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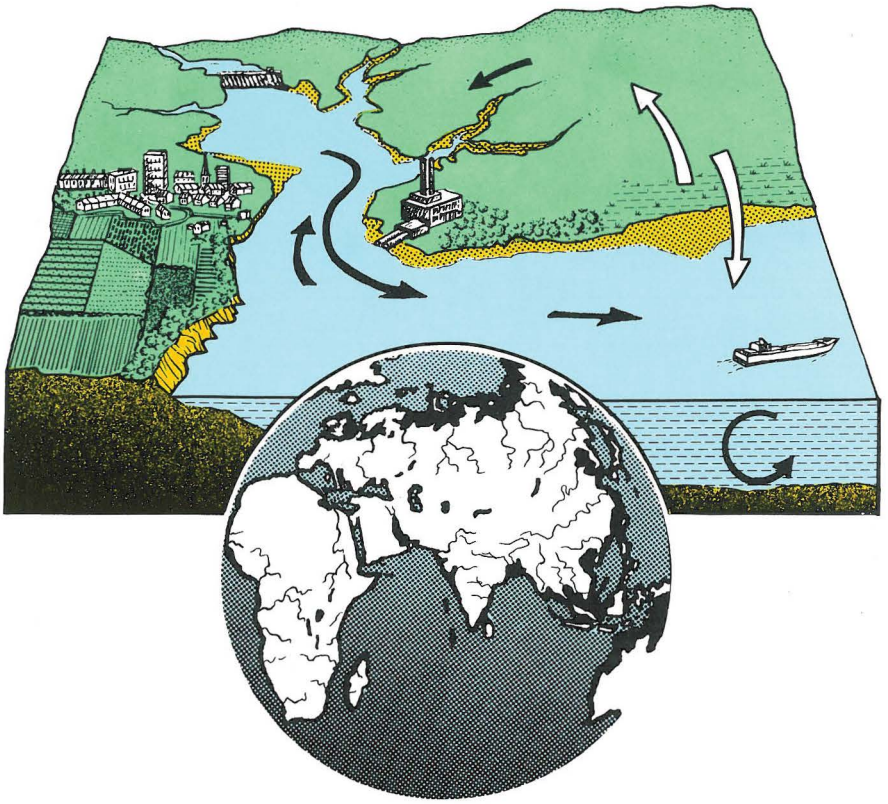

Land-Ocean Interactions in the Coastal Zone

Science Plan

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)
of the International Council of Scientific Unions (ICSU)
Stockholm, 1993

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Edited by P.M. Holligan and H. de Boois
with the assistance of members of the
LOICZ Core Project Planning Committee

The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP)
of the International Council of Scientific Unions (ICSU)
Stockholm, February 1993

The international planning and coordination of the IGBP is currently supported by IGBP National Committees, ICSU, the Commission of the European Communities, government departments and agencies, the United Nations Environment Programme, other organizations, and private industry. Special support for the coordination of LOICZ is provided by the Netherlands government.

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The IGBP Report Series is published as an annex to the Global Change Newsletter and distributed free of charge to scientists involved in pertinent aspects of global change research.

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Cover illustration by P Williamson, based on artwork by the Plymouth College of Art and Design.

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1. Introduction

1.1 The coastal environment as a part of the Earth system

The main aim of the International Geosphere-Biosphere Programme (IGBP, 1990a) is to gain a quantitative understanding of the interactive physical, chemical and biological processes that regulate the Earth system and its capacity to support life. Predictions of the impacts of global change will focus on timescales of decades to centuries, and will be based on global and regional models that simulate the effects both of climate and human activities on the biota and of the biota on the climate system. Validation of the models will be achieved through measurements of key environmental parameters, using reconstructions of past changes in global climate and ecology to set constraints on the interpretation of different model results. Reductions in the uncertainties about the future rates and impacts of global change will be of vital economic and social value in the efforts to sustain the rapidly increasing global human population.

The present atmosphere, climate and living resources of the Earth reflect the properties of the major oceanic and terrestrial ecosystems. The processes at the interface between the land and oceans are easily overlooked. However, coastal plains and shallow coastal seas, which comprise about 8% of the surface area of the world, contribute around 25% of global biological production (Figs. 1 and 2) and support most of the world's fisheries as well as other important living resources. The coastal zone is also the region of the globe where variations in climate and sea level and the effects of a wide range of human activities have the greatest environmental impacts.

No complete study of the Earth system can be undertaken without attention to the coastal zone. The unique properties of the land-sea interface are not explicitly considered by the other process-oriented IGBP Core Projects (IGAC, JGOFS, GCTE, BAHC) that primarily focus on vertical fluxes between the atmosphere and ocean or land.

The boundary between land and ocean is physically dynamic. Littoral landforms are strongly influenced by the riverine delivery of sediment and by episodic climatic events and vulcanism, and have been subjected to the effects of large changes in sea level and tectonic movements during recent geological time. Coastal sedimentary records and geomorphological structures provide abundant evidence of extensive environmental changes in the past.

Coastal ecosystems strongly modulate the environmental effects of land on ocean and *vice versa*. The transport and transformation of matter affect the functioning of terrestrial and oceanic ecosystems to either side, and the composition of the atmosphere as a result of trace gas exchanges. Various biotic and abiotic processes in the coastal zone affect the hydrological cycle and coastal geomorphology. However, the temporal

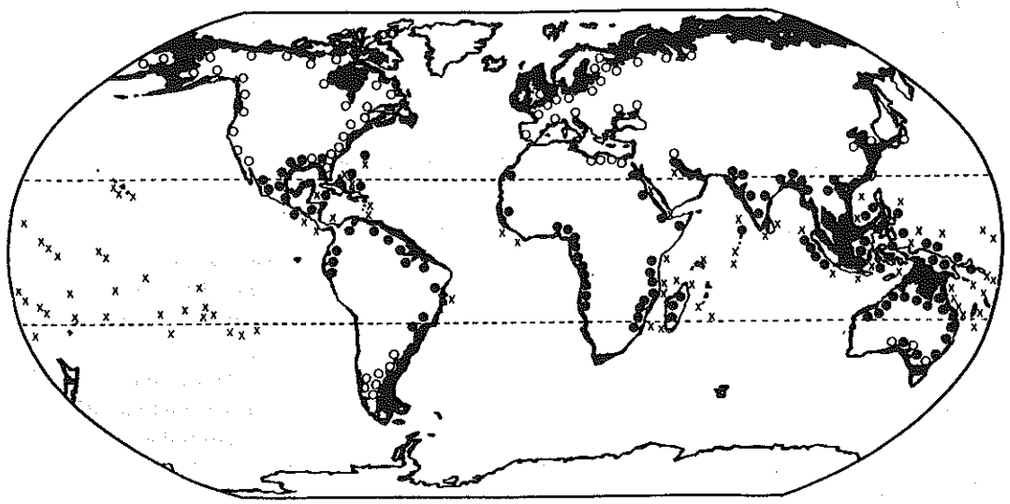

Fig. 1 Continental shelves of the world, and distribution of mangroves (•), saltmarsh (o) and coral reefs (x). (After Postma & Zijlstra, 1988; Chapman, 1977; and Brown & Ogden, 1993).

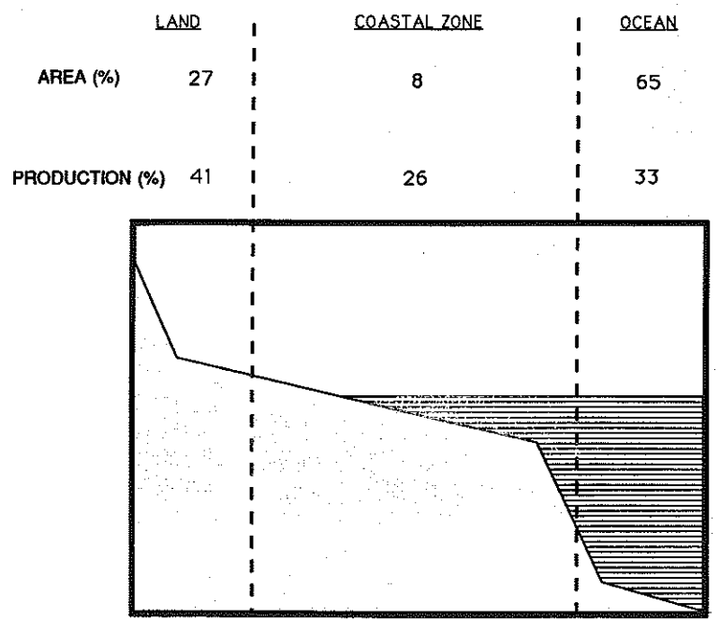

Fig. 2 Estimates of the relative area and biological production (as % of global total) for non-coastal land, the coastal zone, and the open ocean

and spatial scales of physical, chemical and biological processes determining the fluxes of materials into and out of the coastal zone are not yet well characterised.

Today, under conditions of high (and rising) sea level, the retention of sediments on continental shelves results in very different conditions compared to those prevailing at times of low or falling sea levels, when ice and riverine erosion transported great quantities of sediments to the ocean margins. In both situations, biological productivity, biogeochemical cycling and sediment dynamics are closely linked at the land-ocean boundary, but generalised models incorporating such processes have yet to be developed.

The future behaviour of coastal systems in response to changes in climate and other environmental factors is of direct socio-economic importance in terms both of biological feedback effects on the global environment and of the availability and sustainability of living resources for human consumption.

Traditionally, scientific work with a coastal focus has been organised along disciplinary lines, and carried out in a geographically piecemeal manner. More recently, multidisciplinary studies of estuaries and semi-enclosed seas have used a broad ecosystem approach, but there are no ongoing or planned research programmes with the aim of investigating on a global basis the links between events in catchment basins and the oceans, and their implications for coastal processes such as the biological control of trace gas exchanges with the atmosphere and of coastline geomorphology.

1.2 Development of the LOICZ Science Plan

The conclusions of a preliminary workshop, organised in 1989 by the late Professor T. Nemoto, were summarised in IGBP Report No. 14 (1990b). The first account of the LOICZ project in IGBP Report No. 12 (1990a; Chapter 4) took into consideration the land/sea interface as well as the coastal ocean/open ocean interface, particularly in relation to the influence of river catchment processes on the nearshore marine environment. More than 20 relevant scientific themes were identified and grouped into three main research activities dealing with the dynamics of catchment basins, the carbon cycle, and human impacts on coastal ecosystems. At that stage little attention had been given to the global significance of the land-ocean interface in relation to the functioning of the Earth system, or to the need for generalised models as a basis for understanding how coastal systems respond and contribute to global change. As a result, the interfacing of LOICZ with other IGBP Core Projects was not adequately addressed.

A Core Project Planning Committee (CPPC) for LOICZ was appointed in early 1991 and met four times to produce a Science Plan for the project. Its second meeting was held in conjunction with a NATO Advanced Research Workshop (ARW) in October 1991. The ARW provided the opportunity to develop a consensus within a larger group of scientists on the scientific objectives for the new project. A Core Project meeting for

about 100 participants, including experts on the main components of the Science Plan and representatives from countries with an interest in participation, will be held in May 1993 to consider the initial stages of the implementation of the LOICZ project.

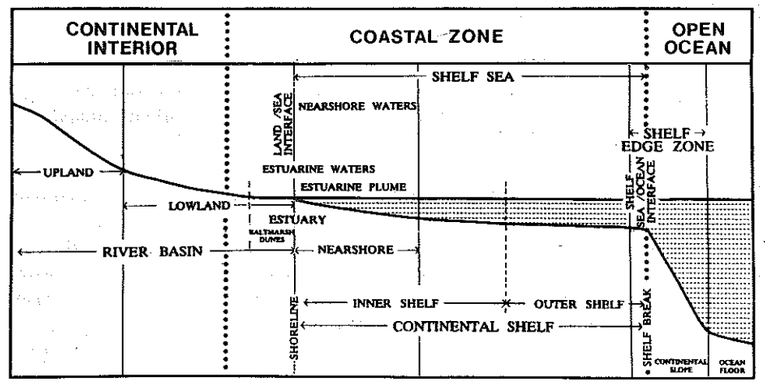

Fig. 3 Definition of coastal zone, continental shelf and other features of the land-ocean boundary. The relative size of these components shows considerable geographic variability.

2. Scientific Background

2.1 Definition of the coastal zone

Definitions of the "coastal zone" may extend to the landward and seaward limits of marine and terrestrial influences respectively, so that few parts of the Earth's surface are excluded. At the other extreme, the coastal zone can be restricted to the coastline and adjacent geomorphological features determined by the action of the sea on the land margin.

For the purpose of the LOICZ project, the coastal zone is considered to extend from the coastal plains to the outer edges of the continental shelves (Fig. 3), approximately matching the region that has been alternately flooded and exposed during the sea level fluctuations of the late-Quaternary period. Within the coastal zone are a very wide range of coastal systems (swamp forest, saltmarsh, estuary, lagoons, intertidal, inshore, reef, offshore etc.) which are characterised by distinct biotic and abiotic properties and processes.

In planning LOICZ, the coastal zone was considered in two ways:

(i) As an integral part of the Earth system which contributes significantly to global biogeochemical cycles and their interaction with climate. The coastal zone is a transitional region of high physical energy and biological productivity in which large quantities of dissolved and suspended materials are transported, transformed and stored. Coastal environments are influenced by saltwater, freshwater, ice, precipitation and evaporation, land and the atmosphere, and are therefore sensitive to environmental fluctuations caused by a wide range of natural processes, including sea level change, as well as by various human activities.

(ii) In relation to the sustainability of the living resources of coastal systems, and their capacity to support the needs of humans under conditions of strong exploitation and of fluctuating climate and sea level. More than 50% of people are now thought to live within 60 km of the sea (equivalent to the entire global population of the 1950s) and the coastal zone is a vital resource in terms of food and mineral supplies, the disposal of waste materials, habitation, recreation space, and transport. The land-ocean boundary includes some of the most productive ecosystems on earth, and provides more than 90% of the world's marine fish catch and other valuable living resources associated with biological communities such as coral reefs, mangrove forests, and coastal marshes and wetlands (Fig. 1).

2.2 Global perspective of the coastal zone

Episodic events and scales of dynamics

The dynamics of the land-ocean boundary are most easily studied either at short timescales (days to years) corresponding to the duration of most observational programmes, or at long timescales (>100 years) corresponding with the resolution limit of most types of marine sediment record. Extreme events with intermediate return periods of decades to centuries appear to be a major cause of significant changes in the state of coastal environments. Such events include severe climatic conditions (floods, storms), changes in prevailing winds, ocean currents and upwelling, occurrences of earthquakes and tsunamis, anomalous variations in sea level, and sudden biological changes (e.g. species introductions and spread of diseases). By contrast, trends and events in physical forcing at the shorter, more familiar scales corresponding to the effects of waves, tides, and seasonal storms are largely accommodated without large and persistent perturbations of coastal, as well as nearshore benthic and pelagic ecosystems.

The environmental impacts of extreme events are usually only observed by chance and are often difficult to characterise from geological evidence due to the masking effects of bioturbation on sedimentary structures. Basic information is lacking on the spatial characteristics of episodic interactions between land and ocean, especially in alongshore directions. For example, buoyancy-driven currents associated with major rivers and on-shelf flows of oceanic water can affect coastal environments over distances of several hundred kilometers, but such processes remain poorly understood and difficult to predict. Forecasting the coastal impacts of El Niño-Southern Oscillation (ENSO) events is another example of this problem.

Hydrological and hydrodynamic forcing

The hydrological properties of catchment basins (which determine river flows and groundwater exchanges between fresh and salt waters) and the hydrodynamic properties of estuaries and shelf seas (controlled by winds, tides, buoyancy and rotational forces as well as exchanges of water across the shelf edge), play a dominant role in the transport and exchange of suspended and dissolved materials between land and ocean. Movement of water and associated chemical processes in soils are a major influence on riverine transport to estuaries and deltas. Complex mixing processes within the coastal zone affect chemical transformations related to particle-water reactions and flocculation processes at salinity gradients. Mixing also affects the availability of light and nutrients for primary production (which strongly influences, directly or indirectly, air-sea exchanges of trace gases), and the conditions for sediment accretion and erosion along coastlines. Various physical factors also affect the exchanges of materials across the land-air, water-air and water-sediment interfaces.

Ecosystem structure and functioning

Coastal ecosystems are biologically very productive, and support the major marine fisheries and mariculture activities. Biodiversity is expressed both at the functional (species groups) and structural (community) levels and plays an important role in determining system responses to environmental change. The biota of the coastal zone have a major influence on sediment supply (e.g. by the production of carbonates), on accretion processes, and on biogeochemical fluxes between seawater, the atmosphere and marine sediment.

Sediments

Rivers transport large quantities of suspended sediment from land to sea. Small rivers are now thought to account for a high proportion, as well as much of the variability, of the total sediment flux. This material is deposited in estuaries and nearshore deltaic environments, with relatively small quantities reaching the continental slope under present conditions of high sea level. Most coastlines also exhibit substantial alongshore transport of sediments, often associated with active erosion or accretion. In regions of accretion, sediments may be supplied either from offshore waters by currents, tides and wind (e.g. dune formation) or from land sources.

In all cases the biota of the coastal zone have a strong influence on the supply (carbonates and other biogenic minerals and particles), cohesiveness (due to organic material) and accumulation of sediments, and on coastal weathering and erosion processes. An understanding of *biogeomorphological* processes is central to any attempt to predict the dynamic behaviour of coastal ecosystems. In general, living organisms and natural ecosystems slow down the rate of land erosion by the sea, through the formation and retention of particulate matter in the coastal zone.

Trace gases

The coastal zone contributes significantly to the global fluxes of the climatically-active trace gases in the atmosphere and of key elements such as carbon, nitrogen and sulphur. For example, coastal waters are both a source of CO_2 to the atmosphere due to the oxidation of organic mater of terrestrial origin, and a sink for organic carbon buried in estuarine, shelf and slope sediments (Fig. 4). Models of the global carbon cycle that treat the terrestrial and marine biota independently provide an inadequate basis for predicting how biological processes affect levels of atmospheric CO_2. In the case of the sulphur cycle, biogenic emissions of dimethysulphide (DMS) from the coastal oceans return sulphur from the sea to land, influence the acidity of rainfall, and are thought to affect cloud formation in coastal areas. Coastal systems may also be globally important sources of nitrous oxide (N_2O) and methane (CH_4).

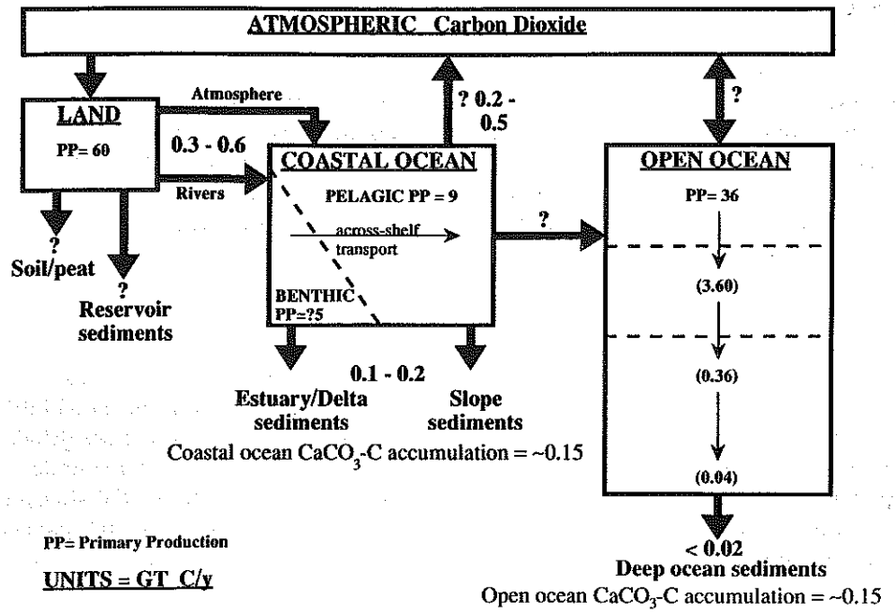

Fig. 4 Estimates of net photosynthetic carbon fixation, and fluxes of CO_2 and organic carbon between the land, coastal ocean and open ocean

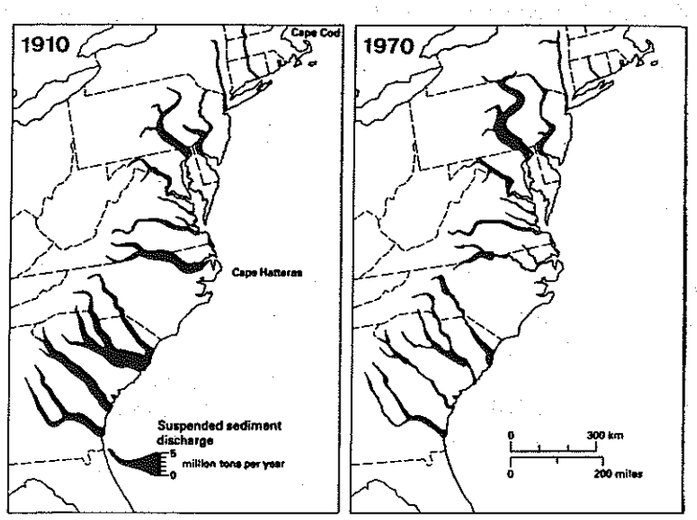

Fig. 5 Changes in suspended sediment discharge to the eastern seaboard of the United States 1910 -1970, mostly due to dam construction and land use changes (after Meade & Trimble, 1974; Goudie, 1990)

2.3 Global change in the coastal zone

As a result of the increasing human population, and the trend for a greater proportion of people to live close to the sea, anthropogenic impacts on the coastal zone have become severe over the past few decades. Coastal environments are being altered by man in all parts of the Earth due to a combination of direct and indirect (climate, sea level) global change effects (Table 1). The resultant ecological modifications affect the diversity and stability of coastal ecosystems – and also contribute in turn to global change as a result of feedback effects on climate, geomorphology and the value of living resources to humans. The long term environmental implications are very uncertain.

Table 1. Nature of change at the land-ocean boundary*

Type of Change	Scale of Impact	Environmental Recovery Time
Natural climate variability; storminess	Local/Regional	Weeks-Years
Monsoons; variability of shelf circulation patterns and upwelling	Regional	Months
ENSO events	Regional	Years
Physical disturbance (e.g. coastal engineering)	Local/Regional	Years-Decades
Chemical disturbance (eutrophication, pollution)	Local/Regional	Years-Decades
Biological disturbance (use of living resources)	Regional/Global	Years-Decades
Continental-scale land and river usage	Regional/Global	Decades-Centuries
Sea level rise	Global	Decades-Centuries
Global climate	Global	Decades-Centuries

* Based on analysis by Bardach (1989)

Direct effects

The main direct effects of man are related to large scale changes in land use (agriculture, deforestation/reforestation) and fresh water management which lead to changes in the delivery of materials to estuaries and the coastal zone (Fig. 5); the urbanization and industrialization of the land margins; and the exploitation of marine living and non-living resources. Land-to-sea fluxes of water, organic matter (see Fig. 4), nutrients and sediments have been altered globally, leading to significant ecological modification of most estuarine and deltaic environments. The present level of physical disturbance (e.g. upstream river damming, coastal engineering, barrages, and dredging), chemical disturbance (eutrophication and release of toxic pollutants), and biological disturbance (fishing, destruction of reefs and mangroves, and drainage of coastal marshes) represents an unsustainable use of coastal systems, reducing their capability to adapt to natural or anthropogenic variations in environmental conditions. In this sense, both the extent and rate of change in the coastal zone are of concern if catastrophic losses of coastal resources at a global scale are to be avoided.

Changing climate

Climatic factors have a strong influence on both the land and ocean boundaries of the coastal zone. Variations in ocean circulation, upwelling and, at high latitudes, seasonal ice cover all affect the exchanges of materials between the oceans and shelf seas, especially inputs of dissolved nutrients from the oceans to shelf seas. Precipitation and temperature changes alter the rates of weathering and erosion processes on land, and the riverine and aeolian transports of terrestrial dissolved and particulate matter into coastal waters. In turn, biological processes respond to variations in nutrient supplies from the oceans and land, in ambient temperature and light conditions, and in the degree of exposure to harmful ultraviolet radiation.

Sea level

Changes in relative sea level can be caused by global eustatic effects associated with climate change; by regional isostatic and climatic effects (related to ocean wind fields and currents); and by local effects stemming from coastal subsidence (as ground water, oil and gas are extracted, and as delta systems are starved of sediment due to the building of dams). The combination of a mean rise in global sea level (1-2 mm per yr) and human activities is resulting today in the retreat of much of the world's coastline at a faster rate than experienced over the last 5000 years. These problems will be exacerbated if sea level rise accelerates in a warmer world, even if only to the extent of 2-4 mm per yr, as suggested for thermal warming alone by the Intergovernmental Panel for Climate Change (IPCC). Of particular concern in this context is the worldwide destruction by humans of coastal ecosystems, in particular coral reefs, mangroves, sea grasses and salt marshes, which act as natural barriers against marine erosion processes as a result of the upward growth of organisms, thereby trapping sediment.

Changes and feedbacks

Another area of great uncertainty concerns the strength and direction of feedback effects, resulting from the impacts of environmental change on fluxes of materials between land and sea, and on the structure and functioning of biological communities in the coastal zone. Three main types of feedback (biogeomorphological, biogeochemical and socio-economic) are recognised to be of global importance (Fig. 6). In each case the need for improved information on the biological responses to the environmental change is crucial for the development of new policies on the use, conservation and restoration of living resources of the coastal zone.

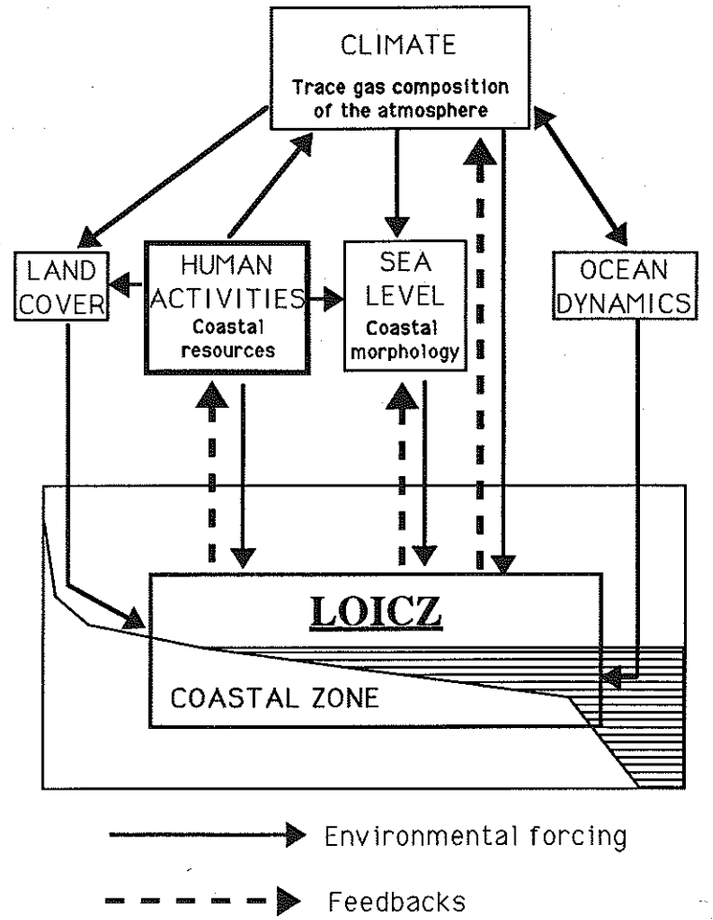

Fig. 6 Main effects of global change on the coastal zone, and of changes in the coastal zone on the global environment

2.4 Geographic considerations

The properties of the coastal zone show great spatial variability on account of local and regional climatic, terrestrial and oceanic influences. Any synthesis of coastal processes on a global scale, whether based on observations or models, must therefore represent the sum of regional properties – with the realisation that, for different coastal regions, the nature of global change (environmental forcing factors, system responses and feedbacks etc.) will vary.

The minimal requirements for a global analysis of environmental change in the coastal zone can be defined in terms of a matrix based on climatic (latitude) and physiographic factors (shelf morphology, inputs of energy and materials from land and ocean), and on the main forcing parameters of change. Categories of coastal areas and environmental issues identified in this way are likely to include:

- Tropical and sub-tropical coastal areas affected by rapid increased in population, urban pollution, and severe exploitation of living resources, as well as the effects of deforestation. Many low-lying islands and reefs will be threatened by accelerated seal level rise.

- Temperate coastal areas characterised by industrial and agricultural pollution, extensive coastal engineering and highly efficient fishing practices.

- Polar and sub-polar areas that are vulnerable to a combination of strong coastal erosion by sea level rise, permafrost degradation by global warming, and increased exposure to ultraviolet light.

- Delta systems which are major population centres strongly susceptible to the effects of sea level rise and subsidence, due to starvation of riverine sediments and locally strong human-induced lowering of the ground surface.

- Upwelling systems representing major inputs of oceanic nutrients to the coastal zone that are controlled by variations in ocean climate (e.g. ENSO events).

2.5 The coastal zone as a focus for global change research

Coastal zone research relates in many ways to the objectives of other global change research projects (Fig. 6). Coastal systems are directly influenced by human activities, sea level change, and climate change. Indirectly, variations in external forcing of the coastal systems follow from the impacts of human activities and climate change on land and from climate-induced changes in ocean dynamics. Conversely, changes in the functioning of coastal systems, due to both external forcing and human activities in the coastal zone itself, result in different types of (mainly biological) feedbacks to human activities, relative sea level and climate.

The present state of knowledge of the functioning of coastal systems at a global scale is limited. The impacts of changes in external forcing and the feedbacks from coastal systems to global systems are largely unknown. As a consequence, we have only a very rudimentary ability to predict future changes in coastal systems and their role in global change.

The LOICZ project is expected to lead to new global databases and classification systems for coastal environments, and to an objective scientific approach for determining the economic and social value of the coastal zone in relation to needs for long term investment into the protection and restoration of coastal environments. In addressing these aims, LOICZ will contribute significantly to the overall objectives of the IGBP, including the integrating Global Analysis, Interpretation and Modelling (GAIM) activity. LOICZ will be closely linked with the SCOR/IGBP Joint Global Ocean Flux Study (JGOFS) with regard to the carbon budgets of oceans; with the IGBP projects on Biospheric Aspects of the Hydrological Cycle (BAHC) and Global Change and Terrestrial Ecosystems (GCTE) with regard to inputs in coastal areas; and with the IGBP International Global Atmospheric Chemistry project (IGAC) with regard to atmospheric fluxes. The IGBP Data and Information System (IGBP-DIS) and the Global Change System for Analysis, Research and Training (START) will facilitate global-scale data acquisition.

In addition, it is expected that collaborative links will be developed with relevant projects of the World Climate Research Programme (WCRP), in particular the Global Energy and Water Cycle Experiment (GEWEX) and Stratospheric Processes and their Role in Climate (SPARC), and with the Human Dimensions of Global Environmental Change Programme (HDP). The proposed Global Ocean Observing System (GOOS; of WMO, UNEP, ICSU and IOC) is also complementary to LOICZ, and should provide an important new source of global data on the properties of coastal systems.

Table 2. Types of environmental change relevant to LOICZ

Regional Changes		Aspects of Coastal Systems		Global Changes
		The Functioning of Coastal Systems	<---	Population increase and demography
Water & land use in river basins	--->	Sediment, Suspended Matter and Coastal Morphology	<---	Global sea level rise
Uplift or subsidence	--->			
Aquatic pollution	--->	Carbon Fluxes and Trace Gases	<---	Elevated CO_2
			--->	Global budgets
Exploitation	--->	Ecosystems and Resources	<---	Climate change
Management	<-->		<---	Airborne pollutants

3. Scientific Objectives

3.1 Rationale: uncertainties

The way the coastal environment is being altered and managed today will inevitably affect its use by future generations. The exploitation of many coastal ecosystems is presently so intense – and so weakly regulated – that major economic investment is likely to be required for their maintenance or restoration in the future, particularly in relation to the impacts of likely rises in sea level. The creation of long-term, sustainable policies for coastal management requires a predictive understanding of the impacts of changes in climate, land use and sea level on the global functioning of coastal systems (Table 2).

The worldwide data on types, rates and, in some cases, causes of change to coastal ecosystems are inadequate, largely due to a lack of suitable means for data collection and analysis. Improved information on the dynamic properties and present state of coastal systems and on feedback processes that result from natural and anthropogenic modification is required. New methods to simulate and predict over decadal timescales the responses of the coastal zone to global change will have to be developed and implemented in order to guide the formulation of rational and integrated long term economic and social policies for the continuing use of the coastal zone. These will depend upon better knowledge of ecological, biogeochemical and biogeomorphological processes in the coastal zone, and the development of new techniques to predict the large scale impacts of continuing population growth, land use and global change on the functioning of the coastal zone.

3.2 Research issues

Three types of basic scientific research are required concerning key aspects of coastal system dynamics:

(i) *Intensive process studies* and related models in order to understand how such systems behave with respect to changing environmental conditions

(ii) The acquisition of *extensive observational data* for key environmental parameters in order to establish the significance of coastal processes in determining the global distribution of those parameters

(iii) *Simulation and prognostic modelling* of coastal systems in order to simulate and predict over a range of space and time scales the effects of global change on the land-ocean interface.

A wide range of research issues can be defined; for example, those relating to

- the mode of operation of coastal systems, such as: the transport and transformation of materials between land and ocean, the structure and functioning of coastal ecosystems; the nature of interactions between ecological sub-components of coastal systems and the impacts of extreme events (storms, floods etc.); and the influence of coastal processes in global processes.

- the impacts of regional and global environmental change, such as: the biogeomorphological and biogeochemical responses of the coastal zone to change, and the associated feedback effects on the global environment.

- the structure, initialisation and validation of models, required for: establishing the role of coastal systems in global systems; defining specific future scenarios of climate change, population growth and socio-economic activities in the coastal zone; predicting changes in coastal systems; and predicting changes in the sustainability of coastal resources.

3.3 Project goals

The goals of the LOICZ project are as follows.

(i) To determine at global and regional scales:

   a) the fluxes of materials between land, sea and atmosphere through the coastal zone

   b) the capacity of coastal systems to transform and store particulate and dissolved matter, and

   c) the effects of changes in external forcing conditions on the structure and functioning of coastal ecosystems.

(ii) To determine how changes in land use, climate, sea level and human activities alter the fluxes and retention of particulate matter in the coastal zone, and affect coastal morphodynamics.

(iii) To determine how changes in coastal systems, including responses to varying terrestrial and oceanic inputs of organic matter and nutrients, will affect the global carbon cycle and the trace gas composition of the atmosphere.

(iv) To assess how the responses of coastal systems to global change will affect the habitation and usage by humans of coastal environments, and to develop further the scientific and socio-economic bases for the integrated management of the coastal environment.

4. Research Foci and Activities

The four goals of LOICZ define four corresponding foci of research, each of which includes a number of activities that relate to specific issues of global change in the coastal zone.

4.1 Focus 1: The effects of changes in external forcing or boundary conditions on coastal fluxes

This focus provides the foundation for the project as a whole. It is generally accepted that the production, transformation, and transportation of nutrients, carbon, pollutants, and sediments in coastal systems are strongly influenced by physical and chemical forcing at the land, ocean and atmosphere boundaries, and that biological forcing may also be important. However, surprisingly little is known, on a global scale, about the quantitative responses of coastal systems to changes in external environmental conditions.

Such changes may arise from direct human activity such as dam building and sewage discharge, from short- or long-term changes in climate and ocean dynamics, or from ecological processes such as succession in watershed plant communities. Both observational and modelling studies are needed to quantify existing relationships between the fluxes of energy and material at system boundaries, and to examine system behaviour. To test specific hypotheses, comparative investigations of different coastal systems and experimental perturbation studies (using field plots and contained ecosystems or mesocosms) are also required.

Activity 1.1 Catchment basin dynamics and delivery

Human activities and climatic factors are causing changes in land use and vegetation cover at continental scales. These changes often result in major modifications of fresh water runoff, sediment transport, and the fluxes of carbon, nutrients, and some pollutants to coastal systems. As these fluxes vary, they may significantly affect the metabolism, biogeochemical cycling, and the biogeomorphology of coastal areas. Reductions in fresh water input also have large effects on salinity distribution, flushing rates, and the habitat value of estuarine areas. An important task, to be done in close collaboration with the IGBP BAHC and the WCRP GEWEX projects, is to quantify these relationships.

Activity 1.2 Atmospheric inputs to the coastal zone

It is well known that the composition of the atmosphere has been altered in important ways by human activities. Under certain conditions, atmospheric deposition is a

significant source of materials such as nitrogen, certain trace metals, some organic pollutants, and even sediments. More information is needed, however, to quantify the atmospheric inputs to coastal areas on a global scale. It is also critical to assess the impacts of changing atmospheric deposition on watersheds that drain to coastal systems. For example, it is not at all certain how the fluxes of carbon, nutrients, or sediments from various terrestrial systems will, in the long term, be affected by increased nitrogen deposition, by acid deposition, and by changes in rainfall and temperature.

Activity 1.3 Exchanges of energy and matter at the shelf edge

Interactions between coastal water and the open sea are strongly dependent on upwelling, eddy and frontal dynamics at the shelf edge, wind-induced and density-driven exchanges of water, and other ocean circulation processes controlled by the ocean-atmosphere system. ENSO events are a good example of periodic ocean forcing of coastal environments. Further studies are needed to determine how the exchanges of energy and materials (especially inorganic nutrients) between the ocean and shelf seas affect coastal systems.

Activity 1.4 Factors influencing the mass balance of materials in coastal systems

A great variety of processes interact to determine the net exchange of carbon, nutrients, sediments, and other materials across the boundaries of coastal systems. It will be an important task to investigate at regional and global scales the input, transformations, storage, and loss of major elements in coastal systems. The influence of changing boundary conditions on the processes that regulate these exchange must also be quantified.

Activity 1.5 Reconstruction of past changes in the coastal zone

A new programme of observational, experimental and modelling studies can only provide insight into the state of coastal systems under a rather limited range of environmental conditions. External perturbation studies can only encompass a limited subset of system components and spatial/temporal scales. In order to examine the responses of particular coastal systems to relatively large changes in external forcing that might occur in the future, it will be necessary to develop historical reconstructions of boundary conditions and to relate these to historical indicators of past conditions within the system. For example, by reconstruction of sea level transgressions and regressions; assessment of past rates of peat accumulation; analysis of dated intertidal and sub-tidal sediment cores; and historical reconstructions of industrial development, land-use change in watersheds, and habitat alterations.

Many of these analyses directly complement studies of the IGBP project on Past Global Changes (PAGES): it is expected that close collaboration will be developed in areas of mutual interest.

Activity 1.6 Development of coupled land-estuarine-ocean models for coastal systems

Previous modelling work has tended to focus on particular geographical components of the coastal zone, such as models of vegetation succession, land-use runoff, river transport, estuarine circulation, water quality, and coastal ocean hydrodynamics. Such studies were necessary and appropriate in the early stages of model development, but sufficient progress has now been made to begin linking these components in unified coastal system models. Recent developments in computer capabilities, and in our ability to couple GIS (Geographic Information Systems) technology to simulation algorithms, have eliminated some of the practical barriers to achieving such a synthesis.

4.2 Focus 2: Coastal biogeomorphology and sea level rise

Considerable research has been (and is being) done on measuring the rate of sea level rise as well as determining its causes. The physical effects and mitigating responses to sea level rise in coastal areas also are being addressed; for example by the Coastal Zone Management subgroup of the IPCC Response Strategies Working Group. However, the significance of biological interactions is often ignored, mainly because of the lack of precise information regarding the rates of supply of terrigenous and biogenic components to coastal systems, as well as the role of coastal biota in trapping and affecting the cohesiveness of sediments. New work should focus on how major ecosystem types interact with the sedimentary environment, as well as assessing the implications of ecosystem perturbations on coastal stability with a rise in sea level.

Activity 2.1 Role of ecosystems in determining coastal geomorphology

The interactions between sea and land as they affect coastal dynamics are the result of a complex set of processes and responses. The external driving forces are susceptible to change by direct and indirect consequences of human activities at local, regional and global scales, of which climate change is the most obvious. Before anthropogenic changes can be addressed, however, the relative importance of various sediment sources, the effects of changes in relative sea level, and the effects of the wave/wind field on coastal erosion and accretion must be better defined, particularly with respect to episodic events, such as floods and storms. Moreover, an understanding of biological processes in sediment trapping and sediment cohesion is necessary.

Activity 2.2 Biogeomorphological responses to change in land use, climate and human activities in the coastal zone

How will environmental change at local, regional and global scales affect the rates of sediment supply to the marine environment? To answer this question, the fluxes and fates of terrestrial (e.g. rivers and cliffs) and marine (e.g. reworked and new biogenic) sediments to coasts and estuaries must be better documented. Changes in sediment

significant source of materials such as nitrogen, certain trace metals, some organic pollutants, and even sediments. More information is needed, however, to quantify the atmospheric inputs to coastal areas on a global scale. It is also critical to assess the impacts of changing atmospheric deposition on watersheds that drain to coastal systems. For example, it is not at all certain how the fluxes of carbon, nutrients, or sediments from various terrestrial systems will, in the long term, be affected by increased nitrogen deposition, by acid deposition, and by changes in rainfall and temperature.

Activity 1.3 Exchanges of energy and matter at the shelf edge

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budgets, in addition to fluctuations in sea-level, affect the state of coastal ecosystems (e.g. mangroves, marshes, sea grasses and coral reefs), which in turn influences sediment retention and coastline geomorphology.

Activity 2.3 Prediction of coastal geomorphology for different scenarios of relative sea level change

Local sea-level change depends on the tectonic character of the coastline as well as rates of change of eustatic sea level. The impact of local sea-level rise, moreover, will be affected by the influence of climate change on wind patterns, wave fields and coastal circulation. Rates of subsidence, particularly in low-lying coastal areas, can be many times greater than the rate of global sea-level rise, and are greatly affected by human activities, both directly (e.g. by extraction of water, oil or natural gas) and indirectly (e.g. by dams and other river management practices, causing sediment-starvation of deltas). Therefore defining absolute as well as relative changes in sea level becomes increasingly important. Tide-guage measurements of mean annual elevation are still the most commonly used method to determine local sea-level change, but meaningful change using this technique can only be delineated over tens of years, thus marking it harder to define short-term accelerations in the local rise or fall of sea level. New, more sensitive techniques, are clearly needed. Moreover, spatial variations in local sea level must be known in order to predict large scale changes to coastal systems.

4.3 Focus 3: Carbon fluxes and trace gas emissions

Present and possible future changes in the structure and function of the coastal zone may alter biogeochemical processes in ways that ultimately have global consequences. The most evident of these are processes involved in the global carbon cycle, and in the production and consumption of biogenic trace gases.

Recent models of the global carbon cycle have demonstrated that knowledge of carbon fluxes in the coastal zone is crucial to understanding long and short term changes in atmospheric levels of CO_2, partly because coastal sediments are the major marine sink for organic carbon, and partly because important interchanges between the terrestrial, marine and atmospheric pools occur in this region. There are significant uncertainties regarding coastal fluxes of carbon, and how carbon burial rates might be influenced by sediment and nutrient supply to the coastal zone. Initial discussions with JGOFS on these topics took place in October 1992, and a joint JGOFS/LOICZ Continental Margins Task Team has been established. The LOICZ project will take responsibility for studies of riverine fluxes of carbon, and of carbon cycling and storage by nearshore marine ecosystems (including coral reefs).

Coastal zones include sub-areas featuring confluences of high inputs of nutrients and labile carbon, and steep redox gradients. In these environments there can be rapid fluxes of biogenic trace gases such as CH_4 and N_2O within and from soils, sediments and even water columns. Differences in environmental conditions and gradients will

dictate whether local areas are net sources or sinks for such gases. These processes must be studied within the complicated spatial/temporal context of the entire coastal zone. Coastal zones are also important in terms of emissions of dimethylsulphide, which may be important as a feedback to regional climate and are a source of sulphur aerosols including sulphuric acid to coastal lands. Discussions with IGAC on joint interests in these gases are planned.

Activity 3.1 Cycling of organic matter within coastal systems

Poorly known aspects include the rates and variability of riverine and atmospheric delivery of organic matter to the sea; of estuarine and slope burial for organic carbon; of exchanges of dissolved and particulate organic carbon (DOC and POC) between shelf seas and oceans; of the distributions of coastal air-sea gradients in the partial pressure of CO_2 (pCO_2); and the effects of eutrophication and toxic pollutants on organic carbon budgets.

This Activity will be composed of several specific tasks. The present-day fluxes and storage terms of the carbon cycle need to be better quantified, especially with respect to transient states. Better estimates (based on recognition of the spatial heterogeneity of the coastal zone) are also needed with regard to organic matter inputs from land; outputs of POC to coastal and slope sediments and of DOC to oceans; and coastal accumulation of particulate inorganic carbon (PIC, mainly biogenic calcium carbonate).

Efforts must be devoted to determining contemporary and future anthropogenic influences on carbon budgets for the coastal zone, especially with respect to the effects of changes in sedimentation rates and nutrient supply on the burial of organic carbon and their implications for the global cycle of carbon.

A third task concerns the assessment of how global changes such as sea level rise, change in storm intensity and frequency, river damming and climate change, will affect the rates of sediment supply to the coastal zone from both reworked and new biogenic sources derived from terrestrial, estuarine and off-shore sources.

Activity 3.2 Estimation of net fluxes of N_2O and CH_4 in the coastal zone

The production and consumption of nitrous oxide (N_2O) and methane (CH_4) vary spatially and seasonally in coastal plains, wetlands, and waters, both within given areas, and over broader geographic distances. This Activity will consist of direct measurement; model development for gas fluxes from terrestrial, wetland and aquatic environments, and deployment of these models over global spatial databases for the global coastal zone. As noted above, close links with IGAC will be developed with regard to this Activity, and also to the one described immediately below.

Activity 3.3 Estimation of global coastal emissions of DMS

Dimethyl sulphide (DMS) production occurs through different mechanisms, and in different parts of the coastal zone, than N_2O and CH_4 production, so that the estimation

of DMS fluxes represents a separate Activity. As for the other trace gases, however, tasks must include experiments, direct observations, model building, and model application in space and time, in order to evaluate the spatial and temporal emissions of DMS, and their implications for acid deposition and climatology.

4.4 Focus 4: Economic and social impacts of global change on coastal systems

Coastal environments account for around 25% of global primary production, and the plant and animal communities (natural and managed) of the coastal zone provide a vital resource for human populations. Global change will add new stress factors on all coastal ecosystems, influencing both their structure and behaviour, in addition to those caused by local and regional human activities such as exploitation of mineral and biological resources, recreational use, and various forms of waste disposal.

Essential properties that are likely to be altered include biodiversity and food chain dynamics, including fishery yields. Loss or modification of ecosystems will have strong effects on sediment erosion and accretion processes. Flood protection requires integrated coastal defense and water management, as does safeguarding against salt penetration in river mouths, groundwater and soils.

Development of a better predictive capacity is necessary for future management strategies. Such strategies will have to include more effective protective measures and lead to greater efforts to attain sustainable use of living resources. Successful introduction of appropriate management tactics requires a profound insight of economic and social consequences. Acceptance of further regulations and restrictive measures by a growing human population, in the coastal zone and elsewhere, needs careful guidance. The problems should be studied by combined teams of economists, social scientists, and coastal scientists. An appropriate *ad hoc* group of experts will meet as soon as possible to determine the most effective way of developing such an approach. In such initial definition work - and its subsequent implementation - active participation by the appropriate components of the Human Dimensions of Global Change Programme (HDP) has been invited by LOICZ.

Activity 4.1 Evolution of coastal systems under different scenarios of global change

From the perspective of human needs, this activity should investigate the evolution of the coastal systems under specific scenarios of climate, sea level, land use and human activities over the next decades. A strong interdisciplinary approach is needed for the development of consistent projections. To achieve that end, models of various aspects of coastal processes should be linked and tuned to each other.

Activity 4.2 Effects of changes to coastal systems on social and economic activities

The socio-economic effects of alterations in the climatic, physico-chemical and ecological properties of the coastal zone should be assessed, in close collaboration with HDP. Actions required to promote protective measures and sustainable use of coastal resources need to be determined.

Activity 4.3 Development of improved strategies for the management of coastal resources

Increasing human populations, changing socio-economical structures, changing environmental conditions and exploitation of resources require integrated management strategies that are directed at development that is sustainable in the long-term. Such strategies may set bounds to activities which are aimed at fulfilment of the short-term needs or of quick profits. Whilst HDP would be expected to take the lead in investigating economic consequences and conditions, and societal acceptance of regulations, LOICZ research should also contribute to this work.

A summary listing of the LOICZ Foci and Activities is given in Table 3.

Table 3. The Foci and Activities of LOICZ

FOCUS 1: The effects of changes in external forcing or boundary conditions on coastal fluxes

1.1 Catchment basin dynamics and delivery
1.2 Atmospheric inputs to the coastal zone
1.3 Exchanges of energy and matter at the shelf edge
1.4 Factors influencing the mass balance of materials in coastal systems
1.5 Reconstructions of past changes in the coastal zone
1.6 Development of coupled land-estuarine-ocean models for coastal systems

FOCUS 2: Coastal biogeomorphology and sea level rise

2.1 Role of ecosystems in determining coastal geomorphology
2.2 Biogeomorphological responses to changes in land use, climate and human activities in the coastal zone
2.3 Prediction of coastal geomorphology for different scenarios of relative sea level change

FOCUS 3: Carbon fluxes and trace gas emissions

3.1 Cycling of organic matter within coastal systems
3.2 Estimation of net fluxes of N_2O and CH_4 in the coastal zone
3.3 Estimation of global coastal emissions of DMS

FOCUS 4: Economic and social impacts of global change on coastal systems

4.1 Evolution of coastal systems under different scenarios of global change
4.2 Effects of changes to coastal systems on social and economic activities
4.3 Development of improved strategies for the management of coastal resources

5. Project Framework

5.1 Integration of scientific activities within LOICZ

The structure of the LOICZ project must reflect the need to understand better the dynamics of the land-ocean interface at a global scale, and to predict how further changes in climate, sea level and human activities will affect the functioning of coastal ecosystems and the resources of the coastal zone.

Any set of questions about the dynamic properties and future behaviour of coastal systems leads to a range of linked research activities with the general aim of developing prognostic models. Extensive and intensive observations, and related databases provide the means for designing, initialising and validating numerical models. A good balance needs to be maintained between observational and modelling work so that resources are not wasted on models that are structured inappropriately, cannot be validated or do not address important regional or global issues. One-dimensional models of coastal processes are of limited value. In 2-D and 3-D models, special attention needs to be paid to scaling-up in space and time.

The relationship between the different research elements of the LOICZ project is illustrated in Fig. 7. A key feature is the development of a sequence of different types of models that together will provide a capability for predicting environmental changes to coastal systems and their implications for coastal geomorphology, global climate and human society (i.e. the three types of feedback identified in Fig. 6). Prognostic environmental models (with particular attention paid to spatial scaling, and physical-biological interactions) should be the basis for assessing feedback effects on the global environment and resources and for designing integrated coastal management policies. Model validation will depend on the availability of suitable long term observational data.

The successful development of such models demands a strong interdisciplinary approach based on fundamental understanding of:

- hydrological and hydrodynamic processes
- ecosystem structure and functioning, and
- chemical transformations, especially particle-water reactions.

There will also be need for new methods of data analysis and interpretation, and of relating effects of environmental change to socio-economic needs. Socio-economic scenarios have to be developed (in collaboration with social scientists), and quantitative assessments made of the degree of environmental change that is likely to affect significantly future activities in the coastal zone.

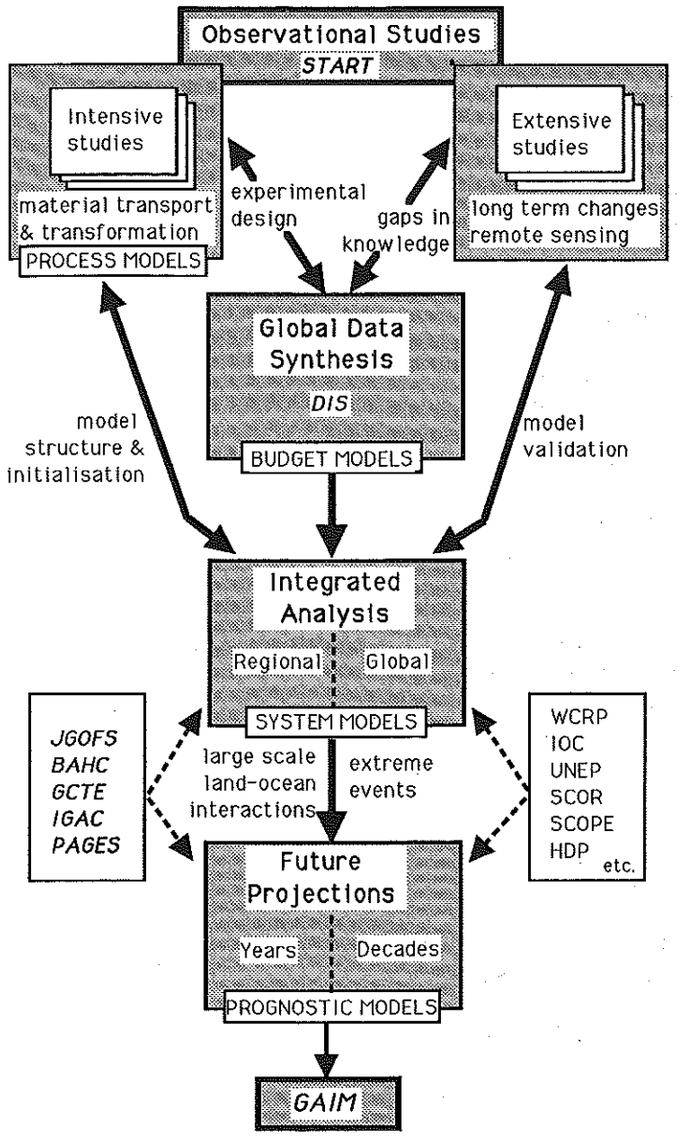

Fig. 7 Research elements of the LOICZ project, and their links with other projects and programmes

Each of the research foci and tasks of the LOICZ project will depend upon a sound knowledge of basic physical and ecological processes that determine the intrinsic properties of coastal systems. Integrating studies are of particular importance to the implementation of the LOICZ project. Resources must be made available for supporting (or establishing) linked regional databases that incorporate existing as well as new information. Work in this area does not correspond to any of the primary research objectives, and must be undertaken either as an integral part of the core research described in the previous section or in conjunction with related programmes.

5.2 The scales of interactions between land and sea, and within coastal systems

The highly interactive and variable nature of terrestrial and marine processes within the coastal zone creates formidable challenges in attempts to model the behaviour of coastal systems over large (regional) scales. Any environmental management policy will have to take account of how changes in one component may affect others over longshore distances of hundreds of kilometers and over many years, with unexpected non-linear and feedback effects. Processes in coastal areas have a variety of characteristic time scales. Interactions between processes of different time scales are difficult to comprehend. Both spatial and time scales of human influences in the coastal zone are tending to increase, which has consequences for management options.

5.3 Coastal system structure and functioning

Ecological work must be focussed on the interdisciplinary objectives, related to investigations of feedback processes in the coastal zone. For that reason ecosystem studies are essential to all of the LOICZ project, and may be a major activity for certain parts. New research must take into account:

- the relationships between different types of biological communities that characterise the transition from land to ocean (e.g. mangroves to seagrasses and coral reefs; saltmarshes to intertidal and subtidal mudflats)
- the relationship between different functional groups of species (e.g. benthic and pelagic species)
- the ways in which ecosystems are perturbed as a result of the exploitation of living resources and physical and chemical disturbance in the coastal zone. In particular, the wider implications of eutrophication and pollution events need to be more carefully assessed.

5.4 Data synthesis and analysis

Global syntheses of the features and dynamic properties of the coastal zone require methods for combining local and regional knowledge into a global database, and for classifying coastal systems. Procedures to establish reliable control of data quality and to indicate degrees of uncertainty in measured or estimated values for particular properties will be necessary. New techniques will also be needed for assimilating data with different sampling frequencies in space and time (e.g. ship observations and remote sensing); for integrating and displaying such data; and for interfacing the database to numerical models. A key issue will be spatial referencing of information relating to the strong land-to-sea gradients in all properties, and in this context new advances in Geographic Information Systems must be exploited. Close working links with the IGBP-DIS activity will be developed in these areas.

A comprehensive global database for the coastal zone will probably be made up of a number of regional databases with appropriate networking facilities to enable input from centralised sources of new information (e.g. satellite remote sensing) and output to related activities such as the development of global models. The LOICZ Core Project Office should explore options for the design and use of such a database, in liaison with the research community, and initiate its formation. For example, existing data sets on the global land-to-ocean transports of fresh water, suspended sediment and organic carbon and on primary productivity could be brought together in a common format and made available on a regional basis for updating with new information.

Potential elements for a global database include the following:

- key physical, chemical and biological properties of the land-ocean interface as a basis for the global classification of coastal systems in terms of environmental conditions (such as tidal range, sea level, temperature, salinity, light, energy inputs due to wind and tide)

- the distributions of the main plant and animal communities and associated geomorphological structures (such as dunes, saltmarsh, mangroves, reefs, kelps, sand and mud deposits)

- data on the fluxes of materials (such as water, suspended sediment, organic carbon, nutrients and pollutants) between the coastal zone and the land, atmosphere and oceans.

5.5 Modelling

A complete dynamical analysis of coastal systems is impossible to achieve through observational studies alone on account of complexities related to the physical, chemical and biological heterogeneity of coastal environments and to the large range of scales at

which the land, oceans and atmosphere interact. Numerical modelling is a vital research tool in the design of large scale observational programmes and in attempts to understand and predict the spatial and temporal properties of the coastal zone. A variety of approaches will be required according to the hypotheses being tested and the relative importance of particular environmental factors. Special care is needed for the assimilation of information on fine scale processes into coarse scale models.

A global analysis and incorporation into Earth system models of land-ocean interactions is likely to be based on nested models of the coastal zone representing distinct topographic/ecological units. The ultimate objective of such models is the provision of decadal forecasts of the state of coastal environments for a range of climate, sea level and human population scenarios. The proposed approach within LOICZ is as follows:

- Modelling work must consider different types or combinations of coastal systems over a range of time and space scales, and incorporate realistic descriptions of physical forcing (climatic and hydrologic factors, hydrodynamic and geomorphologic processes) and of biological responses, interactions and feedback.

- The concepts within system models of energy flow, life support, and nature and quality of products should be further explored with respect to assessing the broader implications of change in the coastal zone.

- Basic transport and ecological models will be developed to support more specialised models of biogeochemical processes and of the influence of biological and chemical processes on the trapping and cohesion of sediments in the coastal zone.

- Scaling up from process models linked to observational work presents a dual challenge in defining how ecological units across the transition from land to ocean interact with one another, and how extreme (episodic) environmental events such as storms or changes in riverine delivery affect the coastal zone as a whole. New methods of scaling up to apply fine-scale environmental and ecological information within large scale models will be needed.

- The models should take account of ecological resilience to environmental change and capacity for recovery as the basis for deriving objective economic cost-benefit analyses of alternative management policies for the coastal zone.

- The output of coastal system models need to be validated by comparison with reconstructions of past changes from studies on coastal sediments, and with long term environmental observations.

The difficulties of constructing useful prognostic models must not be underestimated. The limited availability of reliable data, sufficient computer capacity especially for hydrodynamic models and coupled land-sea models, manpower to develop, maintain and test large models, and appropriate knowledge about the functioning of complex coastal systems will continue to limit predictive capability in the foreseeable future. The successful linking of different types of models is also a major challenge.

5.6 Scenarios

Predicting future changes requires scenarios for both regional and global changes as external forcing for the models. Global scenarios deal with CO_2-concentration, climate change, sea level rise, and UV-B radiation. These scenarios can be based on external studies, like those of the IPCC. Development of regional climate projections is essential for prognostic models.

Regional scenarios within LOICZ will need to take account of socio-economic developments, as well as the feedbacks from the local impacts of global change and depletion or destruction of resources. Scenarios for different regions should also consider the effects of supra-regional policy measures. Notwithstanding their individual features, the development of all regional scenarios must be coordinated – since, in combination, they will provide the basis for global models of the coastal zones. Such work will need to be closely linked with the Human Dimensions of Global Environmental Change Programme (HDP), and also to the regional structure of the IGBP Global Change System for Analysis, Research and Training (START).

6. Implementation

6.1 General considerations

The LOICZ research foci correspond to critical areas of ignorance concerning the role of coastal systems in the functioning of the Earth system. New knowledge, providing a predictive capability, is needed to establish rational policies for sustainable development of the coastal zone into the 21st century. Some aspects of the required research are already being undertaken, or are planned within various national and international programmes. The LOICZ project, however, offers a unique framework for such work – by providing a global perspective for investigating land-ocean interactions; by prescribing full integration of relevant terrestrial, marine and atmospheric studies; and by focusing on feedback processes that are likely to have important effects over the next few decades on the global environment, on the coastal environment and on human uses of coastal resources. Through cooperative IGBP and HDP efforts, and liaison with other programmes, the necessary connections can be made between biogeochemical research and the human causes and impacts of environmental change in the coastal zone.

During the early implementation phase, most of the research relevant to the LOICZ project will be initiated and carried out through already-existing national research programmes. However, the LOICZ project will complement and assist these efforts by adding components that provide a more complete global picture of the interactions between land and ocean. This will be achieved by encouraging the participation of less developed countries in coastal zone research of strategic importance, and by providing new opportunities for collaboration and exchange of information between scientists from different countries. The latter activity should include formal links that facilitate comparative experiments and the transfer of new technology, related to both observational and modelling studies of coastal systems.

It is envisaged that the initial research projects within LOICZ will have relatively modest, but clearly defined and practical, objectives relating to the main themes and activities of LOICZ: namely, measurements and experiments; data assimilation and analysis; database management; integrated modelling; linking up with other IGBP activities and other relevant research programmes; and scenarios and prediction.
The early work will focus on particular problems that are not being covered by other programmes, and that will provide new research opportunities for scientists from both developed and less developed countries. A Scientific Steering Committee for LOICZ will be appointed in early 1993 to plan these first steps, to initiate the implementation of the project, and to prepare a more detailed Operational Plan to guide its further development.

6.2 Links with existing and planned initiatives for coastal research

National research programmes on the dynamics and prediction of land-ocean interactions will tend to address issues of known local or regional importance. Such studies are unlikely to provide a close match to the globally-oriented objectives of LOICZ. However, all national programmes can be expected to include some elements that will provide new information relevant to global fluxes and global change, and may also contribute to the development and application of new technologies for observing and modelling coastal processes. Information on such programmes should be collated and distributed as it becomes available, with points of contact identified in order to promote scientific collaboration.

Regional research programmes that are either being established as a result of direct links between the research communities of two or more countries (for example, in the Mediterranean region, north west Europe, and eastern Asia) are more likely to address coastal processes at the larger time and space scales of concern to LOICZ. For example, pioneering work has been carried out over the last two decades by the countries surrounding the Baltic Sea, and provides some important lessons in terms of the scientific challenges – and of the logistic difficulties – in establishing real collaboration involving environmental issues and geographic boundaries that are politically sensitive. These efforts represent valuable operational models for the LOICZ project.

Various international organisations and agencies also support or sponsor research on the coastal zone. The most important are the Intergovernmental Oceanographic Commission (IOC, within UNESCO), the UN Environment Programme (UNEP), the European Community (EC), the Scientific Committee on Oceanic Research and the Scientific Committee on Problems of the Environment (SCOR and SCOPE, both of ICSU). Many of their projects are concerned with summarising the present state of scientific knowledge, making recommendations for future work, and technology transfer and education – generally with regard to particular aspects of coastal processes or the coastal environment. One of the most significant for the LOICZ project is the proposed Global Ocean Observing System (GOOS, of WMO, UNEP, ICSU and IOC) which includes a major component for the coastal ocean. New initiatives are also being developed within the Intergovernmental Panel on Climate Change (IPCC) on coastal zone management; the World Climate Research Programme (WCRP) on the atmospheric penetration of UV-B; and the International Union of Biological Sciences (IUBS) on marine biodiversity. Close liaison will need to be established and maintained with all these organisations in the planning and execution phases of LOICZ.

As already discussed in Sections 4.1 - 4.4, it will also be essential for LOICZ to have strong links with all other components of IGBP projects – to define research areas of mutual interest, and to integrate system and prognostic models, with regard to the land (GCTE), freshwater (BAHC), the oceans (JGOFS), the atmosphere (IGAC), past changes in sea level (PAGES), and global data acquisition, analysis and modelling (IGBP-DIS and GAIM). The regional implementation of LOICZ is expected to be closely associated with START initiatives, particularly in tropical areas.

6.3 Categories of LOICZ research

Certain types of regional and national research activities will not automatically fit into the structure of the LOICZ project. Therefore, as for other IGBP projects, three categories of research within LOICZ will be distinguished. The following criteria are based on those originally defined in the GCTE Operational Plan (IGBP Report 21):

Core Research

Large scale, integrative research that is international in scope. Projects within the LOICZ Core Research programme will be designed specifically to meet the LOICZ objectives, and will be derived from two sources:

i) Initiation directly by the LOICZ Scientific Steering Committee (SSC)

ii) Adoption by the SSC of appropriate components of national IGBP research programmes, where these components have been identified by the SSC as contributing directly to the LOICZ project as outlined here and subsequently developed.

These projects will be eligible for assistance from the LOICZ project in obtaining funds from national and international agencies, and should maintain close communication with the LOICZ Core Project Office.

Regional/National Research

Research arising from national IGBP committees or other national and regional groups of research organisations. It may meet LOICZ goals but will be primarily national and regional in scope. Only those components identified by the SSC as contributing directly to the Science Plan will be incorporated into the LOICZ core research programme. Nevertheless, LOICZ Regional/National Research will be an important part in the overall LOICZ effort because it will provide a critical link between the global-scale Core Research and the national and regional scales which are of concern to individual countries and regions.

Relevant Research

Smaller research projects initiated by individual investigators or institutions. These projects add incrementally, through process studies and locally specific research, to the broad knowledge that underpins the overall LOICZ effort. Both the management and funding of this research will be the responsibility of the individual investigator(s), but some of these projects will be recognised by the LOICZ SSC as significant contributions to the international LOICZ project.

6.4 Initial activities

Several issues raised in the Science Plan need early attention, and may require specialised workshops or the appointment of small working groups. These include:

- **Regional and global databases for LOICZ**: structure and management; sources of existing information; policies for entry of new data and for user access; and funding requirements.

- **System and prognostic models for LOICZ**: design, initialisation and validation procedures; linking different model types; representation of biological processes including feedback effects; and application to economic and social problems.

- **Technological and human resources**: application of new optical and acoustic sensors and new advances in sediment analysis and dating, remote sensing and GIS; training in research areas where there is a shortage of skilled people (e.g. in hydrodynamics, interdisciplinary modelling, and remote sensing); technology transfer to less developed countries; and education in interdisciplinary coastal sciences.

- **Interfacing to other IGBP projects**, especially JGOFS, BAHC, and GCTE. A JGOFS/LOICZ group has already been formed to address continental margin issues.

The opportunities should also be considered for initiating, with the joint support of national IGBP committees or as part of START activities, field projects to examine urgent practical problems or central issues for which more information is needed. Possible studies should reflect geographical considerations (Section 2.4). Improved understanding of land-ocean interactions in the coastal zone are of paramount importance for many developing countries. Collaborative research in one or more of relatively small projects would also provide early experience with regard to the funding, organising and implementing an international project in coastal zone science. Possible studies are:

- The combined effects of sediment starvation, sea level rise and loss of coastal vegetation in deltas

- The effects of climatic warming, sea level rise and increased levels of UV-B radiation on low-lying Arctic coastlines

- Development of strategies to resolve the damaging impacts of multiple uses of land and coastal resources in heavily populated tropical regions

- Long term impacts of toxic pollutants in estuaries and coastal sediments on living resources and biogeochemical fluxes

- Studies of small island systems as models for investigating the social and economic implications of change in the coastal zone

- Studies of inland seas as models for investigating the effects of changes in sea level, water quality and other factors on "simple" benthic and pelagic ecosystems.

Consultation with research organisations concerned with coastal environments (the IOC, other UN and international bodies, and national agencies) should be maintained both at the planning and implementation phases of the LOICZ project.

6.5 Establishment of the LOICZ Core Project Office

The LOICZ Core Project Office (CPO) is currently being established at the Netherlands Institute of Sea Research (NIOZ), Texel, and is expected to be fully operational by September 1993. The CPO will assist the LOICZ Scientific Steering Committee in planning and carrying out new scientific research as outlined in the previous section; it will also serve as a much-needed channel of communication between scientists working in different countries on various aspects of global change in the coastal zone. An important early task of the CPO will be to assist the SSC in collating information on national and regional programmes of coastal research – to ensure that there is no unnecessary duplication of effort, and that the LOICZ project makes effective use of existing knowledge in its analysis of coastal processes and change at global scales.

The general tasks of an IGBP Core Project Office were identified in IGBP Report 12, as follows:

- Administering the project on a day-to-day basis, under the long term guidance of the SSC

- Coordination of research efforts, and planning and coordinating research campaigns and field programmes

- Providing project advocacy and promotion, enlisting wide international participation in the project

- Maintaining needed connections with relevant national and regional projects

- Ensuring effective coordination with other components of the IGBP, and other relevant international research programmes

- Disseminating information and research results

- Securing support for the operation of the Office.

In addition, the CPO will coordinate the setting up of databases for the LOICZ project, either at the site of the Office or through a networking system. The early availability of information on the global distributions of coastal zone features will be essential for the design of field experiments and the development of models.

7. Key References

The scientific literature on land-ocean interactions and on global change in coastal zones is extremely diverse, not only with regard to the topics that have been investigated but also in terms of the source journals and books. Some aspects are covered by a large body of relevant information, whereas others have received little attention. As part of the planning for the LOICZ project, a set of key references has been compiled. These are given here; however, for the sake of clarity, only a limited number have been individually cited in the preceding text. The edited books all contain important chapters which have not been individually listed.

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Membership of the LOICZ Core Project Planning Committee

The LOICZ CPPC (1991- 1992) was responsible for the preparation of this Science Plan. A Scientific Steering Committee is currently being established, under the Chairmanship of Dr P M Holligan, to guide the implementation of the project.

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Acronyms and Abbreviations

ARW	Advanced Research Workshop
BAHC	Biospheric Aspects of the Hydrological Cycle (IGBP)
CPPC	Core Project Planning Committee
DIC	dissolved inorganic carbon
DMS	dimethylsulphide
DOC	dissolved organic carbon
ENSO	El Niño - Southern Oscillation
GAIM	Global Analysis, Interpretation and Modelling (IGBP)
GCTE	Global Change and Terrestrial Ecosystems (IGBP)
GIS	Geographic Information System
GOOS	Global Ocean Observing System
HDP	Human Dimensions of Global Environment Change Programme
ICSU	International Council of Scientific Unions
IGAC	International Global Atmospheric Chemistry project (IGBP)
IGBP	International Geosphere-Biosphere Programme
IGBP-DIS	IGBP Data and Information System
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
IUBS	International Union of Biological Sciences
JGOFS	Joint Global Ocean Flux Study (SCOR/IGBP)
LOICZ	Land-Ocean Interactions in the Coastal Zone (IGBP)
PAGES	Past Global Changes (IGBP)
PIC	particulate inorganic carbon
POC	particulate organic carbon
SCOPE	Scientific Committee on Problems of the Environment (ICSU)
SCOR	Scientific Committee on Oceanic Research
SSC	Scientific Steering Committee
START	Global Change System for Analysis, Research and Training (IGBP)
UN	United Nations
UNEP	United Nations Environmental Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
WCRP	World Climate Research Programme
WMO	World Meteorological Organisation

IGBP Reports

(Listing limited to Reports that are still in print)

No. 12 The International Geosphere-Biosphere Programme: A Study of Global Change (IGBP). The Initial Core Projects. (1990)

No. 13 Terrestrial Biosphere Perspective of the IGAC Project: Companion to the Dookie Report. Edited by P A Matson and D S Ojima. (1990)

No. 14 Coastal Ocean Fluxes and Resources. Edited by P M Holligan. (1990)

No. 15 Global Change System for Analysis, Research and Training (START). Report of the Bellagio Meeting. Edited by J A Eddy, T F Malone, J J McCarthy and T Rosswall. (1991)

No. 16 Report of the IGBP Regional Workshop for South America. (1991)

No. 17 Plant-Water Interactions in Large-Scale Hydrological Modelling. (1991)

No. 18.1 Recommendations of the Asian Workshop. Edited by R R Daniel. (1991)

No. 18.2 Proceedings of the Asian Workshop. Edited by R R Daniel and B Babuji. (1992)

No. 19 The PAGES Project: Proposed Implementation Plans For Research Activities. Edited by J A Eddy. (1992)

No. 20 Improved Global Data for Land Applications: A Proposal for a New High Resolution Data Set. Report of the Land Cover Working Group of IGBP-DIS. Edited by J R G Townshend. (1992)

No. 21 Global Change and Terrestrial Ecosystems: The Operational Plan. Edited by W L Steffen, B H Walker, J S I Ingram and G W Koch. (1992)

No. 22 Report from the START Regional Meeting for Southeast Asia. (1992)

No. 23 Joint Global Ocean Flux Study: Implementation Plan. Published jointly with SCOR. (1992)

No. 24 Relating land use and global land cover change. Published jointly with HDP. (1993)