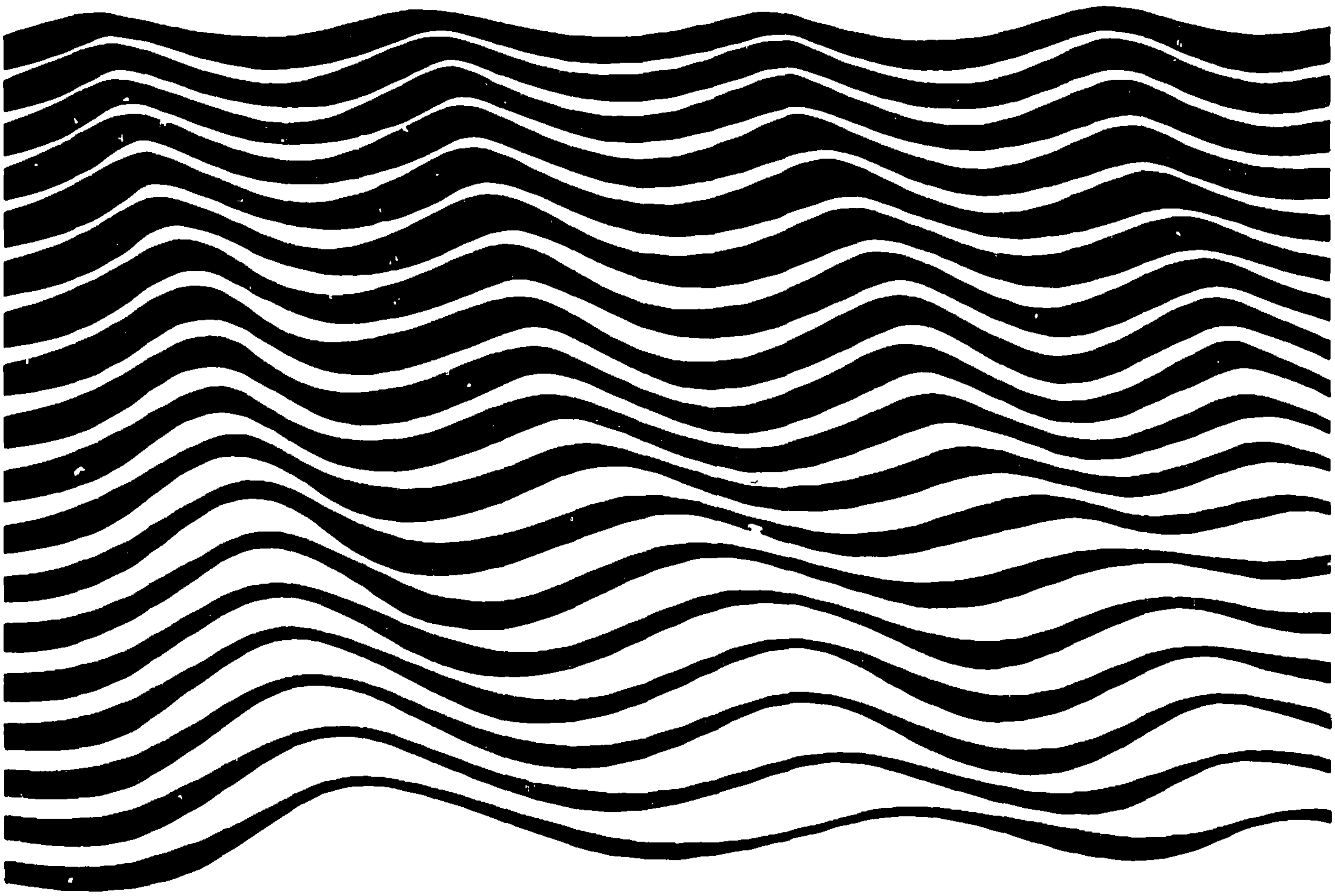
Unesco technical papers
in marine science 32

Coastal lagoon research, present and future

Report and guidelines of a seminar
Duke University Marine Laboratory
Beaufort, NC
U.S.A.
August 1978
(Unesco, IABO)



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No.		Year	SCOR WG
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16	Sixth report of the joint panel on oceanographic tables and standards, Kiel, 24-26 January 1973; sponsored by Unesco, ICES, SCOR, IAPSO	1974	WG 10
17	An intercomparison of some current meters, report on an experiment of Research Vessel Akademic Kurchatov, March-April 1970, by the Working Group on Current Velocity Measurements; sponsored by SCOR, IAPSO, Unesco	1974	WG 21
19	Marine Science Teaching at the University Level. Report of the Unesco Workshop on University Curricula - *Available in French, Spanish and Arabic*	1974	-
20	Ichthyoplankton. Report of the CICAR Ichthyoplankton Workshop - *Also published in Spanish*	1975	-
21	An intercomparison of open sea tidal pressure sensors. Report of SCOR Working Group 27: "Tides of the open sea"	1975	WG 27
22	European sub-regional co-operation in oceanography. Report of working group sponsored by the Unesco Scientific Co-operation Bureau for Europe and the Division of Marine Sciences	1975	-
23	An intercomparison of some current meters, III. Report on an experiment carried out from the Research Vessel Atlantis II, August-September 1972, by the Working Group on Continuous Velocity Measurements: sponsored by SCOR, IAPSO and Unesco	1975	WG 21
24	Seventh report of the joint panel on oceanographic tables and standards, Grenoble, 2-5 September 1975; sponsored by Unesco, ICES, SCOR, IAPSO	1976	WG 10
25	Marine science programme for the Red Sea: Recommendations of the workshop held in Bremerhaven, FRG, 22-23 October 1974; sponsored by the Deutsche Forschungsgemeinschaft and Unesco	1976	-
26	Marine science in the Gulf area - Report of a consultative meeting, Paris, 11-14 November 1975 Also published in Arabic.	1976	
27	Collected reports of the joint panel on oceanographic tables and standards, 1964-1969	1976	WG 10
28	Eighth report of the joint panel on oceanographic tables and standards, Woods Hole, U.S.A., sponsored by Unesco, ICES, SCOR, IAPSO	1978	WG 10
29	Committee for the preparation of CLOFETA - Report of the first meeting, Paris, 16-18 janvier 1978	1979	-
30	Ninth report of the joint panel on oceanographic tables and standards, Unesco, Paris. 11-13 September 1978	1979	-
31	Coastal lagoon survey (1976-1978)	1980	-
32	Costal lagoon research, present and future. Report and guidelines of a seminar, Duke University Marine Laboratory, Beaufort, NC, U.S.A., August 1978. (Unesco, IABO). To be published in 1981	1981	-
33	Coastal lagoon research, present and future. Proceedings of a seminar, Duke University, August 1978. (Unesco, IABO). *To be published in English*	1981	-
34	The carbon budget of the oceans. Report of a meeting, Paris, 12-13 November 1979	1980	WG 62
35	Determination of chlorophyll in seawater. Report of intercalibration tests sponsored by SCOR and carried out by C.J. Lorenzen and S.W. Jeffrey, CSIRO Cronulla, N.S.W., Australia, September-October 1978	1980	-
36	Tenth report of the joint panel on oceanographic tables and standards, Sydney, B.C., Canada, 1-5 September 1980; sponsored by Unesco, ICES, SCOR, IAPSO	1981	WG 10

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PREFACE

This series, the *Unesco Technical Papers in Marine Sciences*, is produced by the Unesco Division of Marine Sciences as a means of informing the scientific community of recent developments in oceanographic research and marine science affairs.

Many of the texts published within the series result from research activities of the Scientific Committee on Oceanic Research (SCOR) and are submitted to Unesco for printing following final approval by SCOR of the relevant working group report.

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INTRODUCTION

As part of the Unesco programme for the research and development of the coastal systems and as a contribution to the Man and the Biosphere Programme, the seminar was an important step of the programme devoted to the coastal lagoon areas. Sponsored by Unesco, Division of Marine Sciences, the Duke University Marine Laboratory and the International Association for Biological Oceanography (IABO), the seminar was held at the Duke University Marine Laboratory, Beaufort, N.C., USA, from 29 August to 2 September 1978.

John C. Costlow, Director of the Duke Marine Laboratory, the Convenor, opened the Seminar and addressed a welcoming speech to the participants. Marc Steyaert, representative of Unesco, introduced the subject matter of the Seminar within the context of the Unesco programme for the research and development of coastal systems, while Pierre Lasserre, Unesco consultant, led the discussion for the adoption of the Agenda.

The present guidelines and report are the result of four task groups composed of the scientists listed in Annex I.

The editing was accomplished by the following :

General Editors: P. Lasserre and H. Postma

Editors:

Task Group I: G. Allen, E. Mandelli and J.P.F. Zimmermann

Task Group II: W. Krumbein, P. Lasserre and S.W. Nixon

Task Group III: A. Bentuvia and C.I. Olanyian

Task Group IV: R.N. Parker

Objectives

The objectives of the seminar were to review the major trends in coastal lagoon research, to highlight subject areas and produce guidelines for future investigations that the participants believed to be of primary importance. Four study sessions (2 days) were devoted to "present" coastal lagoon research; two other sessions (2 days) focussed on "future" coastal lagoon research. A last session was devoted to the question of training and education.

The seminar was a focal meeting ground for a diversity of scientific problems that are of immediate concern to all who are interested in the evolutionary history of coastal lagoons and their role in long term or more immediate economic national needs.

Present coastal lagoon research

A number of individual papers concerned with some important aspects of contemporary research on coastal lagoons were presented. Although this review of knowledge did not provide a complete and comprehensive account of these unique formations, their treatment explored the relevant fields both in breadth and depth, and constituted the background material for the task group discussions during the next sessions. The papers will be bound to form No. 33 in the series of Unesco Technical Papers in Marine Science.

The future of coastal lagoon research (An outline of research programmes for regional co-operation)

A thorough examination of the scientific problems involved in understanding coastal lagoons and their role in the marine environment is necessary in order to plan further and develop research programmes, bearing in mind in particular the needs of developing countries.

Great interest has been shown by the numerous responses received in reply to the SCOR/Unesco inquiry (Coastal lagoon survey, no. 31 in this series), and also by letters expressing interest. The replies to the inquiry suggested that there will be a sufficient nucleus of laboratories with a wide geographical spread to operate a minimum field programme. Other laboratories may be equipped to deal with narrowly specialized but important (critical) topics within the general objectives of the programmes.

Four groups were formed to study each of the problem areas that had been pre-selected.

It was not intended that the seminar would produce a catalogue of all the relevant problems regarding coastal lagoon research. It was meant lather to serve as a guide for identifying specific areas when a large scale field programme can be useful and successful. Examples will be given, not as specific guidelines for the future, but as samples of the kinds of programmes and surveys that may be carried out in the next few years.

A central theme of a proposed research programme would be the study of seasonal variations, and, through international co-operation, the comparative analysis of spatial variation of totally functioning lagoon ecosystems. The study of seasonal variation was proposed as a basis for the programme because one of the most consistent features of events in coastal lagoons is a wide range of geographical variation in the magnitude, regularity and pattern of these cycles. However even the basic description of them is known for only a few localities in which intensive studies have been carried out. Seasonal variation is relatively slight in many tropical areas, so one of the main objectives of the research programme would be the detection and analysis of the factors which maintain stability in these areas, compared with those which result in maximal variation in temperate and cold latitudes. It is believed that this approach would contribute as a good example towards an understanding of controlling mechanisms and limiting factors affecting eutrophic production and animal colonization.

In general, the research programme should be directed towards an understanding of totally functioning ecosystems. Particular attention should be paid to such fields as physics, biogeochemistry, population dynamics, energetics and physiological ecology (environmental adaptation).

GUIDELINES FOR RESEARCH PROGRAMMES ON COASTAL LAGOONS

Introducing remarks

The present guidelines for research programmes on coastal lagoons are not strictly guidelines as such but rather constitute a compendium of major topics according to subject areas, to be kept in mind when studying coastal lagoons. Although they are the results of the work of Task Groups I, II and III reported hereafter, for easy reading and utilization of the report, they have been placed at the beginning of the text.

PHYSICS (P)

P.1 WATER BALANCE - SALINITY - FLUSHING TIME SCALES

Water Balance and Salinity Budget

Salinity

River runoff

Rainfall

Evaporation (including influence of plants)

Ground water fluxes

Flushing time scale - Short term and seasonal variations (case study of a particular lagoon with regular freshwater input)

River runoff

Salinity

Meteorological parameters

Sea level

Water fluxes through the inlet (by means of moored current velocity meters)

P.2 HEAT BALANCE AND TEMPERATURE

Temperature cycles

Heat balance equations (less easily obtained)

Complete heat balance of a selected lagoon. This programme is to be combined with the programme on salinity budgets (P.1)

- provides either flushing time scale of the lagoon with the sea

- or, if this is known by other means, it provides extra information to obtain measurements of the heat balance by means of the evaporation terms.

P.3 OPTICS (of utmost importance with respect to its relation to primary production)

Complete investigation of the sunlight regime on a lagoon (urgently needed)

Vertical distribution of solar irradiance

Distribution of suspended matter dead or living and interactions with the seasonal cycle of primary production

Spectral composition of sunlight under water, absorption spectrum and distribution of substances responsible for that spectrum.

---> Special attention to be given to shallow lagoons (water depth from 0 to 2 m).

GEOLOGY (G)

G.1 SUSPENDED SEDIMENT TRANSPORT AND SEDIMENT INFLUX

Determination of spatial and temporally varying rates of transport within the lagoon and at the landward and seaward interfaces

In lagoons with large tidal influence:

- examine short period variations of tidal events (semi-diurnal, diurnal, fortnightly neap to spring cycle)

In lagoons with large seasonal fluctuations: (meteorological cycles/fresh water inflow/morphological changes such as inlet closure).

- make seasonal repetitive studies to evaluate the effects of those variations on suspended sediment transport

Measurements of flux of suspended sediment in and out of the seaward inlets of the lagoons

Gives information on:

- the relative amounts of sediment entering or escaping through different inlets
- the vertical distribution of fluxes
- the temporal or seasonal variations in transport intensity

Sampling

Sampling transects established at slack tides give information on the spatial distribution of suspended sediment (help localize zones of intense sedimentological activity within the lagoon).

Repeated transects as function of tides, river flow, seasons ... (gives information on time scale of suspended sediment transport).

Point measurements of the flux of suspended sediment during a complete tidal cycle (gives information on relative amounts of sediment deposited and eroded at each tide; net direction of transport; quantitative estimate of transport rates).

Foraminifers used as tracers for redistribution or "mixing" of sediment and flux of sediment into and out of the lagoon.

Remark: Programmes P + C.1 constitute a global study of the transport system.

G.2 BEDLOAD TRANSPORT

Sediment grain size map and analysis

Geographical distribution of sediment types within the lagoon help in localizing bed transport.

Regional grain size gradients indicate directions of net bedload transport and estimates of transport intensity.

Analysis of bedforms

Bedform type, size and orientation give extensive information on the direction and rates of sand movement by bedload transport.

Repetitive bedform mapping over spring-neap tidal periods, storm events, etc ... enable the study of time variation of bedload transport rates.

Bedding geometry: in intertidal zones, examination of bedding geometry by trenches indicates the resultant or net direction of transport in bidirectional tidal systems. In subtidal zones, box coring can be utilized for this purpose.

Analysis of morphology and morphological evolution.

Systematic mapping and morphological analysis at large scale.

Long term transport rates:

- comparison of historical documents (old sea charts, maps, serial photographs, pilot logs, etc ...) with present bathymetry.

- repetitive profiling or surveying in localized areas.

Current and wave measurements (enables quantitative estimates of bedload transport by applying bedload formulas currently employed).

If current induced bedload, a precise knowledge of the near bottom velocity profile and sediment characteristics is required: gives good estimates of directions and relative rates of bedload transport in different areas.

Longshore drift is evaluated with a fair degree of accuracy by well established formulas if regional bathymetry, sediment characteristics and wave regime are known.

Remark: a comprehensive and complete analysis of bedload transport (rates, direction and time scales) implies: study of the different time scales of transport fluctuations (semi-diurnal, fortnightly, seasonal) in relation to the major events affecting the lagoon: tide storm, morphological evolution, etc ... repetitive studies carried out over a period of at least 2-4 years. The 4 approaches must be used in conjunction with one another. Avoid relying on the results of merely one of them.

G.3 PATTERN OF SEDIMENTATION

General: location and nature of the sediment accumulated in the lagoon

Spatial distribution of sediment types: easiest and most efficient way is to do systematic bottom sediment sampling; sampling network planned both to cover the entire lagoon and zones of marked lithological gradients.

Cores of sediment taken to study the vertical succession of sediment types, bedding characteristics and biological activity in the sediment.

If marked seasonal fluctuations due to storms, river inflow or inlet closure, it is necessary to repeat the sediment sampling during each period characteristic of a specified environmental condition.

Rates and geometry of sedimentation

Analyze rates of sedimentation and erosion in different parts of the lagoon.

Analyze geometry of sedimentation.

Measure the rates of sedimentation:

- by direct methods: slow process, wide fluctuations.

- by indirect methods:

  repetitive profiling and surveying in localized areas.

Analysis of historical records: charts, maps and serial photography.

Microfaunal analysis: ratio of living forms to total content of foraminifera or other small organisms having preserved hard parts such as micromolluscs.

Radiocarbon dating in cores.

Remark: a comprehensive global understanding of the sedimentology of the lagoon with respect to environmental energy inputs implies a bottom sampling and sediment rates analyzed together with data on sediment sources and transport mechanisms.

G.4 LONG TERM EVOLUTION IN THE LAGOON MORPHOLOGY

Historical analysis

Old charts, maps, historical records, etc ... when dating back a few centuries, provide qualitative information on the morphological evolution.

Archeological findings provide information on evolution over a long time scale.

Sediment stratigraphy

Stratigraphic analysis of the lagoon system during the past few 1000 years: by study of sediment sampling seaward of the lagoon, coupled with borings in the lagoon and the barrier.

Isotope dating on sediment and/or organic constituents in the borings: give quantitative data.

Paleontological analysis

Foraminifera, and, in some instances, molluscs, is in most or all ancient lagoons the only method for identifying the deposits as belonging to lagoons.

Remains of Foraminifera are also useful tracers of post-depositional modifications.

G.5 REWORKING OF SEDIMENTS AND INTERSTITIAL WATER RENEWAL

Determination through the seasons

Rate of reworking in the upper decimeters of the deposit.

Rate of interstitial water renewal.

Concentration of nutrients, metals and man-made compounds (e.g., chlorinated hydrocarbons).

Depth of the oxic upper layer.

CHEMISTRY (C)

C.1 INFLUXES AND EFFLUXES OF DISSOLVED AND PARTICULATE MATERIALS

Contribution of materials to the lagoon

Discharge of materials into the lagoon by rivers.

Estimation of the exchange rates of inorganic and organic materials between the lagoon and the adjacent sea.

Inventory of the amount and quality of substrates introduced as wastes from human activities.

Estimation of substances introduced by rainfall.

C.2 OVERALL CHEMICAL PROCESSES

Questions:

What are the reservoirs of the elements utilized by lagoon organisms?

What are the pathways by which the elements may be transferred between the reservoirs?

What is the relative importance of each pathway?

Water column

Nutrient utilization by primary organic producers (planktonic and benthic plants) considering the spatial and time scales.

Decomposition of organic matter in the water column.

Chemical exchange of substances in boundary layers of different salinity.

Chemical alteration of substances in boundary layers of different salinity.

Chemical transformation under anoxic conditions.

Chemical precipitation, floculation and aggregation of suspended particles, with absorption and desorption of dissolved substances.

Sediments

Understanding of chemical and biochemical processes: distribution in sediment cores of redox potential, organic carbon, organic nitrogen.

Information on the source of organic matter accumulated in the sediments, notably in detecting changes in the input of organic matter from the different sources into the lagoon, by studying variations of the stable carbon isotopic ratio in sediment cores.

Interfaces

Air-water interface

- exchange level of O_2 and CO_2 in space and time.
- accumulation and concentration of dissolved and suspended matter in surface films.

Water-sediment interface

- regeneration of nutrients: *in situ* and laboratory experiments using radioactive tracers (32P and 15N)
- mobilization of interstitial waters to the overlying water column.

C.3 PRIORITIES OF RESEARCH IN CHEMISTRY FOR THE RESPONSIBLE MANAGEMENT OF LAGOON RESOURCES

Eutrophication and nutrient budget

Metabolism

Chemical assessment of decomposition rate of organic matter within the water column and in the sediment (no appropriate method for the moment).

Determination of organic production rate (well established methods).

Mobilization and circulation of nutrient and of potentially toxic metals and pollutants

Qualitative processes may be enhanced by chemical desorption and a variety of biological processes (metabolic activity, bioturbation).

Quantitative data on reservoir sizes and transfer between reservoirs.

Mixing and exchange processes in the lagoons.

Particular composition of the water sources entering the lagoon, utilization of dissolved conservative materials, such as changes in the total alkalinity of the water can be used for that purpose.

BIOLOGY (B) Ecosystem analysis

First step: Define the system boundaries:

Flux of materials across the boundaries is small relative to the cycling of materials within the system.

Upland watershed and ocean boundaries to be included in the system boundary.

B.1 SYSTEM MAPPING

Lagoon and watershed morphology

Lagoon bathymetry, watershed topography

Distribution of major sediment types in the lagoon

Distribution of major bottom community types in the lagoon

Distribution of major soil types in the watershed

Land use in the watershed

B.2 DEFINITION OF SUBSYSTEM

Areas set off by distinct water circulation patterns (e.g., coves and bays, channels with the lagoon).

Areas with distinct biological characteristics (e.g., macrophyte beds, sand or mud flats, marshes, mangroves, free waters, oyster reefs).

B.3 SPATIAL AND TEMPORAL VARIABILITY (Frequency: at least one sampling station shall be made in each major ebb system in the lagoon).

Biomass estimates monthly over one annual cycle

Benthos

Major macrophytes in the lagoon and in surrounding marshes.

Primary productivity

Chlorophyll, a measurement weekly

- in surface and bottom water
- in surface (top 1 cm) sediments

Particulate carbon and nitrogen

Bloom examined visually to determine major groups

Zooplankton biomass biweekly over the annual cycle

Peak period examined visually to determine major groups

Replicate or oblique or vertical hauls should be used and occasional night samples taken.

Major nutrients (NH_3, NO_3, PO_4, DOP, $Si(OH)_4$, perhaps DON)

- in surface and bottom water over the annual cycle

- salinity (to ± 0.1 parts per thousand) and temperature (to ± 0.1°C).

Major shellfish species-biomass estimate, size and reproductive state

Major finfish-size, age structure and reproductive state as a representative sub-sample of the population

Routine weekly or bi-weekly seine, gill net or trawl samples can pinpoint the migration time of major species, as can local commercial catch. Local knowledge of the lagoon as possible may be worth effort to estimate population sizes of fish and other mobile animals in the lagoon using marks and recapture techniques.

Suspended sediment measured biweekly in the rivers as periodically over tidal cycles in the lagoon

Good aerial photographs and satellite data may be useful.

Particular attention should be paid to:

Storm events, strong winds, high river discharge, etc. ... to measure their effects on nutrient levels, suspended sediment, detrital inputs, etc.

B.4 PHYSICAL FORCING FUNCTIONS

Tide gauges (or at least tide staffs) should be installed:

near the breakway and near the extremes of the lagoon.

Basic meteorological data should be collected:

on a routine basis for correlation with hydrographic and ecological data - wind and rainfall are important as site specific parameters; atmospheric pressure, air temperature and solar radiation may be available from nearby stations.

Fresh water inputs should be gauged and gauge inputs determined

Estimates of freshwater sheet floor and runoff on surrounding lands using small weirs:

eventually estimates of ground water flow, drilling of a number of small wells around the lagoon.

Estimate of the flushing rate under different conditions; of freshwater inputs, wind and tide (first order task).

Gas exchange estimate for oxygen (and perhaps CO_2):

at the air-water surface under various conditions of wind and tide (so that oxygen changes can be used for metabolic estimates in the lagoon: floating dome method best used).

B.5 METABOLISM AND NUTRIENT CYCLING

Total metabolic balance estimated biweekly over the annual cycle

If flushing absent or minimal: free water diurnal curve method is the best way to measure tidal energy balance (autrotrophic vs. heterotrophic) in the system (oxygen diffusion can be corrected by using the gas exchange data, see gas exchange estimate for O_2, above).

Detailed partitioning of metabolic activity:

- plankton metabolism of the water column using O_2 change (and/or ^{14}C for production).

- macrophyte (including seaweeds) metabolism best measured over long periods, using growth increments.

- benthic metabolism measured biweekly or monthly using *in situ* bell jars in large cores taken from the bottom and brought into laboratory.

- nutrient fluxes from the sediments to the water column and vice versa, measured simultaneously.

- CO_2 fluxes at the sediment-water interface measured with pH meter (0.001 unit).

- measuring production by benthic micro-algae notably using ^{14}C.

- nutrient content variations - oxygen production - oxygen consumption - ^{14}C uptake in the water column.

- inputs of the organic matter from marshes and mangroves difficult to measure but should receive attention.

Material budgets for the lagoon

Does the lagoon import or export nutrients or organic matter? (primary production).

How much of the primary production is supported by:

- internal nutrient recycling?
- new inputs of nutrient?

What fraction of solar energy is being incorporated into organic matter?

What percentage of primary production is being incorporated into animal tissue?

What percentage of the organic matter is being exported as detritus or as migrating animals?

How much is buried in the sediments (require knowledge of the lagoon sediment budget and sedimentation rate)?

Determine bathymetry changes, radioactive isotope profile, sedimentation rate curve or sediment budget.

Metabolic studies on groups of organisms and energy budgets

Oxygen consumption

- macrofauna: total respiration of macrofauna computed from biomass and known relationship between respiration estimation, biomass, and if possible temperature.

- meiofauna, microfauna (e.g. ciliates) and microflora: total respiration estimated from biomass and respiration rates using suitable micromethods (notably cartesian diver respirometer).

- bacteria: the bacterial respiration can be estimated indirectly by difference between total respiration rates of water and/or sediment (bell jars or sediment tubes) and the sum macrofauna + meio + microfauna + microflora (estimated).

Anaerobic metabolism

- facultative and true anaerobes whose respiration must be estimated by means other than oxygen consumption such as direct calorimetry (e.g., flow microcalorimetry applied to microbial and meiofaunal processes).

Ingestion and assimilation of food

- radioactivity labelled food: labelling of particulate organic matter (e.g., detritus) by incorporation of radioisotopes, so that its nutritional value may be investigated. For such methods, it is necessary to determine the role of bacteria and other microbiota, such as diatoms, which may be selectively consumed by some or all metazoan and protozoan.

- assimilation of dissolved organic molecules: metazoan and protozoan organisms and certainly bacteria can take up dissolved organic molecules (sugars, amino acids). This approach needs more experimental work.

With aid of these techniques, in addition to data on respiration rates, weight growth and reproduction rates, valuable information will be obtained on daily energy budgets.

B.6 PHYSIOLOGICAL ECOLOGY

Ecophysiological adaptation of microflora, ciliates and metazoans (planktonic/meiobenthic/microbenthic).

Metabolic compensations: represent the possibility for organisms to exhibit similar metabolic rates under widely different environmental factors (temperature, oxygen tension, salinity, etc. ...). This approach needs sophisticated techniques (microrespirometers, microcalorimeters notably).

Influence of body size and metabolic levels: the possibility of subdividing microflora, zooplanktonic and meiobenthic species into groups of species presenting different rates of oxygen consumption, provides stimulating perspectives. The techniques are complex (see point above) and time consuming.

<u>Growth and production</u>

Bacteria: estimates of micro-organisms production carried out by different techniques give largely different results. Estimates of growth and production gained from laboratory cultures.

Meiofauna and microfauna: may be very active in energy flow. There is a significant relationship between production and respiration. Estimates from laboratory cultures.

Macrofauna: estimates of growth and production can be gained from <u>in situ</u> and laboratory studies.

<u>Ecophysiological adaptation of macrofauna</u>: (including exploited organisms - algae, fish, molluscs, crustaceans) homeostatic capabilities and stress effect.

Survey of the principal environmental parameters and their apparent effects on the distribution of the species:

- salinity

- ions (mainly Na^+, Cl^-, Ca^{2+} and their ratios in natural waters of varying salinity)

- oxygen tension: effect of oxygen depletion.

Multiple factor effects and survival tests.

Patterns of osmoregulation and differential penetration in the lagoon.

- chemical determinations on plasma and other internal milieu samples.

  total osmolality (osmometer)

  electrolytes: Na^+, K^+ (flame photometer), Cl^- (chlorimeter).

Such determination will be made on samples taken in the field and on experimentally adapted organisms to different salinities and temperatures (short- and long-term adaptation).

Participation of physiological and biochemical mechanisms in osmoregulatory responses, such as:

- ATPase activity in different organ responses of euryaline species. In amphialine fish, the sodium-potassium ATPase activity in branchial chloride cells is involved in some migratory pattern (seaward migration generally).

- changes in the free amino-acid content, and its relation to an isosmotic intracellular/regulatory mechanism (present in several crustaceans and some amphialine fishes).

- levels of circulating hormones (prolactin, cortison and other steroids).

B.7 EXPERIMENTAL ECOSYSTEM STUDIES

Experimental field plot

Effect of fishes predations on bottom communities: using cages of varying mesh size to exclude different sized predators from the bottom.

Small replicate lagoon microcosms in tanks on land in which natural lagoon sediments are placed along with varying densities of predators.

This approach teaches us about:

- the dynamics of the natural system

- the probable response to future perturbations such as salinity regime and nutrient addition.

B.8 FIRST ORDER TASK TO STUDY A LAGOON ECOSYSTEM

I - OXYGEN CONCENTRATION AND CHANGE IN OXYGEN CONCENTRATION: (see B 5)

- physiological limits for many aerobic species
- rates of photosynthesis and respiration
- contribution of other environments to the food webs of lagoons
- conditions for many chemical transformations

Oxygen must be sampled over space and time:

- sample over 24h at 3h intervals at selected stations
- throughout the lagoon at biweekly intervals over a year.

Methods:

- free-water O_2 methods can be used where water exchange is low to measure photosynthesis and respiration

- planktonic and benthic contribution can be gained from light-dark bottle methods and benthic chamber.

II - POPULATION DYNAMICS (see B 3).

III - ADAPTATION OF MAJOR SPECIES (see B 6).

TASK GROUP REPORTS

TASK GROUP I - PHYSICS - GEOLOGY - CHEMISTRY

CONTENTS

Outline of research programmes in Geology

Sediment influx and sediment transport processes

Bedload transport

- Sedimont grain size map and analysis
- Analysis of bedforms
- Analysis of morphology and morphological evolution
- Current and wave measurements

Patterns of sedimentation

- Spatial distribution of sediment types
- Rates and geometry of sedimentation

Longterm evolution in the lagoon morphology

- Historical analysis
- Sediment stratigraphy
- Paleontological analysis

Reworking of sediments and interstitial water renewal

CHEMISTRY

Specific features

Influxes and effluxes of materials

Overall chemical processes

- Water column
- Interfaces
- Sediments

Outline of research programmes in chemistry

Eutrophication

Decomposition of organic matter

Nutrient elements

Mixing and exchange processes.

TASK GROUP I: PHYSICS - GEOLOGY - CHEMISTRY

Introduction: Environmental Characteristics

The first part of this study is concerned with the physical, geological and chemical aspects of lagoon research. It is stressed that there is a very wide spectrum of lagoon-type environments with, on the one hand, lagoons with very little water exchange with the ocean, influenced chiefly by the adjacent draining basin, and on the other hand, those with a wide connection with the open sea and without much continental influence. Special attention is also given to seasonal and non-seasonal variation.

The physical section stresses the importance of determining the rates of flushing, not only in the concept of transit times of river water, but also from the point of view of the residence times of various water masses. It also discusses the light regime and the heat balance.

The geological part discusses sediment influx, sediment transport processes and patterns of sedimentation. A clear distinction is made between transport of sand and other coarse grained material, which mainly proceeds as bedload transport, and that of fine grained matter, which takes place chiefly in suspension. Attention is also focussed on materials such as shells and evaporites formed inside lagoons, which become part of the sediment assemblage, and on long-term evolution.

A discussion on influxes, effluxes and reservoirs of dissolved and particulate materials in coastal lagoons, and how the fate of these materials are dependent on the biological, chemical and physical factors form an introduction to the chemical section. Follows an overall description of the chemical processes in the water column, in the sediments and at the interfaces. The question of eutrophication is touched upon, as well as that of the introduction of pollutants.

In every section recommendations are made for future research and on the necessity of integrated studies.

PHYSICS

Specific features

Water balance - salinity - flushing time scale

The total water volume of the lagoon is determined by the various fluxes from the continent, the sea and the atmosphere - i.e., runoff and ground water flow, sea water flow through the inlets, evaporation and precipitation. These fluxes should be known, at least in order of magnitude to see whether or not some of them may be neglected. Intimately connected with these water fluxes is the overall salinity pattern. Salt is brought in from the sea and diluted with freshwater runoff and/or rainfall, so as to decrease the salinity of the lagoon as compared with that of the adjacent sea, or in hypersaline environments, evaporation may increase the salinity. If the fluxes maintain for a certain time interval a (quasi) stationary state of the salinity distribution in the lagoon, either the excess of the lagoon salinity as compared with the sea or the deficit, may be used to compute a flushing time scale of the lagoon if the dominant flux producing the excess or deficit is well known. The latter will be easily achieved in those cases where only a small number of rivers are decreasing the salinity of the lagoon. In cases of rainfall, evaporation or ground water flow dominate, the method may not do well because of great uncertainties in the relevant fluxes. Although salinity survey should always be recommended as a relatively easy method to estimate a flushing time scale, the particular situation in a lagoon may often not allow the use of this procedure. In such cases, the following more expensive and/or difficult methods may do:

a. Non-conservative tracers. These are dissolved substances which are either produced or consumed in the lagoon. If their production or consumption rate is known and their overall distribution is estimated by a survey, the ratio of total content in the lagoon and production or consumption rate gives a flushing time scale. If the latter rate is not known, but the total content has been obtained by a survey of the lagoon, a flushing time scale may be calculated by measuring the flux of the constituent through the coastal inlet. Again, the ratio of the total content and the flux gives the desired time scale. In some cases, dissolved reactive silicate has been used with success. The estimation of the flux through the inlet requires the measurement of substances concentration and current velocity over as many points in the inlet cross-section as is practically possible. Use of only one point of measurement in the cross-section may produce appreciable errors.

b. Artificial dye-tracers may sometimes be used to estimate the diffusion of a dye patch giving a representative diffusion coefficient, which under many assumptions may be translated in a flushing-time scale of the lagoon. The method is, however, not recommended for this purpose.

c. Estimation of the flushing-time scale from moored current velocity measurements is a difficult task. It may work well in cases where the transport pattern is purely advective (more or less steady currents), provided that the current meter network is sufficiently extensive in space. In cases where the transport has a large diffusive component, the estimation of a representative diffusion coefficient is required to estimate the flushing-time scale. Estimation of a diffusion coefficient from moored current velocity measurements is a tricky and hard task not to be recommended as part of a more general survey programme for coastal lagoons.

d. Numerical modelling of the transport processes in a lagoon will certainly provide an insight in the flushing of the lagoon, provided of course that the model does sufficiently reproduce the situation in the field. This requires an optimalization of the different transport parameters. This can only be achieved by carrying out an extensive survey programme in the field. It should, therefore, never be recommended to use numerical models without calibrating them against measurements in the lagoon itself. The latter may directly supply the overall flushing rate of the lagoon. Therefore, the numerical model should be looked at as a refinement of insight in the transport processes once their overall effect is already known.

Heat balance and temperature

The annual, daily or tidal temperature cycle of a lagoon can be easily estimated either by simple continuous recording of temperature at one or more fixed positions or by surveying (together with other parameters like salinity, suspended matter and so on). The different temperature cycles in the lagoon have amplitudes that depend on their periods relative to the time scale of thermal inertia of the lagoon (primarily a function of its mean depth) and on the latter time scale relative to the time scale of flushing with sea water. In areas having extensive tidal flats which fall dry during the tidal cycle the interaction between the solar radiation and the semidiurnal tide gives rise to a beat in the daily mean temperature with a period of about 15 days. Apart from the temperature cycles themselves, the actual heat fluxes are much less easily estimated. However, a detailed knowledge of the balance is often not necessary for ecological purposes, except in cases where evaporation should be accurately known.

Optics

The general properties of the sunlight regime in coastal lagoons are, of course, of utmost importance with respect to primary production. Simple underwater radiation measurements or Se disc depths should provide a first insight into the depth of the euphotic zone. In many lagoons, this depth is determined by the amount of suspended matter present, either inorganic or organic. In the latter case, the interaction between the light regime and the living organic material it produces may provide a feedback mechanism for primary production. More difficult to measure is the spectral composition of sunlight in lagoon waters, of which much is unknown. Strong absorption of blue parts of the spectrum by yellow substance may cause a large shift of the spectra from blue to green or yellow.

Outline of research programmes in physics

The survey given above may provide a simple scheme to set up a programme of physical investigations for ecological purposes in coastal lagoons. However, there are still a lot of physical processes that need further (or even first) investigation from the more fundamental point of view. Some of them which come to mind are listed in the following paragraphs.

Water balance - salinity - flushing time scales

As salinity provides such a simple means to estimate the flushing intensity, it should be recommended to investigate in more detail those situations in which the (fresh) water fluxes are of a more difficult character than a simple river-runoff which is easily measured. Attention should, therefore, be focussed on methods providing rainfall, evaporation (see Heat balance and temperature, below) and ground water fluxes. As to the flushing time scales themselves, knowledge of their variation in time is urgently needed. An extensive survey programme in a well chosen lagoon having a regular freshwater input should be carried out for at least some years to get insight into seasonal, or more rapidly varying, effects on its flushing. Together with the runoff and the salinity, meteorological parameters and sea-level should be recorded and preferably also the water fluxes through the inlet by means of moored current velocity meters.

Heat balance and temperature

Whereas temperature cycles may be easily estimated, it is much more difficult to obtain the different terms of the heat balance equation of a lagoon. A meteorological research programme should be set up to investigate the complete heat balance of a lagoon. Such a programme should preferably be carried out in a hypersaline environment. In that case, the heat balance together with a salinity survey may provide either the flushing time scale of the lagoon with sea water, or, knowing the latter by other means, it may provide extra information to obtain the difficult closing of the heat balance by means of the evaporation term. As to the latter, the influence of plants (evapotranspiration) on the salinity budget of the lagoon should not be overlooked.

Optics

A complete investigation of the sunlight regime in coastal lagoons is urgently needed. It should be concerned with the vertical distribution of solar irradiance in connection with the distribution of suspended matter either dead or living and with the interaction of the latter during the (seasonal) cycle(s) of primary production. Moreover, the spectral composition of sunlight under water should be investigated together with the absorption spectrum and the distribution of the substances responsible for that spectrum. Special attention should be given to those parts of the lagoon where the euphotic depth is greater than the actual water depth. Sunlight touches the bottom in that case forming a specific environment for benthic primary producers.

GEOLOGY

Specific features

Sediment influx and sediment transport processes

Sediment influx

Sediment accumulating in a lagoon (and bordering marshes, and tidal flats), is derived from a variety of local sources.

The source of lagoon sediments needs to be established in order to evaluate the overall sediment budget and to determine the rates of dispersal between sediment sources and sinks (sites of deposition). If deposition is a practical problem, such as in shoaling or shipping channels, knowing the source of shoaling sediment may contribute to alleviating the problem.

Sediment is derived from (1) external sources, both landward and seaward, (2) internal sources from organic production and precipitation within the lagoon or erosion of margins.

External sources include:

- sediment from erosion of the upland watershed delivered by streams and rivers,

- sediment from upland slopes delivered by sheet-flooding and surface runoff,

- sediment from the barrier island delivered by wind or washovers during storms,

- sediment from the shelf and nearshore bottom delivered by longshore currents and tidal currents through the inlets.

Internal sources include:

- sediment from production of organisms in the form of shells, tests, grass, reef debris, etc.,

- sediment derived from lagoon water by precipitation or chemical reactions,

- sediment derived from erosion of lagoon banks and shores,

- sediment derived from manmade wastes.

The relative importance of these varied sources depends on the rate of supply which in turn depends on the availability of erodable sediment and the rate at which it is transported into the lagoon.

Routes of supply are affected by land use and modifications of man that tend to either (1) reduce supply by stabilization (vegetative or paving) or (2) increase the supply by mobilizing sediment through mining, cultivation, land clearing, etc. Both the rates and routes of supply are modified by engineering works as dams, jetties, river diversions, etc.

Sources of sediment are revealed by (1) examination of the sediment mineral and biological composition; and (2) by observation of active transport routes and related directional indicators such as minor structures and grain size changes with distance from the source.

Problems of identifying sources arise from the large fluctuations in supply, first from one source, or direction, and then from another. Fluctuations arise from large temporal variations whereby the bulk of sediment from a single source may be delivered during short periods of storms. Sources best understood, and most easily measured, are river inputs. Erosion of lagoon shores is often readily discerned from charts and aerial photographs. Except for biological skeletal sediment produced in the lagoon itself, other sources are less discernible and rates of supply are unknown. Tracers and contaminants offer a promising approach to identifying sediment sources and rates of supply.

Transport

Sediment can be transported by one of two mechanisms: suspension and bedload. Each of them is related to different types of sediment and hydrodynamic phenomena, and hence will be treated separately.

Suspended sediment transport

The distribution of suspended sediment in a lagoon develops three distinct patterns: (1) a broad horizontal gradient of increasing concentration with distance inward from the sea (and toward the river sources); (2) a localized concentration or maximum near the head of the intrusion of salt water; (3) an increase in concentration with depth. These patterns result from wave and tidal current energy that transport sediment in suspension, and depend on grain size and density of the sediment and the patterns of circulation that tend to either disperse or to accumulate sediment.

The broad horizontal gradient develops in tidal flat lagoons probably as a result of the decrease in average and maximum tidal current velocity with distances inward from the inlet. Moreover, the ebb and flood velocity curves, which develop an inward assymetry, provide an inward transport in areas where the average water depth is greater at low tide than at high tide.

Inward transport of fine grained suspended material also results when the erosion velocity is considerably greater than the deposition velocity; that is, the minimum current velocity needed to pick up the material exceeds the minimum velocity necessary to keep it in suspension. Continued resuspension of fine grained sediment by tidal currents from the lagoon flood creates vertical gradient of suspended sediment with increasing concentrations near the bed, the local sediment source. Re-suspension may release stored material into overlying water and exchange constituents with the water. Wind waves generated within the lagoon or ocean waves that penetrate the lagoon through the inlet are effective in resuspending bed sediment, mixing it into overlying water and transporting it when a mass transport of water develops. In some large lagoons having long fetch, a wind set-up may support a drift along the lagoon margins and thus transport suspended sediment to far corners of the lagoon where it can deposit in low energy environments.

Density differences caused by river inflow into a lagoon creates an estuarine type of circulation whereby river inflow converges with salty lagoon water near the bottom. This acts as a dynamic barrier for river-borne suspended sediment transported landward while sediment carried in the landward flow from the lagoon entrance or lagoon itself may also become trapped in the zone. This gives rise to suspended concentrations that are higher in the convergence than in source river and as lagoon water; a feature called "turbidity maximum". As a result of these transports, lagoon sediments are often moved, reworked and redistributed internally prior to final deposition.

Bedload transport

Bedload transport, contrary to suspension, occurs on or near the sediment-water interface, and usually involves sand to pebble size granular sediment. The energy for this transport comes from the shear stress generated by vertical velocity gradients in flowing water, active on the sediment surface. This force is transmitted to the individual sediment grains mainly by the numerous and repeated collisions between the individual particles colliding in the near bed zone of transport.

The intensity of the transport, as well as the maximum size of the particles transported is a direct function of the fluid bed shear, hence of the velocity of the flow. Generally, this mechanism is important in lagoons with large tidal ranges, with frequent and intensive waves, or subject to high velocity river flow, and with an abundant source of sand. Bedload transport occurs mainly in and about the seaward inlets of the lagoon, and in the channels, and can bring about large movements of sand. In time, these movements can cause considerable changes in the morphology of the lagoon, in particular the location and bathymetry of the channel and bar systems.

Bedload transport is not a continuous phenomenon, but is linked to periods of particularly strong current or wave activity. Hence, the process will often occur as infrequent bursts, or pulses, of intensive sediment transport, separated by quiescent periods. These impulses of intensive sediment transport can create important morphological changes, such as the closure of inlets in barrier islands. These modifications can, in turn, profoundly modify the circulation and hydrologic regime of a lagoon.

The transport of sand by bedload is always materialized by the formation of various bedforms. The geometry (ripples to antidunes) and size of the bedform is a function of sediment grain size, water depth, and transport intensity.

Patterns of sedimentation

Among the more important aspects of lagoon geology that must be studied are the location, and nature of the sediment sinks in the lagoon. Since the nature of the bottom sediments, and the rates of deposition control to a large extent the benthic biological communities of the lagoon, it is essential to have a clear understanding of where and how sediments accumulate in the lagoon, and erode, when and at what rate. If a pollutant is discharged into the lagoon, a certain amount of polluting substance (metals, PCB's, etc.) will probably be absorbed on the sediment. Evaluation of the impact of the pollutant will therefore require knowledge of the sedimentary sinks in the lagoon, as well as the sources and pathways of transport (treated in previous chapters).

It is recommended that the research and study effort be aimed at obtaining:

- spatial distribution of bottom sediment type.

- rate and geometry of sedimentation and erosion.

Both of these phenomena are highly variable in space and time, in relation to variations in sediment influx, transport, barrier morphology, etc., and are controlled by the transport mechanisms which were discussed in the previous chapter.

Long-term evolution in the lagoon morphology

Probably no lagoon in the world is in a long-term steady state equilibrium. Rising sea level, tectonic movement, sediment influx, morphological evolution all act to make lagoons highly evolutive systems, undergoing long-term evolution, visible on a 100 to 1000 year time scale.

Generally speaking, lagoons can be considered as positive sediment sinks, with more sediment coming into the lagoon than escaping it. The various sources and mechanisms of sediment and its transport have been discussed in the previous paragraphs. Unless some other factors intervene, such as sea level rise, or tectonic subsidence, lagoons will eventually fill up with sediment, and evolve from a subtidal aquatic environment to a supertidal environment only intermittently submerged by water. On most of the coasts of the world which are not affected by tectonic activity, the major effect controlling the long-term evolution is the relative balance between the present day sea level rise (which is on the order of a few cm a century) and sedimentation (which is a function of influx and energy). Generally speaking, outside of zones of massive fluvial sediment influx, most lagoon coasts are being transgressed by sea level rise. It appears in many cases that the very existence of barrier island lagoons is related to the rise of sea level, which has been occuring for the past 18-20,000 years, and that the lagoons on today's coasts are very young, in the order of a few 1000 years.

This transgressive movement tends to cause a landward migration on lagoon barriers, over the lagoon sediments. This appears to be the case in the lagoons of the east coast of the US. If this migration is not accompanied by a concomittant influx of sediment on the seaward side of the barrier, the lagoon will probably not be preserved (partially or totally) in the geological record. At the same time that this landward migration of the barrier occurs, some lagoons can fill with tidal flat and marsh sedimentation, i.e., with the landward edge of the lagoon prograding seaward.

If there is abundant sand on the continental shelf in the near shore zone, it is expected that the lagoon barrier may grow upward and seaward with rising sea level. This will have no appreciable effect on the filling of the lagoon which may be rapid. These long-term movements can profoundly modify the physical and chemical environment of a lagoon, and hence the ecosystems would also be subjected to long-term evolutive trends.

Reworking of sediments and interstitial water renewal

In shallow water bodies such as lagoons, processes in the sediments and exchange between the sediments and the overlying water play a dominant role in the biogeochemical cycles. Basic characteristics which should be measured are rate and depth of sediment reworking, and rate of renewal of interstitial water. The first is determined by bioturbation, erosion and deposition; the second is influenced, in addition, by porosity, molecular diffusion, evaporation and hydrodynamic forces. On intertidal flats, moreover, residual water movements in the bottom may be important.

The residence time of interstitial water can be determined, for example, by measuring the time lag between concentration changes of salinity or another conservative property in the sediments and in the water column. The exchange rates may show large seasonal variations and are often much higher in tidal lagoon deposits than in non-tidal or deep water deposits. Not withstanding high renewal rates, interstitial waters in lagoon deposits contain high concentrations of dissolved organic matter, of dissolved materials such as, nutrients, heavy metals and other chemical compounds. These high concentrations are due to the abundance and rapid decomposition of organic matter, desorption and dissolution of elements under anoxic conditions and chemically stabilizing processes such as chelation. The concentration gradients between the sediment and the water column, together with the interstitial water renewal rate, determine the rate of release of substances to the main water body of a lagoon. Measurement of the amount released and of their seasonal variations is essential to understand quantitatively the role of sediments in the organic production cycle and the possible negative effect of liberated harmful substances on biological systems.

In polluted lagoons a much larger assembly of chemical species, natural and manmade, is present in the sediments. Sudden release, either by natural phenomena or by dredging, may be a threat to the biological communities. Dredging, especially, should then be preceded by a chemical survey.

In most healthy lagoons, even if the deposits are mainly anoxic, the upper layer is mostly well aerated. An important sign of overloading with organic matter is the thinning of this layer. After it has vanished the conditions in the overlying water may change very rapidly from oxic to anoxic, whereas at the same time the release of chemical species is strongly accelerated.

Outline of research programmes in Geology

Sediment influx and sediment transport processes

It is recommended that research center on the determination of the spatial and temporally varying rates of transport within the lagoon, and at the landward and seaward surface. In lagoons with large tidal influence, important variations of suspended sediment, and therefore the depth and extent of the photic zone can occur. In these cases it will be necessary to examine the short period variations associated with semi-diurnal or diurnal tidal events, as well as the fortnightly neap to spring cycle. In lagoons with large seasonal fluctuations, either related to meteorological cycles and freshwater inflow, or to morphological changes such as inlet closure, it is important to do seasonal repetitive studies to evaluate the effect of these variations on suspended sediment transport. Also, measurements of flux of suspended sediment in and out of the seaward inlets of the lagoon can be carried out. These measurements are usually too limited in time and space to enable quantitative estimates of the net budget of sediment between the lagoon and the sea. However, these measurements can give useful information on the relative amounts of sediment entering or escaping through different inlets, the vertical distribution of fluxes (possible existence of two layered systems), and temporal or seasonal variations in transport intensity.

Suspended sediment sampling transects should be established at slack tides throughout the lagoon. These can give extremely important information on the spatial distribution of suspended sediment within the lagoon, and help localize zones of particularly intense sedimentological activity. Repeated transects as function of tides, river flow, seasons, etc., can indicate the time scale of suspended sediment transport within the lagoon, as well as give an indication of the relative importance of different environmental parameters: tides, winds, waves, river flow, biological productivity, etc.

Point measurements of the flux of suspended sediment during a complete tidal cycle will also have to be established in lagoons with an appreciable tidal range. These measurements will establish the relative amounts of sediment deposited and eroded at each tide, as well as the net directions of transport, and as well as some quantitative estimate of the transport rates. These point measurements will also have to be repeated during different conditions of tides, seasons, etc. Foraminifera can be used as tracers for redistribution or "mixing" of sediment if the faunal patterns within the lagoon being studied are established. Flux of sediments into and out of the lagoons can be measured by "environmental displacement" of foraminifera when the sediments being moved are deposited. All of these results must be correlated and analyzed together with the physical oceanography studies in order to understand the global dynamics of the transport systems.

If the rate of supply of benthic lagoon organisms having hard parts can be established, this would aid in solving rates of influx of sediment and the rates of deposition of this sediment.

Bedload transport

At the present time, the only method available to directly measure bedload rates is to artificially mark a sediment with a tracer (fluorescent or radioactive) and measure the direction and rate of movement of the tagged grains. This method, however, can be very time-consuming, and the results are usually very limited in time and space. Generally, tracers can be more effectively utilized in a specific, localized problem, requiring the precise determination of bedload rates at a certain time. Even in these cases, a tracer study must be thought of more as a method to verify an existing hypothesis, rather than as a general survey or research tool in a relatively little studied lagoon.

Several bedload traps exist and have been used by engineers working in fluvial environments. These traps, however, tend to induce a relatively high error in zones of reversing tidal transport, or wave transport. It is recommended that bedload transport in the lagoon be studied and analyzed by a number of indirect methods:

Sediment grain size maps and analysis

Bedload concerns principally sand size, or levels, sediments. A knowledge of the geographical distribution of sediment types within the lagoon can help localize the zones where bedload transport is apt to be predominant. Also, regional grain size gradients can indicate directions of net bedload transport, and estimates of transport intensity. Repeated samplings for grain size analysis in localized areas can indicate time variations in bedload, related to periods of strong current, or wave activity.

Analysis of bedforms

Bedforms are an excellent indicator of the relative magnitude of bedload, as well as its direction. Numerous studies in many lagoons and coastal zones have shown that maps of bedform type, size and orientation can give extensive information on the direction and rates of sand movement by bedload. Repetitive bedform mapping over spring-neap tidal periods, storm events, etc., can enable the study of the time variation of bedload transport rates. In intertidal zones, the examination of bedding geometry in trenches can indicate the resultant, or net direction of transport in bidirectional tidal systems, and box coring can be utilized for this purpose in subtidal zones.

Analysis of morphology and morphological evolution

In zones subject to intensive bedload transport, such as in tidal inlets and channels, sediment tends to form distinct and recognizeable large scale accumulations. The geometry of these accumulations is often a diagnostic of the prevailing transport mechanism (tides, wind, waves), and numerous classification schemes have been proposed to group the numerous types of shoals, bars, tidal deltas, etc., in which sand accumulates. Systematic mapping and morphological analysis of these large scale features can be an effective tool in analyzing regional transport rates and directions, as well as the mechanisms causing the transport. If historical documents (old sea charts, maps, aerial photographs, pilot logs, etc.), of the lagoon can be obtained, then quantitative estimates of long-term transport rates can be made, by comparison with present bathymetry. Even during one or two year periods, in zones of intensive sediment transport, repetitive profiling or surveying in localized areas can give quantitative information on rates and directions of sediment movement. This is particularly true on the seaward side of barrier islands and barrier inlets, where longshore drift and tidal currents can bring about rapid changes in morphology.

Current and wave measurements

A good knowledge of bottom currents and waves can enable quantitative estimates of bedload transports. These estimates are made by applying one or more of several bedload formulas currently employed. In the case of current induced bedload, a precise knowledge of the near bottom velocity profile and sediment characteristics is required. Even in this case, there can be a difference of more than 100% between actual rates and those predicted by the formulas. However, this method can give good estimates of directions of transport, and relative rates in different areas. Longshore drift can be evaluated with a fair degree of accuracy by formulas, if the regional bathymetry is well known, as well as the sediment characteristics and wave regime. In general, it is extremely important to study the different <u>time scales</u> of transport fluctuations (semi-diurnal, fortnightly, seasonal) in relation to the major events affecting the lagoon: tides, storms, morphological evolution, etc. Therefore, repetitive studies will have to be carried out over a period of at least 2 - 4 years. These four methods of study must be used in conjunction with one another, and to avoid relying on the results of merely one of them. If the results of all the methods can be superposed, and give results of the same order, and can then be related to the dominant dynamic systems acting on the lagoon, a fairly comprehensive and complete analysis of bedload transport (rates, directions, and time scales) in the lagoon can be established.

<u>Pattern of sedimentation</u>

Spatial distribution of sediment types

It is important to have a complete knowledge of the types of sediment which accumulates in the entire lagoon. The easiest and most efficient way to obtain this information is to do systematic bottom sediment sampling. The sampling network must be planned both to cover the entire lagoon and zones of marked lithological gradients. Cores should also be taken in order to study the vertical succession of sediment types, bedding characteristics, and biological activity in the sediment.

In lagoons with marked seasonal fluctuations due to storms, river inflow, or inlet closure, it is necessary to repeat the sediment sampling during each period characteristic of a specified environmental condition. In this way, the sedimentological effects of the environmental fluctuations can be analyzed and related to sediment transport mechanisms and the resulting patterns and rates of deposition.

Rates and geometry of sedimentation

In addition to the regional patterns of sediment distribution within the lagoon, it is necessary to analyze the rates of sedimentation and erosion in different parts of the lagoon. Also important is the geometry of sedimentation, i.e., whether sedimentation is by vertical accretion (as in the case of deposition from suspension), or by lateral migration (often the case in zones of predominating bedload transport). It is difficult to directly measure the rates of deposition, since sedimentation is a relatively slow process, marked by wide temporal fluctuations. Several indirect methods, however, can be recommended:

- repetitive profiling and surveying can give quantitative sedimentation rates in localized areas.

- analysis of historical records: charts, maps, aerial photos, etc.

- microfaunal analysis: ratio of living to total fauna content of foraminifera or other small organisms having preserved hard parts, such as micromolluscs.

- radiocarbon dating in cores.

It is important that the results of bottom sampling and sedimentation rates be analyzed together with data on sediment sources and transport mechanisms, in order to obtain a comprehensive global understanding of the sedimentology of the lagoon with respect to the environmental energy inputs.

<u>Long-term evolution in the lagoon morphology</u>

Several indirect methods can be recommended to analyze and study long-term evolutive changes in the lagoon morphology, sedimentation, and to relate these to biological changes.

Historical analysis

Old charts, maps, historical records, etc., when dating back a few centuries can provide qualitative information on the morphological evolution of a coastal lagoon. Also, archeological fir-ings can provide information on evolution over a longer time scale.

Sediment stratigraphy

Sediment sampling seaward of the lagoon, coupled with borings in the lagoon and barrier can permit the stratigraphic analysis of the lagoon system during the past few 1000 years. Quantitative data can be furnished by isotope dating on sediment as organic constituents in the borings.

Paleontological analysis

Identification of various ancient environments within lagoon deposits can be made with foraminifera and in some instances with molluscs. In most or all ancient lagoons this is the only method for identifying the deposits as belonging to lagoons. Also, the remains of foraminifera are useful tracers of post-depositional modifications.

Reworking of sediments and interstitial water renewal

It is recommended to determine, through the seasons (a) the rate of reworking of the upper decimeters of the deposit, (b) the rate of interstitial water renewal, (c) the concentration of nutrients, metals and manmade compounds such as chlorinated hydrocarbons and (d) the depth of the oxic upper layer.

CHEMISTRY

Specific features

A coastal lagoon provides the site for a large variety of chemical interactions to take place. These include interaction within and between the reservoirs of material present: dissolved substances, suspended particulates and lagoon sediments. For the present consideration, a coastal lagoon will be regarded as a basin having overall inputs and losses, and in which a variety of internal processes are acting. The fate of the dissolved and particulate materials brought by natural sources or introduced by human activities within the lagoon environment, is largely dependant on biological, chemical, and physical factors. Perhaps the most important factors determining the chemistry, and hence, the ecology of coastal lagoons, are the freshwater inputs (runoff), the rate of evaporation and the mixing and circulation processes with the adjacent sea. On the other hand the circulation of elements metabolically active in coastal lagoons is strongly influenced by biochemical processes in the water column, sediments and the interfaces.

Influxes and effluxes of materials

The supply of dissolved and particulate materials into a coastal lagoon depends upon the external reservoir of each of the materials and the availability of a transport mechanism to carry them into the lagoon.

It seems reasonable to assume that by far the most important source of substances of metabolic importance entering the lagoons are from continental reservoirs, mobilized by weathering, biological processes and human activities. Thus, in the case of lagoons having river inputs, the river may often be identified as the principal source of these materials. Conversely, a lack of river input or a depleted continental reservoir may lead to environments like the so-called "neutral" lagoons of similar salinity to the sea, and to the classical hypersaline lagoons which maintain communication with the sea. In many lagoons an important part of materials results from direct rainfall. While the effect of such an input is often to "dilute" the lagoon, the rain may carry an appreciable amount of substances of metabolic importance and also pollutants. An increasingly important source of nutrient materials in the coastal lagoons is from domestic, agricultural and industrial waste. In any study of coastal lagoons it is impossible to describe chemical processes without a previous consideration of the physical processes acting on the system. The flushing time of a lagoon may be related to the residence time of substances within the system. On the other hand, exchange with the adjacent sea could in some areas represent a considerable input of materials to the lagoon system.

In order to obtain information on the contribution of materials to the coastal lagoons from different sources, it will be necessary to gather the following information, giving particular importance to the time scale:

a) discharge of materials into the lagoon by rivers

b) estimation of the exchange rates of inorganic and organic materials between the lagoon and the adjacent sea

c) inventory of the amount and quality of substances introduced as wastes from human activities

d) estimation of substances introduced by rainfall.

Overall Chemical Processes

Before contemplating studies of chemical fluxes in the lagoon environment, it is necessary to establish which are the reservoirs of the elements utilized by lagoon organisms, the pathways by which the elements may be transferred between reservoirs and finally the relative importance of each pathway. As coastal lagoons are generally shallow environments, they offer favorable conditions for bacterial activities. Consequently, the metabolic circulation of elements in the environment is strongly influenced by biochemical processes, not only in the water column, but also in sediments and interfaces.

Water column

a) Nutrient utilization: the estimation of primary organic production is a useful tool in chemical investigations of coastal lagoons as it both reflects the rate of fixation of inorganic carbon and the rate of utilization of nutrient substances in the lagoon environment. However, it is necessary to consider that in coastal lagoons the production of organic matter at the primary level is carried out by planktonic and benthic plants. The chemical assessment of nutrient utilization by primary production should be conducted considering the time and spatial scales.

b) The present state of knowledge on chemical processes in coastal lagoons has been mainly directed to the study of biologically important substances such as nutrients, micronutrients and certain pollutants. However, very little is known about the chemical transformations that take place in these complex environments. In this regard it is possible to consider the following studies:

Decomposition of organic matter in the water column

Chemical exchange of substances in boundary layers of extremely different salinity

Chemical alteration caused by changes in the salinity parameter

Chemical transformations under anoxic conditions

Chemical precipitation, floculation and aggregation of suspended particles with absorption, and desorption of dissolved substances.

Interfaces

Interfaces provide an important place for chemical and biochemical processes to take place particularly in shallow environments such as those found in coastal lagoons. Within this context it is necessary to consider two important interfaces, the air-water interface and the water-sediment interface. Most of the research completed up to the present time has been done on the release of ammonia and to a lesser degree on phosphates from sediment-water interfaces. These studies showed important evidence of nutrient regeneration in shallow water environments. Important biochemical processes such as nitrification and de-nitrification also do occur at sediment-water interfaces. Very little has been published on exchanges of materials taking place at the air-water interface. Two important areas of research in air-water interfaces of coastal lagoons are on the gas exchange processes such as the variations of the exchange ratio of the O_2 and of the CO_2 systems recorded on the time and space scale. The accumulation and concentration of dissolved and suspended matter in surface films of coastal lagoons is another important parameter to be associated with the biological activity and the input of pollutants to the lagoon environment.

With regard to the water-sediment interface, the regeneration of nutrients seems to be of primary importance in establishing the productivity of the lagoon environment. The interface provides an important site for the bacterially mediated oxidation of detritus and permits chemical absorption and desorption of critical nutrients such as phosphates and ammonia. As a consequence of the regeneration processes chemical exchanges at the water-sediment interface may represent one controlling factor in the supply of limiting nutrients to the water column. This information can be obtained in situ with experiments using radioactive tracers such as 32P and 15N or recording changes in small parcels enclosed in plastic domes. Another process to be considered at the water-sediment interface is the mobilization of interstitial waters from underlying sediments to the water column, the nature of the process has been explained elsewhere in this report.

Sediments

The chemical composition of sediments gives a useful indication of the past situation of metabolic and depositional processes in the coastal lagoons. One of the characteristics of most coastal lagoons is the accumulation of organic matter in the sediment. This organic reservoir plays an important role in the metabolic circulation of nutrients within the lagoons, as well as being a source of food for some benthic organisms. Part of the deposited organic matter is decomposed by bacterial action returning as dissolved forms to the overlying water. Therefore, biochemical processes that are proceeding in the sediments are very important in the mobilization of nutrient elements within the lagoon.

In order to gain some understanding of these chemical and biochemical processes taking place in the sediments, the vertical distribution in sediment cores of the following parameters must be considered: Redox potential, organic carbon, organic nitrogen and other substances of particular importance in the studied lagoon. To gain some information on the source of organic matter accumulated in the sediments, when possible, one has to conduct determinations on the variation of the stable carbon isotopic ratio in the cores. This information is very useful in detecting changes in the input of organic matters from different sources into the lagoons.

Outline of research programmes in chemistry

Eutrophication

Perhaps one of the most important and immediate chemical problems in coastal lagoons arises from excessive eutrophication induced by nutrient contamination. The source of contaminant nutrients may be from natural sources carried by runoff to the lagoon basin, or from agricultural, domestic and industrial waste waters. The results of eutrophication is a lowering of the dissolved oxygen in the water and the production of toxic hydrogen sulfide. Although coastal lagoons are generally shallow systems, isolation from wind or tidal mixing may result in stratification and anoxic conditions frequently developed in eutrophied environments. Variation in the hydrographic regimes of some coastal lagoons caused by climatic stresses can also produce conditions of temporary eutrophication.

A considerable amount of research is necessary to deal with problems of eutrophication in coastal lagoons, information on the nutrient budget of the lagoons are of basic importance to manage eutrophication.

Decomposition of organic matter

The decomposition (or mineralization) of organic matter, as well as the organic production are important processes, in the metabolic circulation in the coastal lagoons. The methods for determination of organic production rate have been well established. On the other hand, there are no appropriate methods for the determination of the decomposition rate of organic matter in the coastal lagoons. In order to obtain a clear picture of the metabolic circulation in the coastal lagoons, a chemical assessment of decomposition rate of organic matter in the water column and in the sediments must be considered.

Nutrient elements

Studies on the mobilization and circulation of nutrient elements as well as potentially toxic metals and pollutants are important. The principal difference between the mobilization and circulation of elements between coastal lagoons and the open ocean is the increased number of pathways that prevail in the former. In coastal lagoons these processes may be enhanced by chemical desorption, and a variety of biological processes. Although this fact suggests the existence of a greater nutrient flux in the lagoon environment, such an hypothesis cannot be verified without quantitative data on reservoir sizes and transfer between reservoirs. The obtention of these data provides the central challenge for investigating the chemical cycles in the lagoon environment. Such information is essential for the responsible management of lagoon resources.

Mixing and exchange processes

As it was pointed out in the physical section of this report, the use of dissolved conservative materials present in lagoon water can be used as indicators of mixing and exchange processes in coastal lagoons. In this regard the particular composition of the water sources entering the lagoon system can offer the possibility of expanding the use of these techniques. For example, changes in the total alkalinity of the water of some lagoons can be used for that purpose.

A review of some general features of coastal lagoons

The flushing of well-mixed tidal lagoons and their seasonal fluctuation

Sedimentary processes in lagoons

The hydrography and chemistry of some coastal lagoons of the Pacific coast of Mexico

Biogeochemistry and geomicrobiology of lagoons and lagoonary environments

Processes in the sediments and at the water-sediment interface

Inorganic and organic nitrogen contents in some coastal lagoons in Venezuela

A coastal lake of the Nile Delta: Lake Menzalah

Spatial and temporal variations of phytoplankton production in lagoons

Ecology in the entrance of Puerto Real, Terminos Lagoon

The occurrence, diversity and abundance of fishes in two tropical coastal lagoons with ephemeral inlets on the Pacific coast of Mexico

A review of the potentialities for research and fish culture in the coastal lagoons of West Africa

Production dynamics of a temperate sea: the Baltic

Guidelines for ecosytem research in coastal lagoons

The flux of carbon, nitrogen and phosphorus between coastal lagoons and offshore waters

TASK GROUP II - Biological Processes and Ecology

CONTENTS

Physiological studies of major components

Experimental ecosystem studies

How do we study a new lagoon?

TASK GROUP II - Biological Processes and Ecology

Introduction: The lagoon ecosystem

Defining ecosystem characteristics

Before discussing lagoons as ecosystems, we shall describe the context within which we address the question. Ecosystems have often been analyzed in terms of their structure and function. The parts of components make up the structure and the interaction between the parts or the processes are the functions. The elucidation of the structure and function is a logical process. The elements are not arbitrarily identified and studied, rather they are the functional units of the ecosystems.

Components commonly used to describe structures include heterotrophic and autotrophic population, trophic structure, and inorganic and organic nutrients. These have been quantified in terms of standing crop, biomass, physiological adaptation, community structure, changes in time and space. Processes used to describe function include community metabolism; primary and secondary production and respiration; migration; food and energy flow; cycling, regeneration, uptake, and import and export of nutrients. The nature of boundary conditions or forcing functions are also important in understanding the structure and function of ecosystems; this is especially so for coastal ecosystems due to their open nature.

All of these are common ecosystem elements. They vary from one ecosystem to another in both absolute magnitude and relative proportion. Thus in developing the theme of coastal lagoons as ecosystems, we shall describe the nature of the various elements in these systems.

Coastal lagoons as ecosystems

Coastal lagoons' ecosystems are directly related to the physical and chemical environment, i.e. coastal lagoons are dynamic and open systems which are dominated and subsidized by physical energies. In this section we want to discuss several ecosystem characteristics which are a function of these features. Then we shall illustrate these points by investigating the nature of the functional structure of lagoon ecosystems.

Coastal lagoons have the following characteristics:

1. They are highly productive
2. They are ecologically complex
3. They are ecologically stable
4. They have many boundaries

Of course these characteristics apply to many ecosystems, but in the following discussion, we hope to illustrate more specifically why these characteristics are appropriate.

Specific features

Coastal lagoons are highly productive

Coastal lagoons are characterized by high rates of primary and secondary production and high biomasses of both autotrophs and heterotrophs. These rates of production are among the highest measured for natural ecosystems. In addition there is a high net production. This allows a large, economically valuable harvest by man, of fish, shellfish, waterfowl, mammals, etc. Why are coastal lagoons so productive? They are "subsidized" ecosystems. Moving water and its effects are very important. There are rich nutrient supplies and efficient means of conservation. There are several different types of primary producers and often year round production. Physiological and behavioural adaptations (i.e. salinity tolerance and migration) allow much higher biomasses at certain times than could be supported on a year round basis.

Coastal lagoons are ecologically complex

From an ecological standpoint, complexity can have several meanings. It can mean that there is a high diversity of species. It also can mean that there is a high diversity of environmental factors, habitats, a high connectivity in the food web, and a high diversity of couplings both internally and with neighbouring systems. Both these definitions are useful ways of describing ecosystems. Coastal lagoons have a relatively low species diversity and a relatively high environmental diversity.

The diversity of important forcing functions is high (sun, wind, tide, rivers). There is a high diversity of habitat types of primary producers, a highly complex food web, and a number of different types of life histories of estuarine organisms.

Chemical cycling is very complex. There are many behavioural adaptations, and physiological tolerances. Each of these will be dealt with in more detail in the next section.

Coastal lagoons are ecologically stable

As with the concept of complexity, stability can be considered in a number of ways. One view of stability is that of systems which exist in constant, predictable environments, such as coral reefs or tropical forests. These systems are not very resistant to perturbations. The opposite view of stability is that of a system such as a coastal lagoon which has evolved in a highly variable environment and mechanisms have developed to deal with this variability. These mechanisms include physiological and behavioural adaptations of different species as well as the development of alternative pathways and structures. Wide physiological tolerances, migrations, a highly connected food web, and complex chemical cycles are examples of these mechanisms. Thus complexity increases to the stability of the system.

Coastal lagoons have many boundaries

Coastal lagoons have many boundaries, both external and internal. Externally, they are bounded by marine, freshwater, and terrestrial systems and the atmosphere. Internally there are boundaries between water and bottom, aerobic and anaerobic, fresh and salt, wetland and open water, shallow and deep, different water masses, etc. Much of the reason that coastal lagoons are productive, stable and complex is because of the nature and number of these boundaries.

The existence of a boundary implies the existence of a gradient, and as mentioned earlier, work can only take place where a gradient exists. Thus an ecosystem can be more productive (one can do a greater amount of work) where there are many gradients. Of course there must be an outside force to maintain a gradient, and hydrology is very important in accomplishing this. These boundaries also allow for the development of many different habitats and increases both the stability and complexity. In the next section we shall analyze the structure and function of coastal lagoons so as to illustrate the preceding points.

Functional structure of coastal lagoons' ecosystem

Biota

The complexity of the physical environment produces a diversity of potential habitats. The biota has exploited this diversity to create an even more complex mosaic of biological habitats. Consider the different physical environments, high energy passes, intertidal, shallow littoral areas, deeper central bays, and the low salinity, riverine-influenced oligohaline. Primary producers have fully exploited these areas. Salt marsh grasses or mangroves grow in the intertidal, submerged grasses; macroalgae, and benthic microalgae may exist in the littoral; phytoplankton dominate open waters, and freshwater swamps and marshes are often found at the fresh-saline boundary. Floating vegetation may also be important in fresh areas. Epiphytic communities utilize submerged and emergent plants as a substrate. Animal communities have also exploited the full range of habitats. Different benthic communities exist in passes, marshes, grass beds, deeper waters and oligohaline waters. Both meio- and macrobenthos are important. Where conditions are favourable, reef building organisms, such as oysters, create new habitats with a unique community structure. Zooplankton are most important in phytoplankton areas. Nektonic organisms exist throughout the system acting as regulators. Thus there is a diversity of habitats and of different kinds of autotrophs and heterotrophs.

There are high rates of primary and secondary productivity. This high productivity results because of many subsidies. Two important subsidies are rich nutrient supplies and currents. Constantly wet roots allow evapotranspiration, in emergents to approach theoretical maxima. Productivity of different types of plants are often complementary so that there is significant year round production. Physiological tolerance of varying salinity and temperature and dryness in the intertidal is important. Fast growing phytoplankton and epiphytes allow quick response to favourable conditions such as increases in nutrient availability and higher temperature.

This high primary productivity supports a high secondary production. Animals are able to make most efficient use of food resources because of a number of adaptations. As with plants there are physiological tolerances and fast growing organisms. In addition to being able to adapt to cope with variation in salinity and temperture, and to dessication, many benthic organisms are able to adapt to cope with high sedimentation and low oxygen. Organisms such as zooplankton, jellyfishes, meiofauna and small fishes have high potential growth rates. Benthic organisms such as oysters and clams are able to withstand long periods of low food availability. A large number of lagoon species are migratory. This allows a much higher biomass during favourable conditions such as at times of high food availability.

Metabolism and energy flow

Coastal lagoons are very dynamic systems, developing a high turnover rate of organic material produced inside and outside the lagoon. Important and sometimes drastic changes in the environment, however, result in dynamic spatial and temporal distribution patterns of transient (= temporary immigrants) and resident (indigenous) organisms.

The resident organisms generally are highly adapted and thus can monopolize the habitat. Nutrient and organic matter input, together with shallow water conditions, light penetration to most of the bottom parts and good wind mixing in most cases lead to high peaks in productivity, very often followed by outburst of bacterial blooms in the water. Bacterial activity is so fast, that the total daily production can be turned over within the same day. This, combined with similar peaks in respiration activity of the meiofauna may lead to distrophic crises of the system, often forcing the immigrants to retreat. Caused by nutrient abundance, fast production and partial recycling, the storage potential and actual storage of organic matter in lagoon sediments is higher than in other comparable systems such as estuaries or offshore shallow water systems. Thus lagoons are ephemeral geographic situations leading to an upheaval of reduced organic compounds and speeding up of biogeochemical and biological reactions as a consequence of the constant supply of material, combined with a high trapping potential.

Food webs: order-disorder

The trophic structure is characterized by a number of different primary food types, a highly connected food web of generalized feeders, and a number of feeding habits. Food enters the base of the food web in different ways. All of the plants can be grazed directly, but this is the dominant mode only for phytoplankton. Much of the emergent and submergent plant material enters the food web as detritus. Because of net nutrient uptake during the formation of detritus, this material has a higher food value than the plant material alone. For both detritus and epiphytes, it is not just plant material, but an entire community which is consumed. The community includes bacteria, fungae, microalgae, protozoans, and higher animals.

Although the principal structures of the food-webs in coastal lagoons do not differ from those in marine systems elsewhere their enclosed character and the shallowness of the water, meaning good mixing and light down to the bottom, cause a somewhat different channelization of the fluxes of energy and matter. Due to the good light conditions the submerged macrophytic vegetation flourishes, making a large area of substrate for epiphytes like diatoms. In many lagoons free-floating mats of green algae and diatoms occur in cases where there is luxuriant light at the sediment surface. These are covered with thick carpets of primary producers like blue-green algae and diatoms.

There are two types of food chains: one based on grazing and another based on detritus. There are several different types of grazer phytoplankton in open waters. Some benthic organisms such as oysters, clams, and anemones filter phytoplankton and other particulate matter in areas where there is sufficient current. Snails and some fishes graze on epiphytic and benthic algae. There is also some direct grazing on emergent and submergent plants. Detritus is an important food item for many small fishes, shrimps, and meiofauna - especially in faunal deposit feeding species. Carnivores become more generalized higher in the tropical structure. The increased pool of autochtonous particulate matter induces an intensive activity of the microorganisms in the sediment. This might be further enhanced through the close spatial connection to the primary producers in the topmost layer of the sediment. The mineralization processes probably work to a lesser extent to low molecular end products than in other habitats as more energy and

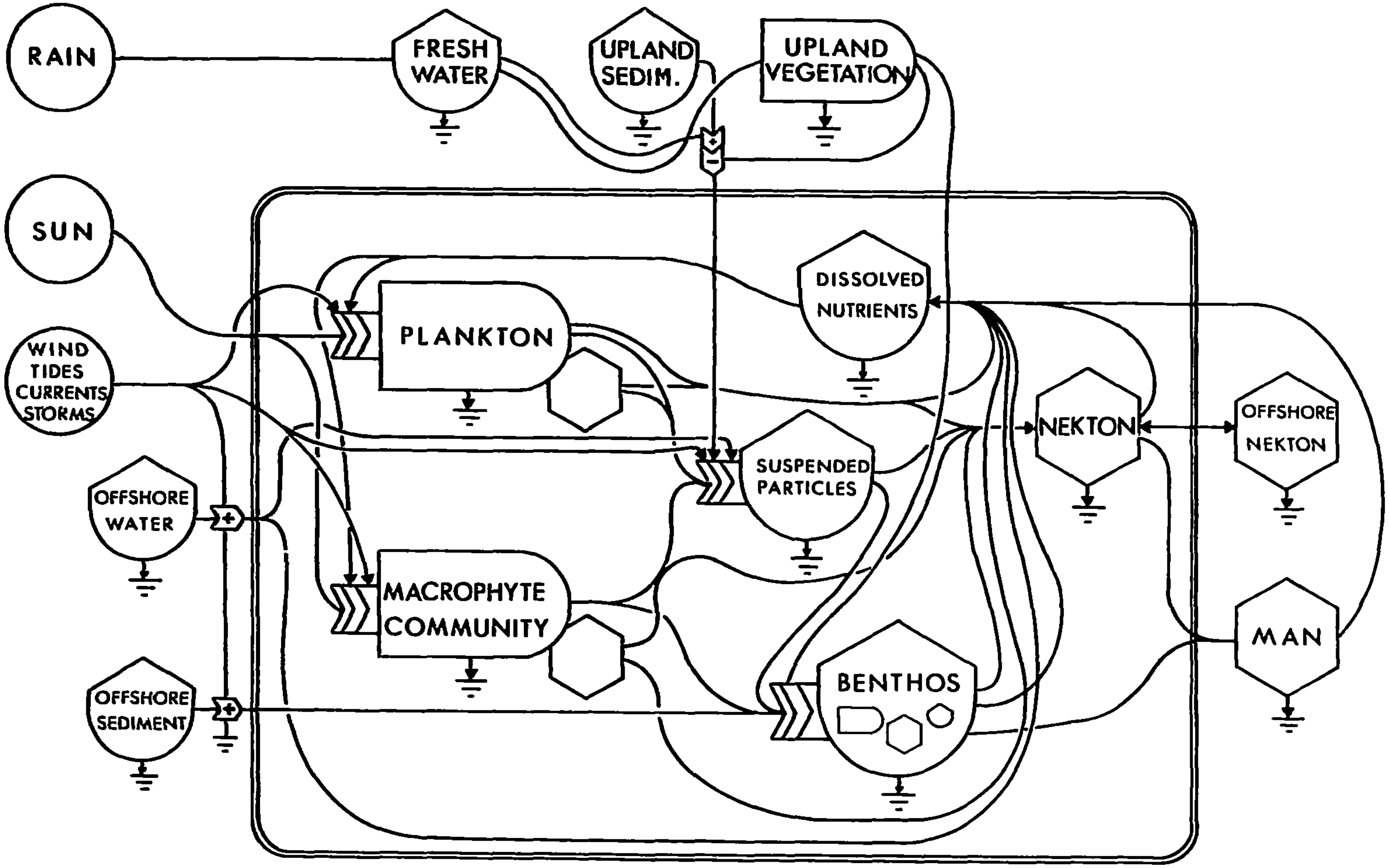

Fig. 1 Generalized energy flow diagram for coastal lagoons.

matter is channelized to primary producers due to the good light conditions and close mechanical contact. This means that the pool of particulate organic matter is increasing in the sediment and the "fossilization" or transport of it out of the system is high. As stated elsewhere, the nutrient cycling in coastal lagoons is probably higher than in, for example, estuaries.

From the point of building biological structure, two extreme types of lagoons can be recognized: the one with stable or predictable environment and the one with high frequency or physical and chemical disturbances.

1. The first type shows high diversity of the biological components; complex food webs and steady state conditions. Good examples are Lake Menzalah in Egypt (Halim, 1978) and Laguna de Terminos in Mexico (Yañez, 1978).

2. The second type is characterized by periods of relatively stable conditions during which an elaborate community structure is being built and the system is mainly biologically forced. These periods are every now and then interrupted by heavy flushing of water of different properties and causing stress and disorder (see Fig. 2).

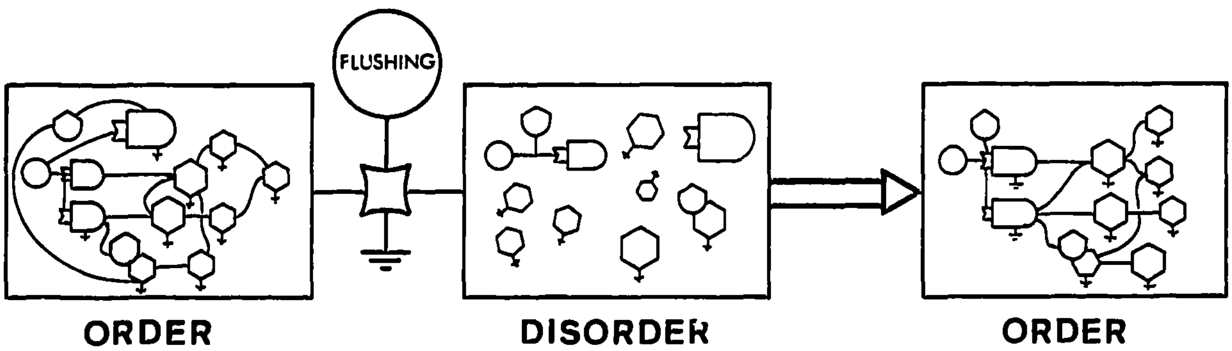

Fig. 2 Food webs order-disorder sequence as a result of water flushing.

During this period osmoregulatory and adaptatory processes are dominating and less energy can be spent on interactions between organisms. The stress is registered in, for example, the behaviour of the organisms, the fish grow sluggish, do not eat, have high respiration costs, etc. An example of this lagoon is the Arcachon Bay in France (Lasserre et al., 1975). The concept of succession, as exemplified here, is central to much current thinking of the structure of ecological communities (Margalef, 1968; Odum, 1969; Johnson, 1972). Odum describes it as:

1) an orderly and directional process which

2) results from modifications of the physical environment of the community and

3) culminates in a stable climax. This paradigm can and has been challenged although it is clear that certain biological interactions are indeed orderly and do have predictable outcomes.

During periods of high environmental stress opportunistic species ("r-strategists") create a high temporal heterogeneity which produces, generally, unbalanced conditions for K-strategists. Those immigrant species which constitute the great majority of the living resources in lagoons create spatial heterogeneity through predation. These species, however, are hardly limited in their competitive ability by the deleterious effects of stress (see paragraph on physiological ecology). In a coastal lagoon a transient physiological capability to cope with the lagoonary conditions will give to immigrants (K-strategists mostly) a competitive advantage over the r-strategists, at least on a temporary time scale (Fig. 3).

Adaptation to the lagoon environment (physiological ecology)

Research has now entered a stage where we are beginning to understand the competitive interactions of multi-species systems in terms of different modes of adaptation. The biochemical properties of adaptation of individuals and populations are very important for a true understanding of stressed lagoon systems, and emphasis is placed on the evolution of these adaptations in the formation of communities.

The very existence of any organism will depend on its capacity to adjust to daily end seasonal changes. Each organism does not regulate by any single pattern but is resourceful in utilizing a wide range of regulatory mechanisms, e.g., the euryhaline homeosmotic species are able to regulate the composition of their body fluids by passive or active mechanisms which maintain a steady state of ionic and water flux between external and internal media. All these adaptive properties imply different specializations. A considerable amount of work has been done during the last decade on the cooperative biochemistry and physiology of species living in estuaries and lagoon systems. However, most of the attention has been directed towards physiological or biochemical end points.

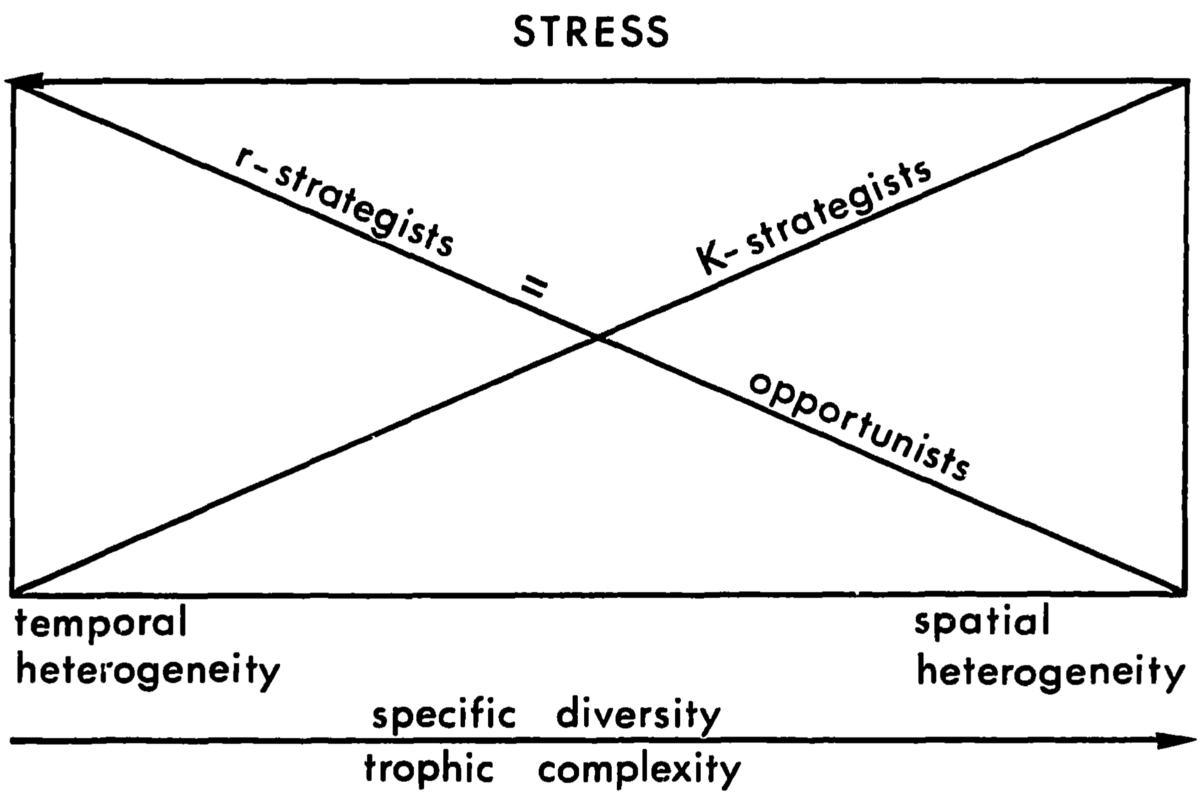

Fig. 3 Autochtone versus immigrant species responses to stress in coastal lagoons.

There is, at present, widespread interest in rearing and harvesting organisms of nutritional value in the coastal lagoons, salt marshes, mangroves that are extremely productive and are, nevertheless, in a state of borderline excess of eutrophication. Coastal lagoons receive temporary immigration from the sea, and, to a lesser extent, from the land-based waters. While some species may actively seek the most favourable environment by migrations, others, with limited locomotive ability or which are herded in lagoon enclosures, must deal with the environment.

Stress is an inescapable part of life in coastal lagoons: e.g., the salinity effects are complicated by the interaction of other environmental factors and are mediated, eventually, through an osmotic behaviour which is highly adapted in nature. Conversely, isolation of temporary immigrants in lagoon enclosures can alter the *ad libitum* migratory tendencies and trigger osmoregulatory disfunctions. It is very probable that periods of prolonged neuronal and hormonal activity, often related to prolonged environmental stress, may produce some shortage of energy demands for growth or maturity, which is reinforced at a certain moment by some generalized reduction of metabolic energy (reduction of ATP production) as in the case of low temperature in winter, accidental anoxia due to high eutrophication in summer, hypoglycerinia due to starvation or to some unbalanced condition of nutrient availability. It is noteworthy that apart from naturally occuring stress, many polluting substances can alter the osmoregulatory and other metabolic mechanisms. Osmotic balances as derived from a study of blood chemistry and tissue composition can indicate a "healthy" or "unhealthy" state relative to given environmental conditions. Modification in the gill ATPase activity of amphihaline fish can give some significant indication of their migratory tendencies.

Microfaunal and meiofaunal communities are very successful in reproducing and growing in coastal lagoons. Those opportunistic species have short generation times and their production/biomass tend to be considerably higher than for macrofauna. They must therefore require a high level of metabolic energy and food consumption to complete their life cycle and it may be anticipated that their protein metabolism is elevated. Little systematic work has been done, for example, in comparing the osmotic adjustments of laboratory adapted organisms with field populations from contrasting habitats. It is necessary therefore to increase our knowlege on the DYNAMIC ASPECTS of adaptative adjustments, with ECOLOGICAL BIAS, of species that have been shown to exhibit differential penetration of lagoons. The key variable of salinity, temperature, oxygen tension, and other major environmental factors influence greatly differential penetration, colonization, and establishment of animal and vegetal communities. Such approaches, however, are beset by methodological and interpretive difficulties, and therefore, it is necessary to standardize the methods of sampling, capture, handling and laboratory techniques. Physiological periodicities, temporal shifts due to localized abiotic effects and variations due to reproductive conditions, should all be taken into consideration in the future.

Ecological strategies of microflora, ecophysiological strategies of meiobenthos and zooplankton. Adaptation of halophytes.

A high degree of tolerance to many environmental factors has been shown in many meiobenthic and zooplanktonic species. Recent studies using sophisticated methodology have shown the independance of metabolic activities over large environmental temperature, salinity and oxygen ranges, suggesting the existence of metabolic compensations.

Furthermore, increased evidence of many original features of ecophysiological adaptation presented by meiobenthic organisms and the general importance of meiobenthos in coastal lagoons tends to encourage future studies which try to define the complex picture of all the acquired adaptative features of meiofauna in their habitats.

Ecophysiological strategies of macrobenthos

Sampling evidence and the examination of fishing and collecting records from coastal lagoons and other embayment systems indicate that fish and many macrobenthic economic species, such as crustaceans and molluscs, invade periodically these estuarine habitats. The key variables of salinity, temperature, and to a lesser extent, oxygen are important and probably influence greatly the differential penetration and movements of animal populations. Osmotic balances derived from the study of blood chemistry and tissue composition can indicate a "healthy" or "unhealthy" state relative to given environmental conditions.

Blow-up

The benthic communities

Soft bottom communities of lagoons differ largely from offshore soft bottom communities and estuarine communities for physical and biological reasons. The main differences can be expressed in terms of transport and sedimentation potentials of the hydrographic regime and in terms of grain size, accumulation of organic matter and storage potential derived from both, transport processes and production. Soft bottom of lagoons tend to have higher surface volume ratios than estuaries or especially offshore sediments, leading to a more extended area suitable for primary production by benthic autotrophic communities.

Lagoons and their sediments thus have finer grain size, high benthic productivity, high planktonic productivity, high supply of organic matter and low export (transport) energy. This establishes a reservoir for DOM and POM and a special cycle of energy and nutrients in the sediments which in exchange feeds back to the open water. Before general characteristics of the soft bottom system are described, a short review of additional factors in sediments of lagoons should be mentioned.

(1) Seasonality, (2) salinity, (precipitation/evaporation), (3) permanent or episodal, (4) flushing, (5) pollution, (6) terrestrial material supply, (7) existence of wetlands or (8) mangroves, and (9) internal and (10) external sediment regime largely influence productivity and remineralization patterns in lagoon sediments.

Generally high latitude lagoons have a very well defined seasonal cycle, smaller changes in salinities, and lower salinities than the open sea. They have salt and freshwater marshes but no mangrove systems. Frequently the marsh systems are very productive and interacting with the lagoon. Peat swamps may extend into the lagoon system when freshwater supply is high, causing holigotrophic conditions with low benthic production and low turnover rates but still high storage capacity for organic matter. Lagoons of low latitudes, especially in dry climates, have strong fluctuations in salinity and generally coarser sediments, which are caused by shell detritus and carbonate sand being preserved, but they may also have carbonate mud conditions. They tend to be hypersaline at least for certain periods of the year. This leads to stress on certain kinds of producers and consumers in the lagoon sediments and to the development of mangrove in addition to marshes. The production of the benthic flora and microflora is partitioned between seagrasses (Zostera, Posidonia, Ruppia, Halophila, etc.), eukaryotic algae (brown and green algae and diatoms mainly, red algae in a few cases) and prokaryotic cyanobacteria and photosynthetic bacteria. Brown algae are typical for high latitudes, while cynobacteria represent the most important benthic producers in low latitudes and hypersaline lagoons. Faunal elements of the sediments (including protozoans, meiofauna, lamellibranchs, gasteropods, annelids and crustaceans) undergo large seasonal variations in northern systems during the year, while variations in the low latitudes are restricted to lagoons with (a) changing salinity, (b) monsoon character or (c) seasonal heliothermal stratification. Hypersaline lagoons have a stable and poorly developed fauna which undergoes changes with seasonal heat stress and drying. Tidal adaptation is similar in high and low latitudes, except that the fauna of low latitudes tends to exhibit more heat-protecting stress adaptation patterns while in high latitudes freshwater adaptation patterns may prevail. Very little is known, however, about the latter.

The detrital food chain in lagoon sediments is usually characterized by (1) high productivity, and high supply of organic matter, (2) high oxygen demand of the organisms, (3) high turnover rates of the aerobic and anaerobic flora and (4) high storage potential for POM. The vertical zonation of different subsystems is more varied and more distinct in low latitude sediments than in high latitudes. The sulfur cycle in lagoon sediments is relatively well-studied and has been qualified to some extent. Less exact information is available on the nitrogen and the phosphorus cycles, although such cycles are being worked out recently in estuaries. The partitioning between respiration and fermentation is known in some cases but very little information exists so far on the distribution between respiration of the fauna and the flora under aerobic and anaerobic conditions. In very general terms, the respiration ratio between animals and microbes is higher in the aerobic system, than in the anaerobic. Recently however, it has been shown that several genus of the benthic fauna are capable of anaerobic respiration pathways.

In a generalization it can be said that aerobic respiration peaks in summer in higher latitudes, while it tends to be high all over the year in low latitudes. The tendency of a chemocline for oxygen reaching the surface in general is higher in low latitudes, but under certain conditions (fine grained sediments, high supply of detritus, stagnant conditions, high consumption in the water column), it occurs in high latitudes as well. Special bottom systems (microbial laminated mats) may develop frequently in different forms. They are composed of diatoms, cyanobacteria and photosynthetic bacteria. In high latitudes and at low salinities, they have a tendency to be inside the sediment, while in low latitudes and under high salinity regime they tend to be above the sediment surface. Sedimentation rates also play a role in this. All soft bottom sediments of lagoons may be divided horizontally in three zones:

1) rooted seagrass and mangrove systems

2) microbial mat systems and some macroalgae systems

3) nonproductive aphotic systems (only at water depth below 5 m or at very high turbidity or sedimentation rates and sediment transfer, e.g. tidal channels with strong currents transporting high amounts of fine-grained material and detritus).

The bacterial mechanisms in general are the same as in any other sediment, but the energy transfer rates are usually considerably higher. Except for freshwater lagoons, the main controlling factors of respiration and remineralization are:

a) aerobic respiration by chemo-organotrophic bacteria and by the fauna;

b) transfer of buried materials to the aerobic zone by burrowers and oxygen channel producers back to (a);

c) and anaerobic respiration by mainly chemo-organotrophic bacteria and anaerobic fermentation with varying end-products released into the water or captured and trapped in the sediment. The main metabolic processes are summarized in Fig. 1.

Macrophytes and microphytes

Inside lagoons

Though seagrasses are of common occurrence in shallow marine waters, the macrophyte ecosystem is of particular importance to the total economy of coastal zone lagoons. Analogous mechanisms govern the community structure in mixohaline lagoons in spite of their diversity. In oligohaline lagoons, the macrophytes are represented by the tolerant freshwater Potamogeton pectinatus, P. crispus and Ceratophyllum demersum and in mixohaline ones by Thalassia, Ruppia, Zostera and macroalgae. Oligohaline macrophytes are favoured by soft silt clay bottoms while the mixohaline ones appear to be always associated with sandy bottoms. Propagation is mainly assured by rhizomes embedded in the soft bottoms, though seeds are also produced.

Seasonal variations in growth and exchanges with the system are temperature programmed, being less pronounced in tropical lagoons. In temperate lagoons, growth is accelerated in spring, the growth rising from 2 to 10 g dry weight m^{-2} day^{-1}. The Potamogeton-Ceratophyllum macrophytes extend to the water surface, up to 0.5 to 1.5 m, depending on depth, but the sea grasses are more limited, rarely exceeding 0.5/0.75 m in length. The biomasses are of the order of 2/10 kg m^{-2}, and almost 0.500 kg m^{-2} respectively for the Potamogeton-Ceratophyllum and the Thalassia macrophytes.

During the growth, the macrophytes draw heavily on the available nutrients and regulate the level of dissolved oxygen. The activity shows a pronounced diurnal cycle, the respiratory or nocturnal phase is accompanied by a drop of dissolved oxygen, in the pH and in the rate of nutrient assimilation. In winter, the plants deteriorate, settling and decomposing on the bottom. This is accompanied by an increased input of dissolved particulate organic material and of bottom detritus.

Macrophytes are not consumed by secondary producers. They function as a transient store for the assimilated nutrients which will be fed back to the system at various levels of detritus. The major function of the macrophytes is in providing a substratum and a shelter for a complex and well structured community of sessile diatoms and epiphytic filamentous algae (Chladophora, enteromorpha, chaetomorpha, as well as vagile and sessile epizoans and meiofauna).

The rhizomes of seagrasses also harbour a variety of burrowing organisms. Epiphyte and detrital grazers and filter feeders are dominant. They include gastropods (Hydrolia sp. in European lagoons) isopods, amphipods, tube-worms, sessile protozoans and meiofauna. Fish-fry are usually entirely epiphyte grazers. Adults are omnivore. The high productivity of fish associated with the macrophyte ecosystem, such as Tilapia in the Nile delta lakes, is mostly caused by their low trophic level.

Around lagoons; salt marshes and mangroves

Many lagoons are surrounded by salt marshes, or, in some cases, fresh or brackish water vegetation. Spartina alterniflora is the characteristic vegetation where sea meets land in boreal, temperate and subtropical waters in regions protected from the direct action of the sea. Salt marshes are among the most productive ecosystems, average net production ranging from approximately 500 g C m^{-2} yr^{-1} in temperate regions to 2000 g C m^{-2} yr^{-1} in tropical and subtropical regions. This substantial production is thought to be important to marine foodwebs through the detrital food chain. Spartina stems, broken off during the season or left over from winter will decompose slowly, forming smaller and smaller particles called detritus. These salt-plant particles are colonized by bacteria, which collectively increase the protein (and nitrogen) content of the detritus, increasing the quality of the detritus as food. It is thought that in many areas this detritus is important in the food chain leading to fish, although there have been few direct studies confirming this pathway. It may be possible to identify the importance of Spartina- derived food, vs other plant source-derived food by carbon isotope ratios in organisms, since Spartina, a C4 plant, has a different isotope ratio than other C3 plants. This method may offer the potential for assessing the contribution of Spartina marshes to lagoon production.

Salt marshes provide other contributions to estuarine life besides direct contribution through food chains: they stabilize land areas, provide flood protection to land areas, provide habitat for birds, marsh animals, and in tide channels, fishes and invertebrates.

In the United States, a number of studies have indicated that salt marshes are probably, in general, nitrogen limited. Salt marshes have been shown experimentally to be effective absorbers of sewage. Addition of fertilizer or sewage nitrogen to the surface of salt marshes dramatically increases the Spartina standing crop. However, marshes are not infinite sinks of nitrogen. Apparently they take up oxidized forms (NO_3, NO_2) and give off reduced and organic forms (NH_3, DON). It is unclear how rates of uptake or release of nitrogen from marshes surrounding lagoons will vary in response to seasonality, salinity pulses, or wide fluctuations between oxic and anoxic conditions.

Phytoplankton, zooplankton and meiofauna

The shallow depth and high turbidity of many coastal lagoons often minimizes the contribution of phytoplankters to the primary production of these systems. However, lagoon waters also tend to be quite high in nutrients and intense blooms may develop periodically, particularly in temperate lagoons. While the standing crop and productivity of phytoplankters per unit volume may be considerably higher in lagoons than in offshore coastal waters, the production of plankton per unit area of the lagoon is often lower than that of the macrophytes or epibenthic microflora.

Because of their much longer generation time, the zooplankton of lagoons are strongly influenced by the flushing rate of the system. Particularly at lower temperatures, the length of time required for eggs to hatch and for nauplii to develop may be long enough so that an appreciable portion of the population is lost offshore. Even at higher temperatures, the flushing rate of a lagoon may dampen predator-prey cycles in the plankton.

Because of the difficulty of making measurements of secondary production, little is known of the energy flow through lagoon zooplankton populations. An important characteristic of the lagoon zooplankton community, however, is often the large contribution of meroplankton-bivalve, gastropod, and polychaete larvae, fish eggs and larvae. Because of the large amount of sediment surface to water volume and the role of lagoons as fish nursery areas, the meroplankton are usually much more dense in lagoons than offshore. These elements often enter the plankton in sharp pulses that may exert an intense grazing pressure on the phytoplankton. In a number of cases, these zooplankton, as well as some copepods and the larger gelatinous forms such as Ctenophores exert carnivorous feeding pressure on the smaller zooplankton. Little is known of the importance of predation in lagoon zooplankton population dynamics and even less information is available on the microzooplankton or bacterioplankton of these systems.

Because of the interactions of varying salinity, temperature, flushing, predation and food supply, the dynamics of lagoon zooplankton populations may be complex. It may be that the most important components are the transient larval stages of fish and benthos. In terms of energy-flow and production, the benthic harpacticoïd copepods may be most important as a food source in lagoons.

Community structure of fish

The community structure of fish can be described by: number of species, number of abundant species, biomass, productivity, other measures of diversity, dominant-diversity relations, and population dynamics in particular. The methods for measuring such indices in <u>shallow</u> (< 3 m) coastal lagoons are fairly well established, relatively inexpensive and suitable for most nations with biologists trained to a moderate technical degree.

Probably, relative species abundance, biomass, productivity, and trophic relationships, are the most important parameters to study in any new programme. We may conclude tentatively from some studies and our own experience, that coastal lagoons tend to have a more complex community structure and higher levels of biomass and productivity.

The fish community structure of lagoons is different from adjacent coastal waters in that the percentage of all fish that are juveniles tends to be much higher in lagoons. Such few comparative studies as exist show higher numbers and biomass per area in lagoons than in adjacent coastal waters. In addition, smaller fish tend to be found in shallower waters, and larger fish in deeper waters. Lagoons appear to be important in the life histories of many commercial fish species including those that are caught offshore.

Migration patterns

The utilization of estuaries and lagoons by marine organisms is not random. Many species have selected through evolution behavioural, morphological and physiological adaptations that optimize the use of the food richness of these regions during the juvenile stages of organisms by the timing of reproduction and migration patterns. What are these patterns? In general, estuarine and lagoon-dependant organisms utilize coastal regions as follows: Adults migrate from their normal feeding regions, which are often far from the coast, and spawn so that eggs or larvae will drift into coastal environments. The young hatch in or on their way there and upon arrival exhibit various behavioural and morphological characteristics that tend to keep them there. For example, young finfish maintain their position in estuaries and lagoons by swimming, by day-night vertical movements, or by settling on the bottom. Shellfish often attach themselves to substrates by various claws and shrouds. The young spend from a few weeks to 1 or 2 years in estuarine systems and may later drift with currents or swim to adult feeding regions.

The salt-wedge circulation pattern (Fig. 1) characteristics of estuaries and lagoons with large freshwater inflows consist of freshwater moving seaward near the surface, and salt water moving inward on the bottom. The deep salt water moves landward to replace other salt water that mixes with surface water and is carried to sea: the inward-flowing salt water that supplies the salt wedge may be found from many tens to hundreds of kilometers offshore, and the boundaries of the salt wedge shift landward and seaward in response to tides and seasonal variations in freshwater input.

This bidirectional flow of water has allowed for the development of three major patterns by which organisms use estuaries for reproduction and juvenile feeding. These three patterns are (1) ocean spawning, followed by immigration of the larvae in the landward moving, deeper salt water, (2) estuarine spawning in which the larvae do not move appreciably, and (3) river-spawning, followed by downstream drift, or swimming of larvae or juveniles. The commercial shrimps of the Gulf of Mexico (genus *Panaeus*) and a lot of marine fishes in the same area, are examples of a group of organisms that use the first pattern, various *Fundulus* or killifishes are examples of the second, and salmon and the striped bass (*Morone saxatilis*) are examples of the third.

The entrance of juvenile fish into coastal lagoons without large freshwater inputs appears to be a somewhat more haphazard affair since there are not either landward or seaward flowing currents to follow. The specifics by which juvenile fish "find" lagoons is known for a few cases. In the United States, some oceanic fish will spawn in lagoons, moving into the lagoon in early spring. In other regions the pattern seems to be, spawning by adult fish in shallow coastal waters, followed by drift of fish in longshore currents during the larval stage and then entrance into coastal lagoons and ponds at a few months of age. Others spawn well offshore then come to estuaries as fish of several months of age. As a rule, lagoons are important feeding areas for both juvenile and adult fish.

Thus the utilization of coastal waters by migrating fish tends to be strongly seasonal due to the closely-timed reproductive cycle of most boreal, temperate, and subtropical fishes. In addition, seasonal patterns may be determined by the opening and closing of some lagoons which are associated with winter storms and/or periods of high freshwater discharge. The strong seasonal timing of migrations and reproduction in temperate waters is an adaptation to the pulses of food availability that occur in spring and early summer. Such pulses are not as strong in tropical environments or may be related to other seasonal factors such as rain water input. We do not have information at this time as to the timing of tropical lagoons migrations, and spawning is tied into the seasonal cycle of productivity.

Sea grasses and mangrove subsystems

The sea grasses and mangrove communities represent interesting subsystems because many studies have shown that they are fundamentals in the control and modification of the habitat: 1) they can serve as food for direct grazing, even if all the food cannot be digested; 2) they serve as substrata for numerous epiphytes which in their turn are grazed upon; 3) they provide large quantities of detritus which serve as food for different species and microorganisms which in their turn, can be consumed by fishes; 4) they have a high rate of production and can produce between 2 and 10 g dry weight m^{-2} day^{-1} (*Thalassia*) and 8 tons of organic matter Ha^{-1} yr^{-1} (*Rhizophora*).

Frequently the juvenile fishes are found associated with sea grasses and mangrove root systems. Two aspects are interesting to consider in this sense:

1) apparently the marine grass fields and the mangroves are efficient ecological systems to convert energy from solar radiation capable of sustaining important fish populations, and 2) the quantity consumed by fish is considerably less than the biomass of sea grasses and mangrove leaves. Therefore it is reasonable to suppose that an excess of organic matter unable to be used by consumers is produced, which is deposited and retained in sediments but must also be exported to neighbouring ecological systems.

Patterns of migrations, food relationships, analysis of frequency in the samples during time, and the state of gonads and length weight relationships, are parameters considered in order to establish if the populations are: 1) permanent residents, 2) seasonal residents, 3) temporary visitors which feed in a larger area than that occupied only by grasses and mangroves, and 4) migratory occasional species. Sea grasses and mangrove root systems are habitats in which fish find nursery grounds, protection and availability of food.

Methods for sampling fish population

It is easy to get samples of fish but difficult to get a sample that is a reliable estimate of the community structures of the area sampled. Trawls are probably most frequently used but are thought to be inefficient, perhaps by a factor of 10, in shallow lagoon-like areas. Other means of quantitative sampling include shore seines, purse seines, various push and drag nets and drop nets. Drop nets are probably the best means for quantitative sampling in most shallow lagoon areas, especially if the water is not clear. The net can be built on a movable floating frame so that samples can be taken from different areas. The deepest of these nets that may be used is probably 3 or 4 m. The "triple seine" technique is a cheap and effective method for quantitative samples of tidal channels. A 400 or so square meter area is blocked off quickly by two seines with floats and chains, then the water in between is seined. The method is especially well adapted for salt marsh channels. There may be no really effective sampling methods for water more than 4 m deep. Other trawls are most frequently used but we do not know of any systematic study of their efficiency (which may be quite low). Large purse seines used in random sampling schemes may be effective for sampling pelagic fishes in deep water. Planktonic fish are normally sampled with towed nets: the efficiency of these nets increases with speed of towing up to at least 10-15 km hr^{-1}, indicating net avoidance at low sampling speed. Our experience indicates that drop nets and other trawls are the best appropriate net to collect fish in the same order of efficiency.

Hypersaline lagoons: a special case

In tropical arid areas, very often a life cycle of lagoons occurs that can be described as follows:

An embayment is gradually closed off from the sea. This results in increased salinity; no nutrients coming from freshwater sources and exchange with the sea decreasing in speed and quantity. The consequence is an initial decrease in productivity, because many of the symbiotic communities (e.g. benthic foraminifera, plants and reef organisms) are excluded by salinity. Gradually green algae, mytilids and gastropods are excluded. The lagoon ends up as an almost totally microbial system. Since export of organic matter decreases and consumers decrease in importance, while primary productivity increases due to light conditions, gradually more and more organic matter is built up by oxygenic and anoxygenic planktonic and benthic diatoms, cyanobacteria and photosynthetic bacteria. The typical stromatolitic microbial ecosystem builds up.

As long as high evaporation rates (up to 4 m $annum^{-1}$) lead to constant supply of small amounts of nutrients, these get trapped into the system. Anaerobic conditions are more and more established in the bottom parts, with a thin aerobic surface layer. When the primary production reaches a certain maximum in the benthic microbial mats, a fast turnover of the organic matter starts, thus furnishing more and more recycled nutrients. At maximal development, the sum of planktonic and benthic production may reach values of 12-15 g C fixed m^{-2} day^{-1}. It has been found that about 95-98% of this production is immediately recycled in the aerobic zone. Sulfate reduction measurements have shown that the remaining material is recycled also in orders of magnitude which necessitate constant migration of photosynthate to deeper layers. According to equilibrium conditions either carbonate and gypsum muds are developing below mats and the planktonic zone; or laminated carbonate sediments without any gypsum but richer in remaining organic matter are produced. This is the case when sulfate is completely used up in the interstitial water through sulfate reduction as terminal electron acceptor. Gradually the system fills up with biogenic carbonates, evaporites and some wind-blow allochtonous material. Finally salt and gypsum crusts develop and the stromatolitic mats are embedded in these as it can be observed in salt pans.

At this stage, the evaporating pumping system, with reflux of the heavy brines through the bottom sediments is gradually sinking downwards into the accumulated sediments. This results in shortage of water and drying out of the photic zone. Gypsum is no longer reduced to sulfide because productivity decreases and the interstitial spaces are cemented. Therefore less water and nutrients are seeping in, photosynthesis stops and the lagoon system falls back to extremely low or no production. After the bar is closed completely and salinities jumped up to more than 10%, the food chain is practically reduced to microbial production and consumption and degradation, with some participation of Artemia salina, coleopterans and protozoans. This system therefore is an excellent model to study seasonal and spatial variations, in productivity and degradation and nutrient release. Also, changing conditions of H_2S and oxygen borderlines are easier to study than in any other ecosystem. Furthermore, this system is interesting because it happens frequently within the mats that the large amounts of oxygen produced by oxygen photosynthesis coexist with H_2S migrating constantly upwards from the sulfate reduction zone.

It is suggested that within the frame of lagoon studies, examples of such a simplified hypersaline lagoonary system are studied in terms of microbial metabolism and energy transfer rates. They also may serve as a simplified model of the processes of eutrophication and trapping of nutrients in lagoons, since the nutrient flows are restricted to very few groups of organisms. Such hypersaline systems have received some interest recently also because they represent excellent solar energy collectors in two senses:

1. They are very fast and efficient anaerobic systems for the production of reduced carbon compounds, which can be used as food or energy sources in the form of hydrogen.

2. When stratification is developing by layering of seawater above brine, the brine can heat to 110°C. This can be used for several purposes as energy yielding systems.

The study of these end members of the lagoon development in tropical dry climates therefore is urgently suggested, because they may be sources of 3 types of energy.

Outline of Research Programmes in Biology

A suggested research programme for lagoon ecosystem analysis

An ecosystem analysis of lagoon environments should follow the same general procedures that have been developed for other areas. The first step is to define the system boundaries. If possible, they should be selected so that the flux of materials across the boundaries is small relative to the cycling of material within the system. It makes no sense to draw boundary lines across water bodies if the lines are based on arbitrary geographical or political considerations. In the case of lagoons, the upland watershed is also a vital part of the lagoon and shall be included in the system boundary. This is also true of the ocean boundary, where beach processes and sand transport play an important role in lagoon ecology through the regulation of beachways and sedimentologies within the lagoon. Once the boundaries are defined, the research programme might proceed as follows:

System Mapping

Lagoon and watershed morphology

Lagoon bathymetry, watershed topography

Distribution of major sediment types in the lagoon

Distribution of major bottom community types in the lagoon

Distribution of major soil types in the watershed

Land use in the watershed

Definition of the subsystems:

- areas set off by distinct water circulation patterns (e.g. coves and bays, channels with the lagoon); areas with distinct biological characteristics (e.g. macrophyte beds, sand or mud flats, marshes, free waters, mangroves, oyster reefs).

Spatial and temporal variability

Spatial and temporal variability in a system will be measured in a number of areas in the lagoon, in at least 1 offshore station and in water streams. At least one station shall be made in each major ebb system in the lagoon.

- biomass estimates monthly over one annual cycle and major macrophytes in the lagoon and in surrounding marshes.

- chlorophyll: a weekly measurement in surface and bottom water and in surface (top 1 cm) sediments over the lagoon (particulate carbon and nitrogen if possible), during an annual cycle. Blooms should be examined visually to determine major groups.

- zooplankton biomass biweekly over the annual cycle - peak periods should be examined visually to determine major groups. Replicate oblique or vertical hauls should be used and occasional night samples taken.

- major nutrients (NH_3, NO_3, PO_4, DOP, $Si(OH)_4$, perhaps DON) measured in surface and bottom water biweekly over the annual cycle, along with salinity (to $\pm$ 0.1 parts per thousand) and temperature (to $\pm$ 0.1^{0}C).

- major shellfish species-biomass estimate, size and reproductive state.

- major finfish-size, age, structure and reproductive state of a representative subsample of the population. Routine weekly or biweekly seine, gill net or trawl samples can pinpoint the migration times of major species as can local commercial catch. As much use as possible should be made of local internal knowledge of the lagoon. This may be especially helpful for fisheries. In some cases, it may be worth the effort to estimate population sizes of fish and other mobile animals in the lagoon using mark and recapture techniques.

- suspended sediment should be measured biweekly in the rivers and periodically over tidal cycles in the lagoon. Good aerial photographs and satellite data may be especially useful.

- particular attention should be paid to storm events - strong winds, high river discharge, etc., to measure their effect on nutrient levels, suspended sediment, detrital inputs, etc.

Physical forcing functions

- tide gauges (or at least tide staffs) should be installed near the breakway and near the extremes of the lagoon.

- basic meteorological data should be collected on a routine basis for correlation into hydrographic and ecological data - wind and rainfall may be particularly important as site specific parameters. Barometric pressure, air temperature and solar radiation may be available from nearby stations.

- freshwater inputs should be gauged and gauge inputs determined.

- estimates of freshwater sheet floor runoff should be made at different times of year on land surrounding the lagoon using small weirs. Chemical analysis of sheet flow water should also be made. An estimate of ground-water flow should be attempted if there is a reason to suspect that it may be important, e.g. from temperature or salinity anomalies in the lagoon. This may involve the drilling of a number of small wells around the lagoon.

- an estimate of the flushing rate of the lagoon under different conditions of freshwater input, wind and tide is a first order task. In some cases where the lagoon is large or its geometry is complex, it may be most meaningful to make measurements of flushing of various areas of the lagoon.

- gas exchange estimates for oxygen (and perhaps CO_2) should be obtained for the air-water interface in various areas of the lagoon under various conditions of wind and tide so that oxygen changes can be used for metabolic estimates in the lagoon. The floating dome method is probably the best used to obtain these data.

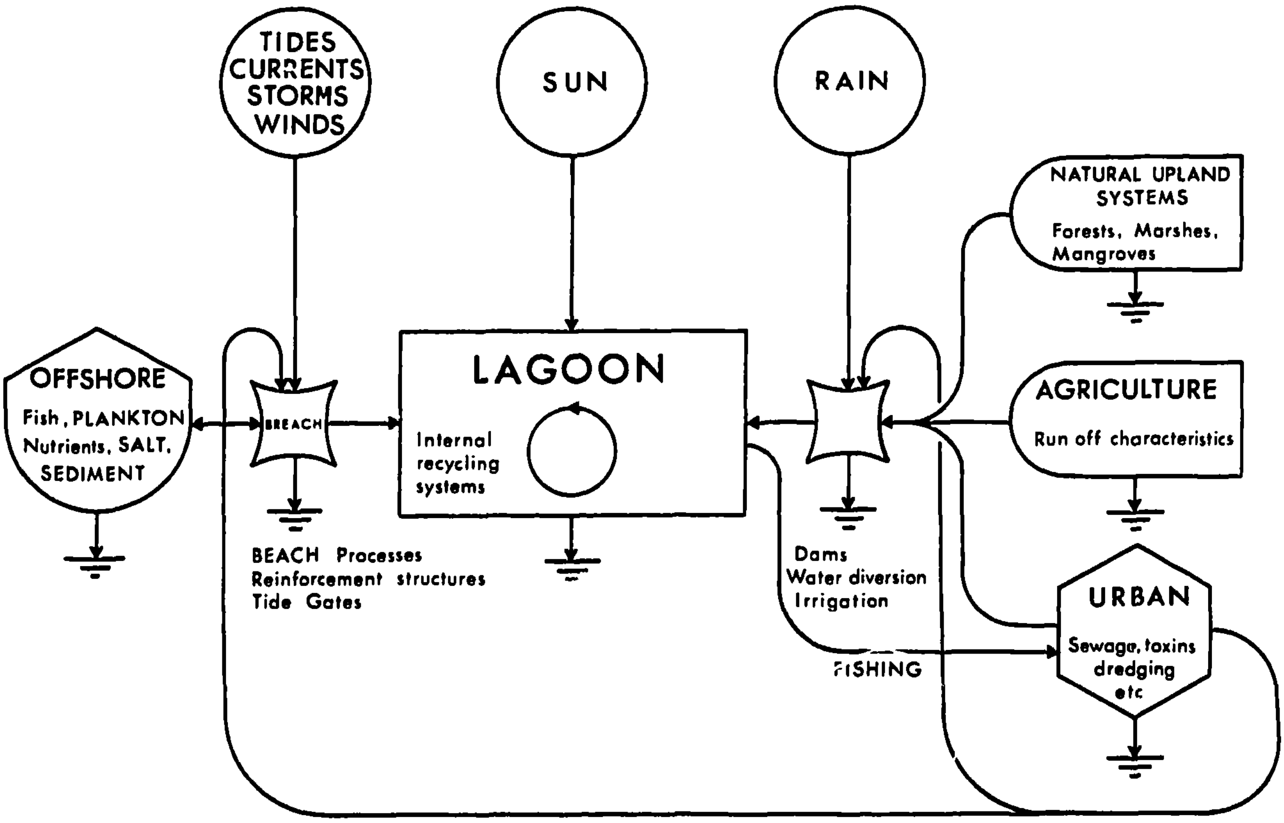

Fig. 4 The lagoon as concentrating mechanism and controllable interface between land and sea.

Metabolism and nutrient cycling

- the total metabolic balance of the lagoon should be determined biweekly over the annual cycle. If flushing is absent or minimal, the free water diurnal curve method is probably the best way to measure the tidal energy balance (autotrophic vs heterotrophic) in the system (oxygen diffusion can be corrected for using the gas exchange data discussed above). If the dirunal curve method cannot be used, or to provide a more detailed partitioning of metabolic activity, the plankton metabolism of the water column should be measured using O_2 changes (and/or ^{14}C method for production) in vertical arrays of bottles *in situ* or ashore in a light gradient box. Macrophyte (including seaweeds) metabolism is best measured over longer periods using growth increments. Sediment metabolism should be measured bi-weekly or monthly using *in situ* bell jars in large areas taken from the bottom and brought into the laboratory. Nutrient fluxes between the sediments and the water should be measured simultaneously. With care and a good quality ($\pm$ 0.001 unit) pH meter, it is also possible to measure CO_2 fluxes at the sediment-water interface. Particular attention should be given to measuring production by benthic microalgae, perhaps using ^{14}C method. Nutrient changes in the water column should be included as well as oxygen production and consumption and ^{14}C uptake. Inputs of organic matter from marshes and mangroves are difficult to measure, but should receive attention. Little pam and trap nets may provide some information.

- data on metabolism and nutrient cycling should be combined within the framework of material budgets for the lagoon. Attention should be directed towards using the data to determine the total annual primary production and its distribution among the major sources and comparing it with inputs of organic matter from outside the lagoon. Does the lagoon import or export nutrients and organic matter? How much of this primary production is supported by internal nutrient recycling and how much is based on new inputs of nutrients? What fraction of solar energy falling on the lagoon is being incorporated in organic matter? What proportion of primary production is being incorporated into animal tissue in secondary production? How much of the organic matter is being exported as detritus or as migrating animals? How much is being buried in the sediments? The last question, of course, requires a knowledge of the lagoon sediment budget and sedimentation rate. The latter may be determined from bathymetry changes, radioactive isotope profiles, or the sediment budget.

Physiological studies of major components

- since lagoons are variable salinity environments, particular attention should be paid to the effects of salinity and salinity changes in the physiology, reproduction, growth and behaviour of major species.

- since lagoons are often sedimentary environments in which organic matter accumulates, low oxygen or anoxic conditions often prevail, and studies of their effect on physiology would be useful.

degradative pathways in lagoon sediments

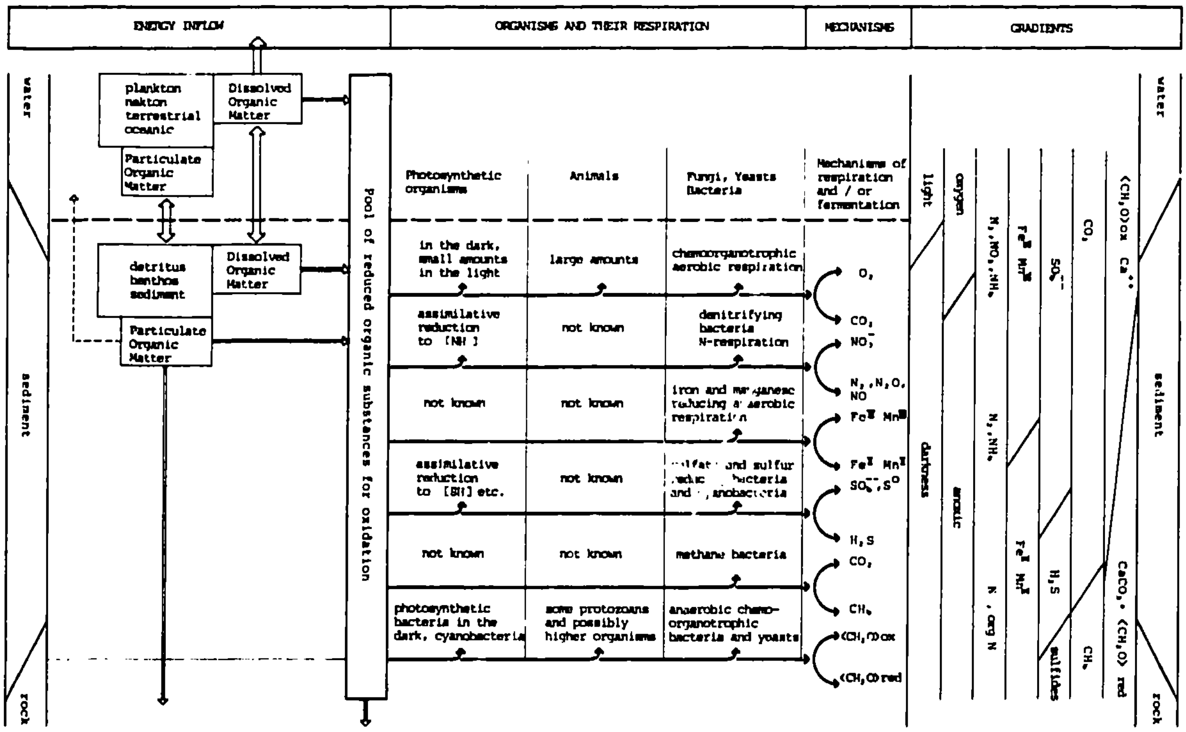

Fig. 5 Degradative pathways in lagoon sediments

The effect of low oxygen in certain geochemical cycles is also important, particularly in the sediments.

Experimental ecosystems studies

A number of ecosystems processes may be studied by experimental manipulations of the natural systems. For example, the effect of fish predations on bottom communities may be examined by using cages of varying mesh size to exclude different sized predators from the bottom. Alternatively, small replicate lagoon microcosms can be developed in tanks on land in which natural lagoon sediments are placed along with varying densities of predators. While there are certainly many limitations to these approaches, the experimental field plot and the experimental microcosm are gaining increasing area and they can teach us a great deal about the dynamics of a natural system as well as help us to anticipate its probable response to future perturbations, such as different salinity regimes or nutrient additions.

<u>How do we study a new lagoon</u>?

An author has written that more could be learned from studying oxygen in a lake than any other element, and the same statement probably applies to lagoons. Oxygen concentration, and change in oxygen concentration, can be used to determine: physiological limits for many aerobic species, rates of photosynthesis and respiration, contributions of other environments to the food chains of lagoons, conditions for many chemical transformations and so on. It is important to sample oxygen over space and time. A recommended plan is to sample over 24 hours at 3 hour intervals at selected stations throughout the estuaries at biweekly intervals over a year. As the basic patterns are determined and objectives clarified a less intensive sampling schedule can be devised. Free-water oxygen methods can be used where water exchange is low to measure photosynthesis and respiration, and estimates of planktonic and benthic contribution can be gained from light-dark bottle methods and the benthic chamber (see Holland Moll, 1975, for an introduction to these methods).

TASK GROUP III - Potential Utilization of Coastal Lagoons

INTRODUCTION

Lagoons have been historically important as sheltered sites of habitation providing access to both the land and the sea. Not only are they important for transportation, they also provide natural food resources rich in protein and easy dumping places for waste material. Some of these multiple uses are compatible; others are not. It is important that the maximum benefit from these areas be obtained without jeopardy to future options or continued use. To achieve this purpose, it is first necessary to acquire a knowledge about the systems producing renewable resources and how they are affected by both natural and human alterations.

A first step in defining these requirements is to list the potential uses to which a lagoon with its resources may be used (Table 1). These are grouped into 9 categories with titles and abbreviations. Not all of these uses are applicable to any particular lagoon, however this list may be modified to represent any specific site. These 9 categories form the basis of a multiple use interaction matrix shown as in Table 2.

The lagoon environment should be viewed as essentially ephemeral and transitory over a long term period. Natural changes resulting from geological/physical/chemical factors and the influence of climatic changes will alter the essential character and hence the ecosystem. These natural changes should be borne in mind in planning research for better understanding and utilization.

In Table 2 those uses which affect others are further identified by reference numbers (1) and/or (2). Number (1) signifies that the effect is essentially a non-biological perturbation. Number (2) signifies that the perturbation will affect the ecosystem and hence those beneficial uses depending upon the renewable living resources, essentially a problem demanding a community dynamics approach.

Where (1) and (2) are both used the problem calls for an analysis of the whole ecosystem, i.e., an interdisciplinary approach. These distinctions are not always clear-cut. Each of the identified problem areas is discussed below.

Harvest

Harvest, Recreation and Aesthetics, Conservation and Storm Buffering

These interactions describe the trade-offs encountered when natural living resources are harvested commercially from a lagoon. Commercial harvest of a species may alter the harvest of interdependent species. Additionally it is possible that a particular

Table 1 - Potential uses of lagoon based resources

Potential use	Title (Table 2)
Living resources	
Harvesting	
Fish	
Invertebrates	
Turtles	Harvest (a)
Mammals	
Birds	
Plants	
Aquaculture	
Fish	
Invertebrates	
Turtles	Aquaculture (b)
Mammals	
Birds	
Plants	
Non-living resources	
Raw materials	
Sand	
Shell	
Phosphate	
Nitrate	Minerals (c)
Salt	
Coral	
Sulphur	
Water	
Hydrocarbons	
Rock	
Lagoon area development	Reclamation (i)
Services	
Recreation and aesthetics	Recr. & Aesth. (d)
Transportation	Transportation (e)
Conservation and buffering zones	Cons. & buff. (f)
Dumping	Dumping (g)
Energy generation	Energy (h)
Reclamation	

Table 2 - Multiple use matrix showing intercompartment effects

Scoring was determined by asking the question: will the use of a lagoon for one activity affect the environment in relation to its use for another activity?

0 = no recognized important effect
C = possible effect (s) which are site specific and warrants further investigation
+ = a recognized generally beneficial effect
- = a recognized deleterious effect, site specific, and warrants further investigation
1 = Geological/physical
2 = Biological processes

a = Harvest
b = Aquaculture
c = Minerals
d = Recr. & Aesth.
e = Transport
f = Cons. & Buff.
g = Dumping
h = Energy
i = Reclamation

	a	b	c	d	e	f	g	h	i
HARVEST	C,2	0	0	C,2	0	C,2	0	0	0
AQUACULTURE	C,2	+	0	0	0	0	0	0	0
MINERALS	-,1,2	C,1,2	C,1	C,1,2	+	-,1	0	0	0
RECR. & AESTH.	C,1,2	C,1,2	0		0	C,1,2	0	0	0
TRANSPORT	C,1,2	0	0	0		C,1	0	0	0
CONS. & BUFF.	+	0	0	+	0		0	0	0
DUMPING	C,1,2	C,1,2	C,1	C,1,2	0	0		0	0
ENERGY GENERATION	C,1,2	C,2	0	0	0	0	0		0
RECLAMATION	-,1	-,1	-,1	-,1	-,1	-,1	-,1	-,1	

species is harvested to an extent (for example clearing a mangrove swamp) that the aesthetic and storm buffering benefits are decreased. Biological research into food web dynamics and physical research into storm energy dissipation will be required to analyze accurately the processes occuring in these situations.

Aquaculture: Harvest

Aquaculture may reduce the yield of the commercially harvestable fishery by removing from the natural system the area allocated for aquaculture. Some research has indicated a positive correlation between fisheries harvest and wetland area in a lagoon, consequently any aquaculture project will have to be judged with this trade off in mind. Research in this field will basically involve food web dynamics.

Minerals: Harvest, Aquaculture, Minerals, Recreation and Aesthetic, Conservation and Storm Buffering

This series of interactions involves the relationships between the extraction of minerals or fuel from lagoons and the harvesting of renewable resources. It also considers the impact of storm buffering capacity and aesthetic benefits. Mineral extraction often involves canal digging in wetlands, wetland loss, development of large and deep pits, and the production of highly turbid water. It is assumed that these actions will affect the productivity of the lagoon and consequently alter the wildlife, aquaculture, recreation, and storm buffering potential. An additional interaction involves a mineral-mineral interaction. This may be exemplified by sand mining in such large quantities that the use of the area for salt production is limited. As the impacts associated with mineral extraction involve hydrological, geomorphological, and biological modifications, a multidisciplinary approach by hydrographers, geologists and ecologists will be necessary to analyze these effects.

Recreation: Aesthetics, Harvest, Aquaculture, Conservation and Buffering

Recreation and Aesthetics are important activites which are essential for man's well-being. These activities could be detrimental to the environment if they are not carefully pursued. These possibilities are identified in the matrix as deserving critical study. These are: harvesting of living resources, both uncultivated and cultivated, and their effect on nature preserves and buffering zones. Various pollutants resulting from man's recreational activities, for example petroleum products, and the byproducts of combustion resulting from boating could be harmful to the biota if they exceed certain levels. Another example is the destruction of nature reserves and buffer zones through intensive recreational use as occurs in natural reserves.

Transportation: Harvest, Conservation and Buffering

Transportation is another area of activity which could affect the environment. In this case, water-borne transport, including boats, ships, submarines, seaplanes, and amphibious crafts, is involved. For example, development and dredging of channels could lead to changes in flushing time, water currents and stratification which are of importance for some species within the ecosystem. Consequently, the production of living resources both in areas where they are harvested and in conserved areas could be adversely affected. Transportation may also affect nature reserves and buffering zones either by direct invasion or by the energy of wakes.

Conservation and Buffering

We cannot identify any serious cases where the creation of conservation and buffering areas has altered the environment in relation to its use for another activity. It does, however, prevent those specific areas from alternate use.

Dumping: Harvest, Aquaculture, Minerals and Recreation, Aesthetics

Dumping of residential, industrial, agricultural and commerical wastes may cause physico-chemical and biological alterations in lagoons. Such additions might be either beneficial or deleterious. This to a large extent depends on the nature and amount of materials dumped. For example, the kinetic response of the organisms to residential wastes that are essentially biodegradable would be different from that of the industrial, agricultural and commercial wastes that contain heavy metals, pesticides, herbicides, etc. Wastes alter the chemical environment, induce competition between species, cause variations in temporal and spatial progression of species and eventually the size spectrum of dominant phytoplankton. Needless to say, the trophodynamics in the lagoon will be altered.

Industrial and commercial wastes besides altering the chemical milieu, can also cause changes in temperature and density structure. The impact of temperature elevation will be site specific and seasonal. Populations of tropical lagoons may not be able to tolerate the elevated temperature while in the colder northern latitudes growth of the populations will be accelerated.

Bioaccumulation of toxic chemicals along the food webs will also occurs, should the wastes contain pesticides and heavy elements. Massive blooms of algae, humic materials, color of the effluents and the odour of the wastes will have a negative impact on the aesthetics and the recreational value of the lagoons.

Energy: Harvest, Aquaculture

The use of lagoons as a source of energy would be of considerable value in view of the rapid depletion of the more traditional hydrocarbon sources such as petroleum and coal. In lagoons with a vast tidal range, the reversing flow of tidal water could be used for the generation of electricity. Although there are already a few examples of such installations in some parts of the world (e.g. in France) very little is known about the possible consequences of such installations on living resources. Research which would lead to the elucidation of the possible effects of such installations on the environment would be worthwhile.

Reclamation: Harvest, Aquaculture, Minerals, Recreation and Aesthetics, Transport, Conservation and Buffering, Dumping, Energy Generation, etc.

Reclamation for residential, industrial, agricultural and commercial purposes of lagoons amount to converting lagoon areas into the adjacent land. Besides contributing wastes to the lagoons, this will change the flushing rates and exchange of water between lagoons and their adjacent seas. The consequences of the alteration of the flushing rates are severalfold and far-reaching on the physical, chemical and biological cycles in the lagoons. Changes in the breeding habits, growth, and migratory patterns of commercially important species may occur.

Geological/Physical/Chemical

Harvest, Aquaculture, Recreation, Transportation, Conservation and Storm Buffering, Renewable Energy Extrusion

Long-term natural changes in the geological, physical and chemical features of the lagoon will be reflected by the living and non-living resources of the ecosystem. Examples are the effects of silting, slow or rapid changes in the amount of freshwater or the inflow of seawater; the opening up of new channels connecting the lagoon with the sea or the closing of existing ones. Such changes may affect the environment in relation to almost all the activities listed in the matrix. These include harvesting of living resources, aquaculture, recreational activities, transport, conservation and the use of a source of energy. In the long run, changes in physical and chemical characteristics lead to the eventual disappearance of the lagoon itself, and only adequate study will determine if action to prevent such disappearance be either desirable or feasible.

Climatic variations: Harvest, Aquaculture

Both short-term and long-term climatic variations affect the use of the lagoons, particularly harvesting and aquaculture activities. Some of the short-term variations, such as floods and offshore winds deliver nutrients to the lagoon that stimulate the production processes. Conditions of excessive runoff also may precipitate a chain of events as follows: increase in sediment load --> turbidity --> reduced light penetration --> lowered primary productivity.

Long-term unpredictable climatic variations such as tidal waves, tsunamis and hurricanes might cause irreversible changes through sediment loading, alteration of flushing rates of lagoons and production processes.

Lagoons should be considered complex open systems with connexion to terrestrial, atmospheric, and oceanic realms. Changes in any of these adjacent systems can influence the function and structure of the lagoon ecosystem itself. An example of this is where runoff contains soil, fertilizers, pesticides or herbicides from agricultural land and precipitates physical, chemical, and biological changes to the lagoon ecosystem. Often socio- and economic structures develop as dependent upon the structure of the lagoon system itself. In this sense the analysis of any system should be at a level that includes the next larger surrounding system. Only in that way can the effect of system inputs and outputs be understood.

Identification of core problems is only the beginning of the battle. Solutions demand trained scientists assisted by trained technicians and at least a modicum of sophisticated equipment. Much thought must be given about both choice and availability of key personnel and the time needed and appropriate methods for training indigenous personnel. These preliminary requirements may take five or more years before research is really underway.

TASK GROUP IV - Training and Education

INTRODUCTION

Three questions were posed as guidelines to this seminar:

a) What information is necessary for better understanding and utilization of coastal lagoons?

b) What research programme is needed to find this information?

c) What training programme is needed to provide for the research programme?

RECOMMENDATIONS

It was established that the goal is to build a self-sustaining capacity for on-going research on the lagoon environment. The object is not to teach but to progress with research and experience and to do the teaching which is necessary. The group recommends:

1. A project, which is to serve on a national or regional level, should be organized as a multidisciplinary programme to form an entity housed on the campus of existing universities or research institutions, and which should be as close as possible to a lagoon suitable to serve as a focus for a case problem study.

2. Three levels of people are needed.

   a) Students of post graduate levels having a general science background averaging about 22 years of age and working toward a master's degree.

   b) Scientists who are already specialists, to serve as both key researchers and teachers.

   c) Technicians to be trained on the job.

   Interdisciplinary research team structure is called for and ongoing training in group dynamics will be necessary to achieve this.

3. The establishment of a working group to prepare a handbook on methodology for coastal lagoon research.

ANNEX I - AGENDA

OPENING SESSION

Address: J.D. Costlow

Introductory remarks: M. Steyaert

Adoption of the Agenda: P. Lasserre

PRESENT COASTAL LAGOON RESEARCH (2 days)

Session I	Physics, geology, non-living resources Chairman: F.B. Phleger
F.B. Phleger	A review of some general features of coastal lagoons.
J.P.F. Zimmermann	On the flushing of well-mixed tidal lagoons and their seasonal fluctuations.
G. Allen/M. Nichols	Suspended sediment transport in coastal lagoons and estuaries.
Session II	Chemistry, biogeochemistry Chairman: E. Mandelli
E. Mandelli	On the hydrography and chemistry of some coastal lagoons of the Pacific Coast of Mexico.
W.E. Krumbein	Biogeochemistry and geomicrobiology of lagoons and lagoonary environments.
H. Postma	Processes in the sediments and in the water-sediment interface.
T. Okuda	Inorganic and organic nitrogen contents in some coastal lagoons in Venezuela.
Session III	Biology "A" Chairman: Y. Halim
Y. Halim	Coastal lakes of the Nile Delta Lake Menzalah
D.U.S. Rao	Some aspects of the spatial and temporal variations of phytoplankton in coastal lagoons
A. Yanez	Ecology in the entrance of Puerto Real, Terminos Lagoon
A. Yanez	Fish occurrence, diversity, and abundance

	of two tropical coastal lagoons with ephemeral inlets on the Pacific Coast of Mexico
C.I.O. Olanyian	A review of the potentialities for research and fish culture in the coastal lagoons of West Africa
Session IV	Biology "B" Chairman: B.O. Jansson
B.O. Jansson	Production dynamics of a temperate sea: the Baltic
R.R. Parker	Guidelines of ecosystem research in coastal lagoons
P. Lasserre	Biological approach to coastal lagoons: metabolism and physiological ecology
S.W. Nixon	The flux of carbon, nitrogen, and phosphorus between coastal lagoons and offshore waters

FUTURE OF COASTAL LAGOON RESEARCH

(An outline of research programmes for regional cooperation) (2 days)

TASK GROUP I - Physics - Geology - Chemistry

Chairman: H. Postma

Members: G. Allen
E. Mandelli
T. Okuda
F.B. Phleger
J.P.F. Zimmermann

TASK GROUP II - Biological processes and Ecology

Chairman: B.O. Jansson

Members: Y. Halim
C. Hall
B.O. Jansson
W.E. Krumbein
P. Lasserre
S.W. Nixon
M. Steyaert
A. Yanez-Arancibia

__TASK GROUP III__ - __Potential utilization of Coastal Lagoons__

Chairman: A. Ben Tuvia

Members: J.D. Costlow
C. Olanyian
R.R. Parker
C. Hopkins

__TASK GROUP IV__ - __Training and Education__

Chairman: R.R. Parker

Members: All participants

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No.		Year	SCOR WG
1	Incorporated with Nos. 4, 8 and 14 in No. 27	1965	WG 10
2	Report of the first meeting of the joint group of experts on photosynthetic radiant energy held at Moscow, 5-9 October 1964. Sponsored by Unesco, SCOR and IAPO	1965	WG 15
3	Report on the intercalibration measurements in Copenhagen, 9-13 June 1965. Organized by ICES	1966	-
4	Incorporated with Nos. 1, 8 and 14 in No. 27	1966	WG 10
5	Report of the second meeting of the joint group of experts on photosynthetic radiant energy held at Kauizawa, 15-19 August 1966. Sponsored by Unesco, SCOR, IAPO	1966	WG 15
6	Report of a meeting of the joint group of experts on radiocarbon estimation of primary production held at Copenhagen, 24-26 October 1966. Sponsored by Unesco, SCOR, ICES	1967	WG 20
7	Report of the second meeting of the Committee for the Check-List of the Fishes of the North Eastern Atlantic and on the Mediterranean, London, 20-22 April 1967	1968	-
8	Incorporated with Nos. 1, 4 and 14 in No. 27	1968	WG 10
9	Report on intercalibration measurements, Leningrad, 24-28 May 1966 and Copenhagen, September 1966; organized by ICES	1969	-
10	Guide to the Indian Ocean Biological Centre (IOBC), Cochin (India), by the Unesco Curator 1967-1969 (Dr. J. Tranter)	1969	-
12	Check-List of the Fishes of the North-Eastern Atlantic and of the Mediterranean (report of the third meeting of the Committee, Hamburg, April 1969)	1969	-
13	Technical report of sea trials conducted by the working group on photosynthetic radiant energy, Gulf of California, May 1968; sponsored by SCOR, IAPSO, Unesco	1969	WG 15
14	Incorporated with Nos. 1, 4 and 8 in No. 27	1970	WG 10
18	A review of methods used for quantitative phytoplankton studies; sponsored by SCOR, Unesco	1974	WG 33