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Land–Ocean Interactions in the Coastal Zone

Science Plan and Implementation Strategy

GLOBAL CHANGE IGBP

IHDP

Front Cover Illustration

The cover illustration depicts the diversity, complexity and beauty of the global coastal zone. It highlights land-ocean interactions within this linked socio-ecological system, which are the focus of LOICZ research. Human influences are apparent in the land use mosaic and river sediment plume, in the coastal urban developments and coastal shipping. The illustration emphasises the importance of processes at the landscape scale, down through organism scale to the molecular level. Commissioned by LOICZ, this illustration is the work of artist Glynn Gorick, United Kingdom.

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Preface

The genesis of the LOICZ Science Plan and Implementation Strategy reflects coastal science at the crossroads. From the 'Synthesis and Futures' meeting held in Miami in 2002, through to its transition to a jointly-sponsored project by the International Geosphere-Biosphere Programme (IGBP) and the International Human Dimensions Programme on Global Environmental Change (IHDP) in 2004, LOICZ has opted to take the less travelled path, where inter-disciplinarity and the science–policy interface are essential features of a holistic paradigm for the scientific study of the global coast. Building on its strengths of quantifying material fluxes and the role of coastal and shelf ecosystems in their biogeochemical transformations, LOICZ, for its second phase, has developed a scientific agenda that tightly couples the social-ecological systems as they interactively influence the biogeochemistry of carbon, nutrients and sediments along the catchment–coast continuum. In addition, it brings to centre stage the vulnerabilities of both humans and ecosystems – given the anthropogenically altered and changing state of the coast, and the mechanisms for mitigating these through defining sustainable future scenarios.

The LOICZ Science Plan and Implementation Strategy is without a doubt ambitious, thus implementation will rely on broad global, regional and national communities of coastal scientists, policy makers and managers. As before, scientists can collaborate through site-specific research programs for in-depth process studies, as well as by conducting inter-site comparisons to validate modelling and quantitative estimates.

LOICZ is implementing a distributed organisational structure by establishing regional offices coordinated by an International Project Office. This will facilitate regional syntheses that complement Earth System-scale studies, and facilitate exchanges and links between national and regional science and policy communities.

I strongly encourage colleagues from the science and policy sectors to actively contribute their expertise to the LOICZ research on global environmental change in the coastal zone. The task of understanding the changing global coastal system may not be so daunting if pursued with a collective vision.

Liana Talaue-McManus
Chair, LOICZ Scientific Steering Committee
April 18, 2005

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The Editors and the LOICZ SSC are grateful for the many valuable comments and suggestions received during the 'Synthesis and Futures' meeting held in summer 2002 at the University of Miami Rosenstiel School for Marine and Atmospheric Science, and subsequently during the drafting of this document. Special thanks go to the numerous LOICZ-related projects which, through their science and scientists in the first decade of LOICZ, contributed the underpinning knowledge base for the future work of LOICZ. The IGBP and IHDP Secretariats and projects made constructive inputs to the document, Seth Krishnaswami and Sybil Seitzinger provided constructive reviews, and Hester Whyte at the LOICZ IPO coordinated the drafting and editing.

This work would have been impossible without the generous and continued support of IGBP and, in particular, the Dutch Government funding agencies that have supported the LOICZ International Project Office and its activities at the Royal Dutch Institute for Sea Research. We also acknowledge funding from WOTRO, KNAW, EU, START, IAI, APN, NSF, UNESCO (IOC, IHP), UNEP (GEF, GPA) and SCOR. LOICZ is grateful for the national support that has recently enabled establishment of three Regional Project Offices in Singapore, Germany and Sri Lanka, all of which assisted in drafting this document, and will play a critical role in the implementation of LOICZ.

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Executive Summary

Coastal zones play a key role in Earth System functioning, by contributing significantly to the life support systems of most societies. Human activities modifying riverine hydrology and riverine material fluxes to the coastal zone, have increased in both scale and rate of change in the last 200 years. The underlying processes that drive changes to coastal systems occur at a multiplicity of temporal and spatial scales. These changes alter the availability of ecosystem goods and services. However, disciplinary fragmentation impedes our ability to understand the regional and global changes that affect coastal systems, and thus limits our ability to guide management and decision making.

Since 1993, the Land–Ocean Interactions in the Coastal Zone (LOICZ) project of IGBP, has studied Earth's heterogeneous, relatively small but highly productive, dynamic and sensitive coastal zone. In recognition of the comprehensive integration of human dimensions into its research directions for its second phase, LOICZ has, since 2004, been co-sponsored by IHDP. The primary objective of LOICZ is:

'to provide the knowledge, understanding and prediction needed to allow coastal communities to assess, anticipate and respond to the interaction of global change and local pressures which determine coastal change'.

The science of LOICZ has been focussed on the measurement of biogeochemical fluxes into, and within, the coastal zone. These fluxes are important and relevant to global environmental change (GEC) science because:

- fluxes of CO_2 and trace gases are the key variables for scaling up to global climate change;
- biogeochemical variables describe key connections across coastal boundaries, that is, from catchment to coast, coast to ocean and coast to atmosphere;
- fluxes include primary production, which underpins ecosystems and renewable resources;
- water and sediment quality affect habitat quality, coastal zone amenity value and human use; and
- biogeochemical processes and cycles include important positive and negative feedbacks in coupled land–coastal systems, determining thresholds and boundaries for system resilience.

Progress has been made in understanding the changes in Earth System processes that affect the coastal zone, and the role of coastal systems in global change. This includes identifying proxies that describe the state of coastal systems under existing conditions and change scenarios. Typologies have been developed to assist in the interpolation of results into areas where primary information is lacking. This has enabled a first-order upscaling to a global synthesis.

However, research is still required to develop understanding and tools for the derivation, differentiation and quantification of anthropogenic drivers and global environmental pressures. This distinction is essential to determine appropriate management options for land-ocean interactions in the coastal zone. Consequently, LOICZ aims to overcome traditional disciplinary fragmentation, in particular between natural and social sciences, and focus on the primary issues of sustainable use of coastal systems, through pursuit of the following overarching goal:

'to develop the capacity to assess, model and predict (i) change in the global coastal zone under multiple forcings (including human activity), and (ii) the consequences for human welfare'.

This leads to specific goals (Box A) and the following niche for LOICZ:

- LOICZ is global;
- LOICZ will provide a broader context for the coastal zone beyond the traditional natural and social science boundaries;

- LOICZ will synthesise across disciplines and across global, regional, national and local scales; and
- LOICZ will communicate outputs beyond the scientific community.

LOICZ will undertake research that addresses key issues of coastal change and use, in the context of scenarios of future human activity and environmental change. As well as fundamental coastal zone research, LOICZ will promote research that synthesises and up-scales results for dissemination within the scientific community, and outreach to policy makers and the public.

Science Themes

Managing the consequences of GEC, while securing a sustainable future, requires a more integrated approach that incorporates human aspects within the traditional analytical methods of disciplinary studies. The challenge is to develop integrative global change science, that assembles research from diverse sources in innovative ways in order to understand the interacting dynamics of the Earth's life support systems. LOICZ will focus on how humans are supported by the coastal system, how their activities impact upon it, and what policies and practices will be required to ensure its sustainability. This Science Plan and Implementation Strategy organises the biogeochemical, physical and human dimensions of coastal change into five themes. Because many of the changes that affect the coastal zone occur in river basins and groundwater systems, catchments and coasts must be considered as a single system – the water continuum. The five themes have three common challenges: (i) up-scaling regional science for global science, policy and management, and down-scaling global science for regional management and stakeholders; (ii) understanding the interaction between impacts of local/regional versus global drivers and pressures; and (iii) combining natural and social sciences with stakeholder consultations to understand and advise on sustainable use of the water continuum.

LOICZ will seek to ensure that the outcomes of its science are disseminated as widely as possible. This will include developing a mechanism and organisation that contributes to developing capability and capacity within all stakeholder groups involved in coastal zone management and use.

Theme 1: Vulnerability of coastal systems and hazards to society sets the stage for the subsequent themes which address the wider coastal domain. It considers the hazards to humans from coupled human–ecosystem change, carrying capacities and vulnerability issues, including the risk of degrading the sustainability of coastal goods and services. Key issues include:

Box A. The Specific LOICZ Goals

1. To contribute to Earth System science by researching the relevance and impact of global change on coastal systems – a global-scale commitment.
2. To make scientific knowledge on the scales of coastal change and the options for sustainable use available to policy makers, managers and stakeholders – an issue driven commitment.
3. To develop a research framework for interdisciplinary analysis of existing information, and generation of new research, integrating biogeochemical, biophysical and human components of coastal systems.
4. To provide within this research framework, a flexible infrastructure able to respond to new research demands that includes and integrates disciplines of natural and social sciences.
5. To develop a framework for science dissemination, outreach and capacity building that encourages participation by scientific and non-scientific communities at local, national, regional and global scales.
6. To provide a global platform to facilitate and coordinate international, regional and national coastal research initiatives, that improves the design and implementation of observation and research networks.

- the effect of non-linearities and uncertainties on the vulnerability of coastal societies and ecosystems to global change hazards;
- the community's stakes in the coastal zone including resources, goods and services; and
- external and internal factors of human and coastal vulnerability.

Theme 2: Implications of global change for coastal ecosystems and sustainable development focuses on conflicting spatial, temporal and organisational issues of coastal change, land and sea use, and how these exert pressures on coastal systems and influence natural resource availability and sustainability. Key issues include:

- characterising the nature and location of coastal environmental and social system boundaries, and their tapestry of interactions;
- assessing system sensitivity and robustness to reveal critical thresholds for changes to biogeochemical and/or hydrological cycles that cause permanent state changes;
- quantifying human impacts on coastal areas using natural science methods and ecological-economic indicators;
- identifying options to design and manage system robustness, through a scenario approach that considers critical thresholds and sustainability; and
- evaluating the effects of changing inputs on ecosystem health and coastal zone goods and services, including the links between biological functioning, geochemistry and human drivers.

Theme 3: Human influences on river basin–coastal zone interactions considers river basin drivers/pressures that influence and change the coastal domain. The whole water continuum is considered as a single system. Processes of material transport to the ocean, and human influences due to activities in the Exclusive Economic Zone (EEZ), are considered through links to Themes 2 and 4. Key issues include:

- disentangling the cause–effect relationships of those impacts and human activities which are strictly coast or river basin-oriented (regional), from those which result from wider external pressures on the river–coast system;
- modelling coupled human–ecosystems in river basins, using the Driver–Pressure–State–Impact–Response (DPSIR) approach and assessment framework, in order to identify links between major anthropogenic and natural pressures in catchments that affect coastal ecosystems;
- developing scenarios that predict future coastal change due to land use, climate change and management options; and
- evaluating societal and institutional dimensions and changes in order to establish basin–coastline linkages.

Theme 4: Biogeochemical cycles of coastal and shelf waters focuses on the cycling of carbon, nutrients and sediments in coastal and shelf waters, and their exchange with the ocean. This recognises the vital and changing benthic processes of coastal waters that influence shelf ecosystems and global chemical cycles. Key issues include:

- quantifying material transport within and across the continental shelf, transformation of materials within the water column and sediments, storage of materials in the coastal zone and air–sea exchange;
- assessing regional differences, and understanding why some shelf waters are more resilient or resistant to change than others;
- defining the terrestrial boundary condition for nutrient fluxes by better integration of river basin information, including sediment dynamics and organic inputs; and
- developing regional budgets and flux estimates for shelf and coastal waters, in order to understand and predict the impacts of global and basin-scale changes in ocean climate and biogeochemical cycles.

Theme 5: Towards coastal system sustainability by managing land–ocean interactions integrates across the other four themes, and provides a platform for considering coastal zone development and management (including resource users) in the context of 'strong' and 'weak' sustainability options. Key issues include:

- considering how temporal and spatial scales, including the institutional dimensions, affect scientific and management perspectives of coastal change;
- classifying and comparing different settings of drivers/pressures in coastal system state interactions and existing responses using typologies;
- linking natural, economic and human dimension sciences into 'futures' scenarios; and
- developing management response options and participation derived from 'futures' scenarios, developed and assessed in collaboration with relevant policy, management and investment communities.

Implementation Strategy

LOICZ will engage in GEC science that generates new knowledge and understanding, and will make its results and outputs available to the wider scientific community. LOICZ will also strive to facilitate the adoption and application of its scientific outcomes by policy makers and resource managers. Major coastal change issues will drive the science. LOICZ science should inform management of land–ocean interactions in order to reduce the vulnerability of coastal societies, and in order to enhance sustainable development. In seeking to provide (i) improved scientific information for advanced Earth System analysis and modelling and (ii) science for improved management, LOICZ will adopt an 'adaptive science' approach that recognises short-term information needs.

Products

LOICZ outputs will focus on providing improved understanding of (i) the temporal and spatial relationships between transport of land-sourced materials and coastal impacts, (ii) the complexity of the coastal sea environment in determining critical thresholds, and (iii) the multiple interests of stakeholders and other interests that determine the drivers of change.

LOICZ aims to produce a suite of deliverables for resource managers, including integrated models of coastal system change incorporating management options. Model scenarios will be tailored to assist river basin management for sustainable coastal development, and will rely upon a universal database of environmental and societal information to facilitate integrated coastal zone management.

LOICZ will continue and enhance its strong operational links with START and regional intergovernmental bodies, such as APN and IAI, to foster regional capacity building.

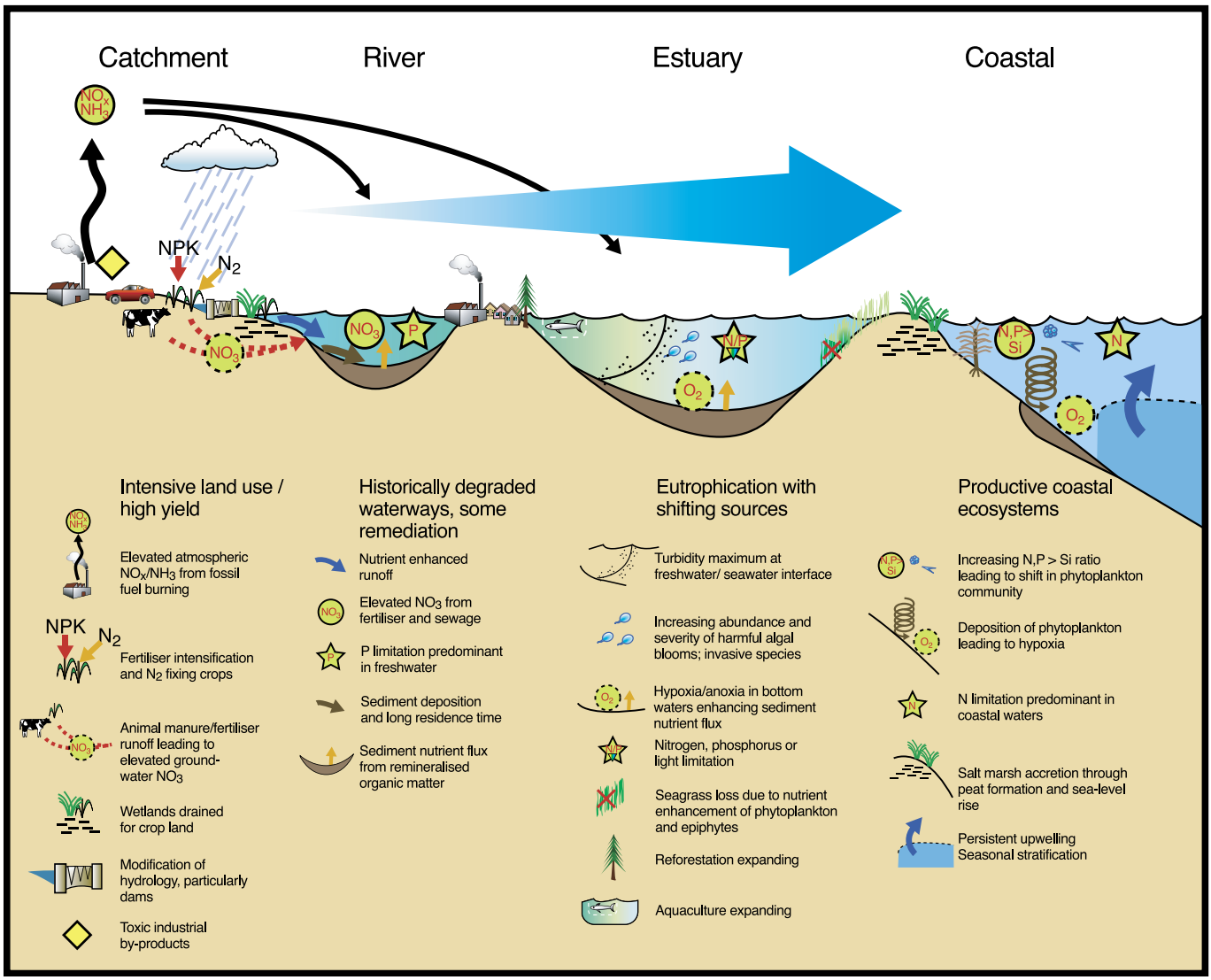
Links with other Programmes

Within IGBP, LOICZ will interface between the land and marine-focussed projects, and will contribute to AIMES. LOICZ will also interact strongly with those projects of IHDP and the other Earth System Science Partnership (ESSP) partner programmes (DIVERSITAS and WCRP), whose activities consider aspects of the coastal zone. LOICZ will promote linkages with the ESSP joint projects, namely GCP, GECAFS, the new Human Health initiative, and in particular GWSP, which deals with catchment-based hydrological and freshwater resource issues. Specific contextual collaboration is planned with IMBER and SOLAS, to design observation and modelling strategies that link coastal systems to oceanic and atmospheric systems.

Introduction

The coastal zone is the long narrow interface between the land and the ocean; it is a naturally dynamic zone which is subject to increasing human use. A 100 km wide coastal zone occupies 19.2% of the total Earth's land surface – excluding Antarctica (Shi and Singh (2003), yet coastal population density in those parts of this zone below 100 m elevation is estimated to be 112 people km^{-2} – about three times the global average (Small and Nicholls 2003). Small and Nicholls (2003) estimate that around 23% of the 1990 global population live in this zone (i.e about 1.2 billion people) – considerably lower than various earlier estimates of 40–60% (see review in Shi and Singh (2003)). However, what is important is not the exact population or population density, but the undeniably rapid demographic growth in this narrow zone – be it in the dominating rural areas and the small to medium-size cities (both of which accommodate most of the global coastal population) or in the many coastal megacities – which will continue to concentrate human activities in the coastal zone. This will impose disproportionate pressures on the Earth System. The challenge of protecting coastal goods and services stems from:

Figure 1. Conceptual model of processes and conditions affecting biogeochemical fluxes and budgets in temperate coastal environments (Source: William C. Dennison).



- global-scale changes, including natural changes and those due to global economy/trade and policy;
- regional-scale changes as a result of trans-boundary and supra-national drivers and pressures in the coastal zone; and
- sub-national regional-scale changes at the river catchment level that affect the coastal zone.

GEC is the set of biophysical transformations of land, oceans and atmosphere, driven by an interwoven system of human activities and natural processes (Steffen et al., 2003).

Since 1993, LOICZ (Pernetta and Milliman, 1995), an IGBP project, has studied Earth's heterogeneous, relatively small but highly productive, dynamic and sensitive coastal zone (Figure 1). Major questions that LOICZ has addressed at the global scale are:

- is the coastal zone a sink or source of CO_2?
- what are the mass balances of carbon, nitrogen and phosphorus in the coastal zone?
- how are humans altering these mass balances, and what are the consequences?
- how do changes in land use, climate and sea-level alter the fluxes and retention of water and particulate matter in the coastal zone, and how do they affect coastal morphodynamics?
- what is the role of the coastal zone in trace gas (e.g. dimethylsulphide, NO_X) emissions? and
- how can knowledge of the processes and impacts of biogeochemical and socio-economic changes be applied to improve integrated management of the coastal environment?

LOICZ science has focussed on the measurement of biogeochemical fluxes into, and within, the coastal zone. These fluxes are important because:

- fluxes of CO_2 and trace gases are the key variables for scaling up to global climate change;
- biogeochemical variables describe key connections across coastal boundaries, that is, from catchment to coast, coast to ocean and coast to atmosphere;
- fluxes include primary production, which underpins ecosystems and renewable resources;
- water and sediment quality affect habitat quality, coastal zone amenity value and human use; and
- biogeochemical processes and cycles include important positive and negative feedbacks in coupled land–coastal systems, determining thresholds and boundaries for system resilience.

The spatial and temporal heterogeneity of coastal zones is considerable (Vafeidis et al., 2004), leading to methodological problems in developing global perspectives on the role and scale of the coastal domain in Earth System functioning. Identifying and quantifying this role and developing scenarios of change – including anthropogenic and natural drivers, requires research, analysis and interpretation that cross the interface between natural and social sciences.

Human activities modifying riverine hydrology and riverine material fluxes to the coastal zone have increased in both scale and rate of change during the last 200 years (Meybeck, 2003; Green et al., 2004). The causes and drivers of change often become modified and/or compounded by other developments, making interpretation of the effects of human activities complex. Box 1 shows the multiplicity of human influences in the coastal zone. LOICZ will integrate human population and development pressures in its investigation of catchment systems, in order to provide new insights into the temporal and spatial scales needed for Earth System analyses.

LOICZ research has shown that 70% of the total material load (e.g. DIP) to the coastal zone comes from regions with low to intermediate area-specific yields (Smith et al., 2003). Medium to high yields come from predominantly tropical, sub-tropical and island-dominated regions, as well as parts of Europe. At the global scale, these medium to high load areas are largely either ocean-dominated coasts, or coasts influenced by small and small–medium rivers. This suggests that at the global scale these systems dominate coastal processes, rather than the continental-scale influences of large rivers (Salomons et al., in press).

Large and small rivers significantly affect coastal zones, from local up to continental scales. For example, the continental-scale Mississippi catchment which has been affected by human activities has impacted much

of its receiving coastal sea. However, the human and natural pressures on smaller catchment–coast systems have comparable or greater impact on coastal system functioning. The impacts from smaller catchments are usually more direct, while those of larger catchments are usually more subtle and dispersed, due to higher buffering capacities and greater time delays between catchment-based change and coastal signals. In all cases, the pressures on coastal systems will increase with increasing population and increasing land-use intensification. Overall, the largest human impacts on local coastal conditions originate in small–medium size catchments. This has major implications for the choice and targeting of catchment/coastal management actions (Meybeck et al., 2004).

This document articulates the LOICZ research planned up until 2012, and the strategy for its implementation including strengthening of relevant collaborations within, and beyond, the ESSP.

Box 1. Human Influences on the Coastal Zone

The coastal landscape and coastal seas are influenced by human activities both in the coastal zone and in river basins (Figure 1). Alterations to upland areas are causing marked changes in the timing, flux and dispersal of water, sediments, nutrients and contaminants to the coastal zone that include:

- water discharges from river systems (catchment areas);
- water extraction for urban development, industry and agriculture;
- energy fluxes within coastal systems;
- regional decreases in sediment and nutrient delivery due to reservoir sedimentation;
- regional increases in sediment and nutrient delivery due to increased soil erosion;
- flow patterns and sedimentation in estuaries due to dredging and reclamation;
- estuarine habitat degradation and loss due to sedimentation;

In addition to the changes in upland areas and their downstream consequences, many other human activities impact upon the coastal zone, including:

- building of shoreline engineering structures, ports and urban developments;
- harvesting, often over-harvesting, of marine resources;
- loss of traditional food resources and cultural value for indigenous people;
- increased use of marine space;
- increased water-borne and atmospheric pollutants from industries and urbanisation;
- modification of the type and quantity of coastal discharges from surface and groundwater flows;
- loss of coastal wetlands and other valuable ecosystems through land use change; and
- modification of habitat structure and functioning due to introduced species.

The consequences of these alterations are far reaching and affect societal and global functions (Figure 1) including changes in: ecosystem health and biodiversity; vitality and productivity of coastal ecosystems; coastal stability and morphology; and the fate and distribution of particulate and dissolved river loads in coastal and shelf waters. All of these tend to diminish the options for sustainable development, and increase the uncertainty in coastal management.

The LOICZ Objective

LOICZ aims to address disciplinary fragmentation and has as its primary objective:

'to provide the knowledge, understanding and prediction needed to allow coastal communities to assess, anticipate and respond to the interaction of global change and local pressures which determine coastal change'.

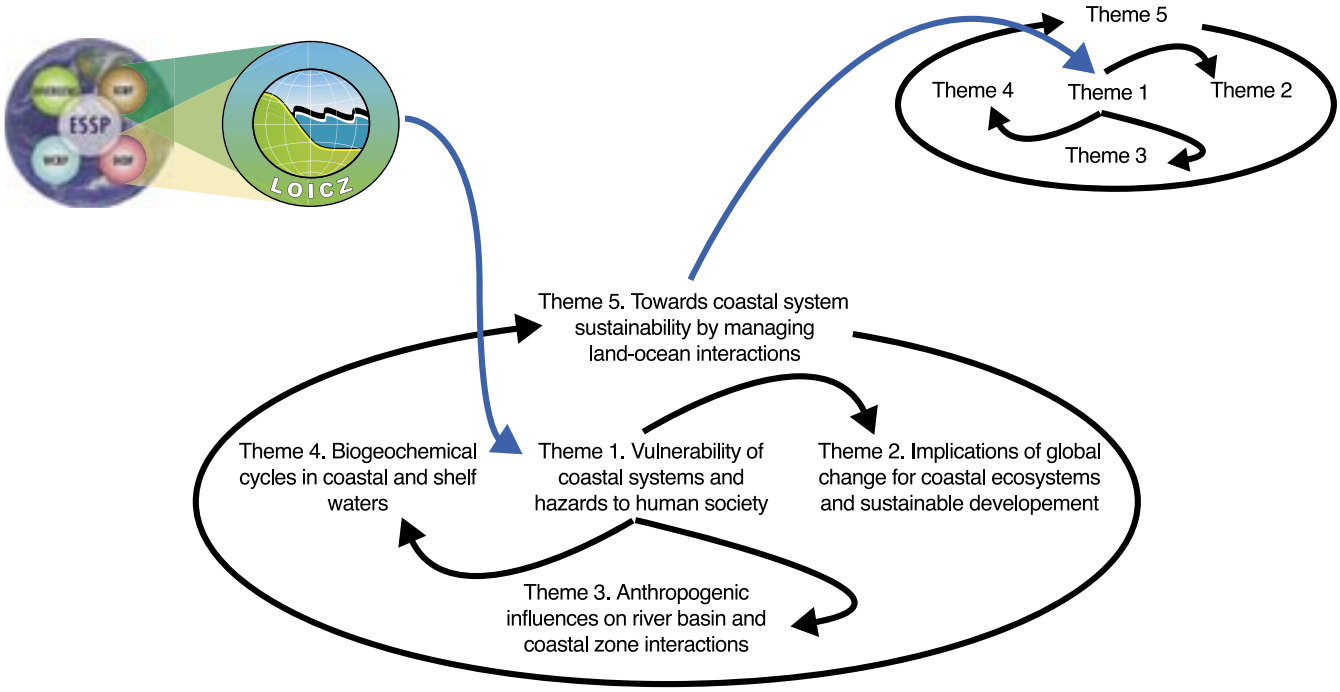
To meet this objective LOICZ will undertake science that addresses key issues of coastal change and coastal use, using scenarios of future human activity and environmental change. This will require LOICZ to expand its research collaborations to engage with the wide range of scientific disciplines and user groups relevant to coastal zone research. LOICZ will also engage in science communication, and will disseminate research outcomes to policy makers and the public.

LOICZ will establish a distributed International Project Office (IPO) structure, with Regional Project Offices to promote and co-ordinate regional and local contributions to the global research. These nodes are expected to increase the visibility and effectiveness of LOICZ, and offer greater opportunities and research support with increased regional networking.

LOICZ in the ESSP Context

LOICZ is an IGBP/IHDP project that will contribute to the ESSP through collaborations with ESSP joint projects (Figure 2). A decade of Earth System science has significantly advanced the understanding of Earth System processes, and the extent of human impacts on these processes. However, much remains to be understood, and the challenge of managing the consequences of GEC whilst securing a sustainable future continues to grow. LOICZ will adopt an integrated approach that incorporates human aspects within the traditional analytical methods of disciplinary studies. The challenge is to develop integrative global change science, that assembles research from diverse sources in innovative ways in order to understand the interacting dynamics of the Earth's life support systems. This will focus on how

Figure 2. Relationship between ESSP, IGBP, IHDP and LOICZ, and the LOICZ science themes designed to address the dual challenges of managing global environmental change whilst achieving sustainability.



humans are supported by, and impact upon, the Earth System. These wider aims are reflected in the objective of IGBP:

'to describe and understand (i) the interactive physical, chemical and biological processes that define Earth System dynamics, (ii) the changes that are occurring in these dynamics, and (iii) the role of human activities in these changes.'

Complementary to this objective are the IHDP aims to describe, analyse and understand the human dimensions of GEC guided by four overarching questions:

I. **Vulnerability/Resilience:** What factors determine the capacity of coupled systems to endure and produce sustainable outcomes in the face of social and biophysical change?

II. **Thresholds/Transitions:** How can we recognise long-term trends in forcing functions and ensure orderly transitions when thresholds are passed?

III. **Governance:** How can we steer tightly coupled systems towards desired goals or away from undesired outcomes?

IV. **Learning/Adaptation:** How can we stimulate social learning in the interest of managing the dynamics of tightly coupled systems?

The goals and objectives of LOICZ are closely affiliated to those of its parent programmes.

The LOICZ Project

Human-induced changes in the coastal zone, and the use of coastal resources continue to grow. Examples are catchment erosion and hydrologic changes that alter material fluxes to the coastal zone, and coastal development and resource use, all of which affect coastal ecosystems.

To reflect the vulnerability of human use of the coastal zone, the overarching goal of LOICZ is:

'to develop the capacity to assess, model and predict (i) change in the global coastal zone under multiple forcings (including human activity), and (ii) consequences for human welfare.'

Box 2. The Specific LOICZ Goals

1. To contribute to Earth System science by researching the relevance and impact of global change on coastal systems – a global-scale commitment.
2. To make scientific knowledge on the scales of coastal change and the options for sustainable use available to policy makers, managers and stakeholders – an issue driven commitment.
3. To develop a research framework for interdisciplinary analysis of existing information, and generation of new research, integrating biogeochemical, biophysical and human components of coastal systems.
4. To provide within this research framework, a flexible infrastructure able to respond to new research demands that includes and integrates disciplines of natural and social sciences.
5. To develop a framework for science dissemination, outreach and capacity building that encourages participation by scientific and non-scientific communities at local, national, regional and global scales.
6. To provide a global platform to facilitate and coordinate international, regional and national coastal research initiatives, that improves the design and implementation of observation and research networks.

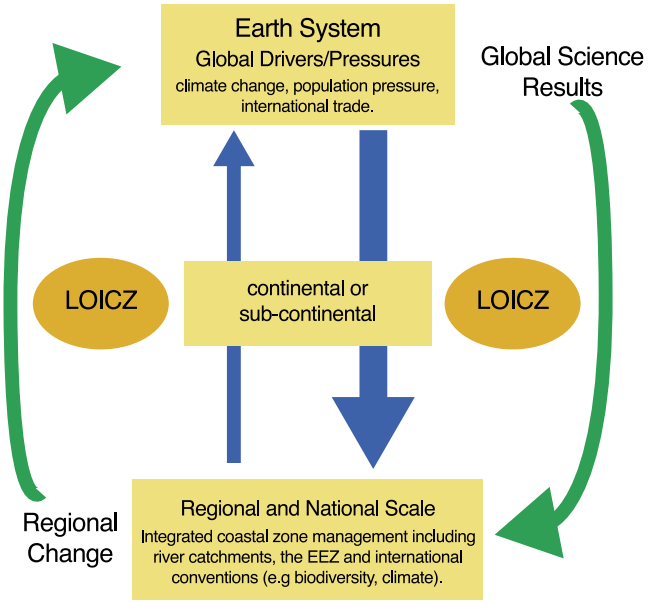
The niche of LOICZ can be described as follows:

- LOICZ is global;
- LOICZ will provide a broader context for the coastal zone beyond the traditional natural and social science boundaries;
- LOICZ will synthesise across disciplines and across the global, regional, national and local scales;
- LOICZ will communicate research outputs beyond the scientific community.

The overarching goal and niche lead to specific goals for LOICZ (Box 2), which recognise that in the coastal zone, natural systems and social systems closely interact in their responses to pressures. In spite of this recognition, there are currently few tools available to policy makers to either clearly quantify and distinguish between anthropogenic and natural drivers, or to support decision formulation.

LOICZ therefore aims to provide a framework for both inovative process studies and integrated analysis of existing information, and to focus on key issues related to human activities in the catchment–coastal zone (Figure 3). In order to achieve the LOICZ goals, it will be necessary to overcome traditional disciplinary fragmentation.

Figure 3. The role of LOICZ in (i) integrating regional and national-scale coastal change and use up to the Earth System scale, and (ii) communicating the implications for coastal zone management of global-scale scientific results.



LOICZ Rationale and Scope

In its first decade, LOICZ explored key drivers and factors that influence land–ocean interactions in the coastal zone, leading to recognition of the growing need for science to inform coastal zone management. This recognition has underpinned the development of the scientific themes for the second decade of LOICZ. LOICZ has affirmed the powerful influence of human-driven catchment-based change, which alter the supply of energy and materials to the coastal zone. Clearly, a "source to sink" approach must be adopted in studying coastal biogeochemistry. Whilst LOICZ's objective is not to manage coastal zones, LOICZ does seek to provide a sound scientific basis for the sustainable use and integrated management of coastal zones in the context of global change.

LOICZ 1993–2002: Results and Achievements

Between 1993 and 2002, LOICZ made major advances in understanding the biogeochemical and physical role of the coastal zone in global cycles and change. The research focussed on material fluxes from the land to the ocean, combining natural and social sciences to elucidate the causes for flux alterations (Crossland et al., in press). Understanding relationships between scales, and integration across scales, was an important and challenging aspect of this combined approach (Figure 3). LOICZ achievements have depended upon national programmes of research, and contributions from over 2,500 scientists from 130 countries. LOICZ output has included more than 1,500 peer-reviewed publications. A synthesis of the first decade of LOICZ research will be published in 2005. Specific examples of achievements include:

Estimation of nutrients fluxes and coastal metabolism to address the role of the coastal zone in global cycling. Data, information and syntheses continue to be made accessible through a dedicated public website (data.ecology.su.se/MNODE). A regional and global synthesis "Carbon and Nutrient Dynamics at Oceanic Margins" is in progress (Atkinson et al., in press)

Clarifying the role of river catchments in the flux of materials to the coastal zone. A common method has been established to estimate human pressures on mate-

rial fluxes and changes in river catchments (including groundwater flux). The method has been applied to the coastal seas of Africa, Europe, Asia, South America, the Caribbean and Oceania.

Application of the Driver–Pressure–State–Impact–Response (DPSIR) concept to address the human dimensions of change in the coastal zone. An interdisciplinary pilot study in Southeast Asia has provided approaches for integrating biogeochemical studies with methods for estimating nutrient wastes.

Development of a coastal zone typology. The web-based typology (hercules.kgs.ku.edu/hexacoral/envirodata/hex_modfilt_firststep3dev1.cfm) comprises a global database (0.5 degree resolution, over 140 variables) linked to assessment and visualisation software (LOICZView) for classifying and scaling (palantir.swarthmore.edu/loicz). Assessments consider parameters of human (e.g. Figure 4) and natural pressures to evaluate regional and global-scale coastal change.

Training and capacity building. Training workshops (in collaboration with START, IHDP, IOC, UNEP, IOI and others) on biogeochemical modelling, typology applications, river basin assessments and coastal zone management have enhanced the dissemination of LOICZ outputs.

LOICZ Expectations

Consideration of seven of the GAIM Earth System questions (Sahagian and Schellnhuber, 2002) has guided formulation of the LOICZ scientific themes, with a view to promoting improved integrative and policy-relevant study of the linked biogeochemical, physical and human dimensions of coastal change. The seven questions are listed below together with the LOICZ expectations:

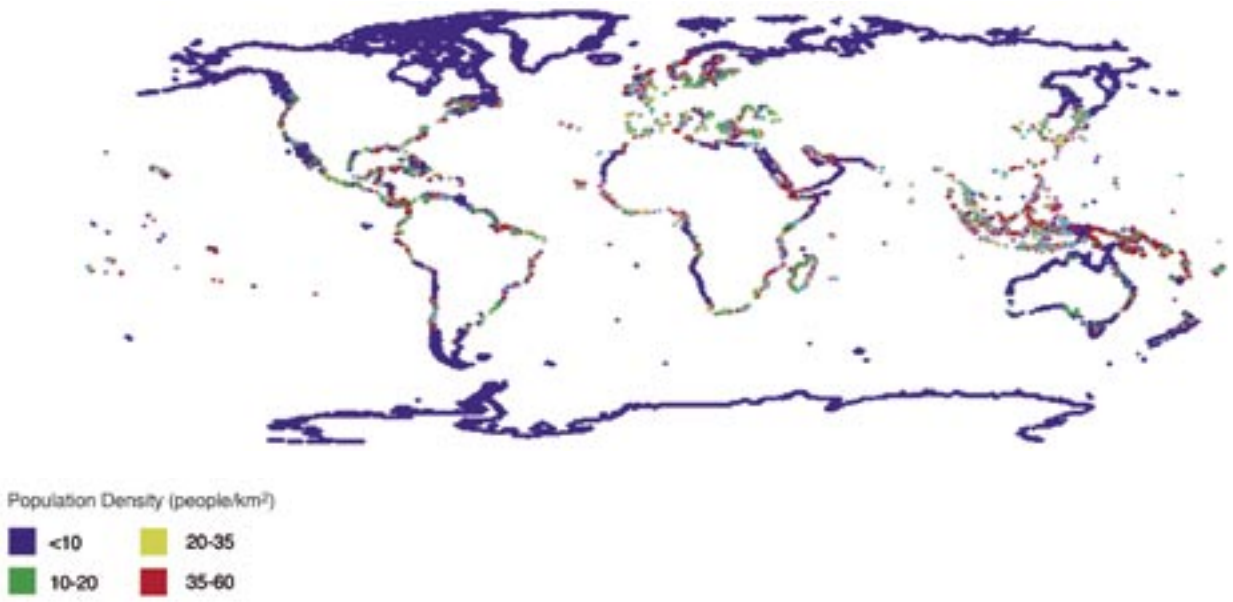
- Question 7 (Analytical): Which are the most vulnerable coastal regions under global change?

  LOICZ Expectation: **A typology of coastal vulnerability to global change on various spatial and temporal scales.**

- Question 8 (Analytical): How are abrupt and extreme events processed through nature–society interactions?

  LOICZ Expectation: **Description of the impact on co-evolving coastal environments and societies of abrupt and extreme events.**

Figure 4. Global typology showing estimated "disturbance" in coastal ecosystems at particular localities due to population density. From Buddemeier et al. (2002).



- Question 14 (Operational): What are the most appropriate methods for integrating natural and social scientific knowledge?

  LOICZ Expectation: **Successful integration of natural and social sciences to overcome the traditional disciplinary divide.**

- Question 15 (Normative): What are the general criteria and principles for distinguishing between non-sustainable and sustainable futures?

  LOICZ Expectation: **Identification of criteria to distinguish, and consequently the indicators to assess, sustainable and less sustainable futures.**

- Question 18 (Normative): What kind of nature does modern society want?

  LOICZ Expectation: **Elucidation of social choices and preferences regarding environmental conditions and living standards.**

- Question 21 (Strategic): What is the optimal global pattern of nature reserves and managed areas?

  LOICZ Expectation: **Contributory advice based on identification of proxies for the land use and cover changes that affect coastal processes.**

- Question 23 (Strategic): What is the structure of an effective and efficient system of global environmental and development institutions?

  LOICZ Expectation: **Investigation of the institutional dimensions of the relationships between coastal change/impact and management response, leading to advice on an effective and efficient system of global environmental and development institutions.**

LOICZ aims to provide both (i) scientific information for advanced Earth System analysis and modelling, and (ii) science for improved management. Short-term management information needs must be met with in-depth interdisciplinary science. This means that major coastal change issues should drive a science agenda that capitalises on the first decade of LOICZ research by:

- maintaining and enhancing scientific networks that bring different cultural perspectives, science priorities and funding opportunities;
- using typologies to determine regional questions and actions, and to visualise and map change, vulnerability and risks;
- consolidating global and regional-scale knowledge (e.g. biogeochemical budgets);
- using the catchment-scale for assessment, synthesis and up-scaling, and identifying management units (and their key environmental system functions) best suited for interventions; and
- pursuing issue-driven research (e.g. restoration, mitigation, thresholds, carrying capacity and links to biogeochemical cycles) and considering pressure/impact scenarios.

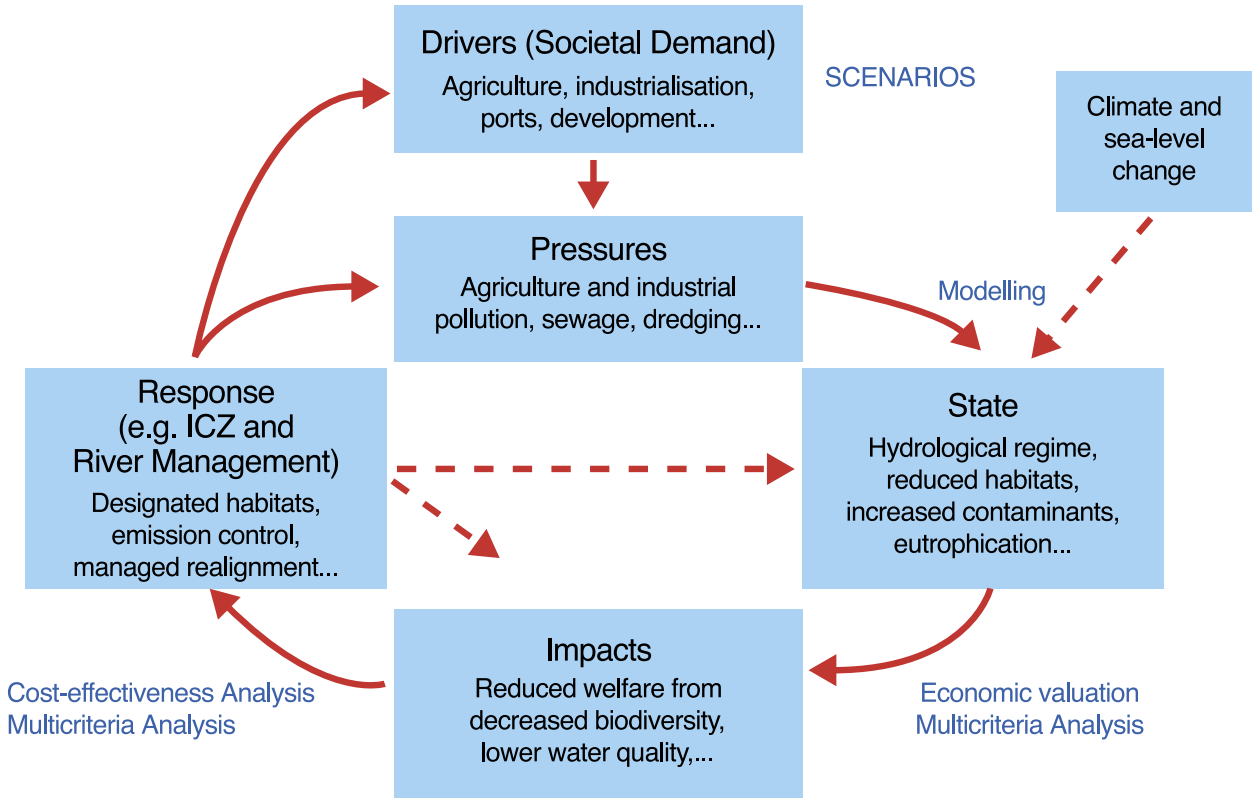
LOICZ will be adaptive in its scientific context, and develop adaptive management options that promote outreach and participation. The co-sponsorship of IHDP is expected to be critical in this ambition.

Scientific Themes

LOICZ will undertake research into land–ocean interactions in the context of GEC. It will do so by undertaking original research, and by integrating outputs from relevant IGBP, ESSP and other projects. LOICZ seeks to provide improved integrative understanding of the linked biogeochemical, physical and human dimensions of coastal change, and thus contribute to the IGBP and IHDP objectives and goals. To do this, it will be important to understand the temporal and spatial scales of GEC, in order to guide appropriate and effective responses. Because many of the changes that affect the coastal zone occur in river basins and groundwater systems, catchments and coasts must be considered as a single system – the water continuum.

The Driver–Pressure–State–Impact–Response (DPSIR) framework (Figure 5) underpins LOICZ science, and will guide the development of conceptual and quantitative scenario models. The DPSIR framework will help (i) strengthen the integration of the outcomes from thematic studies, (ii) identify critical information gaps to guide the science themes, (iii) expand the understanding of the interplay between the natural and human change-drivers, and (iv) identify coastal zone management options which both minimise risks to life and property and promote sustainable and equitable resource use.

Figure 5. The DPSIR framework for scoping complex resource management issues, including the connection between ecosystem change and the social and economic impacts. Adapted from Ledoux et al. (2004).



Box 3. Terms of Reference for LOICZ Theme Operations

- To provide a scientific framework for the project lifetime (broad scope, inclusive).
- To provide an enabling platform for assessment and synthesis.
- To provide a home for a flexible agenda of research topics that informs across the scales of Earth System questions, as well as across national and local management needs.
- To operate as an integration and synthesis mechanism for:
  - existing research,
  - promote upcoming research,
  - create new innovative research.
- Provide a clearing house for the outputs of a multi-disciplinary group of scientists for:
- Establishing and maintaining the networks to source scientific and funding opportunities,
- Generating and supervising science dissemination including portals for different user groups,
- Engaging with users and scientists to revise the agenda periodically and deliver the related products in a time bound fashion.

Overview of Themes

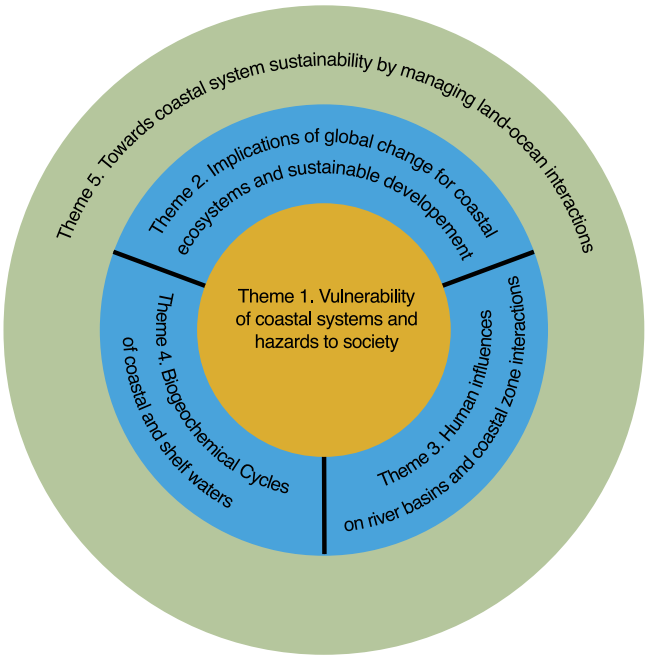
To address its objective, LOICZ has developed five research themes (Figure 6) cross-linked to the five elements of the DPSIR framework, all with common terms of reference (Box 3). An overview of the themes (with relevant DPSIR framework elements indicated) is provided below, with details given in subsequent sections.

Theme 1: Vulnerability of coastal systems and hazards to society (D, I and R) sets the stage for the subsequent themes which address the wider coastal domain. It is integrative in nature, and deals with coupled human-ecological system change and carrying capacities and vulnerability issues, including the risk of degrading sustainability of coastal goods and services.

Theme 2: Implications of global change for coastal ecosystems and sustainable development (P, S and I) focuses on conflicting spatial, temporal and organisational issues of coastal change, land and sea use, and how these influence natural resource availability and sustainability.

Theme 3: Human influences on river basin–coastal zone interactions (D, P, S and I) considers river basin drivers/pressures that influence and change the coastal domain. The whole water continuum is considered as a single system. The processes of material transport to the ocean, and human influences due to activities in the EEZ, are included through links to Themes 2 and 4.

Figure 6. The LOICZ themes as part of a matrix structure in a sequential and iterative process.



Theme 4: Biogeochemical cycles of coastal and shelf waters (P, S and I) focuses on the cycling of carbon, nutrients and sediments in coastal and shelf waters, and their exchange with the ocean. This recognises the vital and changing benthic processes of coastal waters that influence shelf ecosystems and global chemical cycles.

Theme 5: Towards coastal system sustainability by managing land–ocean interactions (R) integrates across the other four themes, and provides a platform for considering coastal zone development and management (including resource users) in the context of 'strong' and 'weak' sustainability options.

The five themes share three common challenges: (i) up-scaling regional science for global science, policy and management, and down-scaling global science for regional management and stakeholders; (ii) understanding the interaction between impacts of local/regional versus global drivers and pressures; and (iii) combining natural and social sciences with stakeholder consultations to understand and advise on sustainable use of the water continuum.

Implementation Approach

LOICZ will continuously synthesise information on priority topics, integrating within and across themes. LOICZ activities will undertake original research based on new and existing data; the new data being primarily associated with the biogeochemistry of Themes 3 and 4. Existing data will be sourced from prior LOICZ research, other IGBP and IHDP projects and elsewhere, particularly with respect to human dimension aspects. LOICZ will share data and collaborate with IGBP and IHDP projects, and with the joint projects of ESSP.

LOICZ will adopt output/outcome focussed project management, and will undertake regular reviews so as to ensure a flexible scientific agenda. For different coastal change issues, this will assist in identifying appropriate stakeholders and relevant scientific disciplines.

The balance between original research (Theme 4), original research mixed with assimilation and integration of other research (Themes 2 and 3), and primarily assimilation and integration of other research (Themes 1 and 5), is described in the following sections.

Theme 1: Vulnerability of Coastal Systems and Hazards to Society

Introduction and Rationale

The coastal zone is a focus for natural and anthropogenic change, and is therefore vulnerable to degradation (Lindeboom, 2002). The socio-economic drivers of anthropogenic change are themselves prone to modification by change, because change affects the available goods and services (Kremer and Crossland, 2002). This threatens sustainable use of the coastal zone.

Understanding interactions between human activities and coastal ecosystems is difficult, because methods and scales of analysis tend to differ between natural and social sciences. Finding ways to combine social and natural science analyses is therefore essential. The scales of analysis are particularly important, because use of inappropriate scales can hide or obscure human–ecosystem interactions.

Environmental research in the social sciences seeks to understand how human behaviour and its consequences, are integral to natural ecosystems and how they are affected by global change (Gläser, 2002). Hence for LOICZ biogeochemical science to be useful in management and decision making, it must be integrated with an understanding of human behaviour and its consequences.

Theme 1 will therefore focus on understanding (i) how human activities alter material fluxes along the water continuum and within the coastal zone, and (ii) the processes (including feedbacks) that threaten sustainability of coastal goods and services.

The principal rationale of Theme 1 is that hazards originating from change, both natural and anthropogenic, constitute the greatest risk to human populations and threaten sustainable coastal resource use.

State of the Science

The observation and measurement of human drivers of coastal change has increased. However, current indicators and metrics of change and adaptive capacity within and between ecosystems are imperfect, and the ability to express, model and understand the synergies of multiple forces and their scales of interaction is limited. Coastal systems often behave in non-linear ways of which we have inadequate understanding. Research must therefore consider both causal chains and complex networks. Holistic research is required from an interdisciplinary scientific community (Salomons et al., 1999), including sociology, human geography and anthropology, complemented by policy sciences.

Science Gaps

Research must consider non-linearities and uncertainties, and how they affect the vulnerability of coastal ecosystems and society to global change. Analyses should consider how different coastal changes – natural and anthropogenic – affect our perception of risk, uncertainty and predictability, and should consider societal responses to such changes in different cultural and historical settings. LOICZ will therefore embrace socio-economics, not only in its conceptual work on co-evolution from an ecological economics perspective, but also in its place-based analyses of vulnerable coastal communities and their responses to hazards.

Current science gaps are encapsulated in the following questions:

- what changes are occurring in coastal habitats?
- what environmental risks are arising from socio-economic and natural change?
- what is the intensity, frequency and predictability of climatic and human forcing; and what are the consequent risks to society from flooding and loss of ecosystem services?
- what are the time lags between local changes and regional impacts (for example, land management changes altering catchment delivery)?

- what are the important biogeochemical or socio-economic state-transition thresholds in coastal systems?
- what are the probabilities of crossing these thresholds under different scenarios?
- can we identify and aggregate related ecological and institutional scales?
- what are the political, economic, cultural and social incentives for stakeholder involvement and participation? and
- what are the risks to natural and human capital, especially in relation to management and policy options?

Theme Goals

Theme 1 has the following two foci that consider the external and internal factors (and their dynamics) that determine coastal risk and vulnerability:

I. Research on environmental and social vulnerability, including environmental (e.g. climate change and sea-level rise) and human-induced hazards, and risks to natural and human capital and welfare in relation to response options.

II. A review of the effect of global trends at the regional scale, including community perceptions and responses to environmental change. This internal response, while a component of vulnerability, would not be captured by a risk assessment.

Promising Scientific Approaches and Implementation Strategy

Multidisciplinary determination of system thresholds and the probabilities of crossing these can be tackled using three approaches described in the sections below.

Conceptual Classification of Coastal Vulnerability

Biophysical and anthropogenic threats to the coastal zone will be analysed at continental, regional and sub-regional scales. This will involve the development of regional-scale indicators for use in early-warning systems, and for identifying 'hot spots' of change. Risk distribution will be assessed by considering the multiple spatial and temporal scales of vulnerability and impact changes. Habitat carrying capacities, adaptive capacities and critical thresholds will be considered in the context of changes in frequency and magnitude of extreme and hazardous events. Lesser pressures and economic drivers will also be considered, including land use change, agricultural practices and demography.

An ecological economics study of the co-evolution of environmental and social systems, will seek a connection between state changes and social system vulnerability. This is a major component of an integrated assessment approach to link observed or projected state changes to impacts, and to value these impacts.

Integrated Modelling of Biophysical Processes and Socio-economic/Anthropogenic Influences in the Water Continuum

A multi-agent system model will be developed that supports both top-down integrated assessment modelling, and bottom-up integrated modelling of the water continuum. Agent-based models can assist in communicating scientific results to stakeholders. This work will contribute to the further development of LOICZView and its successors (palantir.swarthmore.edu/loicz). A multi-scale approach will be adopted, considering the range of different environmental and anthropogenic drivers that operate from the local up to the global scale. An example is the issue of coastal freshwater availability, where land use, demographics, ocean cycling and climate change must all be considered. This approach will help elucidate the distribution, dynamics and uncertainty of risks to coastal goods and services at global, regional and local scales.

Initially, LOICZ will undertake a global assessment of the principal causes of changes such as sea-level rise and altered marine hydrology. Following this assessment, a development of a regional-scale typology may be appropriate, with particular attention paid to:

- climate change and its effects on ice cover in the **polar regions**;
- eutrophication in **temperate regions**; and
- erosion and sediment delivery to the coast in **tropical regions**.

Identification of Management Strategies

Identification of management strategies will be a cross-cutting activity with Theme 5, based on (i) an integra-

tive analysis of regional and sub-regional vulnerability and risks, and (ii) identification of region-specific strategies for adaptive management or mitigation. Efficient and effective strategies for coping and adaptation that are identified, will be presented to regional science-policy fora. This will provide a useful basis for regional collaborations, multi-lateral agreements on coastal zone governance and management, and the development of regional early-warning systems.

Linkages with Other Projects

Close links with the IDGEC, GECHS and Urbanisation projects of IHDP are envisioned, as are links to the AIMES and PAGES projects of IGBP. Links with PAGES will help consider the long-term fluctuations and cyclical events that provide the baseline for ecosystem function and define natural variability. Collaboration with project in the ESSP and beyond, are also vital.

LOICZ will draw upon information generated in other programmes such as IHP, MAB, GMA and MEA. LOICZ will contribute indicator systems to the monitoring work of Coastal GOOS, the IGOS Geohazards Theme, ICAM, GPA, the EU Water Framework Directive and its Integrated Coastal Zone Management and Marine strategies.

Products and Benefits

Products will include (i) change and response scenarios, from which dynamically analysed risk elements and derived system vulnerability information will direct related research; (ii) vulnerability maps; and (iii) conceptual diagrams of the world's coastlines identifying key features, threats/vulnerabilities and management strategies.

Theme 2: Implications of Global Change for Coastal Ecosystems and Sustainable Development

Introduction and Rationale

The changing nature of coasts is the result of global and regional drivers and pressures, operating at different spatial and temporal scales. Coastal zone development and other anthropogenic changes alter material fluxes, with consequences for coastal ecosystem structure and functioning (Salomons, 2004), including modification, or even total loss, of particular habitats (Reaka-Kudla, 2001; Furnas, 2003). As species diversity is not linearly related to habitat extent, habitat loss can have a disproportionately large impact on species diversity.

Of the global coastal population, 71% live near estuaries, 45% near mangrove swamps and 31% near reefs. Thus coastal communities are concentrated in the most productive coastal regions. These regions are also the most critical ecologically, and the most vulnerable. MEA has noted the limited extent of coastal land, the development pressures and the extreme competition for space, and it is therefore important to quantify the pressures on, and ensuing changes to, the coastal zone.

Theme 2 will focus on the increasingly complex spatial, temporal and organisational aspects of coastal zone change, and how these influence natural resource availability and natural systems sustainability. The two specific foci are:

I. Assessment of global, regional and local changes, and the implications and feedbacks to local-scale ecosystem function and process. Examples include changing mangrove and salt marsh dynamics, and changes to deltaic coasts due to mangrove clearing, coastal erosion, sand mining, dredging and land reclamation.

II. Quantification of human impacts on coastal resource sustainability. Including for example, quantification of the impacts of coastal urbanisation, in collaboration with the IHDP Urbanisation project.

The principal rationale of Theme 2 is that development and change in the coastal zone affects the interactions and processes that determine the nature of the land–ocean boundary, and the functionality of coastal systems that may be critical at regional and/or sub-regional level.

State of the Science

The relationship between local human uses/pressures and coastal functionality was investigated during the first decade of LOICZ in the following four major ways:

I. Development of a simple, robust method for coastal nutrient budgeting (Gordon et al., 1996), that has been applied to over 200 estuaries (data.ecology.su.se/MNODE). The method uses a box-model of freshwater and salt balances and dissolved inorganic nitrogen and phosphorus (DIN, DIP) concentrations to compute internal source/sink rates and fluxes. Tools were also developed for estimating model inputs for coastal systems with few or no relevant direct measurements; for example, estimates of DIN and DIP for specific sources such as household sewage, cattle farming and aquaculture (Talaue-McManus et al., 2001). Use of these estimates in the box-model demonstrated the impacts of coastal activities on coastal biogeochemical cycles and production.

II. Compilation of global datasets on coastal waters and their catchments, and transformation into web-based forms (Maxwell and Buddemeier, 2002; hercules.kgs.ku.edu/hexacoral/envirodata/hex_modfilt_firststep3dev1.cfm). These datasets were to investigate relationships between individual or combined coastal/catchment variables and nutrient fluxes, to identify proxies for use in up-scaling the 200 budgets to a global estimate. Key findings were that terrestrial nutrient loads are strongly influenced by specific discharge and population density, and that global DIN and DIP exports from human activities have tripled since the 1970s (Smith et al., 2003).

III. The DPSIR concept of the OECD (Salomons et al., 1999) was modified as a framework for integration of human and natural dimensions and resources assessments. It was subsequently applied to determine the effects of human activities on material fluxes and other catchment changes that affect coastal seas. Applications ranged from catchment to continental scale, and included future scenario development (coast.gkss.de/loiczbasins) (Ledoux et al., 2004).

IV. A sediment discharge inventory and dataset (GLORI) was established. Analysis of the dataset revealed the significance of human intervention in modifying coastal sediment transport, as a result of altered sediment dynamics caused by catchment activities around the world (Syvitski, 2003).

Other notable studies relevant to Theme 2 are:

- implementation of a standard method for global assessment of vulnerability to sea-level change (www.survas.mdx.ac.uk);
- assessment of anthropogenic modification of coastal land (<100 km from the coast), revealing that as much as 20% is highly altered for urban (including mega-cities) or agricultural use (Klein et al., 2002);
- the ELOISE cluster conducted over 60 studies since 1996 (www2.nilu.no/eloise/index.cfm), many of them relating nutrient fluxes to land-based activities and atmospheric and river processes, and determining the effects of altered nutrient discharges;
- USGS studied coastal change and coastal conflict in continental US, specifically addressing system-wide responses to sediment starvation, pollution, coastal degradation and water-level change (pubs.usgs.gov/circ/c1075); and
- within the MEA, 400 natural and social scientists from 66 countries, assessed the current and future capacity of ecosystems to provide services to humankind, and assessed human responses to ecosystem change (www.millennium assessment.org/en/index.aspx).

In summary, both at the global scale and at specific localities there is information concerning how specific pressures affect explicit coastal dynamics. It is recognised that habitat is being lost as a result of human activities that modify biogeochemical fluxes into, and within, the coastal zone, with a tight feedback to human welfare and coastal functionality.

Science Gaps

Science gaps for this theme are primarily related to determining and quantifying the significance of, and relationship between, different human activities and coastal impacts. LOICZ has demonstrated that DIN and DIP fluxes reflect specific human activities, however, a wider range of human activities needs to be considered, including transport developments and urbanisation (including mega-cities), water transport infrastructure, tourism that affects ecosystem productivity, aquaculture in sensitive tropical ecosystems, exotic species and pathogens introduced by shipping, wind farms, sand mining and artificial islands.

Additionally, analysis of catchment–to–shelf pressures and integrated system-wide responses need to be extended to other coastal areas, and up-scaled for regional and global perspectives. System-wide responses include loss of ecosystem services, increase in material flow (including contaminants), loss of habitats and biodiversity, all of which lead to human vulnerability.

Theme Goals

Theme 2 goals fall into two focus areas:

I. Quantifying local human impact:

- develop methods to characterise the heterogeneity of human activities in the coastal zone, and quantify their effects on coastal ecosystem function;
- assess critical thresholds and identify indicators of coastal systems, in order to evaluate their resilience to change; and
- identify sustainable levels of resource use.

II. Integrating effects of changes on coastal functionality:

- design and evaluate simple monitoring strategies to better distinguish between globally and locally generated pressures;

- characterise and distinguish between systems that are more vulnerable to global/regional pressures than to local pressures; and
- model scenarios of future change to guide policy, mitigation and adaptation.

Promising Scientific Approaches and Implementation Strategy

Theme 2 will employ approaches and tools in the following two major groups:

I. Typology approaches:

- develop a national/regional typology of estuaries based on controlling factors and differing spatial and temporal scales;
- use this typology to guide biogeochemical budgets, leading to:
- improved up-scaling of budgets to the global scale;
- improved understanding of the relationship between biogeochemical fluxes and ecosystem composition and dynamics;
- improved regional networking attracting further regional commitment;
- guidance for future activities, research needs and budget analyses; and
- space-time substitution as a predictive modelling tool.
- incorporate environmental and economic aspects of land loss, degradation and increasingly competitive use of scarce coastal land into typologies.

II. Cross-disciplinary project-based:

- undertake case studies of land and sea use such as reclamation, mining, aquaculture and urban interactions, that place different demands on the filter/buffer capacity (resilience) of estuaries to change, allowing identification of various levels of sustainability;
- consider the full range of urban system scales in determination of resource impacts and the extent of coastal process change;
- evaluate the relative impacts of hard and soft engineered systems, and assess the economic relationships and trade-offs for development options; and
- link economics and anticipated development impacts to potential coastal geomorphic change, using 'weak' and 'strong sustainability' criteria (links to Theme 5).

To accomplish the Theme 2 goals, LOICZ will both undertake new innovative research and value-add by building on useful existing tools and approaches. A value-adding example could be the application of biogeochemical budgeting results to coastal problems, for example, by tying C–N–P budgets to the evaluation of how ecological interactions can constrain or enhance sustainability. This approach will help inject natural science into management, where sustainability is often economically defined.

Linkages with Other Projects

Theme 2 deals with large and complex topics requiring careful targeting of effort, and conceptually integrative approaches in both science and management. Within LOICZ, close integration is envisioned between Theme 2 and Themes 4 and 5.

Expertise from, and collaboration with, GLP, and the GECHS, IT and Urbanisation projects of IHDP, will greatly assist and add value to LOICZ. The development of marine information systems such as Seawatch within Coastal GOOS, SCOR and GMES, may also benefit. Issues relating to fisheries and aquaculture – as a form of land and sea use (in conjunction with Theme 4), will be supported by exchange with GLOBEC, in particular GLOBEC Focus 4.

Products and Benefits

An advanced database, models and scenarios, capable of generating reasoned projections of trends in coastal development and related pollution and resource exploitations (in terms of economic, institutional, political and social forcing), will be developed. This will be based on quantification of coastal human impacts, using natural science methods and ecological economic indicators and valuation methods.

Strong stakeholder involvement is anticipated to support the value of theme outcomes and delivery.

Theme 3: Human Influences on River Basin–Coastal Zone Interactions

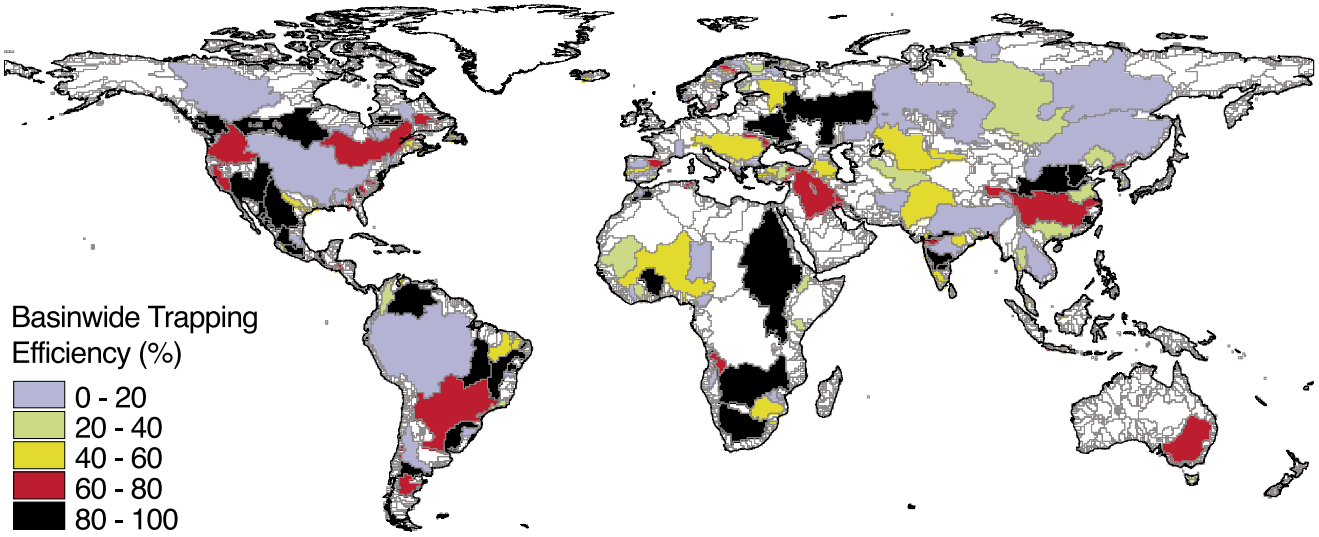
Introduction and Rationale

Even relatively unexploited coasts are impacted by human activities in the hinterland, such that virtually none of the world's coasts can be considered pristine. Catchment activities can increase or decrease the export of materials to the coast, affecting coastal morphology and/or ecosystems. Similarly, all coastal systems and catchments are indirectly affected by anthropogenic global climate and atmospheric change.

The delivery of water and sediment from catchments to the coastal zone depends not only upon natural catchment filters (e.g. wetlands, lakes, floodplains), but also upon structures built for water diversion, flood control, power generation and recreation (Meybeck and Vörösmarty, in press). Reductions in sediment supply due to damming occur world-wide. Conversely, hundreds of years of intensive agriculture and deforestation have increased sediment and nutrient flux to the coast.

In trying to provide management options, science is challenged to consider large regional differences in the definitions of 'natural' and 'acceptable' environmental conditions. These differences have a cultural aspect, affecting societies' perception of the coastal zone and its value. Rather than define standards, LOICZ aims to provide sound scientific information on trajectories of catchment–coast change (including projections into the future), and highlight system switch points for decision and intervention. Improved understanding will be needed of the linkages between sub-catchments and estuaries, and of those catchment areas where intervention would be most beneficial. However, coastal benefits are likely to mean catchment costs, and *vice versa*. Evaluating such trade-offs will require a close engagement between natural and social scientists.

Figure 7. Basin-wide trapping of suspended sediment by large reservoirs (236 regulated basins with 633 large reservoirs – equivalent to about 70% of registered impoundment storage). Basin boundaries at 30' (long x lat) including draining and non-draining areas (Vörösmarty and Sahagian, 2000; Vörösmarty et al., 2000). All numerical calculations represent discharge weighting and corrections for non-draining areas). From Vörösmarty et al. (2003). Reproduced with permission from Elsevier.



The principal rationale of Theme 3 is that catchment–coast interactions reflect a coupled human–natural system. Activities will focus on the magnitude of, and variations in, catchment loads to coastal seas and the atmosphere, and on the implications of these fluxes for resource use and coastal functioning.

State of the Science

Coastal currents and morphology drive coastal material transport, mixing and biogeochemistry. For example, nutrient state (dissolved or particulate) changes with mixing and salinity, and while coarser fluvial sediments settle near river outlets, finer sediments are transported by coastal currents. Nutrients are used and recycled at different rates depending on concentrations, delivery ratios, nutrient form, season, phytoplankton community and biological and physical controls on primary production (Smith et al., 2003).

Rivers dominate sediment delivery to the coastal zone (95%) (Syvitski et al., 2005). Initial global estimates of the sediment delivery to the coastal zone were based on the extrapolation of measurements from a few large rivers. For example, using a data set of 280 rivers Milliman and Syvitski (1992) estimated global sediment delivery to be to 18 Gt yr^{-1}. More recent studies put the estimate at about 22 Gt yr^{-1} (e.g. Syvitski et al., 2003). Sediment delivery has been affected in recent decades by widespread construction of reservoirs; continuing construction will increase this effect (Vörösmarty et al., 2003).

Rivers are also crucial for nutrient delivery, and catchment modifications can cause either substantial increases or reductions in transport. In the Mississippi catchment and in the sub-basins draining to the North Atlantic (especially the Baltic catchments), anthropogenic riverine nitrogen loads far exceed atmospheric inputs, coastal point sources and nitrogen fixation (Howarth et al., 1996; Grimvall and Stålnacke, 2001). Phosphorus loads to the coast are also dominated by river loads (Bennett et al., 2001; Grimvall and Stålnacke, 2001). However, from local to global scales, one of the most rapidly increasing sources of nitrogen to freshwaters and the coastal zone is the atmosphere. As much as 40% of the nitrogen input to coastal catchments comes from the atmosphere, originating from agricultural, industrial and urban sources (Duce, 1986). The atmosphere also contributes from 10% to over 40% of the 'new' nitrogen loading to many estuaries (Paerl et al., 2001), especially those associated with smaller rivers. Groundwater and offshore nutrient supplies may supplement catchment and atmospheric loads, but are poorly quantified.

Reservoirs and irrigation channels can retain a large proportion of fluvial sediment discharge (Farnsworth and Milliman, 2003). According to Vörösmartry et al. (1997, 2003), large reservoirs globally store about 5,000 km^3 of water. Globally, large reservoirs intercept more than 40% of global freshwater discharge, and trap as much as 25% of the current sediment load from the land to the coastal zones (Figure 7). Reservoirs also retain sediment-adsorbed nutrients and lengthen water residence times, creating conditions more favourable to phytoplankton growth and biomass accumulation, thus changing biogeochemical cycling of nutrients within the catchment and thus their delivery to the coastal zone.

Changes in coastal morphology are amongst the most visible impacts of sediment delivery (Chen et al., 2004; Thanh et al., 2004). Bed load is normally no more than 10% of the total sediment delivery, hence it has been assumed that a load decrease of around 5% is a threshold beyond which significant coastal deterioration is likely (Lacerda et al. 2002).

Sediment load reduction due to upstream dams, increases coastal erosion which degrades coastal marine ecosystems (Syvitski, 2003). There are many dramatic examples of catchment disturbance and river engineering affecting coastal systems. For example, from the 1950s to the 1960s sediment export from the Yangtze (Changjiang) River increased by 10%, largely due to deforestation and cultivation of hillslopes. From the 1960s to the 1990s sediment export decreased by 34%, because of the construction of the Three Gorges Dam. Sediment load reductions have slowed accretion in the sub-aqueous delta, and led to erosion of the outer delta front (Yang et al. 2002). A second example is the Aswan Dam that was completed in 1964, causing a 95% reduction in the productive fishery, and subsidence of the Nile Delta. The fishery began a dramatic recovery during the 1980s, coincident with increasing fertiliser use and thus nutrient delivery, expanded agricultural drainage, and increasing human population and sewerage (see Nixon, 2003). A third example is the Colorado River, where reductions in sediment and nutrient delivery following dam construction, led to collapse of the shrimp catch in Baja California.

A recent global study of annual river sediment loads shows many examples of non-stationary behaviour (Walling and Fang, 2003). Compared to the past five decades, both river discharge and sediment load will probably decrease 30–40% for some large fluvial systems in the next 50 years (Vörösmartry and Meybeck, 2000), decreasing to 50% in 100 years due to human activities including dam construction (Yang et al., 2000, 2002). Coastal zone erosion, including estuaries, deltas, and associated beach systems, is probably inevitable.

Eutrophication is becoming a major, global environmental problem in estuarine and coastal waters, driven by agricultural expansion in major river basins and population growth focussed in coastal regions (Rabalais, 2004). Humans have altered the global nutrient cycles, including increasing the mobility and availability of nutrients to marine ecosystems (Bennett et al. 2001; Green et al., 2004; Smith et al., 2003). Many estuarine and coastal ecosystems are limited by phosphorus, nitrogen or silicon, singly or in combination at various times (e.g. Conley, 2000; Elmgren, 2001; Yin et al., 2001; Rabalais et al., 2002). Understanding these distinctions in coastal systems is important for effective nutrient management. Globally, coastal eutrophication is likely to expand given the projections of nutrient loads for both developed and developing countries (Seitzinger et al., 2002).

Coastal impacts and their causes have often been studied separately, by different research communities. The challenge is to combine natural and social science expertise in integrated studies of the catchment–coastal system, especially in the fields of integrated assessment, transition management, valuation, cost–benefit and multi-criteria analysis, mediation, and policy and conflict resolution. This will enable one to recognise that part of the solution for science-informed management of the coastal zone will lie in activities and interventions within river basins. A comparable challenge is disentangling the cause–effect relationships of those impacts and human activities which are strictly coast or river basin-oriented (regional), from those derived from much wider external pressures on the river–coast system, such as climate change, population pressure and the global economy.

LOICZ research has shown that (i) the river basin and its coastal zone should be viewed as a single system, both for riverine material transfer and fate, and for resource management; (ii) coastal zone issues are dependent on regional-local factors as well as on global climate change and sea-level rise; (iii) human activities can either increase or decrease riverine loads, with either beneficial or detrimental coastal effects; and (iv) the land–ocean interface is highly dynamic at monthly–millennial time scales, and occasionally experiences major restructuring events, hence time scales of river change may differ from those of coastal change and those of human impact and management response.

Science Gaps

LOICZ has taken initial steps to determine coastal cause-effect relationships in South America, the Caribbean, Oceania, the Russian Arctic, Africa, East Asia and Europe. The DPSIR approach has been adapted in this work, and a standardised framework has been used for evaluation and up-scaling. In data-rich areas this has delivered qualitative expert typologies, supported by quantitative data on material flows, pollutants and thresholds. However, full quantification, prediction and risk/vulnerability analysis at the basin-scale remain a major challenge for LOICZ.

Although river discharge data provide an indication of global river inputs to estuaries or direct to oceans, relatively few studies have investigated how estuaries transform riverine materials and thus modify delivery to the ocean. More accurate sediment budgets along the full water continuum – basins to coastal zones are required.

Post-industrial increases in nutrient inputs and their coastal impacts are increasingly well understood for coastal seas downstream of intensive agriculture and industrialised economies, as in the case of the coastal seas of Western Europe and North America (Green et al., 2004). Some contaminant impacts are also well understood. However, there remain major gaps in understanding the implications of hydrology and land use induced changes at different temporal and spatial scales (Behrendt et al., 2002). There is a need to quantify and link the effects of basin land use change, to the resulting coastal material flux changes, in order to identify condition and change indicators for pressures and systems, in particular early-warning indicators. A major need is to develop models which help estimate that proportion of catchment fluxes which is natural, and that proportion induced by human activity (Syvitski, 2003).

Globally, river flows have been well documented. There is a need to similarly document the riverine delivery of sediment, carbon, nutrients and contaminants. Globally, this information is only collected for selected rivers, and is archived by the GEMS Water Programme. Currently,

there are 1–2 orders of magnitude less water quality data in the GEMS Water Programme database than there are river flow data in the GRDC database. The extent of river flow and water quality gauging is reducing worldwide, while at the same time, irrigation on river deltas is increasing, and actual river flows to the ocean are unknown for most rivers in sub-arid and dry regions. Continued effort to populate, maintain and update these important databases is required.

Theme Goals

LOICZ seeks to combine natural and social sciences to study the full water continuum, considering global perspectives of water, nutrient and sediment loads, and the impacts of damming and reservoirs on natural and human systems. This theme has five goals:

I. to identify hot spots where the rate of coastal change exceeds the capacity of the natural and/or social system to accommodate or adapt;

II. to disentangle river basin impacts on the coastal zone from local coastal changes that jointly determine coastal evolution;

III. to develop scenarios to assess possible future influences of rivers on coasts;

IV. to identify conflicts of interest between coastal communities and catchment communities; and

V. to conduct integrated assessments of river basin–coastal systems to ensure that science informs integrated river basin and coastal management.

Promising Scientific Approaches and Implementation Strategy

Linking coastal sediment and nutrient budgets to catchment sediment and nutrient budgets will link data from upstream gauging stations and the coastal ocean, taking into account estuarine processes. LOICZ will refine and continue to apply the 'Basins' approach and scale, but with clear identification and involvement of stakeholders based on redefined coastal regions, that better reflect basin–coast linkages. The status of drivers and state changes that threaten humans and the environment will be described in more detail, by assembling relevant databases and applying advanced typologies to up-scale and expand the assessment of runoff–coast habitat interactions (McLaughlin et al., 2003).

Future work will build on, and extend, the assessment framework for links between major human and natural pressures on the coastal zone, and for long-term riverine ecosystem changes. A focus will be given to model development, testing, improvement and application. In parallel, without constraining dissemination of results, analyses will be conducted, including assessment of water residence effects on sub-catchment scales, and clustering information in functional and management units.

High priority will be given to exploring alternative modelling approaches for coupled human–natural catchment systems. To this end, activities have been identified, and grouped into two broad foci: (i) global and representative, and (ii) benchmark catchment–coast continua.

Global and Representative

Global activities will extend the coastal typology to include river environments (including their biophysical and socio-economic aspects). Specific activities will be:

- development of regional riverine flux trajectories, considering natural and human drivers, and the syndromes of global river change such as damming, regulation, pollution and eutrophication;
- development of a network of palaeo-records of riverine loads from deltaic and riverine cores, from the major natural and socio-economic regions of the world;
- development of global river data archives (time series as well as averages) for use in model validation across the full range of river–coast interfaces;
- participation in the global modelling of river export under natural and altered conditions, particularly with respect to sediment, water and associated materials; and
- participation in development of a global database on occupation, institutions and uses of the water continuum (e.g. transport, alien and migratory species).

Benchmark Catchment–Coast Continua

Activities undertaken on specific systems can be separated into those involving natural scientists, those involving social scientists, and those involving natural and social scientists.

Natural science activities will focus on catchment–coast causalities using historical and environmental records, from the short (30–50 years), to the medium (50–500 years) to the long term (500–18,000 years).

Social science activities will focus on stakeholders and governance. In the first activity, catchment stakeholders will be identified and their awareness regarding their role in coastal change will be assessed. Catchment stakeholders will be linked to coastal stakeholders, to identify the gains and losses (benefits and costs) occurring in the catchment–coast continuum under alternative policies. The second activity will identify a set of relevant indicators to assess the effectiveness of existing river basin management with regard to coastal issues, and the institutional mechanisms needed to implement relevant policy. This aims to bridge the traditional disjuncture between causative activities of stakeholders upstream, with the environmental and socio-economic consequences to stakeholders downstream, through scientifically informed consensus building focused on integrated and sustainable scenarios.

Activities involving both natural and social sciences, will test a range of spatially-nested catchment scenarios (from climate and global change, economic growth, globalisation, demography, to local development or sea-level rise) for selected coastal issues. Integrated assessments will be conducted with the aim of identifying management actions which are robust in the face of uncertain knowledge about system performance and about future trends in system drivers.

In appreciation of the complex regional differences in environmental, socio-cultural and resource use settings, LOICZ will consider application of the 'benchmark basins' approach adopted by the International Water Management Institute (IWMI). This however, will need to be expanded by adding coastal and shelf-scales to achieve full water continuum coverage.

'Type-class' or 'archetype' systems in different regions need to be identified based on regional characteristics (environmental, economic and political) and Earth System and stakeholder- relevance. The criteria for identifying catchment archetypes should be defined to cover the LOICZ research issues and concerns. This includes a focus on priority research issues pertinent to the identified 'typical basins', with extension into adjoining coastal regions. Active participation by, and consultation with, basin stakeholders will be used to set priorities. Science-based policies on land, water and coastal resources will be promoted through regular science-policy dialogues, involving the research community, policy-makers and planners. This approach will promote effective and efficient governance of natural resources, which will ensure sustainable development and management. It should provide information on critical threshold/loads for combined environmental and social system functions, which could be used in a typology. Riverine fluxes will be comprehensively evaluated along the water continuum in economic and socio-economic terms, to demonstrate effects on goods and services and stakeholder activities.

Criteria for basin selection will include the presence of an active research group(s) from either the national research system or from international/regional research institutions. LOICZ will seek to support research leadership and co-ordination of all related activities for selected basins, including dissemination of information to stakeholders. Examples of this type of trans-boundary system research under the wider LOICZ umbrella can be found in EuroCat (www.cs.iia.cnr.it/EUROCAT/project.htm), daNUbs (danubs.tuwien.ac.at) and Catchment2Coast (www.catchment2coast.org).

Linkages with Other Projects

Activities within this theme will collaborate with GWSP and GLP to identify and quantify the impacts of river diversions and land use changes on coastal processes.

An expected output is mapping of sensitive areas. Here, improved science–policy transfer that relies on strengthened links to intergovernmental networks and global change organisations (IAI, APN and EU-based mechanisms) is recommended. The EU Water Framework Directive is a potential template for a 'Basins' science/management platform, as it is comprehensible to both scientists and managers, clearly articulates the science necessary for basin-scale management, and endorses stakeholder involvement and decision making. However, it relies largely on unhampered access to, and use of, existing data, limiting its applicability to data-poor regions.

Value-adding scientific links are also envisioned with catchment-related initiatives, and their science and user frameworks, including those of ICARM, GPA, HELP, FRIEND, WWAP and MEA.

Extended networking will be explored through institutions working in 'benchmark' or comparable basin-scale approaches in order to complement other research programmes. For instance, LOICZ will link with IWMI and the Consultative Group for International Agricultural Research (in particular the Challenge Program on Water and Food), which have adopted this approach. For work on the coastal areas adjoining benchmark basins, LOICZ will explore collaboration with the ICLARM or the World Fish Centre. This could assist collaborative efforts with GLOBEC and GECAFS.

Products and Benefits

Expected products include basin-specific databases encompassing quantitative information on riverine material fluxes, their drivers and effects, including critical loads and thresholds, and in particular, land use and institutional dimensions. Products will be tailored to assist basin-scale resource management, with a focus on sustainable coastal development. For example, information on global river damming may be used to establish maps delineating sediment sources and/or sensitivity to disturbance. Further, delineating the current regional-scale nutrient fluxes will guide management-scenario development in the global change content. This should improve the understanding of human impacts on coastal systems. Regular science–policy dialogues involving Themes 1, 3 and 5 should lead to an effective method for, and a continuous process of, stakeholder participation. This should be underpinned by development of a capacity building framework to help local institutions effectively manage water continuum resources. Local stakeholder capacity building should also include formulation and rationalisation of development scenarios, considering trends in related events and processes, as well as stakeholder priorities and concerns.

Baseline identification on regional and larger scales will rely on a further developed 'typology, database and clustering approach'. This can be used to identify the systems suitable for up-scaling, and provide the platform for doing so.

Theme 4: Biogeochemical Cycles in Coastal and Shelf Waters

Introduction and Rationale

The continental shelf is a continuum of terrestrial influence, interaction between land and ocean processes and change. The changes and variability of material loads in time and space, especially from land and the atmosphere, affect the physical condition and functioning of coastal seas. One of the distinguishing characteristics of the coastal zone is the importance of benthic–pelagic coupling – pelagic/planktonic ecosystems interacting directly with benthic ecosystems as tightly coupled parts of one biogeochemical cycle. The benthic (sediment-water) interface of coastal seas and shelf waters, plays a major role in the responses to anthropogenic pressures and global change. Both bed and suspended sediments are important as substrate, as transport mediators for adsorbed and attached material, and as key determinants of water column and benthic environments. Knowledge of transformation on the continental shelf across the continental margin (Atkinson et al., in press), and the key locations of specific functions, for example, biological pumps for CO_2 (Thomas et al., 2003, Thomas et al., 2004), is still limited. This, and similar information, is vital to understanding the resilience of coastal ecosystems, and for predicting changes in ocean chemical cycles.

The continental shelf includes the shallow marginal ocean regions abutting the land to about 200 m depth adjacent to the continental slope, and comprises a mixture and gradient of biogeochemical processes and conditions. The inner shelf, bays and estuaries are greatly influenced by fluxes of materials from land, rivers, and sea–air exchanges. Increased nutrient inputs as well as changes in the ratios of nutrients, combined with changes in suspended sediment loads, have affected ecosystems, and hence the transformations and fluxes of substances before they enter deeper oceanic realms.

Theme 4 will focus on the impacts of, and on, coastal biogeochemical cycles, and their interactions with coastal ecosystems and socio-economic systems, through the following four areas of activity:

I. **Up-scaling.** Anthropogenic effects on coastal zone processes are mostly exerted at local scales, and have important local impacts on biogeochemical cycles, ecosystems and socio-economic systems. LOICZ will work to integrate these local effects, to deduce current and likely future impacts at regional and global scales, including the implications for global biogeochemical cycles and climate systems.

II. **Down-scaling.** Global and regional changes in climate systems, sea-level and biogeochemical cycles, may have profound consequences for local coastal biophysical and socio-economic systems. LOICZ will work with other IGBP and IHDP projects to make more accurate assessments and predictions of these local impacts available to coastal researchers, managers and stakeholders.

III. **Understanding Coastal Biogeochemical Process.** Biogeochemical cycles vary across temporal and spatial scales, in the continuum from the land interface, across estuarine and near-shore coastal waters, and across the continental shelf to the ocean basin. Many of these processes are poorly understood at multiple scales across this continuum.

IV. **Evaluation and Inter-comparison of Methods.** LOICZ will work with the large community of coastal researchers and managers, to encourage and foster discussion and inter-comparison of methods and approaches that address common coastal research and management questions. LOICZ will also encourage the development and adoption of promising methods and approaches.

The principal rationale of Theme 4 is that coastal water processes are driven by land-derived, ocean-derived and atmospheric loads. Load changes have implications for coastal water processes and Earth System function.

State of the Science

The first decade of LOICZ addressed the problem of quantifying and up-scaling coastal biogeochemical fluxes through a three-pronged approach:

I. Establishment of a simple robust method for coastal zone nutrient and carbon budgeting (Gordon et al., 1996). The method assumes a steady-state mass balance, and uses salt and fresh-water balances and nutrient concentrations, to estimate physical exchanges, residence times and exports of DIN and DIP. It computes internal nutrient source/sink rates, and based on stoichiometric assumptions, estimates net carbon production and net nitrogen fixation. The method has the advantage that it requires only limited data, and can be applied, through workshops and web interfaces, to a large and representative suite of coastal water bodies. Budgets have been undertaken for over 200 estuaries, coastal embayments and marginal seas, and most of these have been published on the web (data.ecology.su.se/mnode) along with detailed method descriptions.

II. Assembly of several global coastal datasets relevant to coastal water bodies and their contributing catchments. The fundamental dataset is at 0.5 degree resolution, augmented by catchment datasets at 1 km resolution, and other high-resolution data such as coast outlines (hercules.kgs.ku.edu/hexacoral/envirodata/hex_modfilt_firststep3dev1.cfm).

III. Development of a suite of powerful statistical techniques for use with the global datasets to up-scale local budgets to global estimates (Maxwell and Buddemeier, 2002; palantir.swarthmore.edu/loicz/). These use regression to link budget variables to surrogates in the global dataset, and a clustering routine to classify regression outputs. Fluxes for each cluster are estimated and aggregated for global coverage. This approach has required an extensive analysis of various surrogate variables as explanatory and predictive factors for coastal biogeochemistry, and analysis of the effects of scale in both budgets and surrogates.

Some of the key findings from this work are:

- Strong relationships exist between catchment variables (especially specific discharge and population density) and terrestrial DIP and DIN loads (e.g. Smith et al., 2003). These relationships have been used to estimate global DIN and DIP loads to the ocean, and load changes due to population increase. Global DIN and DIP delivery is estimated to have tripled between the 1970s and 1990s because of human activity. These findings extend, and are consistent with earlier estimates (e.g. Meybeck, 1982).

- The intensity of biogeochemical transformations is much higher in small coastal systems compared with large shelf seas. This is partly because processing of terrestrial inputs tends to occur close to the input sites. Smaller inshore sites are both more exposed, and more responsive, to anthropogenic perturbation, and more important in terms of human resource use and ecosystem services.

- Higher resolution global datasets are needed to develop better predictive relationships for coastal biogeochemical function.

Smith and Hollibaugh (1993) computed global ocean carbon budgets, and concluded that both the open ocean and the coastal zone are slightly heterotrophic. LOICZ has estimated an increase in global terrestrial DIN load to the coastal ocean of 1.35 Tmol yr^{-1} (Smith et al., 2003), but has not estimated changes in particulate organic carbon (POC) and particulate nitrogen loads. These are especially difficult to quantify, and globally may have either increased (through land clearing) or decreased (due to damming).

The Joint LOICZ–JGOFS Continental Margins Task Team study of the role of the continental margins in global ocean biogeochemical cycles (Atkinson et al., in press), also classified continental margins and used well-studied systems as a basis for extrapolation. In their initial synthesis, they concluded that the continental margins are net autotrophic, with net organic carbon production of about 75 Tmol yr^{-1}, primarily supported by DIN and DIP from the ocean interior, and much of it exported to the ocean as POC and dissolved organic carbon. LOICZ and the Joint Task Team recognised a high level of uncertainty in global budgets, and a need for quantitative error estimates in future syntheses. Part of the apparent discrepancy in conclusions about the net heterotrophic/ autotrophic status of the coastal zone, arises from differences in boundary definitions.

The Joint Task Team included upwelling areas offshore of the shelf in continental margins, whereas LOICZ did not. The LOICZ and Joint Task Team conclusions are consistent in that the fate and impact of terrestrial loads appear to be primarily associated with the inner continental shelf, whereas ocean exchanges dominate biogeochemical cycles across the outer shelf, with relative influence varying by ocean region (Thomas et al., 2004). This suggests that rather than focus solely on box model coastal zone budgets, LOICZ should, in partnership with IMBER and other IGBP and non-IGBP projects, focus on the processes controlling the fate and impact of riverine inputs, their interactions across continental shelves, and ocean–shelf coupling. Determining the contribution of these coastal zone processes and fluxes to the global carbon cycle and climate change feedbacks is not straightforward, and requires further analyses. Brunskill (2004) underlines such analyses call for improved links between site-specific models across many projects, which would provide insight into complex shelf processes.

From the point of view of coastal ecosystems and the associated resources and services upon which humans rely, net primary production and trophic status are important drivers. Most significantly:

- changes in terrestrial inputs are having significant local and regional-scale impacts on coastal biogeochemical cycles and production, particularly inshore;
- in some regions, and probably globally, primary production on shelves may be driven primarily by ocean exchanges of nutrients. For these regions and scales, changes in ocean inputs because of changes in basin-scale ocean circulation and biogeochemical cycles, may hold the greatest potential impact; and
- where both terrestrial and ocean inputs are historically low, and coastal ecosystems are strongly adapted to the resulting oligotrophic conditions, increasing terrestrial inputs may have very damaging shelf-scale ecological impacts, as evident for coral reefs.

During the first decade of LOICZ there was a rapid growth in local and regional studies in various parts of the world directed at understanding, assessing, predicting and managing the response of estuarine and shelf systems to anthropogenic pressures. These studies have varied greatly in the methods adopted, the sophistication of the field instruments and measurements used and the diagnostic and prognostic models which have been developed and applied. There have been a number of exciting developments in methods and modelling, including:

- new remote sensing and *in situ* measurement technologies that offer vastly improved temporal and spatial resolution and coverage, and the potential to address seemingly insuperable problems of variability and scale;
- new methods (e.g. isotopes, biomarkers, genetics) that offer the ability to directly observe, or trace, key biogeochemical processes, and the ecological functional groups responsible;
- advances in computing power, process understanding and modelling that are producing an ability to diagnose, interpolate and predict physical and biogeochemical variables and fluxes in a dynamic, three-dimensional framework;
- sophisticated sediment transport models that now combine forcing functions (winds/waves, currents, river discharge) and ocean–atmosphere physics, allowing predictions seafloor sediment movement. These models can predict seafloor sediment erosion and accumulation, changes in seafloor material properties and water column turbidity, but are not well-coupled to biogeochemical or ecosystem models; and
- increasingly mature models that are capable of predicting coastal morphologic change. These models are used to determine changes in boundary conditions (storminess, current regime, sediment flux, sea level, and long-shore transport) that will eventually lead to landscape and seascape change. Again however, the physical models are not yet coupled to ecosystem or socio-economic models.

In the next decade, coastal scientists can reasonably expect to have access to accurate, highly resolved hind-casts and now-casts of physical properties of the coastal zone, including temperature, salinity and transport, for many ocean margins. Available models enable down-scaling global climate change predictions to coastal zone scales. It is reasonable to expect that advances in physical coastal ocean forecasting and hind-casting and sediment

modelling will lead rapidly to advances in biogeochemical ocean assessment and forecasting that should prove useful to LOICZ.

Given these advances, LOICZ explicitly aims to go beyond assessments and estimates of current biogeochemical budgets, and develop tools and methods for predicting the response of coastal biogeochemical systems to local and global forcing. However, there are reasons to be more cautious in expecting rapid advances for biogeochemical prediction:

- biogeochemical processes are inherently complex, and any process model is a highly simplified abstract of the real world;
- understanding of some key processes (e.g. denitrification and nitrogen fixation) is still very limited; and
- there is no tradition in biogeochemical modelling of rigorous statistical evaluation – partly because of the inherent complexity.

Science Gaps

A key weakness in our knowledge of coastal biogeochemical cycles relates to their inter-dependence with coastal ecosystems. The impacts of severe eutrophication on oligotrophic ecosystems are obvious. However, the dependence of key biogeochemical processes and transformations on benthic and pelagic communities is less clear, and may play a key role in coastal change. Most biogeochemical models implicitly describe a bottom-up driven system, in which nutrient and carbon loads and physical forcing drive changes in productivity, higher trophic levels and trophic interactions. However, arguments have recently been made for large, almost ubiquitous, top-down changes in coastal ecosystems, because of removal of top predators and key herbivores. Climate change is expected to have widespread and major impacts on coastal community structure, composition and function.

As we progress into the Anthropocene, we need reliable assessments of biogeochemical and ecological change at local, regional and global scales, but we also need robust projections and scenarios of future change to guide policy, mitigation and adaptation. The challenge for coastal scientists in general, and for LOICZ in particular, is to find an optimal balance between, and fusion of, the grounded empirical assessment approaches used by LOICZ in its first decade, and the sophisticated technologies and process-based prediction currently under development.

Synthesis of LOICZ science to-date, has identified a number of gaps in the development of coastal biogeochemical budgets, and recommended research initiatives to address these. These limitations apply both to the development of local budgets for coastal water bodies, and to the databases and methods used for up-scaling to global budgets.

Local Biogeochemical Budgets

Identified gaps fall into four main areas:

I. Extension of biogeochemical budgets to include:

- particulate and dissolved organic nitrogen and phosphorus;
- carbon (organic and inorganic, dissolved and particulate) directly rather than implicitly;
- inorganic sediments and other potentially limiting nutrients (e.g. silicate, iron); and
- simple estimates of additional source/sink terms beyond net production and nitrogen fixation–denitrification, such as phosphorus adsorption/desorption and benthic nutrient exchange.

Extending budgets to include particulate tracers is particularly challenging, as particulate tracers are transformed and transported differently from dissolved tracers. Advances in catchment science will help by providing improved knowledge and prediction of catchment loads reaching the coastal zone.

II. It is important to understand the aliasing errors associated with steady-state assumptions and limited spatial and temporal resolution, and develop alternative approaches to address these where needed. This may be particularly important in tropical and sub-tropical estuaries, and for sediments and particulate tracers, where discharge and loads may be concentrated in short events.

III. The current LOICZ budget dataset provides only limited explanation of the controls on coastal sources and sinks of nutrients and

carbon. These can be expected to respond to the composition and temporal pattern of loads, differences in ocean exchange and boundary conditions, and differences in geomorphology and in benthic and pelagic communities. Given the important contribution of smaller systems to these fluxes, and the heterogeneity of these systems, it is important that methods be found to characterise this heterogeneity and its effect on local sources and sinks, in a way that is both quantitative and conducive to up-scaling.

IV. A significant conceptual failing of the original budgeting work was the omission of sufficient information on terrestrial linkages to the coastal systems; in particular, characterisation of the associated drainage basin beyond estimates of runoff and nutrient load. Explicit consideration of the character of the terrestrial side of the coastal zone (e.g. drainage area, population, land uses) at the scale of the coastal system of interest, will considerably simplify future analysis and classification.

Up-scaling

Early LOICZ attempts to up-scale budgets from local to regional and global scales, identified important questions concerning spatial scales; for example:

- at what scale does coastal structure need to be explicitly resolved to explain and predict biogeochemical function, and what can be represented using sub-grid-scale parameterisation?
- what variables are needed in global datasets, and at what resolution, to allow robust and accurate up-scaling to regional and global flux estimates?

To some extent, coastal systems may be better represented as a nested hierarchy of scales (small estuaries, large estuaries and coastal embayments, coastal seas, continental shelves), although some functional types (e.g. major river systems) clearly cut across scales. Up-scaling requires functional as well as statistical typologies, but objective data-based rules need to be established for assigning functional type.

The challenge is to ensure sufficient standardisation of methods to allow comparison and integration of results.

Down-scaling

While the results of LOICZ up-scaling may contribute to IGBP studies of the global carbon cycle, and ultimately, to forecasts of global climate change, LOICZ is not directly concerned with developing climate change models and scenarios. LOICZ should however, take responsibility (along with partners such as IMBER) for addressing the implications of global change forecasts for coastal systems. The science of down-scaling and coastal impacts is just beginning. It is necessary to develop:

- down-scaling tools; both hierarchical nested models and statistical techniques have proved useful in terrestrial applications;
- sufficient understanding of the response of coastal systems to climate and other global drivers to identify key local forcing variables, and to predict or diagnose the response of coastal systems to this forcing; and
- techniques to deal with the interactions between local and down-scaled global anthropogenic pressures.

Understanding Coastal Biogeochemical Processes

Many of the key scientific challenges revolve around the important role of benthic–pelagic coupling in coastal biogeochemical cycles. This includes material flux from the pelagic to the benthic zone, and *vice versa*, the role of sediment dynamics and biogeochemistry, and the role and responses of benthic communities and habitats. While there have been many studies of the biogeochemical fluxes associated with key coastal habitats, such as coral reefs, mangroves and sea grass, it is not always possible to predict changes in these fluxes associated with habitat degradation.

Sediment biogeochemistry continues to be an important research focus, because sediment processes often dominate material fluxes. Knowledge and understanding of key processes is increasing, and there have been significant advances in knowledge for particular systems. However, it has proven difficult to develop robust quantitative predictive relationships across systems. The microbial community plays a critical role in coastal sediment biogeochemistry, but to-date its role has been mostly studied implicitly by measuring the resulting biogeochemical fluxes and transformations. New techniques from molecular biology offer the capability to identify microbial community composition and function, and to better understand its contribution to benthic fluxes and its response to micro-environmental changes within the sediments.

Methods

As discussed above, advances in satellite and airborne remote sensing, automated and robotic *in situ* platforms and new chemical and biological sensors, offer exciting prospects for radical increases in the spatial and temporal coverage, and the nature of concentration and flux measurements. Work in model–data fusion is also expected to yield exciting and rapid advances in the next decade. Advances in both computational power and mathematical and statistical techniques, will allow construction of process models of at least intermediate complexities, and rigorous statistical model–data comparisons and analyses of uncertainty and error-propagation. The challenge for coastal biogeochemistry is to deal with the spatially-intensive computational demands of physical models, and the process complexity characteristic of ecological models.

Aside from offering improved prediction with objective error assessment, these techniques constitute powerful tools for designing more cost-effective observation and monitoring strategies. They allow users to theoretically evaluate the performance of alternative observation strategies, in terms of the resulting error structure in model diagnoses or predictions, and to therefore design strategies which most efficiently sample the complex spatial and temporal features of coastal marine systems.

Theme Goals

Theme 4 has the following goals:

Up-scaling. LOICZ will provide quantitative assessments and predictions of the evolving contributions of coastal biogeochemical fluxes to regional and global Earth System biogeochemical cycles.

Down-scaling. LOICZ will provide access to the tools, datasets and frameworks needed to allow assessment and prediction of the effects of global change on local coastal/shelf biogeochemical cycles, habitats and ecosystems.

Coastal biogeochemical process understanding. LOICZ will focus on key scientific challenges to resolve the important roles of benthic/pelagic coupling, sedimentary processes and microbially mediated biogeochemical cycles.

Methods. LOICZ aims to increase access to, and use of, improved tools and methods for observation, monitoring, analysis and prediction for coastal/shelf biogeochemistry. New observing technologies and sophisticated new modelling and data assimilation techniques, offer potential solutions to problems of resolving and sampling strong spatial and temporal gradients.

Promising Scientific Approaches and Implementation Strategy

Maintaining and Building the Global Network of Coastal Scientists Addressing Coastal Biogeochemistry

One of the notable successes of LOICZ to-date has been the development of a common coastal biogeochemical budgeting method, and its global application through a combination of regional workshops and web-based delivery. This has resulted in the development of a global community of coastal scientists interested in LOICZ science and biogeochemical budgets and processes. There is continuing interest from this community in extending the number of LOICZ coastal case studies.

It is critical that this network, the associated interest and momentum and the information obtained, be continued. LOICZ seeks to support a group of scientists to maintain and build the global database of coastal biogeochemical case studies, and to maintain and extend the LOICZ science community. This will require ongoing support for databases and associated web delivery, and a new series of regional workshops. This is not simply a matter of applying the same methods to additional sites, but requires significant advances in observation and analytical methods. The LOICZ Regional Project Offices should help support this network.

Biogeochemical Exchanges and Processes Across the Coastal–Ocean Interface

This is an area of mutual interest to LOICZ and IMBER, and it is proposed that IMBER and LOICZ jointly sponsor an evaluation of new methods and approaches, and a comparison of regional studies, initially through a joint workshop. This evaluation should lead to recommendations on both observing and modelling strategies, thus contributing to the design of more efficient coastal/ocean observing systems and improved regional analysis and prediction systems. IMBER and LOICZ should work together to promote regional studies using these techniques. IMBER and LOICZ will jointly work with global climate modellers to develop downscaling techniques to address the impacts of global climate change on ocean shelf exchanges and fluxes.

Improved Methods for Biogeochemical Budgets and Predictions for Near-Shore Waters, Estuaries and Coastal Embayments

A number of priorities for extending, or enhancing, the LOICZ biogeochemical modelling and budgeting techniques, include:

- techniques for addressing spatial and temporal variability in concentrations and fluxes;
- techniques for establishing rigorous confidence intervals around flux estimates;
- extensions to include additional tracers and processes; and
- development of prognostic as well as diagnostic models.

There have been substantial advances in the science of observing and modelling estuaries since the LOICZ modelling methodology was established. It is proposed that LOICZ establish a working group to review estuarine budgeting and modelling methods, and develop recommendations for revised methods.

There is now an opportunity for LOICZ to influence monitoring and measurement strategies of the coming decade, by establishing a rigorous conceptual and statistical framework for biogeochemical data analysis and interpretation.

Biogeochemical–Ecological Interactions in Coastal Ecosystems

This is a cross-theme research topic. LOICZ is concerned both with the role of these interactions in mediating 'bottom-up' effects of local and global changes in biogeochemical cycles on ecosystem values and services, and in the potential role of key ecosystem components and processes in 'top-down', or 'feedback', effects on biogeochemical cycling. This is a challenging research area, and it is likely to be pursued, at least initially, through regional process studies. IMBER also has a strong interest in these interactions on continental shelves, and jointly sponsored regional studies should be encouraged.

A number of priorities for the above activities include:

- process studies in coastal domains linked to development of process-based models;
- identification of keystone species and key ecological and biogeochemical processes characteristic at different scales within coastal domains; and
- application of new technologies to identify and quantify the biological mediators (including microbial populations) in coastal biogeochemical cycles.

Coastal Typologies and Global Datasets

This also is a cross-theme activity. Coastal typologies have been used in LOICZ to extrapolate biogeochemical budgets and fluxes from case studies up to regional and global scales. However, they are likely to be applied far more broadly by LOICZ in the future, as a means to extend conclusions about biophysical and socio-economic impacts and responses.

LOICZ needs to acquire and maintain accessible global datasets to apply typologies, as well as to address both up-scaling and down-scaling objectives. There are open questions about which variables need to be included in these datasets and at what scales. Development of typologies, and design and development of the datasets, will need to go forward in concert as core LOICZ activities.

Sediment Dynamics, Fate and Transformation: Local Burial Versus Long-Distance Transport

LOICZ will develop local, regional and global models and analyses of sediment transport and burial, through encouraging local and regional observation and modelling programs. Modelling will be supported through inter-comparison workshops, and by facilitating access to models and model experts. Observations will be supported by recommending sampling designs and process studies, and through linkages with Coastal GOOS.

Use of Global Satellite Data to Support Coastal Monitoring and Prediction

Satellite remote sensing is one of the important approaches for observing and understanding the land-ocean interactions in the context of global change. Satellite remote sensing will also play a key role in coastal monitoring and prediction. It is proposed that LOICZ establish a working group to support and encourage the use of satellite remote sensing for coastal monitoring and prediction, and to maintain links with national and international Earth observation programmes, including IGOS, Coastal GOOS and IOCCG.

Trace Gases in the Coastal Zone

Coastal air–sea flux measurements and evaluation are an activity of mutual interest for LOICZ and SOLAS. Joint actions are described in "Linkages with Other Projects" below.

Groundwater Inputs into the Coastal Zone

Groundwater is an interface for transport of water and materials along the land/coast interface continuum. There are numerous opportunities to interface with Theme 3 and with the members of the former SCOR/LOICZ Working Group (WG) 122 (www.jhu.edu/~scor/wg112front.htm).

Coupled Sediment–Nutrient Dynamics in the Coastal Zone Floodplain

The role of fine-grained particulate materials in nutrient cycling in coastal marine systems and floodplains needs to be understood and quantified on the basis of *in situ* observations, process studies and numerical simulations. This role depends not only on the transport and accumulation of fine-grained sediments (see also *Sediment dynamics: fate and transformation* above), but also exchanges of nutrients between sediments and the water column, as influenced by sediment, biogeochemical and ecological processes. This activity will focus on floodplain, estuarine and continental shelf muds as nutrient sinks/sources. Linkages with PAGES, GCP and SCOR/LOICZ WG122 will be developed.

Assessment and Prediction of Air–Sea CO_2 Exchanges in the Coastal Zone

LOICZ will work with SOLAS to assess, predict and understand CO_2 air–sea exchange fluxes in the coastal zone, and to identify their role in integrative, regional CO_2 (and carbon) budgets comprising the coastal ocean (Thomas et al., 2005), adjacent land, open ocean areas and the atmosphere. The different spatial and temporal scales of these tools will enable CO_2 flux estimates for budgeting purposes (e.g. Thomas et al., 2004), and will improve understanding of these fluxes. Coupled hydrodynamic–ecosystem modelling will help improve the budgeting and understanding of CO_2 air–sea fluxes, and the fluxes within the coastal environment and across its boundaries. Modelling (linked to Themes 2 and 3) will be essential for prediction of future (and past) CO_2 air–sea fluxes, but also for unravelling human impacts on the coastal ecosystem such as eutrophication or climate change. Investigations of CO_2 (and other carbon) fluxes in the coastal zone will link LOICZ closely to IMBER, iLEAPS and the GCP. The core Theme 3 of CARBOOCEAN (an Integrated Project of the EU 6th Framework Program), will serve as a pilot study for Northwest Europe.

Coastal and Estuarine Models and Software: Inter-comparison Workshops and Web Access

There have been many independent attempts to develop models and software to address both scientific and management questions in the coastal zone. Coastal zone managers and field scientists can be faced with a daunting set of alternative model formulations, approaches and applications. There are increasing attempts at national and regional scales to develop frameworks for inter-comparison and even integration of different models through community modelling initiatives. LOICZ will encourage international model evaluation and inter-comparison, through links to national and regional community modelling initiatives, and through facilitating international coastal modelling workshops and experiments.

LOICZ will endeavour to improve access to, and understanding of, model inter-comparisons and models themselves, through developing and maintaining web-based information on coastal models and software.

Linkages with Other Projects

IMBER and GLP projects are expected to be closely linked with LOICZ in this research enterprise, in order to properly establish an interface with the ocean and river catchment boundaries of the continental shelf.

However, while other themes in LOICZ explicitly include socio-economic aspects, Theme 4 is much more focused on the biophysics of the coastal zone, and can be expected to play a key role in up-scaling and down-scaling in an Earth System science context. LOICZ will look primarily to Theme 4 to produce estimates of the contribution of the coastal zone to continental (or ocean basin) and global-scale fluxes of materials (including greenhouse gases) and large-scale biogeochemical cycles. Theme 4 is also likely to serve as the focus for LOICZ considerations of the impacts of large-scale changes in the Earth System at local coastal scales. Theme 4 must look to Theme 3 to provide estimates of the current, past and likely/possible future flows and loads from catchments to estuaries. Theme 4 will interface with

IMBER to address exchanges between shelf and offshore waters, both under existing conditions and under future global change scenarios. Theme 4 will work with SOLAS to address exchanges with the atmosphere over coastal and shelf waters. Where appropriate, collaborative work with SOLAS on gas-flux measurements and their integration into material budgets and biogeochemistry in coastal waters will be carried out.

While Theme 4 needs to quantify fluxes at a range of scales and develop quantitative budgets for sediments, carbon, nutrients, it is not solely about flux estimation and budgets. Theme 4 needs to develop improved understanding of the physical and biogeochemical processes controlling fluxes, and the links and interactions between biogeochemical and ecological processes in estuarine, coastal and shelf systems. This is important because:

- process understanding and modelling can help interpolate amongst observations and develop more accurate or robust flux estimates and budgets;
- process-based models are needed to predict how fluxes and budgets might change under changes in terrestrial, ocean or atmospheric forcing;
- LOICZ needs to address the impact of changes in catchment loads, ocean boundaries and atmospheric forcing on coastal and shelf ecosystems; and
- LOICZ needs to understand the effect of changes in coastal and shelf ecosystems on material sources, sinks and transformations.

Theme 4 must feed into Themes 1 and 5, where spatial and temporal scales of the human dimensions of shelf processes are concerned. There will also be efforts to link to GLOBEC, IDGEC and GECHS.

Products and Benefits

Theme 4 will provide an evaluation of shelf processes and their interaction across the land, ocean and atmosphere boundaries, recognising large and small-scale natural and human forcing. This is expected to result in the development of strategies for monitoring and assessment of the ecological status of coastal waters derived from newly available technological developments including: (i) satellite remote sensing, (ii) automated permanent measuring stations on fixed and moving platforms, (iii) data assimilation techniques, and (iv) integrated modelling. An outcome will be user-friendly, easily accessible databases and protocols for water-quality data coupled to process-based models (ranging from physical to biogeochemical), with the aim of interpolation, data assimilation, budgeting and scenario development. Products will feed into advanced typology development, enabling appropriate up and down-scaling of findings.

Theme 5: Towards Coastal System Sustainability by Managing Land–Ocean Interactions

Introduction and Rationale

An important current challenge for society is the maintenance of the natural systems that provide goods and services in coastal areas. Different human perspectives and values among cultures, societal sectors and interest groups, means sustainable development lacks a uniform definition. It may, however, be undesirable to rely on a single definition (Yin et al., 2000). Considerations of sustainability usually take a long-term (50+ years) and holistic view, in different societal domains (social, ecological and economic) and at different levels (macro, meso, micro) (Rotmans et al., 2001).

The ever growing, and often conflicting, use of coastal and marine resources, calls for an integrated approach to finding a balance between the dynamics of ocean space, and sustainable human use of seas and coastal areas. This includes increasing uncertainty over the scale and nature of climate change, and of the rapidly increasing human impacts on coastal systems. Anthropogenic changes in catchments (including groundwater abstraction) have altered coastal zone sediment loads, leading to increased erosion and subsidence, and/or rapid accretion of shorelines. Increasing sea-level rise will further increase pressure on coastal systems. Extraction of construction materials (sand, gravel, coral) for coastal protection works will increase. With an increasing demand for marine protein, and the over-exploitation of wild fish stocks, fish farming in coastal waters will become widespread. The competition for marine and coastal space will grow rapidly. As a consequence, sensitive coastal ecosystems will be even more affected by future human activity, both directly and indirectly.

Sustainable coastal resource use needs sound information on actual and potential options, including their ecological and monetary evaluation. The limits of marine sustainability call for combining goods and services in the coastal zone, without causing irreversible damage to marine and terrestrial ecosystems. Institutional conditions for resolution of cross-boundary spatial conflicts, including the precautionary principle as a means of coastal zone management, are major issues to be addressed.

The focus on biogeochemical cycles and material fluxes that underpin LOICZ activities describes changes that directly affect the morphology and resources of the coastal zone. These relate to changes in human uses of, and practices in, the coastal zone and contributing catchments. The scientific information generated by LOICZ activities will, therefore, be applicable to sustainable use and conservation of coastal zones. From a policy perspective, scientific knowledge and insights constitute one input to a consultation process with stakeholders. Science-driven policy requires up-front consultations with stakeholders and science users, for the identification of key scientific questions, and the development of new projects and improved approaches. LOICZ will be increasingly responsive to coastal issues, and will contribute to adaptive responses that provide sustainable solutions.

The principal rationale for Theme 5 is that coastal system integrity, resource stability and equitable access are management goals that underpin sustainability.

State of Science

LOICZ research has demonstrated the importance of coastal biogeochemistry to the quality and availability of coastal resources for society. This has included identifying the consequences of natural and anthropogenic changes to natural processes that influence coastal dynamics.

GEC is a major influence on coastal dynamics, and on the ability of coastal systems to support development. A key outcome of the first decade of LOICZ is the recognition that, although major rivers have profound regional influences on coastal and near-shore marine systems, growing development pressures and their coastal effects are felt most acutely at small to medium-catchment scales. Furthermore, LOICZ studies have shown that the cumulative effects of anthropogenic changes in small to medium-scale catchments, may well be greater than those from major rivers. Unfortunately, smaller-

scale systems are less studied than the world's major river systems.

LOICZ research has also demonstrated that investigation of changes to coastal systems should not be confined within human-imposed boundaries. Rather, studies should use catchment boundaries with a catchment–coast continuum perspective. This reinforces emerging concepts of integrated coastal zone management, where the coastal zone is treated as part of a dynamic continuum linking terrestrial and marine components of the global system.

The following four major conclusions can be drawn from the LOICZ research to-date:

I. The coastal realm is the most dynamic part of the global ecosystem, and the realm most subject to global change. Increasing coastal population and associated pressures are driving direct changes in the coastal zone as well as broader Earth System change.

II. Coastal systems help regulate global change. Coastal concentration of population, and poor planning and management of economic activities in coastal areas, has major influences on the health and productivity of all coastal systems. Regionally and locally, there are specific actions that can be taken within the coastal domain to ameliorate human influences on atmospheric, marine and terrestrial systems. However, there are limits to what can be achieved at the global scale solely through adjustments to policy, investment and management of human activities within coastal zones.

III. It is critically important to couple coastal and river basin management. Coastal change cannot be studied, or managed, in isolation from rivers. Anthropogenic impacts on rivers, including material and energy fluxes, have a far greater influence on coasts than is commonly understood. Improved integration of natural and social sciences should help:

- avoid irreversible damage to the dynamic equilibrium of coastal systems that helps regulate global carbon cycles, material fluxes and energy budgets;
- optimise the flow of renewable resources and environmental services that help to sustain human societies;
- meet international standards of environmental conduct, such as marine pollution control and biodiversity conservation; and
- decrease the vulnerability of coastal societies to natural and anthropogenic hazards.

IV. Although large rivers (e.g. the Amazon and the Mississippi) input the majority of the freshwater, energy and materials to coastal and marine environments, small to medium rivers show more immediate changes in hydrology and material fluxes in response to anthropogenic and climatic change. In comparison to large rivers, much less is known about smaller rivers (how they are changing, the response of their receiving coasts and their role in global change).

The continuing challenge for LOICZ is to explore processes and mechanisms to embed scientific knowledge and understanding within the decision-making and policy-framing arena, in a manner that informs and supports sustainable development goals.

Science Gaps

There is mounting concern over coastal zone sustainability and the patterns of coastal ecosystem degradation. It is understood that coastal societies and natural systems are intertwined, both in terms of pressures and resultant states. To better understand these human–natural system interactions, existing tools and approaches need to be better integrated. There are different lexicons used to describe the pressures, changes and states of coastal systems, and comprehensive data and information are limited at all scales – availability and accessibility are two aspects of this problem. Society is demanding improved use and communication of scientific information, for example, in planning, management and policy development. In particular, societal demands for information and knowledge as part of a joint resolution process are increasing, despite the relatively poor history of communication between science and users (Biesecker, 1996; Kremer and Pirrone, 2000). Participatory approaches in programme design, implementation and assessment can assist in improving communication (Crossland, 2000).

Considering the multiplicity of processes, changes and forcings (natural and anthropogenic) across the dynamic and heterogeneous global coastal zone, the following are priorities for future research efforts:

I. **Integrated and multidisciplinary team approaches.** There is an imperative for effective and substantive research collaboration between natural, social and economic disciplines. Global examples exist, and the knowledge benefits from such team interactions are clear. New approaches are needed to assist team actions, such as the DPSIR framework, and the 'wiring diagrams' used in IGBP for the development of cross-cutting projects.

II. **Targeted research.** Thematic and programmatic research approaches, based on 'post-Normal' science (Funtowicz and Ravetz, 1999) will be applied to coastal zone research rather than the traditional, piecemeal approach of task-based, disciplinary or sectoral efforts. Questions of spatial and temporal scales need urgent consideration, along with new tools for assessment and measurement across scales and within socio-economic research. Foci will include understanding: (i) whole ecosystem function and forcing, (ii) vulnerability and risk, (iii) changing pressures, and (iv) feedbacks and integration of forcings. Improved models for top-down and bottom-up approaches are required. Efforts on socio-economic research need to be greatly enhanced.

III. **Synthesis and integration of information.** New data is always welcome, but better use must to be made of existing data, information and knowledge; research funding bodies need to shift policies in this regard. New tools, approaches and efforts, will transform the synthesis of scientific data into information and knowledge, and outcomes will be made accessible to users and the community. Along with further concerted effort to engage with users, science programmes will include a clear strategy for communication and delivery.

IV. **Regionality.** Thematic projects, synthesis and integration, will be directed to regional-scale assessment, so as to more fully understand the global tapestry of the coastal zone. Management options that address the vital trans-boundary and teleconnection elements of the region will be analysed. The application of common methods will increase regional integration of information and options.

V. **Non-linearity of processes (feedbacks and thresholds).** Non-linear relationships of forcing and function are apparent in the coastal zone. New concepts, tools and approaches to encompass such relationships in modelling and prediction, scenario building and vulnerability/risk assessments, will be developed.

VI. **Monitoring and indicators of functions and changes.** Measurement of proxies for processes and variability, and indicators of system function and response, are required to better understand and measure change and the effectiveness of management and policy applications.

Theme Goals

The overarching goal of Theme 5 is to identify and describe probable, sustainable and desirable 'futures' via scenario analysis. A major objective of LOICZ is to deliver science that is useful to coastal management. This will be achieved by developing closer partnerships with end-users in government and the private sector. Key topics under this theme will address sustainability and resource use issues, in an integrative and interdisciplinary fashion. LOICZ's devolved Regional Project Office structure (see Section 5) will provide a platform on which the scientific community can liaise with policy makers and managers (local to multi-national), to develop a dynamic and iterative process of monitoring coastal condition using sustainability metrics and indicators.

Scenarios will be based on provision and application of integrative indicators, allowing the formulation of quality targets (environmental and standard of living) that will feed into target monitoring and analyses. Ultimately, potential management options will be developed and communicated by:

- transforming linked natural, social and economic information into scenarios, and deriving alternative response options that integrate policy/management/investment communities into their assessment and development from the beginning;
- considering multiple temporal and spatial scales and the institutional dimensions relevant for scientific and management aspects of coastal change issues;

- developing advanced DPSIR scenario typologies (based on existing tools and databases that cluster and compare) thus allowing prediction of scenario assessments in data-poor regions; and

- providing understandable regional/local and ecosystem-scale integrated models and scenarios which meet management/policy needs (up/down scaling) and allow identification of potential scenarios.

Development of effective options requires assessment of societal responses to biophysical changes, identified by the environmental analyses of Themes 1–4, irrespective of whether or not they are anthropogenic. This includes capturing the variety of social choices, from large-scale concerted efforts to devise new institutional arrangements, to multiple uncoordinated individual actions.

Promising Scientific Approaches and Implementation Strategy

Integration and interpretation of complex social, economic and natural science information in order to help inform policy and decision making is a major challenge for LOICZ. LOICZ research will build upon advances in coastal typologies for clustering, comparison and up-scaling of information. Research will:

- distinguish between human-induced and natural system variability, relying strongly on information from Themes 1–4;

- identify thresholds of coastal ecosystem change (including societal and environmental pressures and institutional dimensions) in consideration of their adaptive capacity;

- identify and assess cost-effective indicators for monitoring system performance against sustainability criteria;

- develop integrated models for evaluating and optimising use of the coastal zone for food and energy production and coastal protection and transportation, in ways that do not irreversibly change marine ecosystems. This will include evaluation of the patterns and variability in human responses to coastal ecosystem change; and

- identify resource management options to meet social, economic and environmental sustainability objectives.

The examination of management options will encompass the continuum from 'weak' to 'strong' sustainability. Research will be based on interdisciplinary processes for integrating knowledge, in such a way that all relevant aspects of complex ecological and social systems are considered in decision making. Although many analytical and participatory integrated assessment techniques can be applied in sustainable development studies, LOICZ will initially focus on triangular models, for example, SCENE (Rotmans and van Asselt, 1999; van Asselt et al., 2000). Triangular models consider the coastal zone as a complex system consisting of inter-related stocks and flows. Stocks are described quantitatively and qualitatively, indicators are defined, and flows make all exchanges within, and between, stocks explicit.

Flows are either tangible and related to physical or financial flows, or intangible and related to information or knowledge flows. Perspective modelling approaches, such as SCENE, need to consider these flows, in particular the different forms of capital involved. Three forms of capital are distinguished:

- social-cultural capital, which relates to the quality and quantity of the population, or to social and cultural provisions such as demographic structure, knowledge structure and cultural heritage;

- ecological capital, which relates to the quality and quantity of natural stock, for example, minerals, fish, water quality, biodiversity and shipping lanes; and

- economic capital, which relates to the quality and quantity of the economic infrastructure, such as resources and materials, labour structure and transport infrastructure.

The development of policies and supporting management measures to promote sustainable coastal use, which are appropriate to different environmental, economic and social conditions, is a continuing process. Global change, and the corresponding evolution of social and economic priorities, mean that policies and resource management criteria must be adapted to meet changing conditions. This concept of adaptive management will be applied to LOICZ research. The goal is an 'envisioning exercise', assisting definition and communication of sustainable and desirable (quality of life) future states at multiple scales. The major features of this effort will be integration, learning and communication.

To address this theme's questions, LOICZ will engage, by active information exchange, with coastal communities and with local and regional coastal management institutions. The goal for this science–people–management engagement is trust-based learning and cooperation.

Adopting this brokering approach requires that active stakeholder involvement becomes a regular part of project implementation, and of the process of developing future scenarios. LOICZ seeks to develop an effective dialogue with stakeholders, largely by their involvement in integrated assessment and modelling. Hence the traditional focus on the environmental and ecological aspects of coastal issues must be expanded to include:

- consideration of economic, social and anthropologic aspects in scenario generation;
- improved understanding of the major political, management and social choice drivers and agendas;
- identification and application of integrated indicators of socio-economic coastal change that guide monitoring efforts at multiple scales; and
- improved legal/institutional mechanisms to facilitate co-ordination of stakeholder activity and system governance.

Linkages with Other Projects

Links are anticipated primarily with all relevant IHDP projects, but also with existing and proposed programmes, including Coastal GOOS, ICAM, TEMA, the EU Water Framework Directive and its Integrated Coastal Zone Management Strategy, GPA including the ICARM initiative and pilot projects, Regional Seas, and in principle, water-related initiatives such as HELP, WWAP and GWSP. Considerable value-adding is anticipated from operational links with non-government organisations at local, regional and global scales, that engender participatory approaches and scientific translation and dissemination. Crucial partners in the implementation of this theme will be the private sector and coastal communities.

Products and Benefits

LOICZ can assist in the assessment of coastal management options, their effectiveness and their socio-economic cost-benefit relations within a global perspective. This is in contrast to LOICZ's past focus on regional/local scales. Examples of global-scale response include the International Maritime Organisation's ban on tributyltin (a toxin in ship paint that prevents fouling by marine organisms), and deliberations on exotic species introductions in ballast water. The extended focus on competitive resource use along the whole water continuum, and its effects on coastal sustainability, will add considerably to the global relevance of research topics and products.

An important output of Theme 5 will be assembled information relating to scenario-based coastal issues that help develop a global vision and understanding of the global coastal zone situation. Theme 5 will draw upon regional-scale knowledge products generated by Themes 1–4 including:

- vulnerability maps and indicators from land and ocean processes (Theme 1);
- catchment condition assessments and related coastal process impact assessments (Themes 2 and 3); and
- coastal condition assessments (Themes 2 and 4).

These outputs will be used to develop a coastal zone typology indicating critical or conflicting states of resource use, with a view to developing a world coastal zone atlas. Recommendations for restoration and subsequent sustainable resource use will be included. LOICZ will also design natural and social science databases, to facilitate integrated coastal management.

These products will contribute to a framework and infrastructure for science dissemination and communication. This includes extension of research results to diverse stakeholder and end-user communities, and production of communication materials. The involvement of IHDP will be vital for reviewing participatory and communication mechanisms. Outreach and communication products will include synthesis reports, peer-reviewed scientific publications, presentation materials, scientific method tutorials, and web-based and hard copy training materials. Specific products can be tailored in cooperation with stakeholders.

In summary, concrete products will include:

- an overview of critical factors affecting sustainable coastal use;
- world coastal zone atlas illustrating vulnerable areas, sensitive systems, etc;
- integrated information bases of natural and social science factors based on the LOICZ coastal typology; and
- an international Masters programme in Water and Coastal Management based on LOICZ science (approved by the Erasmus Mundus programme and initiated in October 2004).

Integrating Activities

Societies respond to change in order to mitigate or resolve problems, and yet the capacity for scientific information to inform these responses remains limited. There is a lack of tools and understanding that enable clear differentiation and quantification of the anthropogenic drivers and global environmental pressures affecting the coastal zone. LOICZ therefore seeks to:

- describe dynamic interactions;
- determine how changes affect coastal zones and alter their role in global cycles;
- assess how future changes will affect coastal zone use; and
- provide a scientific basis for integrated sustainable coastal management.

In issues of GEC, facts are typically uncertain, values are in dispute, stakes are high and decisions are urgent. LOICZ will therefore promote 'adaptive science', that interacts with, and responds to, coastal resource management.

Particular effort will be directed towards improved involvement of developing economies. Strengthening regional collaboration and institutional networking will facilitate the necessary data and information exchange, and lead to intra and inter-regional flows of expertise and capacity building. LOICZ will support this structurally, and will provide the platform for regional scientists to play leading intellectual roles. Scientific agendas relevant for all regions, but in particular for developing economies *inter alia*, need to address topics where international conventions oblige countries to take action (e.g. Climate, Biodiversity and Wetlands conventions; see Figure 8).

Data Policy and Management

LOICZ aims to produce a suite of deliverables to scientifically underpin management, including integrated models of coastal change with scenarios of change and management options. In the first decade of LOICZ two databases were developed: a nutrient budget database and a global coastal typology database. Their attendant data management protocols differ mainly because of differences in data sources, however, they are linked, and may be manipulated as an integrated database.

Currently, the LOICZ biogeochemical budgets programme maintains a website (data.ecology.su.se/mnode) with hierarchical, map-based linkages to individual web pages describing each budget site. Each budget site web page consists of a narrative overview and description of water, salt and nutrient budgets for the site, as well as downloadable data. A version of these data has also been entered into the LOICZ typology database, together with all of the other global data assembled by the typology group.

The geo-referenced typology and budget data are searchable in a variety of ways, and are downloadable from www.kgs.ukans.edu/Hexacoral/Envirodata/envirodata.html. This database is based on publicly available data, for which LOICZ contributed primary budget data and data sources as part of other co-operative projects, as well as developing the meta-database and visualisation tool LOICZView (www.palantir.swarthmore.edu/loicz/).

Data Management

Biogeochemical data required to construct budgets are organised by the individual contributors following LOICZ budget guidelines (data.ecology.su.se/MNODE/Methods/overview.htm). Typically, a budget is constructed in a workshop by scientists familiar with the system under consideration, and under the supervision of LOICZ project scientists.

One of the limitations in both the budgets and the typology relates to the geospatial linking and identification of the various datasets and points. Therefore, a key development in LOICZ will be to realise the potential offered by GIS techniques for analysis, selection, dissemination and visualisation.

Potential Directions for Data Product Development

Various regional datasets (e.g. DINAS COAST and New Zealand estuaries) have been offered to LOICZ for integration into the budget and typology databases. The New Zealand estuaries dataset allows users to experiment across spatial scales, to see whether modelled patterns vary with spatial resolution.

Linking biological features with the physical and chemical signatures in coastal areas is an area for interpreted data development. Mapping fisheries variables, or changes in indicator organism populations in relation to coastal geochemical changes, are potential projects that would require strong partnerships among interested global change programmes. Given what LOICZ has already initiated, these potential products are realisable in the medium-term, if appropriate investments in expertise and resources are made.

Finally, elucidating the influence of human activities in altering rates of coastal change, (including coastal biology and spatial boundaries), may be possible with the integration of appropriate socio-economic variables in the databases. However, the scales at which these are measured (e.g. national scale) are often too coarse to relate to the environmental variables that are usually available at catchment or coastal basin-scale. New protocols for gathering and managing socio-economic data, need to be developed to allow seamless data integration, and appropriate data assimilation and interpretation.

Cross-cutting Science Activities and Joint Tasks

To provide infrastructural support and integrative capacity collectively to the implementation of all themes, three cross-cutting activities are proposed: (i) scaling and modelling, (ii) variability analyses, and (iii) capacity building. The first two of these activities will guide the development of research questions. All research elements will deal with modelling approaches, and with the scaling and uncertainty in the assessment of spatial and temporal variability across the global coastal zone. Here, an imperative for LOICZ is effort directed towards the development of models applicable to coupled human–natural systems.

Key issues to be addressed in scaling and natural variability are:

- natural variability of the coastal zone in space and time;
- changes in vertical and horizontal fluxes at decadal and centurial scales;
- non-linear changes, isolated events and thresholds in the context of long-term variability;
- tools to integrate 'small pictures' to the 'big picture' (scaling and capacity building using tools/information at regional-local scales);
- linking typologies and biogeochemical budgets through improved tools and concept developments; and
- prediction of changes and outcomes.

Dissemination and Capacity Building

LOICZ will continue to disseminate its outputs widely through conferences, workshops and meetings, as well as through publications available as hard copy and from the website. A challenge for LOICZ is to extend its output and outreach activity to encompass the human dimensions of GEC. These changes affect the quality of human life and sustainable development on a worldwide scale, and it is important that LOICZ makes a significant contribution to sustainable management.

LOICZ will involve experts from the IHDP to review the participatory and communication mechanisms needed to ensure that outputs, and importantly outcomes, of environmental science are made available outside of the scientific community. Failure to transfer useful knowledge and information is a significant impediment to improved environmental management and governance.

The third cross-cutting activity of LOICZ is capacity building that addresses the integration of human dimensions and biophysical issues. Outputs from all five themes will contribute to the curricula of the Water and Coastal Management Masters programmes being developed by ELOISE, and will help link LOICZ research to IHDP. Lifelong training of existing (and future) catchment and coastal managers is a priority. Managers should be trained so that local problems are seen in the global context. LOICZ, based on broad participation and broad cross-disciplinary ownership, will strive to provide and disseminate the underpinning scientific information.

Many contributors to the first decade of LOICZ and to ELOISE, already participate in a Joint Masters in Water and Coastal Management (www.ualg.pt/EUMScWCM/).

LOICZ will build on this to incorporate existing and new LOICZ products. The Erasmus Mundus Action 2 should enable present and past members of the SSC to participate in the Masters Programme, as well as funding exceptional students. The Erasmus Mundus Action 3 enables a global network of universities to be developed.

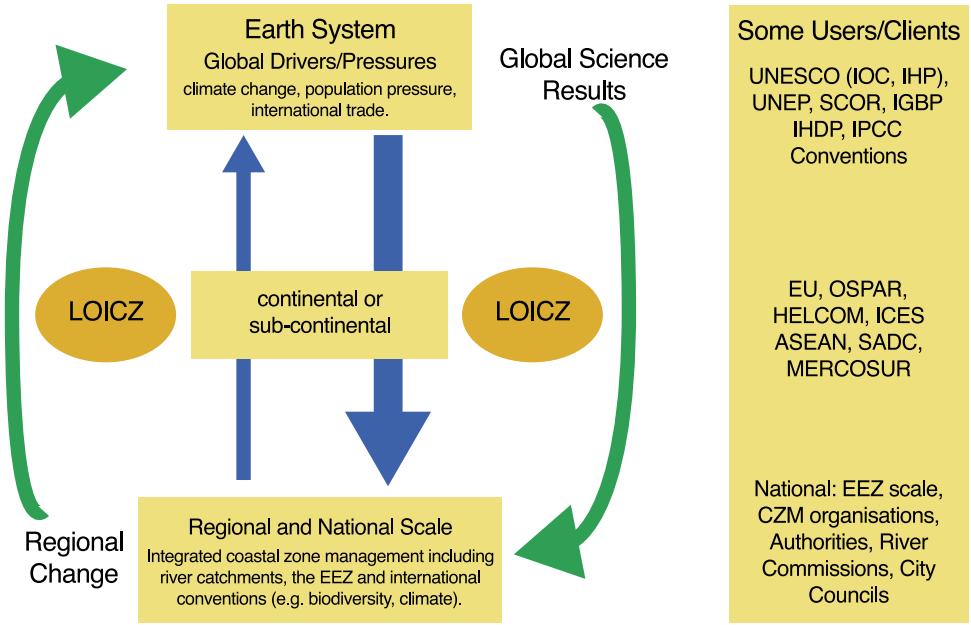
LOICZ will continue and enhance its strong operational links with START, and regional intergovernmental bodies such as APN and IAI, in order to foster regional capacity building. Where appropriate, capacity building and training elements will be built into new LOICZ projects, an approach that proved successful during the first decade. This will include, in particular, method applications and modelling.

Acquisition of Data and Information

Dissemination of information and acquisition of data and funds are programmatic, but are equally vital in the planning and execution of LOICZ projects. Ensuring interactive information flows between LOICZ research, mediated by the IPO, and the science user or 'client' communities, underpins the scientific purpose. This raises the question of 'Who are the clients?', a question that involves scaling issues (Figure 8). LOICZ will broker a joint ownership of the issues and actions that emerge from LOICZ science. The results of regional case studies, and of efforts in down-scaling global pressures and drivers (right hand green arrow, Figure 8), are directly relevant for regional and national managers and policy makers. The up-scaling efforts (left hand green arrow, Figure 8) are relevant at the continental scale for authorities, including (in Europe) the EU and OSPAR. Equally, up-scaling information to the global level, is of interest to agencies such as GEF, UNEP, SCOR, UNESCO (IOC, IHP), the various environmental conventions, and national policy-makers and coastal managers. LOICZ will seek to include these 'clients' in the wider group of sponsors, and as such, they will be able to contribute to the transfer and awareness of scientific information.

Although the benefits that could accrue to various uses of LOICZ science have been emphasised above, the inward flow of information, advice and collaborative activities, from other global and regional research programmes is equally important. To-date, LOICZ has built a number of successful partnerships within IGBP, and with several international agencies. It is expected that this effort will be maintained, and that a close working relationship will be developed with the ESSP and its joint projects on carbon, food systems, water and human health.

Figure 8. The LOICZ challenges, users and clients.



Organisational Structure and Project Management

Project Organisation and Management

LOICZ began in 1993 with the establishment of a Dutch Government-funded IPO at the then Netherlands Institute for Sea Research, Texel, Netherlands. As LOICZ entered its second decade, the Dutch Government funded the IPO for the three-year LOICZ transition. After 2005, the IPO will be re-located with a new funding source.

During the transition, a distributed Project Office, comprising a Central (International) Project Office and Regional Project Offices, is being established to achieve broader geographic representation. The distributed Project Office will not only increase the visibility and effectiveness of the project, but also offers greater opportunities for seeking regional funding to support research and networking that engages regional scientific and user communities.

An Executive Officer and project Administrative Manager will be located at the IPO. The Executive Officer will have responsibility for the entire distributed Project Office. The IPO will have responsibilities for overseeing and implementing the project terms of reference (Box 4). Each Regional Project Office will be represented by a Project Officer (as a minimum) and will receive office support. A Deputy Executive Officer will be based at the IPO (preferable) or at a Regional Project Office. Regional Project Offices have been established (mid-2005) at (i) the Nanyang Technological University, Environmental Engineering Research Centre, Singapore (responsible for Southeast and East Asia); (ii) the GKSS Research Centre, Institute for Coastal Research, Geesthacht, Germany (responsible for Europe); and (iii) the National Science Foundation of Sri Lanka (responsible for South Asia). Further project office options are being explored in other countries/regions, including Africa, Oceania, Canada and China.

Existing relationships with allied regional research and policy programmes (e.g. START, APN, IAI, the EU) and international agencies (e.g. UNESCO (IOC, IHP,) UNEP and GEF) will be maintained, established or strengthened. Increased emphasis will be placed on building and sustaining links and activities through Global Change National Committees and Regional Project Offices.

Box 4. Central IPO Terms of Reference

- Administer the Project on a day-to-day basis, under the long-term guidance of the SSC.
- Coordinate research efforts and plan and coordinate research campaigns and field programmes.
- Provide project advocacy and promotion, enlisting wide international participation in the Project.
- Maintain necessary connections with relevant national and regional projects.
- Ensure effective coordination with other components of the IGBP, and other relevant international research programmes.
- Disseminate information and research results.
- Secure support for the operation of the IPO.

Operational Structure

In recognition of the comprehensive integration of human dimensions into the LOICZ research agenda, IHDP has joined IGBP in sponsoring the project. LOICZ has also implemented a new governance and management structure (Figure 9), the details of which are described in the sections below.

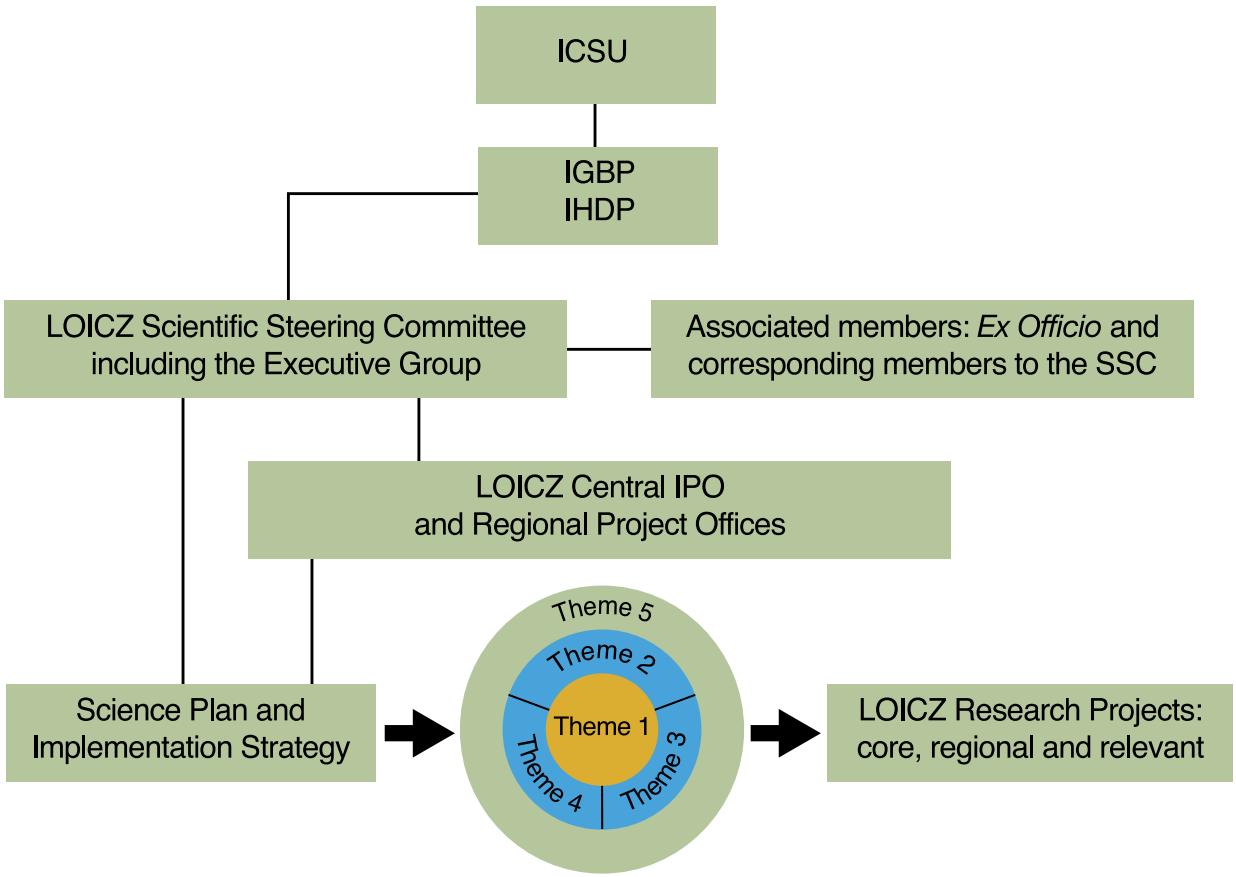
Scientific Steering Committee

The Scientific Steering Committee (SSC) will provide guidance to the Chair on project planning, development and implementation. The sponsoring programmes will nominate SSC members based on the recommendations of the SSC, and the SSC will appoint two Vice-Chairs, one representing IGBP and one representing IHDP.

The primary functions of the SSC are to:

- guide and oversee project development, planning and implementation;
- provide, on request, scientific advice and assistance to Global Change National Committees and to committees of ESSP projects, for use in national/regional research planning that is likely to contribute to LOICZ goals;
- encourage national governments and regional and international funding agencies to support research that contributes to meeting the LOICZ goals;
- encourage collaboration between LOICZ, the ESSP and international programmes and agencies concerned with global change in the coastal zone; and
- recommend to the Scientific Committees of IGBP and IHDP any amendments to these terms of reference as may prove necessary from time to time.

Figure 9. The LOICZ management structure.



Members of the SSC serve in their individual capacities, and are expected to:

- attend in full, SSC meetings as required by the Chair;
- provide the best possible scientific information and advice from their field of expertise as it relates to LOICZ goals;
- affiliate LOICZ-relevant projects with which they are associated or aware;
- provide scientific advice to the Chair on LOICZ development and implementation;
- represent LOICZ at relevant scientific and user community meetings;
- provide a written report to the IPO within one month of representational attendance at any meeting;
- provide a two-way channel of communication between the SSC and national, and where possible, regional and international research and science user communities;
- organise, convene, conduct and provide reports from LOICZ workshops as shall be agreed by the SSC;
- inform the IPO and the relevant Regional Nodes and SSC Chair of all actions directly or indirectly related to LOICZ; and
- assist in securing financial and other support for research activities adopted and approved by the SSC.

The SSC Chair is expected to:

- represent LOICZ and liaise with partners within, and beyond, the ESSP as appropriate;
- Chair SSC and Executive group meetings;
- act as a LOICZ advocate and encourage wide international participation;
- work closely with the IPO in implementing agreed activities between SSC meetings;
- report periodically to the Scientific Committees of IGBP and IHDP on LOICZ progress, and seek the assistance of these committees in addressing implementation difficulties; and
- represent LOICZ at the annual meetings of the SC-IGBP and the SC-IHDP

Box 5. General Tasks of Regional Project Offices with Central IPO support.

- Facilitate and promote the regional synthesis of coastal change, including development of a regional implementation strategy that supports LOICZ science, addresses regional needs and encourages countries to form national committees.
- Provide research platforms and meeting venues for workshops and conferences that disseminate LOICZ science to regional and international scientific communities for use in syntheses and information products.
- Communicate and disseminate knowledge and information products to the coastal management and stakeholder communities, and seek their feedback at national and regional levels, in order to link policy to integrated coastal science.
- Link with international, multilateral and regional funding agencies.
- Identify and undertake capacity building within scientific and management communities.
- Establish links between LOICZ scientists and thematic outputs with user groups.

SSC Vice-Chairs are expected to:

- Chair SSC and/or Executive Group meetings in the absence of the Chair;
- act as LOICZ advocates and encourage wide international participation;
- assist the Chair and the IPO in implementing agreed activities between SSC meetings; and
- represent LOICZ and liaise with partners within, and beyond, the ESSP as appropriate. In particular, the Vice-Chairs will liaise with IGBP as IHDP and their projects as appropriate.

Given the breadth of LOICZ, the SSC is implementing on a trial basis an SSC complement of up to 25 full members organised into two groups: an Executive Group (up to ten) and Additional Full Members. The Executive Group is drawn from the Chair, Vice-Chairs and Theme Coordinators, and at least one other IHDP-nominated member if none are Theme Coordinators. Project Officers from Regional Project Office will attend Executive Group meetings as observers. The Executive Group will co-ordinate the functions of the SSC in consultation with the Additional Full Members. The Executive Group will take responsibility for leading scientific integration, be adaptable in light of new questions, address funding, structural and strategic issues, and assist in 'brokering' or communicating information. Additional Full Members will provide the scientific breadth to support the scope of LOICZ.

Each LOICZ theme requires science beyond any single specialisation, so the success of any theme cannot depend upon individual SSC members. Rather, LOICZ will devolve theme responsibilities to teams of SSC members, led by Theme Coordinators. Individual SSC members will contribute to all themes relevant to their expertise and interests, thereby promoting wide ownership and stewardship of LOICZ. An important role for all SSC members will be to act and contribute as national, regional and/or thematic contact points.

Associated SSC Members

An underpinning LOICZ resource is the network of scientific researchers and managers. To support implementation, LOICZ will seek to (i) continue the commitment of past SSC members, IPO staff and/or substantive LOICZ contributors, and (ii) engage the involvement of new participants by two further categories of LOICZ membership:

I. *Ex Officio* Members will be invited by recommendation of the SSC to fulfil specific and targeted roles requiring specialist skills in one or more of: scientific, technical, institutional and/or governance. Examples include (i) maintaining and developing the LOICZ typology and modelling capacity, and (ii) experience and capacity to access and influence regional funding strategies.

II. Corresponding Members will be appointed by the SSC to contribute to broad thematic planning, identification and resolution of scientific issues and to wider implementation. An important additional role will be to foster national and regional LOICZ outreach.

SSC meetings and regional thematic LOICZ workshops will involve relevant *Ex Officio* and Corresponding Members as appropriate. The unlimited group of Corresponding Members can serve as a recruitment pool for SSC nominations. The common role of both groups will be to:

- identify national and regional research which contributes to LOICZ goals as part of a core, regional or relevant research activity;
- act as national, regional or thematic contact points for the development and implementation of LOICZ;
- liaise with, or assist in, the development of national LOICZ activities, and relevant national representation;
- provide, on request, scientific advice and assistance in the planning of national and regional research which is designed to contribute to LOICZ goals;
- liaise with other scientific bodies within, and beyond, the ESSP, that contribute to LOICZ goals;
- assist the SSC and IPO in securing financial support for (i) national and regional research, and (ii) operations contributing to LOICZ; and
- attend, by invitation, relevant LOICZ meetings.

Decisions and Appeals

Except where the full SSC meets, a decision of the Executive Group (with or without additional attendees) will be considered that of the full SSC. The decisions and outcomes of Executive Group meetings will be recorded and circulated to all full SSC Members, usually within 14 days of the meeting. However, the Additional Full Members (individually or collectively) may appeal an Executive Group decision, by formal notification to the Chair (or the acting Vice-Chair) within 28 days of the date of the relevant Executive Group meeting. Any such appeal will be accompanied by a statement of the grounds for the appeal. The decision and statement of the grounds for the appeal will be provided to all full SSC Members usually within seven days of receipt of the appeal by the Chair (or the acting Vice-Chair). Subsequently, the decision will be either endorsed, or put aside by simple majority vote (by ballot) of the full SSC. A quorum for such a ballot will be more than two-thirds of the full SSC.

Recognition and Endorsement of Research

Parent Programmes and Scientific Sponsors

LOICZ needs to involve a wider group of sponsoring agencies to support core operations and core research activities. Several national governments have indicated an interest in, or are already, co-sponsoring LOICZ, and several international bodies such as UNESCO (IOC, IHP), START, UNEP and SCOR provide support for targeted research and synthesis activities.

Through communication and information exchange, the parent programmes and sponsors (IGBP and IHDP) are expected to assist with LOICZ advocacy, and encourage wide international support including securing financial and other contributions for core research and IPO support. Co-sponsorship by IHDP will lead to close and regular contact with IHDP projects and scientists to assist in shaping and implementing LOICZ.

Operations and Links

Together with AIMES, other IGBP, IHDP and ESSP projects, LOICZ seeks to contribute to the development and application of Earth System models (spanning a range of complexity) that integrate physical climate, ecologic and social systems.

Increasingly, LOICZ is called upon as a source of regional-global coastal science expertise and information. Maintaining and enhancing the ability of LOICZ to respond to scientific and user communities is an important consideration for future planning. The rationale of the LOICZ approach includes:

I. Strong collaborative links with IHDP and its projects, in order to strength the human dimensions of the research, and to foster joint tasks, access to expertise and development of encompassing activities. Human activity in the coastal zone and the EEZ need even more attention than in the past. LOICZ will therefore enhance its efforts to bridge the gaps between biogeochemistry (IGBP) and coastal system functioning, including the human dimensions (IHDP). LOICZ outputs will contribute to the exploration by AIMES of Earth System dynamics.

II. Global and regional-scale projects are in place that complement and can draw upon LOICZ science. For example, ICAM and Coastal GOOS monitoring programmes, assessment programmes such as GIWA, GMA, the ICARM pilot site initiative of UNEP-GPA, and EU initiatives – in particular, the Water Framework Directive, the Water Initiative and the Integrated Coastal Zone Management Strategy. Dialogue with the designers and implementers of these programmes and activities, will provide an effective science–user dimension. Steps have been taken to consolidate these relationships, and further strengthening should lead towards an extended network of operational partnerships.

III. LOICZ will continue, and improve, its cooperation with the research community and policymakers at national levels. This can be assisted through greater interaction with relevant national research, thus attracting more expertise to the project. The distributed IPO and restructured SSC is expected to provide increasing support for regional and national activity.

IV. Communication and information transfer to targeted agencies and fora are fundamental for LOICZ. This requires a funded, operational and skilled task team to assist in communications planning and implementation. Ongoing communications activities and periodic reviews continue to address this need.

Through its extensive regional network, LOICZ will identify regional and national coastal changes, integrate them to the global level and make results and informa-

tion available to managers and decision-makers. This is a challenging task, especially given the goal of integrating human dimensions with natural processes.

The purpose of LOICZ is scientific research and assessments which address agreed goals and objectives, and thus contribute to understanding the role of the coastal zone in Earth System function. Operationally, this requires a structure for scientific networks and activities, and an accompanying administrative element to assist and coordinate the effort.

Additionally, there will be joint and cross-cutting tasks with other IGBP, IHDP and ESSP projects (e.g. IMBER, GLOBEC, SOLAS, PAGES, IDGEC, GECHS, IT, LUCC, GLP, Urbanisation and GWSP), with SCOR providing key support for marine-related projects. Over-arching initiatives will be required across the wider project, for example, development of additional tools and activities for scaling, scenario development, integration and indicators of change. Specific thematic workshops or ad hoc working groups will support this approach. Specifically, discussions are at an advanced stage with a number of other projects:

I. LOICZ foresees beneficial exchanges with SOLAS. SOLAS will measure air–sea gas transfer velocities (SOLAS Focus 2.1) and trace gas concentration fields (SOLAS Foci 1 and 3). Results will be incorporated into LOICZ work, for example, to study the role of coastal seas in greenhouse gas and climate change issues. In cases where LOICZ undertakes similar measurements (e.g. in specific coastal areas), results will be provided for SOLAS synthesis activities.

II. In conjunction with IMBER, LOICZ will coordinate its activities with the coastal modules/activities of GOOS, GTOS and IGOS.

III. LOICZ will work closely with GWSP to draw upon, and benefit from, their research on significant anthropogenic changes to the global water system. In return, LOICZ will provide and link the relevant coastal flux and change information.

SSC-appointed Theme Coordinators, supported by working groups, will lead the planning, implementation and coordination of each theme. Task work under each theme, while addressing the global perspective, will focus on regional studies and evaluations, with support from national research efforts.

Funding

Future LOICZ core funding is directed to the project as a whole. Core funding and in-kind contributions will support each node (staff, operations), as well as the thematic and wider integration work of LOICZ. Regional Project Office locations reflect major national and/or institutional funding sources, and act as key regional centres for wider operations. The IPO will require primarily administrative and management funding, complemented by support for research initiation, synthesis and integration, as compared to the mix of management and research funding of the Regional Project Offices.

Project Timeline

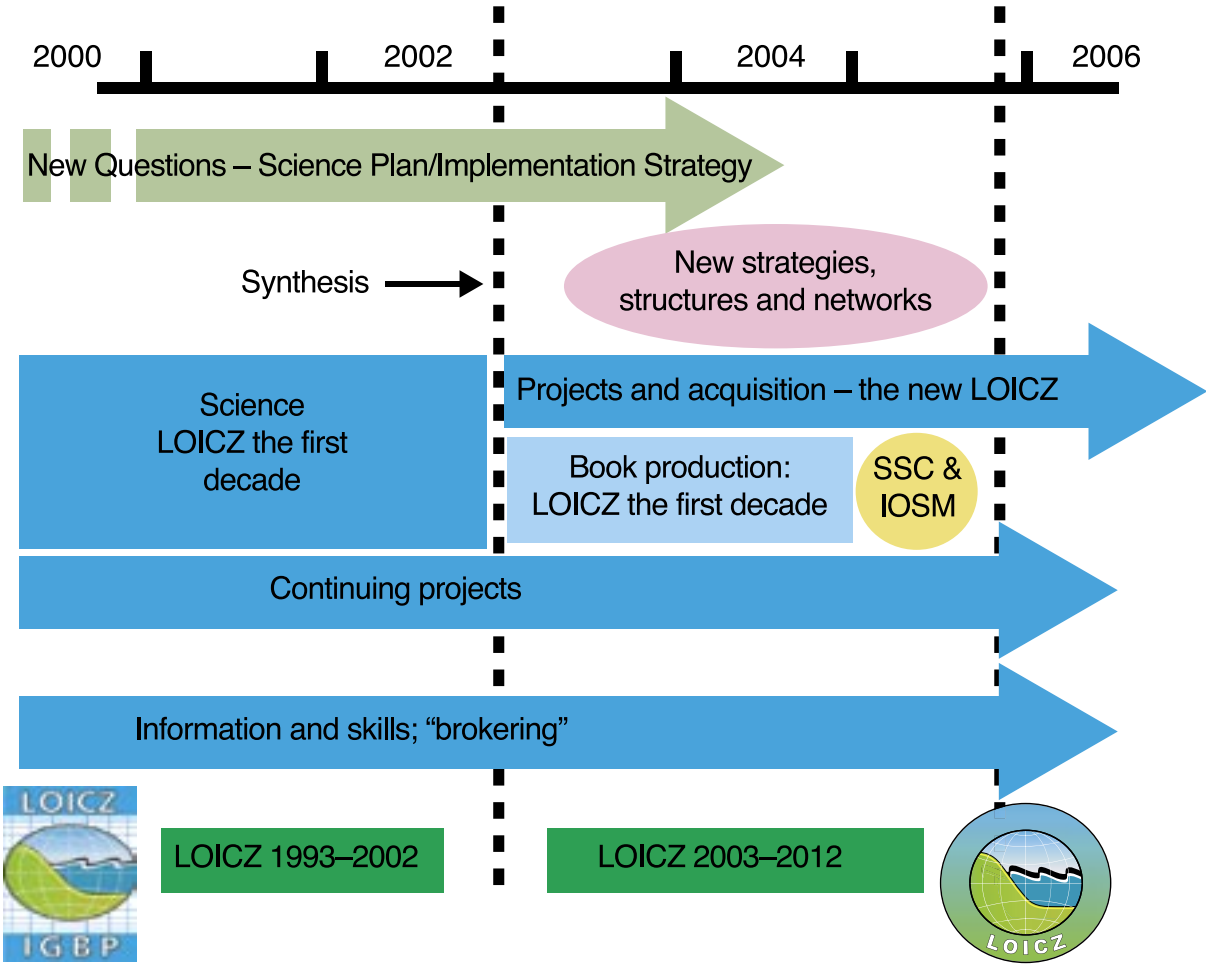
The LOICZ timeline extends to at least 2012, offering a new dimension for LOICZ implementation activities. This Science Plan and Implementation Strategy bridges from the first decade of LOICZ and sets out the priorities for future research.

Numerous activities from the first decade of LOICZ are continuing, including the EU-funded EuroCat and daNUbs, DINAS COAST, the Dutch-funded LOICZ, the EU ELOISE cluster, the biogeochemical assessment synthesis and typology developments and a number of regional and contributing projects. New local and regional-scale LOICZ activities were approved in 2004.

A synthesis of the first decade of collaborative LOICZ research, including a compilation of its findings and gaps was completed in 2002, with work in 2003 and 2004 directed toward preparation of a major book (Crossland et al., in press). This book will be followed by publication of an IGBP Science Series issue targeting a broad scientific, policy and management audience.

Transitional funding will support the IPO until the end of 2005. This will enable distribution and promotion of this Science Plan and Implementation Strategy, continuation and synthesis of research, initiation of new research and IPO and SSC restructuring. Discussions

Figure 10. The LOICZ transition. The line towards the end of 2005 indicates the end of the LOICZ transition. SSC is the first SSC Meeting for the restructured project, and IOSM is the LOICZ Inaugural Open Science Meeting.



with funding bodies will continue, in order to secure long-term LOICZ support.

A priority for 2005, will be identification of, and funding for, a new IPO. Support for this will be sought from IGBP, IGFA and other international bodies. The new IPO will take effect from January 2006. The second edition of the European and Erasmus Mundus Joint Masters in Water and Coastal Management is scheduled for 2005, as is the important Inaugural Open Science Meeting.

More generally, LOICZ will extend and consolidate its networks, IPO distribution and new theme activities in 2005. Transition to the restructured LOICZ will be formally completed late in 2005 with a progress review by project co-sponsors.

References

Cited References

Atkinson L, Liu K.-K, Quinones R and Talaue-McManus L (in press). Carbon and Nutrient Fluxes in Global Continental Margins. Springer, New York.

Behrendt H, Kornmilch M, Opitz D, Schmoll O and Scholz G (2002) Estimation of the nutrient inputs into river systems – experiences from German rivers. Reg Env Change 3, 107–117.

Bennett EM, Carpenter SR and Caraco NF (2001) Human impact on erodible phosphorus and eutrophication: a global perspective. BioScience 51, 227–234.

Biesecker A (1996) The market as an instituted realm of social action. Bremer Diskussionspapiere zur Sozialökonomik. Pp1.

Brunskill GJ (2004) New Guinea and its coastal seas, a testable model of wet tropical coastal processes: an introduction to Project TROPICS. Continental Shelf Res 24, 2273–2295.

Buddemeier RW, Smith SV, Swaney DP and Crossland CJ (2002) The role of the coastal zone in the disturbed and undisturbed nutrient and carbon cycles. LOICZ Reports & Studies No. 24. LOICZ, Texel, Netherlands. Pp83.

Chen C-TA, Liu JT, Tsuang B-J (2004) Island-based catchment – the Taiwan example. Regional Env Change 4, 39–48.

Conley DJ (2000) Biogeochemical nutrient cycles and nutrient management strategies. Hydrobiologia 410, 87–96.

Crossland CJ (2000) Improved strategies for linking coastal science and users. In Pacyna JM, Kremer HH, Pirrone N and Barthel K-G (Ed.s), Socio-economic Aspects of Fluxes of Chemicals into the Marine Environment, Workshop Report. EURO 19089. European Commission, Luxembourg. Pp199–210.

Crossland CJ, Kremer HH, Lindeboom HJ, Marshall-Crossland JI and Le Tissier MDA (Ed.s) (in press) Coastal fluxes in the Anthropocene. Spinger, Berlin.

Duce RA (1986) The impact of atmospheric nitrogen, phosphorus, and iron species on marine biological productivity. In Baut-Menard P (Ed.), The Role of Air-sea Exchange in Geochemical Cycling. Reidel, pp497–529.

Elmgren R (2001) Understanding human impact on the Baltic ecosystem: changing view in recent decades. Ambio 30, 222–231.

Farnsworth KL and Milliman, JD (2003) Effects of climatic and anthropogenic change on small mountainous rivers: the Salinas River example. Global and Planetary Change 39, 53–64.

Funtowicz S and Ravetz J(1999) Post-Normal Science - an insight now maturing. Futures 31, 641–646.

Furnas M (2003) Catchments and corals: terrestrial runoff to the Great Barrier Reef. Australian Institute of Marine Science. ISBN 0642 32223 6. Pp334.

Gläser B (2002) The changing human-nature relationship (HNR) in the context of global environmental change. In: Timmerman (Ed.), Encyclopaedia of Global Environmental Change. John Wiley and Sons.

Gordon DC Jr, Boudreau PR, Mann KH, Ong JE, Silvert WL, Smith SV, Wattayakorn G, Wulff F and Yanagi T (1996) LOICZ biogeochemical modelling guidelines. LOICZ Reports and Studies No. 5. LOICZ, Texel, Netherlands. Pp96.

Green PA, Vörösmarty CJ, Meybeck M, Galloway JN, Peterson BJ and Boyer EW (2004) Pre-industrial and contemporary fluxes of nitrogen through rivers: a global assessment based on typology. Biogeochem 68, 71–105.

Grimvall A and Stålnacke P (2001) Riverine inputs of nutrients to the Baltic Sea. In Wulff, FV, Rahm LA and Larsson P (Ed.s), A Systems Analysis of the Baltic Sea, Ecological Studies Analysis and Synthesis. Springer, Berlin, pp113–131.

Howarth RW, Billen G, Swaney D, Townsend A, Jaworski N, Lajtha K, Downing JA, Elmgren RE, Caraco N, Jordan T, Berendse F, Freney J, Kudeyarov V, Murdoch P and Zhu Z-L (1996) Regional nitrogen budgets and riverine N and P fluxes for the drainages to the North Atlantic Ocean: natural and human influences. Biogeochem 35, 75–139.

Klein RJT, Nicholls RJ and Thomalla F (2002) The resilience of coastal megacities to weather-related hazards: a review. (www.proventionconsortium.org/files/conference_papers/klein.pdf).

Kremer H and Crossland CJ (2002) Coastal change and the "Anthropocene": Past and future perspectives of the IGBP – LOICZ project. In: Low-lying coastal areas – Hydrology and integrated coastal zone management. International Symposium, Bremerhaven, Germany 9–12 September 2002. Pp 3-20.

Kremer H and Pirrone N (1999) Report of working group 4 on Coastal Zone Management and integration of natural and socio-economic science. In: EU Commission EUR 18599 – ELOISE Implementation report, Phase 2. Luxembourg. Pp 49–55.

Lacerda LD, Kremer HH, Kjerfve B, Salomons, W, Marshall JI and Crossland CJ (2002) South American Basins: LOICZ global change assessment and synthesis of river catchment-coastal sea interaction and human dimensions. LOICZ Reports and Studies No. 21. LOICZ, Texel, Netherlands. Pp212.

Ledoux L, Beaumont N, Cave R and Turner RK (2004) Towards integrated catchment-coastal zone management science, policy and scenarios. www.uea.ac.uk/env/cserge/pub/wp/ecm/ecm_2002_05.htm.

Lindeboom H (2002) The coastal zone: an ecosystem under pressure. In: Field JG, Hempel G and Summerhayes CP (Ed.s), Oceans 2020: Science, and the Challenge of Sustainability. Island Press. 49–84.

Maxwell BA and Buddemeier RW (2002) Coastal typology development with heterogeneous data sets. Regional Env Change 3, 77–87.

McLaughlin CJ, Smith CA, Buddemeier RW, Bartley JD and Maxwell BA (2003) Rivers, runoff and reefs. J Global and Planetary Change, 39, 191–199.

Meybeck M (1982) Carbon, nitrogen, and phosphorus transport by world rivers. Am J Sci 282, 401–450.

Meybeck M (2003) Global analysis of river systems: from Earth system controls to Anthropocene syndromes. Phil Trans R Soc Lond B 358, 1935–1955.

Meybeck M, Vogler J, Turner K, Hisschemöller M and van Tilburg M (2004) River-coast integration in European regional seas. EUROCAT project (www.iia-cnr.unical.it/EUROCAT).

Meybeck A and Vörösmarty C (in press) Fluvial filtering of land to ocean fluxes: from natural Holocene variations to Anthropocene. C R Geoscience.

Milliman JD and Syvitski PM (1992) Geomorphic/tectonic control of sediment transport to the ocean: the importance of small mountainous rivers. J Geol 100, 525–544.

Nixon S (2003). Replacing the Nile: are anthropogenic nutrients providing the fertility once brought to the Mediterranean by a great river? Ambio 32, 30–39.

Paerl HW, Dennis RL and Whitall DR (2001) Atmospheric deposition of nitrogen: implications for nutrient over-enrichment of coastal waters. Estuaries 25, 677–693.

Pernetta JC and Milliman J D (1995) Land-Ocean Interactions in the Coastal Zone, LOICZ Implementation Plan. IGBP Report No. 3, Stockholm, Sweden. Pp215.

Rabalais NN (2004) Eutrophication. In Robinson AR, McCarthy J and Rothschild BJ (Ed.s), The Global Coastal Ocean: Multi-scale Interdisciplinary Processes. The Sea, vol. 13, Harvard University Press, pp819–865.

Rabalais NN, Turner RE, Dortch Q, Justic D, Bierman Jr VJ and Wiseman Jr WJ (2002) Review: Nutrient-enhanced productivity in the northern Gulf of Mexico: past, present and future. Hydrobiologia 475/476, 39–63.

Reaka-Kudla ML (2001) Known and unknown biodiversity, risk of extinction and conservation strategy in the sea. In: Bendell-Young L and Gallaugher P (Ed.s), Waters in Peril. Kluwer Academic Publishers.

Rotmans J and van Asselt MBA (1999) Perspectives on a sustainable future, International Journal for Sustainable Development 2, 201–230.

Rotmans J, Grosskurth J, van Asselt MBA and Loorbach D (2001) Duurzame ontwikkeling van concept naar uitvoering. ICIS. Pp1–59 (in Dutch).

Sahagian D and Schellnhuber J (2002) GAIM in 2002 and beyond: a benchmark in the continued evolution of global change research. Global Change NewsLetter 50, 7–10.

Salomons W (2004) European catchments: catchment changes and their impact on the coast. Institute for Environmental Research (IVM), Free University, Amsterdam, R-04/01. ISBN 9053 83923. Pp57+CD-ROM. EUROCAT (www.iia-cnr.unical.it/EUROCAT).

Salomons W, Turner RK, Lacerda LD and Ramachandran S (Ed.s) (1999) Perspectives on Integrated Coastal Zone Management. Springer, Berlin, Heidelberg. Pp386.

Salomons W, Kremer HH and Turner RK (in press) The catchment to coast continuum. In Crossland CJ, Kremer HH, Lindeboom HJ, Marshall-Crossland JI and Le Tissier MDA (Ed.s), Coastal fluxes in the Anthropocene. Springer, Berlin.

Seitzinger SP, Kroeze C, Bouwman AF, Caraco N, Dentener F and Styles RV (2002) Global patterns of dissolved inorganic and particulate nitrogen inputs to coastal systems: recent conditions and future projections. Estuaries 25, 640-655.

Shi H and Singh A (2003) Status and inter-connections of selected environmental issues in the global coastal zones. Ambio 32, 145–152.

Small C and Nicholls RJ (2003) A global analysis of human settlement in coastal zones. J Coastal Res 19(3), 584–599.

Smith SV and Hollibaugh JT (1993) Coastal metabolism and the oceanic organic-carbon balance. Rev Geophys 31, 75–89.

Smith SV, Swaney DP, Talaue-McManus L, Bartley JD, Sandhei PT, McLaughlin CJ, Dupra VC, Crossland CJ, Buddemeier RW, Maxwell BA and Wulff F (2003) Humans, hydrology, and the distribution of inorganic nutrient loading to the ocean. BioScience 53, 235–245.

Steffen W, Sanderson A, Tyson PD, Jäger J, Matson PA, Moore III B, Oldfield F, Richardson K, Schellnhuber HJ, Turner II BL and Wasson RJ (2003) Global Change and the Earth System: a Planet Under Pressure. Springer, Berlin.

Syvitski JPM (2003) Supply and flux of sediment along hydrological pathways: research for the 21st century. J Global and Planetary Change 39, 1–11.

Syvitski JPM, Peckham SD and Hilberman R (2003) Predicting the terrestrial flux of sediment to the global ocean: a planetary perspective. Sedimentary Geology 162, 5–24.

Syvitski JPM, Vörösmarty C, Kettner AJ, Green P (2005) Impact of humans on the flux of terrestrial sediment to the global coastal ocean. Science 308, 376–380.

Talaue-McManus L, Kremer HH, Marshall JI Crossland CJ (2001) SARCS/WOTRO/LOICZ: Biogeochemical and human dimensions of coastal functioning and change in Southeast Asia. Final report of the SARCS/WOTRO/LOICZ project 1996–1999. LOICZ Reports and Studies No. 17. LOICZ, Texel, Netherlands. Pp277.

Thanh TD, Saito Y, Huy DV, Hguyen VL, Ta TKO and Tateishi M (2004) Regimes of human and climate change impacts on coastal change in Vietnam. Regional Env Change 4, 49–62.

Thomas HJ, Pempkowiak F, Wulff and Nagel K (2003) Autotrophy, nitrogen accumulation and nitrogen limitation in the Baltic Sea: a paradox or a buffer for eutrophication? Geophys Res Letters 30, 2130.

Thomas H, Bozec Y, de Baar HJW, Elkalay K, Frankignoulle M., Schiettecatte LS, Kattner G and Borges AV (2005) The carbon budget of the North Sea. Biogeosciences 2, 87–96.

Thomas H, Bozec Y, Elkalay K and deBaar HJW (2004) Enhanced open storage of CO_2 from shelf sea pumping. Science 304, 1005–1008.

Vafeidis AT, Nicholls RJ, McFadden L, Hinkel J and Grashoff PS (2004) Developing a global database for coastal vulnerability analysis: design issues and challenges. The International Archives of Photogrammetry, Remoste Sensing and Spatial Information Sciences, 35B, 801–806.

van Asselt MBA, Rijkens-Klomp N and Molendijk K (2000) Werken met het denkmodel. ICIS Working Paper 100-D002, pp1–89. (In Dutch).

von Bodungen B and Turner RK (Ed.s) (2001) Science and Integrated Coastal Management. Dahlem University Press, Berlin. Pp378.

Vörösmartry CJ, Meybeck M, Fekete M and Sharma K (1997) The potential impact of neo-castorisation on sediment transport by the global network of rivers. In: Human Impact on Erosion and Sedimentation, IAHS Publ No. 245, 261–273.

Vörösmarty CJ and Sahagian D. (2000) Anthropogenic disturbance of the terrestrial water cycle. BioScience 50, 753–765.

Vörösmarty CJ, Fekete M, Meybeck M and Lammers R. (2000) A simulated topological network representing the global system of rivers at 30-minute resolution (STN-30). Global Biogeochemical Cycles 14, 599–621.

Vörösmartry CJ and Meybeck M (2000) Riverine transport and its alteration by human activities. Global Change Newsletter 39, 24–29.

Vörösmartry CJ, Meybeck M, Fekete B, Sharma K, Green P and Syvitski JPM (2003) Anthropogenic sediment retention: major global impact from registered river impoundments. J Global and Planetary Change 39, 169–190.

Walling DE and Fang D (2003) Recent trends in the suspended sediment loads of the world's rivers. J Global and Planetary Change 59, 111–126.

Yang SL, Milliman JD, Galler J, Liu JP and Sun XG (2000) Yellow River's water and sediment discharge decreasing steadily. Eos Transactions 589–592.

Yang SL, Zhao QY and Baelkin IM (2002) Temporal variation in the sediment load of the Yangtze River and the influences of human activities. J Hydrology 263, 56–71.

Yin Y, Cohen S, Huang G (2000) Global climate change and regional sustainable development: the case of Mackenzie Basin in Canada. Integrated Assessment 1, 21–36.

Yin K, Qian P-Y, Wu MCS, Chen JC, Huang L, Song X and Jian W (2001) Shift from P to N limitation of phytoplankton growth across the Pearl River estuarine plume during summer. Mar Ecol Prog Ser 221, 17–28.

Background References by Theme

Theme 1

Bell RG, Hume TM and Hicks DM (2001) Planning for climate change effects on coastal margins. A report prepared for the Ministry for the Environment as part of the New Zealand Climate Change Programme, Ministry for the Environment, Wellington, New Zealand.

Goodwin I, Harvey N, van der Plassche O, Oldfield F and Oglesby R (2000) Prospects of resolving climate-induced sea-level fluctuations over the last 2,000 years. Eos Transactions 81, 311–314.

Harvey N, Clouston B and Carvalho P (1999) Improving coastal vulnerability assessment methodologies for integrated coastal management: an approach from South Australia. Australian Geographical Studies 37, 50–69.

Harvey N, Belperio AP, Bourman R and Mitchell W (2002) Geologic, isostatic and anthropogenic signals affecting sea-level records at tide gauge sites in southern Australia. J Global and Planetary Change 32,1–11.

Kearney MS (2001) Late Holocene sea-level variation. In Douglas BC, Kearney MS, Leatherman SP (Ed.s), Sea-level Rise: History and Consequences. Academic Press International Geophysics Series vol. 75, 13–36.

Nicholls RJ, Hoozemans FMJ and Marchand M (1999) Increasing flood risk and wetland losses due to sea-level rise: regional and global analyses. Global Environmental Change 9, S69–S87.

Nicholls RJ and de la Vega-Leinert A (2001) The SURVAS project at the Overview Workshop. In: de la Vega-Leinert A and Nicholls RJ (Ed.s), Proceedings of the SURVAS Overview Workshop on the Future of Vulnerability and Adaptation Studies. London. Pp1–6.

Peltier WR (2001) Global glacial isostatic adjustment and modern instrumental records of relative sea-level history. In Douglas BC, Kearney MS and Leatherman SP (Ed.s), Sea-level Rise: History and Consequences. Academic Press, International Geophysics Series vol. 75, 65–95.

Peltier WR (2002) On eustatic sea-level history: last glacial maximum to Holocene. Quaternary Science Reviews 21, 377–396.

Steffen W, Jäger J, Carson DJ and Bradshaw C (Ed.s) (2003) Challenges of a Changing Earth. Proceedings of the Global Change Open Science Conference, Amsterdam, Netherlands. Springer-Verlag, Heidelberg, Germany.

Titus JG and Richman C (2001) Maps of lands vulnerable to sea-level rise: modelled elevations along the US Atlantic and Gulf Coasts. Climate Res 18, 205–228.

Yang ZS, Saito Y, Liu B, Zhang J and Wang HJ (2002) Decadal and millennial time-scale changes of water and sediment discharges of the Huanghe (Yellow River) caused by human activities. In: LOICZ Reports and Studies No.26. LOICZ, Texel, Netherlands, pp118–121.

Theme 2

Baker RGV and Haworth RJ (2000) Smooth or oscillating late Holocene sea-level curve? Evidence from cross-regional statistical regressions of fixed biological indicators. Mar Geol 163, 353–365.

Douglas BC (2001) Sea-level change in the era of the recording tide gauge. In Douglas BC, Kearney MS and Leatherman SP (Ed.s), Sea-level Rise: History and Consequences. Academic Press, International Geophysics Series Vol. 75, 37–64.

Harvey N, Belperio AP, Bourman R and Mitchell W (2002) Geologic, isostatic and anthropogenic signals affecting sea-level records at tide gauge sites in southern Australia. J Global and Planetary Change 32, 1–11.

Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ and Xiaosu D (Ed.s) (2001) Climate Change 2001: the Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). New York, Cambridge University Press.

IPCC (2001) The IPCC Third Assessment Report on the Scientific Basis of Climate Change.

Theme 3

Arthurton RS, Kremer HH, Odada E, Salomons W, Marshall-Crossland JI and Crossland CJ (2002) African basins: LOICZ global change assessment and synthesis of river catchment-coastal sea interaction and human dimensions. LOICZ Reports and Studies No. 25. LOICZ, Texel, Netherlands. Pp344.

GESAMP (2001) Protecting the Oceans from Land-Based Activities. GESAMP Reports and Studies No. 71. UNEP, Nairobi.

Gordeev VV, Andreeva E, Lisitzin AP, Kremer HH, Salomons W and Marshall-Crossland JI (in press) Russian Arctic basins: LOICZ global change assessment and synthesis of river catchment-coastal sea interaction and human dimensions. A desk-study of the Russian Arctic. LOICZ Reports and Studies, LOICZ, Texel, Netherlands.

Hong GH, Kremer HH, Pacyna J, Chen-Tung A, Chen, Behrendt, H, Salomons W and Marshall-Crossland JI (2002) East Asia basins: LOICZ global change assessment and synthesis of river catchment-coastal sea interaction and human dimensions. LOICZ Reports and Studies No. 26. LOICZ, Texel, Netherlands. Pp262.

Huntley D, Leeks G and Walling D (Ed.s.) (2001) Land-ocean interaction measuring and modelling fluxes from river basins to coastal seas. IWA Publishing.

Kremer HH (2004) River catchment-coastal sea interaction and human dimensions. Regional Env Change 4, 1–4.

Kjerfve B, Wiebe WJ, Kremer HH, Salomons W, Marshall-Crossland JI (Caribbean) and Morcom N, Harvey N and Marshall-Crossland JI (Oceania) (2002) Caribbean basins: LOICZ global change assessment and synthesis of river catchment/island-coastal sea interaction and human dimensions; with a desktop study of Oceania basins. LOICZ Reports and Studies No. 27. LOICZ, Texel, Netherlands. Pp174.

Lindeboom H, Crossland C and Kremer HH (2002) Land-ocean interactions – towards LOICZ II. Global Change Newsletter 50, 24–30.

Meade RH (1996) River-sediment inputs to major deltas. In: Milliman JD and Haq BU (Ed.s), Sea-level Rise and Coastal Subsidence. Kluwer Academic Publishers, Dordrecht, Netherlands. Pp63–85.

Milliman JD (1990) Fluvial sediment in coastal seas: flux and fate. Nature and Resources (UNESCO) 26, 12–22.

Milliman JD and Meade RH (1983) World-wide delivery of river sediment to the oceans. J Geol 91, 1–21.

Milliman JD, Shan QY, Mei-E R and Saito Y (1987) Man's influence on the erosion and transport by Asian rivers: the Yellow River (Huanghe) example. J Geol 95, 751–762.

Saito Y (2001) Deltas in Southeast and East Asia: their evolution and current problems. In: Mimura N and Yokoki H (Ed.s), Global Change and the Asia-Pacific Coast. Proceedings of APN/SURVAS/LOICZ Joint Conference on Coastal Impacts of Climate Change and Adaptation in the Asia-Pacific Region. pp185–191.

Saito Y, Yang ZS and Hori K (2001) The Huanghe (Yellow River) and Changjiang (Yangtze) deltas: a review on their characteristics, evolution and sediment discharge during the Holocene. Geomorphology 41, 219–231.

Salomons W, Liese W, Behrendt H and Kremer HH (2003) Catchment-coastal zone intercations: LOICZ Basins and EuroCat; LOICZ Newsletter 26, 1–3.

Smith SV, Renwick WH, Buddemeier RW and Crossland CJ (2001) Budgets of soil erosion and deposition for sediments and sedimentary organic carbon across the conterminous United States. Global Biogeochemical Cycles 15(3), 697–707.

van Drecht GAF, Bouwman AF, Koop JM, Meinardi C and Beusen A (2001) Global pollution of surface water from point and non-point sources of nitrogen. Scientific World Journal 1 Suppl 2, 632–641.

Theme 4

Boudreau BP, Huettel M, Froster S, Jahnke RA, McLachlan A, Middelburg JJ, Nielsen P, Sansone F, Taghon G, van Raaphorst W, Webster I, Weslawski JM, Wiberg P and Sundby B (2001) Permeable marine sediments: overturning an old paradigm. Eos Transactions 82, 133–136.

Burnett W and Turner J (2001) LOICZ group investigates groundwater discharge in Australia. LOICZ Newsletter 18, 1–4.

Burnett WC, Chanton J, Christoff J, Kontar E, Krupa S, Lambert M, Moore W, O'Rourke D, Paulsen R, Smith C, Smith L and Taniguchi M (2002) Assessing methodologies for measuring groundwater discharge to the ocean. Eos Transactions 83, 117–123.

Burnett WC, Taniguchi M and Oberdorfer J (2001) Measurement and significance of the direct discharge of groundwater into the coastal zone. J Sea Res 46, 109–116.

Frankignoulle M, Abril G, Borges A, Bourge I, Canon C, Delille B, Libert E and Thiate J-M (1998) Carbon dioxide emission from European estuaries. Science 282, 434–436.

Frankignoulle M and Borges AV (2001) European continental shelf as a significant sink for atmospheric carbon dioxide. Global Biogeochem Cycles 15, 569–576.

GESAMP (2001) Protecting the Oceans from Land-Based Activities. GESAMP Reports and Studies No. 71. UNEP, Nairobi.

Huettel M (2002) Understanding the biocatalytic sand filter in the shelf. LOICZ Newsletter 25, 1–4.

Humborg C, Conley DJ, Rahm L, Wulff F, Cociasu A and Ittekkot V (2000) Silicon retention in river basins: far-reaching effects on biogeochemistry and aquatic food webs in coastal marine environments. Ambio 29, 45–50.

Riebesell U, Zondervan I, Rost B, Tortell PD, Zeebe RE, Morel FM (2000) Reduced calcification of marine plankton in response to increased atmospheric CO_2. Nature 407, 364–367.

Syvitski JPM (2003) Sediment fluxes and rates of sedimentation. In Middleton GV (Ed.) Encyclopaedia of Sediments and Sedimentary Rocks. Kluwer Academic Publishers, Dordrecht, Netherlands. Pp600–606.

Syvitski JPM (2003) The influence of climate on the flux of sediment to the coastal ocean. Proceedings of OCEANS 2003, San Diego, Holland Publ. Pp496–502.

Syvitski JPM, Morehead MD, Bahr D and Mulder T (2000) Estimating fluvial sediment transport: the rating parameters. Water Res Res 36, 2747–2760.

Thomas H, Ittekkot V, Osterroht C and Schneider B (1999) Preferential recycling of nutrients - the ocean's way to increase new production and to pass nutrient limitation? Limnol Oceanog 44, 999–2004.

Webster IT, Parslow JS and Smith SV (2000) Implications of spatial and temporal variation for biogeochemical budgets of estuaries. Estuaries 23, 341–350.

Wolanski E, Richmond, RH, Davis G and Bonito V (2003) Water and fine sediment dynamics in transient river plumes in a small, reef-fringed bay, Guam Estuar Coastal Shelf Sci 56, 1–13.

Wolanski E, Richmond R, McCook L and Sweatman H (2003) Mud, marine snow and coral reefs. American Scientist 91, 44-51.

Wulff F, Rahm L and Larsson P (2001) A Systems Analysis of the Baltic Sea. Ecological Studies 148. Springer, Berlin. Pp455.

Theme 5

Bartley JA, Buddemeier RW and Bennett DA (2001) Coastline complexity: a parameter for functional classification of coastal environments. J Sea Res 46, 87–97.

Burbridge PR (1999) The challenge of demonstrating socio-economic benefits of integrated coastal management. In: Salomons W, Turner RK, de Lacerda LD and Ramachandran S (Ed.s), Perspectives on Integrated Coastal Zone Management. Springer, Berlin, Heidelberg. Pp35–53.

Burbridge PR and Pethick J (2003). Sustainability and management: coastal systems. In Wefer G, Lamy F and Mountoura F (Ed.s), Marine Science Frontiers for Europe. Springer. Pp216–228.

Burke LK, Yumiko K, Kassem, Revenga C, Spalding M and McAllister D (2001) Pilot Analysis of Global Ecosystems: Coastal Ecosystems. World Resources Institute, Washington DC, USA. Pp94.

Cicin-Sain B and Knecht RW (1998) Integrated Coastal and Ocean Management: Concepts and Practices. Island Press, Washington DC, USA. 517pp.

Clark JR (2001) Coastal Seas – The Conservation Challenge. Blackwell Science Limited, London, UK. Pp134.

Commission of the European Communities (1998) Communication from the Commission to the European Council. Partnership for Integration - A Strategy for Integrating Environment into European union Policies. CEC, Luxembourg. Pp10.

Commission of the European Communities (1999) Towards a European Integrated Coastal Zone Management Strategy - A Reflection Paper. Discussion document from the Demonstration Programme on Integrated Coastal Zone Management. CEC, Luxembourg. Pp35.

Crossland CJ (2000) Improved strategies for linking coastal science and users. In Pacyna JM, Kremer HH, Pirrone N and Barthel K-G (Ed.s), Socio-economic Aspects of Fluxes of Chemicals into the Marine Environment, Workshop Report. EURO 19089. European Commission, Luxembourg. Pp199–210.

European Environment Agency (2000) Cloudy Crystal Balls: An Assessment of Recent European and Global Scenario Studies and Models. Env Issues Series No. 17, EEA, Copenhagen.

Gallopin GC and Raskin P (1998) Windows on the future: global scenarios and sustainability. Environment 40, 26–31.

GESAMP (1996) The Contributions of Science to Coastal Zone Management, GESAMP (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Reports and Studies No. 61. FAO, Rome.

Gren IM, Turner RK and Wulff F (Ed.s) (2000) Managing a Sea – The Ecological Economics of the Baltic. Beijer Institute, Earthscan Publications, London. Pp138.

Humphrey S and Burbridge PR (2003) Sectoral and territorial cooperation in the European Demonstration Programme on ICZM. Coastal Management 31, 155–16.

Kremer HH and Crossland CJ (2002) Coastal change and the Anthropocene: past and future perspectives of the IGBP LOICZ project. In German IHP OHP National Committee (Ed.s), Low-lying Coastal Areas – Hydrology and Integrated Coastal Zone Management. International Symposium, Report. Pp3–19.

Lindeboom HJ, Burbridge PR, de Leeuw JW, Irmisch A, Ittekkot V, Kaiser M, Laane R, Legrand J, Prandle D, Reise K and She J (2003) Coastal and Shelf Processes, Science for Integrating Management; Group Report. In Wefer G, Lamy F and Mountoura F (Ed.s), Marine Science Frontiers for Europe. Springer. Pp229–242.

OECD (2001) A New Strategy for the Environment. OECD Observer, Policy Brief July 2000. Pp8.

Rabalais NN, Turner RE, Scavia D (2002) Beyond science and into policy: Gulf of Mexico hypoxia and the Mississippi River. BioScience 52, 129–142.

Turner RK, Adger WN and Lorenzoni I (1998) Towards integrated modelling and analysis in coastal zones: principles and practices. LOICZ Reports and Studies No. 11. LOICZ, Texel, Netherlands. Pp122.

Turner RK and Salomons W (1999) Coastal management principles and practice; introduction and overview. In Salomons W, Turner RK, de Lacerda LD and Ramachandran S (Ed.s), Perspectives on Integrated Coastal Zone Management. Springer, Berlin, Heidelberg. Pp1–10.

UNEP (2002) Integrating Environment and Development: 1992–2002. UNEP, Nairobi.

Wilson MA, Costanza R, Boumans R, Liu S and Portela R (2003) Valuing Ecosystem Goods and Services in the Coastal Zone. A Report to the Land-Ocean Interaction in the Coastal Zone (LOICZ) Project of the International Geosphere-Biosphere Programme, Gund Institute for Ecological Economics, University of Vermont, Burlington, USA.

World Commission on Dams (2000) Dams and Development: A New Framework for Decision Making. The Report of the World Commission on Dams. Earthscan Publications Ltd, London and Sterling, VA. Pp404.

Yin Y, Cohen S and Huang GH (2000) Global climate change and regional sustainable development: The case of Mackenzie Basin in Canada. Integrated Assessment 1, 21–37.

Acronym List

AIMES	Analysis, Integration and Modelling of the Earth System (IGBP)
APN	Asia-Pacific Network for Global Change Research
ASEAN	Association of South East Asian Nations
DIN	dissolved inorganic nitrogen
DINAS-COAST	Dynamic and INteractive ASsessment of National, Regional and Global Vulnerability of COASTal Zones to Climate Change and Sea-Level Rise
DIP	dissolved inorganic phosphorus
DIVERSITAS	an international programme of biodiversity science
DPSIR	Driver-Pressure-State-Impact-Response
EEZ	Economic Exclusive Zone
ELOISE	European Land-Ocean Interaction Studies
ESSP	Earth System Science Partnership
EU	European Union
FRIEND	Flow Regimes from International Experimental and Network Data
GAIM	Global Analysis, Integration and Modelling (IGBP)
GCP	Global Carbon Project (ESSP)
GEC	global environmental change
GECAFS	Global Environmental Change and Food Systems (ESSP)
GECHS	Global Environmental Change and Human Dimensions (IHDP)
GEF	Global Environment Facility (UNEP)
GEMS	Global Environment Monitoring System (UNEP)
GIWA	Global International Water Assessment (UNEP/GEF)
GKSS	Research Centre Geesthacht, Germany (Member of the Helmholtz Foundation)
GLOBEC	Global Ocean Ecosystem Dynamics (IGBP/SCOR)
GLORI	GEMS/Water contribution to the Global Register of River Inputs
GLP	Global Land Project (IGBP/IHDP)
GMA	Global Marine Assessment (UNEP)
GMES	Global Monitoring for Environment and Security
GOOS	Global Ocean Observation System
GPA	Global Programme of Action (UNEP)
GRDC	Global Runoff Data Centre
GTOS	Global Terrestrial Observing System
GWSP	Global Water System Project (ESSP)
HELCOM	Helsinki Commission (Baltic Marine and Environment Protection Commission)
HELP	Hydrology for the Environment, Life and Policy (UNESCO/WMO)
IAI	Inter-American Institute for Global Change Research
ICAM	Integrated Coastal Area Management (UNESCO/IOC)
ICARM	Integrated Coastal Area and River Basin Management (UNEP)
ICES	International Council for the Exploration of the Sea
IDGEC	Institutional Dimensions of Global Environmental Change (IHDP)
IGBP	International Geosphere-Biosphere Programme (ICSU)

IGOS	Integrated Global Observing Strategy
IHDP	International Human Dimensions Programme on Global Environmental Change (ICSU)
IHP	International Hydrologic Programme (UNESCO)
iLEAPS	Integrated Land Ecosystem-Atmosphere Processes Study (IGBP)
IMBER	Integrated Marine Biogeochemistry and Ecosystem Research (IGBP/SCOR)
IOC	International Oceanographic Commission
IOCCG	International Ocean-Colour Coordinating Group
IOI	International Ocean Institute
IPO	International Project Office
IT	Industrial Transformation (IHDP)
IWMI	International Water Management Institute
JGOFS	Joint Global Ocean Flux Study (IGBP/SCOR)
KNAW	Royal Dutch Academy of Arts and Sciences
LOICZ	Land-Ocean Interactions in the Coastal Zone (IGBP/IHDP)
LUCC	Land-Use and Cover Change (IGBP/IHDP)
MAB	Man and the Biosphere Programme (UNESCO)
MEA	Millennium Ecosystem Assessment
MERCOSUR	Common Economic Market of Argentina, Brazil, Paraguay and Uruguay
NSF	National Science Foundation
OECD	Organisation for Economic Cooperation and Development
OSPAR	Convention for the Protection of the Marine Environment of the North East Atlantic
PAGES	Past Global Changes (IGBP)
SADC	Southern African Development Community
SCENE	Social, environmental and economic aspects of sustainability (model)
SCOPE	Scientific Committee on Problems of the Environment (ICSU)
SCOR	Scientific Committee on Oceanic Research (ICSU)
SOLAS	Surface-Ocean Lower Atmosphere Study (IGBP/SCOR/WCRP/CACGP)
SSC	Scientific Steering Committee
START	Global Change System for Analysis, Research and Training (ESSP)
TEMA	Training, Education and Mutual Assistance in Marine Science (UNESCO/IOC)
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational Scientific and Cultural Organisation
USGS	Unites States Geological Survey
WCRP	World Climate Research Programme (ICSU)
WOTRO	Netherlands Foundation for the Advancement of Tropical Research
WWAP	World Water Assessment Programme (UNESCO)

LOICZ

The Land–Ocean Interactions in the Coastal Zone project is a multidisciplinary project of the International Geosphere-Biosphere Programme (IGBP) and the International Human Dimensions Programme on Global Environmental Change (IHDP). Both IGBP and IHDP are interdisciplinary bodies of the International Council for Science (ICSU).

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