Information Service*. UNEP/INF2000/WP/3, 11 September, 2000.

UNEP, 2001. *Ecosystem-based management of fisheries: Opportunities and challenges for coordination between marine Regional Fishery Bodies and Regional Seas Conventions.* (UNEP Regional Seas Reports and Studies No. 175).

UNEP/GPA, 2000. *Recommendations for Decision-making on Municipal Wastewater: Practical Policy Guidance for Implementing The Global Programme of Action for the Protection of the Marine Environment from Land-based Activities* (GPA) on Sewage.

Vitousek, P.M., Aber, J.D., Howarth, R.H., Likens, G.E., Matson, P.A., Schindler, D.W., Schlesinger, W.H., and Tilman, D.G., 1997. Human alterations of the global nitrogen cycle: causes and consequences. *Ecological Applications*, 7, 737-750.

Walsh, E.J., Shay, L.K., Graber, H.C., Guillaume, A., Vandemark, D., Hines, D.E., Swift, R.N. and Scott, J.F., 1996: Observations of surface wave-current interaction during SWADE. *The Global Atmosphere and Ocean System*, Vol. 5, 99-124.

Warner, A.J. and Hays, G.C., 1994. Sampling by the continuous plankton recorder survey. *Progress in Oceanography*, 34, 237-256.

Warrick, R. A., LeProvost, C., Meier, M.F., Oerlemans, J., and Woodworth, P.L., 1996. Changes in sea level, p. 361-405. In: J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell (eds.): *Climate Change 1995*, *The Science of Climate Change*: Cambridge, Cambridge University Press,

Watling, L. and Norse, E., 1998. Introduction, Special section: effects of Mobile Fishing Gear on Marine Benthos. *Conservation Biology*, 12, 1180-1197.

Whelan, G., Strenge, D.L., Droppo, Jr, J.G., Steelman, B.L. and Buck, J.W., 1987. *The remedial action priority system (RAPS): Mathematical Formulations, PNL-6200*. Richland, Wash., Pacific Northwest Laboratory.

Whipple, S., Link, J.S., Garrison, L.P. and Fogarty, M.J., 2000. Models of predation and fishing mortality in aquatic ecosystems. *Fish and Fisheries*, 1, 22-40.

WHO, 1998. *Draft Guidelines for Safe Recreational-Water Environments: Coastal and Fresh Waters, Draft for Consultation, Geneva, October 1998*. Geneva, World Health Organization, 207 pp. (EOS/DRAFT/98.14).

Wilkinson, C. (ed.), 1998. *Status of Coral Reefs of the World: 1998*, Australian Institute of Marine Science, 184 pp.

Wilkinson, C., Lindén, O., Cesar, H., Hodgson, G., Rubens, J. and Strong, A.E., 1999. Ecological and socioeconomic impacts of the 1998 coral mortality in the Indian Ocean: an ENSO impact and a warning of future change? *Ambio*, 28, 188-196.

World Bank. 1991. *Urban Policy and Economic Development: An Agenda for the 1990s*. Washington, D.C.: World Bank.

World Bank. World Development Report, 1993. *Investing in Health - World Development Indicators*. Oxford, Oxford University Press.

World Resources Institute (WRI), 1998. *World Resources 1998-99*. New York, Oxford University Press. 369 pp.

Yao, T., Tang, C.L. and Peterson, I.K., 2000. Modeling the seasonal variation of sea ice in the Labrador Sea with a coupled multi-category ice model and the Princeton Ocean Model. *Journal of Geophysical Research*, 105, 1153-1165.

ANNEX XII – Acronyms

ADCP	Acoustic Doppler Current Profiler
ADEOS	Advanced Earth Observing Satellite (Japan)
APHA	American Public Health Association
ARIES	Australian Resource Information and Environment Satellite
AUV	Autonomous Underwater Vehicle
AVHRR	Advanced Very High Resolution Radiometer
AWWA	American Water Works Association
AXBT	Airborne Expendable Bathythermograph
BOOS	Baltic Operational Oceanographic System
CalCOFI	California Cooperative Fisheries Investigation
CAOS	Co-ordinated Adriatic Observing System
CARICOMP	Caribbean Coastal Marine Productivity (Launched by UNESCO)
CBD	Convention on Biological Diversity (Rio de Janeiro, 1992)
CBS	Commission for Basic Systems (WMO)
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CCI	Commission of Climatology
CDOM	Coloured Dissolved Organic Matter
CEC	Commission of the European Communities
CEOS	Committee on Earth Observation Satellites
C-GOOS	Coastal Panel of GOOS
C-GTOS	Coastal module of GTOS
Chl	Chlorophyll
CITES	Convention on International Trade in Endangered Species
CLIVAR	Climate Variability and Predictability
CODAR	High Frequency Coastal Radar
CoML	Census of Marine Life
COOP	Coastal Ocean Observations Panel (GOOS)
CPR	Continuous Plankton Recorder
CSPI	Center for Science in the Public Interest (USA)
DMAC	Data Management and Communications System
DNA	Designated National Agency
DPSIR	Driver-Pressure-State-Impact-Response
EEZ	Exclusive Economic Zone
ENSO	El Niño Southern Oscillation
ENVISAT	ENVIronment SATellite (ESA)
EOS	Earth Observation Satellite/Earth Observation System
ESA	European Space Agency

EU	European Union
EuroGOOS	European GOOS
FAO	Food and Agriculture Organization of the United Nations
GAW	Global Atmosphere Watch
GBIF	Global Biodiversity Information Facility
GCOS	Global Climate Observing System
GCRMN	Global Coral Reef Monitoring Network
GEBCO	General Bathymetric Chart of the Oceans
GEOHAB	Global Ecology of Harmful Algal Blooms
GESAMP	Group of Experts on the Scientific Prospects of Marine Environmental Protection
GHOST	Global Horizontal Sounding Technique
GHRSST	High Resolution Sea Surface Temperature
GIPME	Global Investigation of Pollution in the Marine Environment (IOC)
GIS	Geographic Information System
GIWA	Global International Water Assessment
GLCCS	Global Land Cover Characteristics Database
GLOBEC	Global Ocean Ecosystem Dynamics
GLOSS	Global Sea Level Observing System
GODAE	Global Ocean Data Assimilation Experiment
GOSIC	Global Observing System Information Centre
GOTOS	Global Ocean Time Series Observatory System
GPA	Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (UNEP)
GPS	Global Positioning System
GRA	GOOS Regional Alliance
GSC	GOOS Steering Committee
GTOS	Global Terrestrial Observing System
HAB	Harmful Algal Bloom
HELCOM	Helsinki Commission Baltic Marine Environment Protection Commission
HOTO	Health of the Oceans (IOC)
IAEA	International Atomic Energy Agency
IATTC	Inter-American Tropical Tuna Commission
IBOY	International Biodiversity Observation Year
IBSFC	International Baltic Sea Fishery Commission
IBTS	International Bottom Trawl Survey of the North Sea
ICES	International Council for the Exploitation of the Sea
ICM	Integrated Coastal Management
ICSU	International Council for Science
IGBP	International Geosphere - Biosphere Programme
I-GOOS	IOC-WMO-UNEP Intergovernmental Committee for the Global Ocean Observing System
IGOS	Integrated Global Observing Strategy
IGS	International GPS Service for Geodynamics
I-LTER	International LTER
IOC	Intergovernmental Oceanographic Commission (of UNESCO)
IOCCG	International Ocean-Colour Coordinating Group
IODE	International Ocean Data and Information Exchange programme (IOC)
IPHAB	Intergovernmental Panel on HABs (IOC)
IPHC	International Pacific Halibut Commission
ITSU	International co-ordination group for the TSUnami Warning System in the Pacific (IOC)
IUCN	International Union for the Conservation of Nature (and Natural Resources)
IWC	International Whaling Commission

JCOMM	Joint Technical Commission for Oceanography and Marine Meteorology (IOC-WMO)
JDIMP	Joint Data and Information Management Panel
JGOFS	Joint Global Ocean Flux Study
LIDAR	Light Detection and Ranging
LME	Large Marine Ecosystem
LMR	Living Marine Resources
LOICZ	Land-Ocean Interaction in the Coastal Zone (IGBP)
LTER	Long-Term Ecosystem Research network
MAMA	Mediterranean Network to Assess and upgrade the Monitoring and forecasting Activity in the basin
MFS	Mediterranean Forecasting System
MODIS	Moderate Resolution Imaging Spectroradiometer
MOS	Modular Optoelectronic Scanner
MSG	Meteosat Second Generation
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration (USA)
NASCO	North Atlantic Salmon Conservation Organization
NEAR-GOOS	North East Asian GOOS
NEMO	Naval Earth Map Observer (USA)
NGO	Non-governmental Organization
NOAA	National Oceanic and Atmospheric Administration (USA)
NODC	National Oceanographic Data Centre (IODE)
NPAFC	North Pacific Anadromous Fish Commission
NRC	National Research Council (Canada/USA)
NRT	Near Real Time
NSEAM	North Sea Ecosystem Assessment and Management
NWP	Numerical Weather Prediction
OBIS	Ocean Biogeographical Information Systems
OCTS	Ocean Colour and Temperature Scanner
OECD	Organization for Economic Co-operation and Development
OOPC	Ocean Observations Panel for Climate (GCOS-GOOS-WCRP)
OOSDP	Ocean Observing System Development Panel
OSPARCOM	Convention Commission for the Protection of the Marine Environment of the North-East Atlantic
OSSE	Observation System Simulation Experiments
PAGE	Past Global Changes (IGEP)
PAH	Polycyclic Aromatic Hydrocarbons
PAR	Phosynthetically Active Radiation
PCB	Polychlorinated Biphenil
PDO	Pacific Decadal Oscillation
PICES	North Pacific Marine Science Organization
POLDER	Polarization and Directionality of the Earth's Reflectances
POP	Persistant Organic Pollutant
PSP	Paralytic Shellfish Poisoning
PSR	Pressure State Response
QUIJOTE	QUickly Integrated Joint Observing TEam
QA/QC	Quality Assurance and Quality Control
RAMP	Rapid Assessment of Marine Pollution
RFBs	Regional Fishery Bodies
RNODC	Responsible NODC
RSC	Regional Seas Convention

RSP	Regional Seas Programme/Convention (UNEP)
SAR	Synthetic Aperture Radar
SCOR	Scientific Committee on Oceanic Research
SEAS	Shipboard Environmental Data Acquisition System
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SIMBIOS	Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (NASA)
SOLAS	Safety of Life At Sea
SOOP	Ship Of Opportunity Programme
SPC	South Pacific Commission
SRA	Surface Contour Radar
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
TEMA	Training, Education and Mutual Assistance (IOC)
TEMS	Terrestrial Ecosystem Monitoring Sites
TOGA	Tropical Ocean and Global Atmosphere
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
VOS	Voluntary Observing Ships
WCMC	World Conservation Monitoring Centre
WCRP	World Climate Research Programme
WEF	Water Environment Federation
WESTPAC	IOC Sub-Commission for the Western Pacific
WHO	World Health Organization
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WRI	World Resources Institute
WSA	World Seagrass Association
WWW	World Weather Watch
XBT	Expendable Bathythermograph