Chapter 5

Synthesis of Main Findings and Conclusions

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5.1 Global Change and Sustainable Use of Earth's Coastal Zones

It is clear that global change to the environment is having a major influence on the functioning of coastal systems and their ability to sustain human development. A key outcome of the first 10 years of LOICZ is that, although major river systems have a profound influence on coastal and nearshore marine systems at a regional level, the mounting pressures from human development and their effects on coastal systems are felt most acutely at small to medium individual catchment scales. Furthermore, it is becoming increasingly evident from the LOICZ studies that the cumulative effects of human-induced changes in small- to medium-scale river systems may well be greater than those attributed to major river systems.

The LOICZ research described in the preceding chapters has demonstrated the importance of biogeochemical fluxes, nutrients and sediments from river catchments in the coastal zone for the availability of living and non-living resources for human society. The outcomes from LOICZ research have demonstrated that investigation of changes to coastal systems cannot be confined within administrative boundaries. Instead, studies need to be oriented towards watershed- and catchment-based perspectives to study coastal dynamics and to integrate the results with management of human activities. This reinforces the emerging concepts of integrated coastal management where the "coastal zone" is treated as part of a dynamic continuum linking terrestrial and marine components, rather than as an isolated "zone" that can be managed without reference to natural and human-induced changes to hydrology, or fluxes of materials in upland and oceanic systems.

The river basins or catchments (LOICZ-Basins) studies have helped to integrate the human dimensions[2] to global environmental change by identifying the major social and economic drivers that lead to pressures with a direct or indirect influence on the state of ecosystems and corresponding impacts on biological, chemical, geophysical, social and economic conditions. These studies demonstrated common as well as unique features concerning the rate and scale of change in human pressures among the different bio-climatic regions.

Integration of natural and social science dimensions in the LOICZ programme has clarified the principal problems and issues associated with global environmental change and consequent sustainability of human uses of coastal systems, including:

- eutrophication;
- pollution;
- changing erosion/sedimentation equilibrium;
- mounting impoverishment in the biodiversity of estuarine waters and coastal seas through a reduction in river-borne nutrients and organic matter;
- loss of ecosystem goods and services that help to sustain food security, economic development and improvements in social welfare; and
- increasing vulnerability of human societies to natural coastal hazards affecting settlements, public and private investment, property and lives.

Given the pivotal role that coastal areas and resources play in sustaining the social and economic welfare of up to 50% of Earth's population, the major challenge that humans face today is to recognise and manage the consequences of adverse impacts from both natural and human-induced changes to coastal systems. History has shown how difficult it is to motivate nations to work together in addressing these issues at a global scale. However, much can be achieved at regional, nation-state and local levels to sustain human use of coastal systems. This can be done through initiating improvements in the management of human activities within catchments as well as within the marine and terrestrial components of the "coastal zone." LOICZ methodologies have allowed up-scaling of local information to a global scale that can

[2] For the purposes here, a definition of human dimensions is "*the effects of human activity on large physical and biological systems, the impacts of environmental change on people and societies, the responses of social systems to actual or anticipated environmental change, and the interactions among all these processes*" (US NRC Committee on the Human Dimensions of Global Change).

then be down-scaled and applied to other local areas where there is a paucity of information. A major benefit from the LOICZ thematic studies is the provision of scientific evidence that could strengthen information available for policy, planning and management initiatives at small to medium to large scales. At the same time, LOICZ studies have greatly enhanced our understanding of the responses of coastal systems at a global scale.

5.2 Progress in Meeting IGBP-LOICZ Goals

During the past 10 years, the scientific effort of the LOICZ project has been directed towards answering the generic question:

How will changes in land use, sea level and climate alter coastal ecosystems, and what are the wider consequences?

The broad goals of LOICZ in addressing this question have been:

1. Determination at global and regional scales:
   a fluxes of materials between land, sea and atmosphere through the coastal zone;
   b capacity of coastal systems to transform and store particulate and dissolved matter;
   c effect of changes in external forcing conditions on the structure and functioning of coastal ecosystems.
2. Determination of how changes in land use, climate, sea level and human activities alter the fluxes and retention of particulate matter in the coastal zone and affect coastal morphodynamics.
3. Determination of how changes in coastal systems, including responses to varying terrestrial and oceanic inputs of organic matter and nutrients, will affect the global carbon cycle and the trace gas composition of the atmosphere.
4. Assessment of how responses of coastal systems to global change will affect the habitation and usage by humans of coastal environments, and to develop further the scientific and socio-economic bases for the integrated management of coastal environments.

These goals and objectives have been addressed by a global network of scientists in which the active and collaborative participation of scientists from developed and developing countries has been vital to the successful conduct of the research and dissemination of results of the LOICZ programme. This network has compiled many local case studies, which form the data and information base that has been up-scaled for construction of the global synthesis.

Progress has been made in generating a comprehensive overview of the changes in Earth system processes affecting the coastal zone, the role of coastal systems in global change and the current state of coastal metabolism. This includes identifying simple proxies in the form of demographic and hydrological parameters, that can support the prediction of the state of coastal systems. Typology approaches supported by analytical and visualisation software have been developed to assist in the interpolation of these results for remote areas where primary information is lacking, thus enabling a first order up-scaling to a global synthesis.

Important scientific questions have been answered. For example, estimates of carbon fluxes and their modification by natural systems and human activities in coastal regions have been developed through the up-scaling of local nutrient budget data collated and analysed by LOICZ. Another success is the identification and analyses of nutrient loads transmitted to coast systems and an evaluation of the global increase in nutrients over recent decades. The LOICZ research has also provided new insights into the influence of global climate change on the dynamics of coastal systems with respect to sediments, groundwater and sea-level and how these may influence the long-term habitation of coastal areas and sustainable use of natural resources.

The main findings from the thematic studies produced new information of value in broadening our understanding of global systems and addressing management challenges at various scales, centring upon three areas of investigation:

1. The Material Fluxes effort relied more heavily on scientific evaluation of fluxes, measurements and models. Although most of the results stemmed from paper studies and scientific workshops, new data were assembled through the publication of compilations of information and model results and a series of field measurements and experiments. The latter activity was a joint LOICZ/SCOR working group on submarine groundwater discharge. The results of the overall effort consist primarily of an enhanced understanding of the issues involved in coastal zone fluxes, of the variety of forcing functions controlling them, and in the development of an inventory of relevant tools and the understanding of where and how they may best be applied.
2. The Biogeochemical Budget effort pursued a course that was in many ways intermediate between, and conceptually linking, the other two – using local expertise to assess the nature and status of biogeochemical fluxes in coastal waters in a quantitative, inter-comparable fashion. The systematic classification of budgets and associated flux data, and the terrestrial and marine systems they represent, provided a basis for identifying potential functional similarities among measured and similar unstudied systems – the typological up-scaling approach.
3. The River Basins effort used a standardised approach to identify and assemble regional "expert judgment"

assessments of the characteristics and conditions of drainage basins and their known or perceived relationship to the conditions of the associated estuarine or coastal waters. These assessments, based on a mixture of quantitative measures and qualitative judgments, were codified in terms of ranked variables that have the potential to be formulated in at least semi-quantitative fashion, and related to typological definitions and known mechanisms of change.

Each of these thematic areas was underpinned by the use of the Driver-Pressure-State-Impact-Response (DPSIR) framework in socio-economic evaluations (Turner et al. 1998) and was enhanced through model developments and application in regional sites (e.g., Southeast Asia) where terrestrial socio-economic models were linked with coastal ecosystem (biogeochemical) models (Talaue-McManus et al. 2001). Awareness of this method of assessing local and regional global changes and management was transferred to other parts of the world through collaborative involvement of LOICZ scientists with international capacity building initiatives by Intergovernmental Organisations (IGOs). Companion work (Wilson et al.2004) revised and extended the values for the world's ecosystem goods and services, earlier estimated by Costanza et al. (1997).

These efforts were not only individually productive, but complementary and convergent in both methods and results. A final, more rigorously integrative evaluation of coastal zone functions in the global context remains the major challenge for the second phase of LOICZ (*http://www.loicz.org*). The results and relationships summarized in this chapter lay out the new framework and starting point.

5.3 Key Findings

LOICZ research has substantiated, and enhanced our understanding of, the critical importance of four principal issues concerning the sustainable human use of coastal areas and their ecological systems.

1. The coastal domain is the most dynamic part of the global ecosystem and the realm most subject to natural and anthropogenically-induced global change. The obvious trends over the last century, of increasing human population in the coastal lands and the allied pressures on coastal systems, will undoubtedly serve as a powerful catalyst for direct changes in the coastal zone and more broadly for Earth's systems.
2. At a global scale, coastal systems play a significant role in regulating global change. The concentration of population and inadequate planning and management of economic activities in coastal areas have a major influence on the health and productivity of all Earth's coastal systems. At a regional and local scale, there are specific actions that can be taken within the coastal realm to ameliorate anthropogenic influences on atmospheric, marine and terrestrial systems. However, there are limits to what can be achieved at a global scale through adjustments to policy, investment and management of human activities within coastal zones.
3. Coastal change cannot be studied or managed in isolation from river systems. Anthropogenic impacts on hydrological systems, sediment and materials fluxes and energy transfers within river basins have a far greater influence on coastal areas and on the resilience and stability of coastal systems than is commonly understood. It is therefore critically important to couple the management of human activities within river basin systems and management of human activities within coastal areas in order to:
   a avoid irreversible loss of the dynamic equilibrium that allows coastal systems to function and continue to help regulate global carbon cycles, material fluxes and energy budgets;
   b maintain the flows of renewable resources and environmental services that help to sustain human societies;
   c meet international standards of environmental conduct, such as control of marine pollution and conservation of biological diversity; and
   d reduce the rate of increase in vulnerability of human societies located within coastal regions to natural and human-induced hazards.
4. Although large river systems such as the Amazon and the Mississippi generate the major input of freshwater, energy and materials into the coastal and marine environment, it is the small- to medium-sized river basin systems that are more sensitive to human-induced and climatic influences on hydrology and material fluxes. For instance, the same town on a large river system/catchment has far less impact than on a small river system because of temporal and spatial scales as well as buffering capacity. The buffering capacity of large versus small systems is reflected in the time between change and when a response is found/observed, and in the magnitude of the response. A large system will show a slow response to land clearing, with a small increase in turbidity, whereas a small catchment will show a fast response and much higher increases in turbidity because downstream impacts of changing land use and changes in hydrology are much greater. In comparison to the large river systems, much less is known about these smaller rivers – how they are changing, the response of associated coastal systems and their role in global change.

5.3.1 The Coastal Domain

The Earth's coastal regions form the interface between the marine and terrestrial realms and are the focus of human-induced and natural global change. Physical, biological and chemical processes drive land–ocean interactions that result in a series of unique coastal habitats adapted to strong terrestrial and/or marine forcings. Human societies have developed a strong dependence on the natural resources and products available from these ecosystems.

Coastal processes and natural ecosystems are subject to changes which vary greatly in geographic scale, timing and duration and lead to very dynamic and biologically productive coastal systems that are vulnerable to additional pressures resulting from human activities. The sustainability of human economic and social development is vulnerable to natural and human-induced hazards as a result of our poor understanding of the dynamics of land-ocean interactions, coastal processes and the influence of poorly planned and managed human interventions.

There is mounting concern about the sustainability of human use of the coastal zone from degradation in ecosystems and habitats reducing the availability of resources and amenities. The LOICZ project developed new insights into how human dimensions and natural systems interact and are intimately combined in the various pressures on, and resultant state of, the coastal domain. However, it is apparent that existing tools and concepts for measurement and analyses are inadequate to meet the needs for understanding human–nature interactions. There is heterogeneity in the expression of pressures, changes and state of coastal systems and that limited comprehensive data and information are readily available and/or accessible at all scales of measurement. In particular, societal demands on the scientific community for information and knowledge to resolve management issues are increasing despite the relatively poor history of communication between science and users (Biesecker 1996, Kremer and Pirrone 2000). In such cases, participatory approaches in programme design, implementation and assessment can prove fruitful (Crossland 2000). Frequently asked questions relate to sustainability issues (e.g., How do we identify wise-use options?), planning and management approaches (e.g., How can we measure and predict impacts and changes?) and policy-related developments (e.g., What are the risks and vulnerability to change?). Answers to such questions are critical to the sustainable improvement of human economic and social conditions. Over the past decade, there have been major advances in our scientific understanding of the chemical, physical and biological processes that maintain the health, productivity and functions of coastal ecosystems that are vital in providing socio-economic goods and services for humankind. Methods and concepts for integrating information across disciplines also continue to be developed.

While our scientific knowledge of coastal zone processes has improved, there remain major challenges for assessing the impact of regional and global change across multiple temporal and spatial scales on the functioning of coastal ecosystems. At the local level these interacting challenges are fourfold:

- Identify, model and analyse *global changes* that affect a local coastal system, such as natural variability, climate change and associated changes in the hydrological cycle, and those due to changes in global economy/trade and policy.
- Identify, model and analyse *regional (trans-boundary and supra-national) changes* that are primarily the result of regional and national drivers and pressures in the coastal zone,
- Model and assess *regional changes* at the level of river catchments (e.g., damming, land use change) that affect the downstream coastal zone.
- Map existing *stakeholders interests and differences* in the perception of coastal values at regional scales – differences that need adaptation of management options to local social conditions, beliefs and attitudes.

Sustainable management and its supporting research have to take these interacting changes into account and this requires a holistic approach. In this holistic approach the coastal region is part of the catchment–coast continuum and part of a regional socio-economic framework, which is embedded in a global setting. Many studies have dealt with isolated aspects of this continuum and framework, while a few integrated studies have dealt with either coastal zone management or river catchment management. The various studies show significant differences in spatial and temporal scales.

The hydrological system that links atmospheric, terrestrial and ocean processes forms the fundamental organising framework for developing our understanding of such complex relationships and changes. The LOICZ programme has therefore given major emphasis to the use of river basins as a functional unit for examining both natural and human-induced changes and their effects on terrestrial, coastal and ocean systems.

5.3.2 River Basins: Assessment of Human-induced Land-based Drivers and Pressures

LOICZ adapted and used the Driver-Pressure-State-Impact-Response (DPSIR) framework to illustrate the dominant pressures and effects on the global coastal realm.

The drivers and pressures on coastal systems that we observe and measure are now predominantly the result of societal function and human behaviour and may be amenable to management and policy decisions (response) in specific situations. In the first instance, small to medium-sized and relatively undeveloped catchments may offer a greater opportunity to modify policies, infrastructure investment and land-use and resources management as intervention will probably be less constrained by cross-boundary issues than would highly developed catchments of major river systems. Further, it is increasingly apparent that the forcing on coastal ecosystems by most natural drivers and pressures is being greatly modified in both extent and intensity by human activities. The characteristics of the LOICZ-Basins studies can be summarised as:

1. Predominantly founded on qualitative data and information gathered through a series of regional workshops, which developed "expert" typologies wherein quantitative thresholds associated with Driver-Pressure-Response parameters have been estimated.
2. Confirming the importance of human-induced changes to land cover, hydrology and material fluxes compared with the effects of cyclic climatic and tectonic events.
3. Creating a mechanism for an overview of human-induced changes in river catchments and their effect on coastal systems.
4. Showing that scale issues related to institutional and biogeochemical parameters are highly variable at both local and regional levels.
5. Having current management practices which are strongly focussed on only water resources issues that hinder the adoption of more integrated management approaches based on consideration of water in a wider goods and services context. Such a strategy would integrate hydrological and material fluxes into policy, investment and resources management strategies and plans, and institutional structures.
6. In a data-rich situation, it is possible to demonstrate that participatory approaches to the integration of science and management can enrich problem definition and the development of pragmatic and effective management of coastal systems use based on the continuum from catchment through to coastal ocean systems. Scenario development is a primary tool to foster such integration.
7. Having identifiable trends and factors that influence progressive change. One example is the periodic flushing of agricultural chemicals into an estuary resulting from major storms. This creates a change in the nutrient fluxes over time and will influence biological production in the estuary and adjacent coastal waters. While such events can be monitored in a discrete time frame, the period over which land management practices or agricultural policies will change to mitigate such events will extend over a far longer time-scale.

An example of the relevance of these findings to the policy arena can be seen in consideration of the European Union's Water Framework Directive (Text Box 5.1).

Where change impacts coastal systems that do not have an inherent inertia to the change imposed upon them from changes in the catchment basin, change cannot be studied or managed in isolation, because it is caused by human activities that are predominantly land-based. Examples include damming that reduces the supply of sediment resulting in major changes in the stability of coastal systems, such as a coastline shifting from an accretionary to an erosional state. Changing land use, for example deforestation, can increase erosion and sediment delivery as agricultural soils are more prone to erosion compared with forested ones. Changing land use can also increase the supply of nutrients, with some time-delay due to the buffering effect of soils after the land-use change occurs. The nature of land-based activities and their impact on the coastal zone may go through a cycle that reflects the industrial landscape and regulatory efforts (Fig. 5.1).

The DPSIR framework adopted by LOICZ has been successfully used in scoping and ranking pressures and drivers within river basins across continents. The overall trend of the drivers affecting coastal seas indicates an accelerated catchment-based influence on coastal zones and their functioning within the Earth's system. Although pressures and drivers are similar between basins, notable differences exist at the large-scale regional level with regard to ranking as well as future trends. Damming is considered an over-riding issue on the African continent; it is also an important issue in other countries, but less so than eutrophication. The main causes of increased

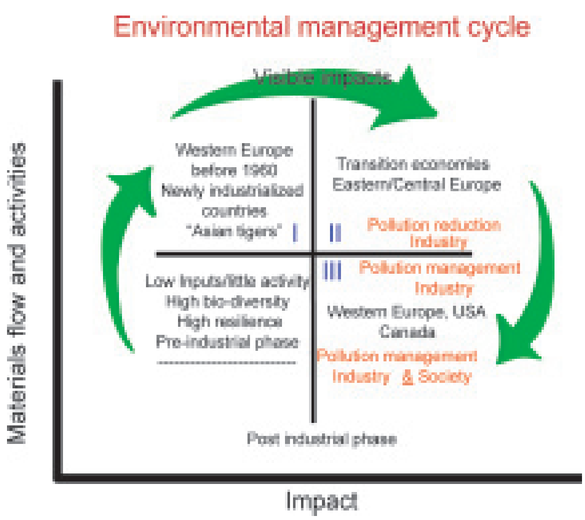

Fig. 5.1. Linkages between governance, economic development and global change in the coastal zone (from Salomons et al. 1995)

Text Box 5.1. An example of policy response at catchment scale: the European Union Water Framework Directive

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Given the generally large fluxes of nutrients and contaminants from catchments, any policy response seeking to improve coastal water quality should target activities at the catchment scale. One example of such integrated catchment-coastal zone management policy is the recent European Union Water Framework Directive (WFD), adopted in June 2000. The new directive integrates previously existing water legislation, updates existing directives according to new scientific knowledge and strengthens existing legal obligations to ensure better compliance (Kaika and Page 2002). Earlier legislation on water had gone through two distinct phases (Kallis and Butler 2001, Kaika and Page 2002). The first one (1975–1987) was primarily concerned with public health and setting standards for water quality for different uses (drinking, fishing, shellfish and bathing). In the second phase (1988–1996), priorities shifted towards pollution control, in particular for urban wastewater and agricultural runoff, with an effort to set emission limit values for different pollutants in water bodies. The third phase, which saw the birth of the WFD, came after a state of the environment report showed that these policies had been effective in terms of reducing point-source pollution, but that diffuse pollution remained a major problem (EEA 1998, Kaika and Page 2002). The new Directive is an attempt at more integrated and sustainable water management, expanding the scope of water protection for the first time to all waters, from surface water to groundwater, and from freshwater ecosystems to estuaries and coastal waters. It encapsulates the new directions in European environmental policy institutionalised in the Maastricht Treaty in 1992 and further reinforced by the Amsterdam Treaty in 1997. The Member States agreed to the objective of sustainable development as a Community policy, to the Community responsibility for environmental policy within the limits of subsidiarity, and to the integration of environmental policy into other community policies. More specifically the precautionary principle, the principle of prevention of pollution at source and the polluter-pays principle were all adopted (Barth and Fawell 2001).

Kallis and Butler (2001) point out that the directive introduces both new goals and new means of achieving them (i.e., new organisational framework and new measures). The overall goal is a "good" and non-deteriorating "status" for all waters (surface, underground and coastal). This includes a "good" ecological and chemical quality status for surface water. Ecological status involves criteria for assessment divided into biological, hydro-morphological and supporting physico-elements for rivers, lakes, transitional and "heavily modified" water bodies. For groundwater, the goal is a "good status" defined in terms of chemical and quantitative properties. A principle of "no direct discharges" to groundwater is also established, with some exemptions (e.g., mining). In addition, "protected zones", including areas currently protected by European legislation such as the Habitats Directive, should also be established, with higher quality objectives.

Organisationally, measures to achieve the new goals will be co-ordinated at the level of river basin districts, i.e., hydrological units and not political boundaries. Authorities should set up River Basin Management Plans, to be reviewed every six years, based on identifying river basin characteristics, assessing pressures and impacts on water bodies and drawing on an economic analysis of water uses within the catchment. Monitoring is also an essential component, determining the necessity for additional measures. Finally, an important innovation of the Directive is to widen participation in water policy-making: river basin management plans should involve extensive consultation and public access to information.

Following the DPSIR terminology, the main "response" element of the WFD is the program of measures (Fig. TB5.1.1). "Basic" measures should be incorporated in every river basin management plan, at a minimum including those required to implement other EU legislation for the protection of water. If this doesn't suffice to achieve good water status additional measures should be introduced following a "combined approach", which brings together the two existing strategies of Environmental Quality Standards (EQS – the legal upper limits of pollutant concentrations in water bodies) and Emission Limit Values (ELV – the upper limits of pollutant emissions into the environment). ELVs are applied first, through the introduction of best available technology for point source pollution, or best environmental practice for diffuse pollution. If this is not enough to reach EQSs, more stringent ELVs must then be applied in an iterative process. Furthermore, Member States should follow the principle of full cost recovery of water services, ensuring that water pricing policies are in place to "provide adequate incentives" for efficient use of water.

Although some aspects of the WFD are specifically adapted to the European situation, some key principles could usefully be considered as a template for other areas of the world. In particular, the principles of ecosystem-based water policy, cost-recovery, administrative management at the scale of river basins and stakeholder participation are all elements of integrated water management that could usefully be considered elsewhere. However, the information and scientific knowledge required within the Directive are very significant, already posing major challenges to scientists in the European Union (Ledoux and Burgess 2002, Murray et al. 2002). Furthermore, administrative and institutional reforms needed for successful implementation of the Directive will involve significant costs in many European countries (Kallis and Butler 2001). This might be a significant barrier towards implementation in less-developed countries where administrative, institutional and information-gathering costs could be even higher. Humphrey et al. (2000) also note that although the new directive provides an integrated approach to river basins associated to coastal waters, any sustainable coastal management policy would need to take a wider geographical perspective, as physical, ecological and socio-economic influences of and on the cost go further than the narrow strip considered. The new EU communication on Integrated Coastal Zone Management: a Strategy for Europe (COM/00/547 of 17 Sept. 2000) is a step towards a more comprehensive coastal zone management policy.

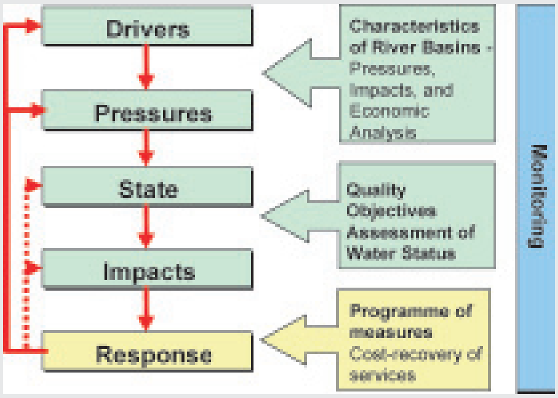

Fig. TB5.1.1. DPSIR framework and WFD tasks

inputs of nutrients are urbanisation and agriculture in South America and Asia. However, in Europe where effective sewage treatment is widespread, agriculture is the main cause of coastal eutrophication. In certain areas of Europe, regulatory efforts have decreased phosphorus release and this decrease has caused, or is expected to cause, a change in the ecosystem, affecting fisheries yields negatively. Thus, the success of regulatory efforts has caused environmental changes that were not anticipated by the general public or the fisheries sector.

In terms of major pressures on the coast, contaminants and industrialisation received in most cases a low ranking, with the exception of the Russian Arctic where large-scale nuclear industries have caused an input of radionuclides into rivers and the Arctic seas.

The global inventory of pressures on the coastal system has clearly shown that many of the drivers are outside the influence/jurisdiction of the local coastal manager; in particular, the economic activities within catchments that have a pronounced influence on the coast. The regulatory frameworks the coastal manager has to implement are rarely related to the regulatory frameworks that exist at the catchment level. The "airshed" also needs to be taken into account as atmospheric deposition is a more important input of nutrients and pollutants than in the past and crosses different boundaries than does the watershed. There is clearly a mismatch between these regulations and the scientific approach, which considers the catchment and the coast as a continuum.

Other examples of pressures outside the realm of the coastal manager's responsibility include those related to transport (shipping), for example, the introduction of exotic species and the use of toxic chemicals for antifouling on ships. Regulatory measures in these cases have to be taken at the global level.

Clearly outside the sphere of influence of the local manager are the effects of global change, such as sea-level rise and increased frequency of storm events. In addition, global change affects the catchments through alteration of the hydrological regime, migration of population and changing patterns in global trade, which in turn affect the nature of economic activities in the coastal zone and in the catchment.

5.3.3 Material Fluxes

The dynamic processes acting on coastal zones are impacted by human influences acting on upland water resources and changing the timing, flux, and dispersal of water, sediments and nutrients. These influences include:

- Changes in the timing of when water is transported to the coast by reservoirs constructed for electrical power generation and flood mitigation, or entire water diversion schemes.
- Changes in the amount of water transported to the coast due to water use for urban development, industry and agriculture.
- Regional decreases in the delivery of sediment to some coasts resulting from trapping within reservoirs, barrages and other water and erosion control structures.
- Regional increases in the delivery of sediment to some coasts resulting from increased soil erosion associated with agriculture, construction (urban development, roadways), mining and forestry operations.
- Changes to the flux rates and loading of nutrients to the coast (e.g., from storing of carbon in sediments of reservoirs, elevated nitrogen fluxes from agricultural activities).

The consequences of these human impacts on the Earth's coastal zones are:

- loss of ecosystem health and diversity;
- reduced vitality of coastal wetlands, mangroves, seagrass beds and reefs;
- reduced production of renewable resources, including environmental services;
- impacts on coastal stability, biostability and shoreline modification;
- changed residence time of contaminants and changed sediment grain size; and
- changes to the dispersal area and plume intensity of particulate loads from rivers.

5.3.3.1 *Impacts of Local, Regional and Global Sea-level Fluctuations*

The last decade has seen an increase in the accuracy of global sea-level measurement with new techniques (e.g., satellite altimetry and geodetic levelling). The historic record of sea-level change interpreted from tide-gauge data shows that the average rate of sea-level rise was greater in the 20th century than in the 19th century. The raw tide gauge data need to be corrected for local and regional influences either with modelling calculations or directly by geological investigations near tide-gauge sites. The estimated mean sea-level rise based on tide-gauge records for the 20th century have been in the range of 1–2 mm yr^{-1} with a central median value of 1.5 mm yr^{-1}.

Current scientific projections of sea-level rise are within a range of 0.09 to 0.88 m for the period 1990 to 2100 with a central value of 0.48 m. The projections could vary by as much as –0.21 to +0.11 m if current rates of terrestrial storage of sediments continue. Irrespective of the local variability resulting from the interaction of sediment supply and coastal erosion processes, achievement of an average sea-level rise of 0.48 m by 2100 would require a greatly accelerated rate (2.2 to 4.4 times) in sea-level rise compared to that of the 20th century.

There is still a need for better information on local and regional sea-level change and more accurate prediction of their impacts. An important element of sea-level change research is the need to improve prediction of impacts on different types of coast, such as rocky coasts, sandy coasts, deltaic coasts, tropical coasts and low latitude coasts. Many of these are already eroding (e.g., sandy coasts), but new threats are appearing in areas such as the Arctic coast, where changes in the extent of sea-ice have in places produced a different wave climate and consequent coastal impacts.

It is equally important to place present and predicted sea-level changes into their geological context in order to provide a perspective on the cyclical nature of sea level and the extent to which present and predicted changes are perturbations from natural cycles, particularly the 100 000 year glacial/interglacial cycles. The geological record also shows that there has been a globally variable but predictable coastal response to the sea-level rise following the last glacial maximum. In addition, recent geological research shows prospects of linking geologically recent records of the last 2 000 years with sea-surface temperatures and regional climate change.

Our ability to assess the scale and rate of change to coastal systems associated with relative sea-level rise is limited, and there is a need to refine and upscale regional vulnerability assessments. Improvement to our ability to conduct such assessments will enhance decision-making concerning an appropriate combination of the three options for intervention: retreat, accommodate or protect.

5.3.3.2 *Sediment Flux to the Coast*

The sediment load delivered by the Earth's rivers has a major influence on the dynamics of coastal change. Ocean energy (tides, waves, currents) reworks river-supplied coastal sediment to form and maintain our varied coastlines: estuaries, beaches and deltas. If the sediment supply from the land is reduced, then ocean energy will begin to relentlessly attack and erode shores, driving the coastline inland.

Climatic shifts are often the major factor driving sediment flux. Large continents are influenced by a number of climatic phenomena operating over different time periods. Individual regions may respond quite differently to climate forcing, which will depend on the duration of the climate fluctuation and the variability in spatial properties of such parameters as relief, geology and hydrological processes. As one example, an increase in the frequency and intensity of El Niño events will increase the supply of sediment to local coastal areas at a sub-global scale – in different hemispheres and different continents.

Human activities have substantially increased the continental flux of sediment during the last two millennia from changes in:

- land-use practices that have increased soil erosion (e.g., agriculture, deforestation, industrialisation, mining),
- practices that have decreased soil erosion, including engineering of waterways, and
- the trapping and retention of sediment by reservoirs and rivers.

Most of the sediment eroded off the land remains stored between the uplands and the sea. Retention of sediment in large reservoirs constructed during the last 50 years has decreased the global flux of sediment to the coastal zone by 30%. This is likely to be exacerbated by the increased development of small impoundments at the farm scale, as management responses for erosion control and matter storage (Smith et al. 2001). Because lower sediment loads are reaching the coast, shoreline erosion is accelerated and coastal ecosystems deteriorate with a corresponding change (including reduction) in local fisheries yields. The coupling of increased nutrient inputs and decreased sediment loads (e.g., the Nile which is now nutrient-enriched due to fertilisers and wastewater although sediment loads are reduced because of the Aswam dam) may promote coastal-zone eutrophication and hypoxia.

5.3.3.3 *Dynamics at the Estuarine Interface*

The amount of sediment in motion and the length of time it is retained in coastal systems such as estuaries and deltas is unknown. Geomorphic processes are the most important single factor controlling the residence time for sediments in the coastal zone. The interactions between geomorphology and advective processes are non-linear, making the prediction of the fate of sediment input into coastal areas difficult, across both short and long time-periods.

In many countries in the wet tropics intense rainfall, coupled with deforestation, land clearing, overgrazing and other poor farming practices, has considerably increased soil erosion and sediment flux. For tropical estuaries and coastal seas, environmental degradation due to increased sedimentation and reduced water clarity is a serious problem.

In contrast, developed countries in mid-latitudes have estuaries that are generally suffering from sediment starvation due to extensive damming and river-flow regulation. Sediment retention by dams leads to accelerated coastal recession (e.g., deltas of the Colorado, Nile, Ebro, Mississippi and Volta rivers; Text Box 4.10), as will soon be the case for the Yangtze River in China. Water diversion schemes also accelerate coastal erosion.

5.3.3.4 *Groundwater Inputs*

Subterranean and sub-seafloor fluid flows in the coastal zone have a significant influence on sediment and nutrient fluxes, and can be a source of biogeochemically important constituents including nitrogen, carbon and radionuclides. If derived from land, such fluids provide a pathway for new material fluxes to the coastal zone and may result in diffuse pollution in regions where groundwater is contaminated.

5.3.3.5 *Management Implications*

Greater attention should be given to the contribution of human activities and natural processes acting on catchments and the resulting fluxes of energy, water and sediment reaching coasts. Reduction of sediment inputs to coastal systems combined with relative sea-level rise will increase the vulnerability of coastal areas, together with associated human activities and corresponding private and public investment, to natural hazards such as flooding, storm over-wash, erosion and salinisation of surface and ground waters. In many humid regions, increased intensity and periodicity of surface water flows and rates of soil erosion can lead to accelerating risks of riverine flooding, rapid accretion of coastlines and degradation of coastal systems through siltation. Human-induced changes to material and energy fluxes will also have an adverse influence on primary and secondary biological production and the ability of coastal ecosystems to sustain demands for renewable natural resources.

Given the high rates of sediment retention associated with the damming of rivers and flood control structures and the corresponding negative effects on coastal systems, thought should be given to the managed release of trapped sediments to help achieve a better balance between erosion and accretion processes within estuarine-nearshore coastal systems. Conversely, increased soil conservation and reduction of sediment loads in humid regions may help to reduce the negative effects of increased siltation rates.

A distinction should be made between natural coastal vulnerability and vulnerability of human lives and property that may be at risk from the effects of climate change, changes in the sedimentary budgets of coastal systems and sea-level rise. In many cases, poor coastal planning results in the need for rapid and expensive adjustment to the consequences of sea-level change. However, there is a need for a better understanding of local sea-level change, in addition to adopting a precautionary approach, in planning for the consequences of the predicted global sea-level rise.

Greater attention should also focus on groundwater inputs to coastal systems. Groundwaters typically have higher concentrations of dissolved solids than most terrestrial surface waters. Submarine groundwater discharge (SGD) often makes a disproportionately large contribution to the flux of dissolved constituents, including nutrients and pollutants. In addition, discharging groundwater interacts with and influences the recirculation of seawater, which can affect coastal water quality and nutrient supplies to nearshore benthic habitats, coastal wetlands and breeding and nesting grounds. One of the more important implications for coastal zone managers is nutrient (or other solute) loading to nearshore waters. Amelioration of impacts in the coastal zone from these inputs could be the basis for improved land-use planning and may place limits on development.

Managers should have increased awareness of the relative relationships and priorities of SGD among the multiple factors considered in coastal management activities. This requires modifications in the current approaches for studying groundwater discharge so that:

- The scale of emphasis becomes that of management areas – probably tens to hundreds of kilometres. Currently, scientists are typically performing investigations at the lower end of this scale (although some tracer investigations work at scales of 10–100 km).
- Scientists may study one area for years, often reflecting the typical 2–3 year grant cycle. Managers, on the other hand, will have need for relatively simple and rapid diagnostic and assessment tools to evaluate local importance and management issues related to SGD in specific settings. The concerns could be either natural processes or human activities.

5.3.4 Biogeochemical Budgets

The LOICZ biogeochemical budgeting effort updated the estimates of dissolved inorganic nutrient (N, P) loading to the ocean, including revised estimates for geographic distribution of that loading and the load response to human population and runoff. These estimates are substantially higher than those of Meybeck (1982) and somewhat elevated above the estimates by Meybeck and Ragu (1997), as shown in Chap. 3. Also, the new estimates contain values for inorganic nutrient load to the ocean under "pristine" or pre-human impact conditions. While direct updates of dissolved organic nutrients or particulate nutrients are not provided, the following general observations can be made:

- globally, inorganic nutrient loads seem likely to have changed the most; this is consistent with earlier estimates by Meybeck and others; and
- although it might be expected that greatly elevated erosion would have increased particulate nutrient delivery to the ocean (based on analyses of the USA; Smith et al. 2001), this seems not to be the case for particulate material in general. Apparently most particulate erosion products have been retained in river channels and impoundments.

It can be argued that the changed inorganic nutrient loading has little impact at a continental shelf scale.

This is based on the loading for the ocean as a whole, where cycling between the deep ocean and surface ocean (for both N and P) and between the surface ocean and the atmosphere (for N) are far larger than can be accounted for by the nutrient load from land. This suggests that, apart from some small but significant fraction of these internal cycling exchanges between the continental margin and the open shelves, the terrestrial load generally is probably not significant at the scale of the continental shelves, excepting some specific examples, such as Mississippi River and adjacent continental shelf.

This does not imply that the terrestrial load is not important or that shelf cycling is not important in the global ocean nutrient cycles. Rather, the argument is that the importance of the shelf is largely felt at a local scale, especially in bays, estuaries and inner shelves. These small-scale features are the "first line of defence" against the delivery of products to the ocean – under both pristine and Anthropocene conditions. Particulate materials tend to sediment near the sites of their delivery to the ocean, and reactive dissolved inorganic materials tend to react there. Some dissolved nutrients, however, may be taken up and regenerated several times close to the source or at much greater distances following dispersal by currents. The strong negative log-log relationships seen between the absolute rates of the non-conservative fluxes and either system size or system exchange time argue that the most rapid rates of net material processing occur inshore. Integration of either the "raw" non-conservative fluxes of ΔDIP and ΔDIN or the derived fluxes of $[p - r]$ and [nfix – denit] suggests that these rapid, small-system inshore fluxes dominate global shelf fluxes i.e., size matters. Internal cycling exchanges within estuaries and nearshore marine areas are thus very important with respect to river basin and coastal zone management.

The scale of analysis used in the LOICZ biogeochemical approach confirms our previous understanding of the coastal zone as a source or sink of CO_2 (see Smith and Hollibaugh 1993). More organic matter is delivered to the ocean than is buried there. About half of the organic matter delivered to the ocean is particulate, and most of that apparently sediments near the point of delivery. Some dissolved organic matter apparently reacts with particles and probably also settles in the nearshore region. Other dissolved organic matter does not have this fate; it is apparently decomposed via a combination of photo-oxidation and microbial processes. More than half of the organic matter delivery is oxidized somewhere in the ocean, with about 7×10^{12} mol yr^{-1} of net oxidation in the coastal zone and 16×10^{12} mol yr^{-1} in the open ocean.

There are, however, two aspects of this analysis of carbon flux that bear elaboration. In the first place, comparison of estimated coastal and open ocean net primary production estimates of 500×10^{12} and $3\,000 \times 10^{12}$ mol yr^{-1}, respectively, indicates that the coastal ocean is substantially more heterotrophic (production/respiration ratio = 0.97) than the open ocean ($p/r = 0.998$). In the second place, the apparently slight net heterotrophy of the global ocean ($p/r = 0.994$; $[p - r] = -23 \times 10^{12}$ mol yr^{-1}) is an important part of understanding oceanic function and linkage to the slightly autotrophic land. However, this net heterotrophy is quantitatively insignificant in the oceanic role as a sink for anthropogenically generated CO_2. That sink strength is about 10 times the source strength of net oceanic heterotrophy and is (globally, on the 150-year time scale over which humans have significantly perturbed this flux) dominated by atmospheric partial pressure and the physical chemistry of seawater. Clearly, on longer time-scales the so-called biological pump and continental shelf pump are influenced by biogeochemical processes in both the open ocean and the coastal ocean.

5.4 Now and into the Future

The inter-relationships among the thematic studies described above can be simplified as follows:

- Material fluxes of water and sediment are the vectors for the nutrients and carbon, and the controls on the exchange times determine the nature and products of the biogeochemical "reactors" formed by estuaries and coastal systems.
- These fluxes are controlled by the natural features of landscape and climate, but are substantially modified by human activities – the focus of the LOICZ-Basins effort.
- Ultimately, more accurate quantification and up-scaling of coastal biogeochemical processes, as well as prediction or management of possible changes both regionally and globally, will involve merging the disparate understandings of the fluxes and their natural and socio-economic controls.
- The coastal budget systems are the natural common focus of these efforts, as shown by initial successes in describing nutrient loads to the coastal zone as functions of runoff and population and by the difficulty of predicting the effects of these loads on coastal systems, both in specific regions and globally.

An illustrative example of integrative linkages between components of LOICZ research is the coupling of land-ocean interactions between specific types of terrestrial basins and coastal configurations. An observation emerging from the biogeochemical budget studies, supported by findings from the material flux studies, is that there are qualitative differences between the functioning of large and small coastal systems and, similarly, between the large and small drainage basins that discharge their fluxes to the reactive inner-shelf zone of the coast. Large-basin fluxes, although quantitatively dominant on a cumulative global scale, directly influence only a minor part of the length of the world coastline.

In addition, there is a similar socio-economic/human dimension dichotomy between the large and small basins. Coastlines that have catchments that are compact enough for social and economic interaction between the nearshore and the more inland inhabitants (so that the entire unit is likely to be contained within the same national or sub-national political or administrative jurisdiction), present qualitatively different needs and opportunities for coastal zone management compared to those where the coast and the hinterland are socio-economically or politically decoupled. Since the former arguably account for more of the coastline, it is important that the visibility of the larger basins is not allowed to divert attention from the quantitative coastal importance of the distinctive smaller catchments.

Another conceptually integrative factor is the issue of coastal exposure and complexity. In Fig. 5.2, red boxes indicate some of the regions where river basins (large or small) discharge into waters that are protected from direct or rapid exchange with the open ocean by barrier islands or deep, complex estuaries and embayments. These environments strongly condition the fluxes of water and sediment in the marine environment that are reflected in the exchange, or residence, time – shown above to be one of the important characteristics of the coastal biogeochemical "reactor" system.

5.4.1 River Basin Factors

New institutional arrangements will be required for the coastal zone to foster inter-sectoral cooperation, coordination and eventual integration of policy, investment, plans and management arrangements to make full use of the results of the emerging scientific knowledge. These can help to improve the sustainability of use of coastal areas and resources while avoiding increased vulnerability in such uses to natural hazards. Development of participatory partnerships between the natural and social sciences and the users of scientific knowledge will be critical to future progress from both a scientific and a management standpoint. Consideration of drivers and pressures requires exploration of the differences in perceptions held by various groups of stakeholders. Often cultural differences lead to separate perceptions of coastal values and hence the "acceptable" or "consensus" management options will require a regional-historical perspective.

The impact of local civil strife and warfare on the coastal system is often insufficiently addressed or unknown. Examples where impacts have been observed are in the Arabian Gulf (after the first Gulf war) and in Nigeria, both cases involving major oil pollution. Delay times between changes and the impact of drivers and pressures, and the potential for a non-linear response of the coastal system (e.g., geomorphologic change, ecosystem change) are recognised, but quantitative information to allow predictive modelling is lacking.

5.4.2 Material Fluxes

A major finding of the LOICZ research is that the influence of humans and/or climate affects smaller river basins more dramatically than larger river basins, due to the modulating capacity of large rivers. Therefore, new techniques must be developed to address the coastal response in these sensitive smaller systems. Scaling techniques must also be employed to address the quality and usefulness of our global databases, since:

1. most of the observational data was determined across only a few years (and intra-annual variability can exceed inter-annual variability by an order-of-magnitude), and
2. observational data sets are already a few decades old during a time of rapid change resulting from human impact. Information on groundwater is a case in point.

Additional data collection describing groundwater dynamics is required in many areas, especially in South America, Africa and southern Asia, where, to our knowledge, no assessments are currently available in the literature. We recommend an approach that targets representative types of coastal aquifers based on geology (e.g., karst, coastal plains, deltaic) and environmental parameters (e.g., precipitation, temperature). The production of a SGD database and globalisation efforts are necessary to understand controls and changes in SGD on broad sub-regional and continental scales.

Improvements must also be made to techniques used for measurements of SGD, including: the development of new non-invasive methods, measuring and sampling strategies in permeable sea beds, modelling of the different transport processes and their effects on biogeochemical cycles and the development of new dynamic models to explain the porewater flow observed in natural environments.

Management of SGD in coastal areas requires greatly improved knowledge about the importance of hydrological flows. Since SGD is essentially "invisible," the problem that arises from both a management and scientific standpoint is determining how to avoid the error of ignoring an important process or wasting valuable resources on an unimportant issue. Where SGD is a significant factor in maintaining or altering coastal ecosys-

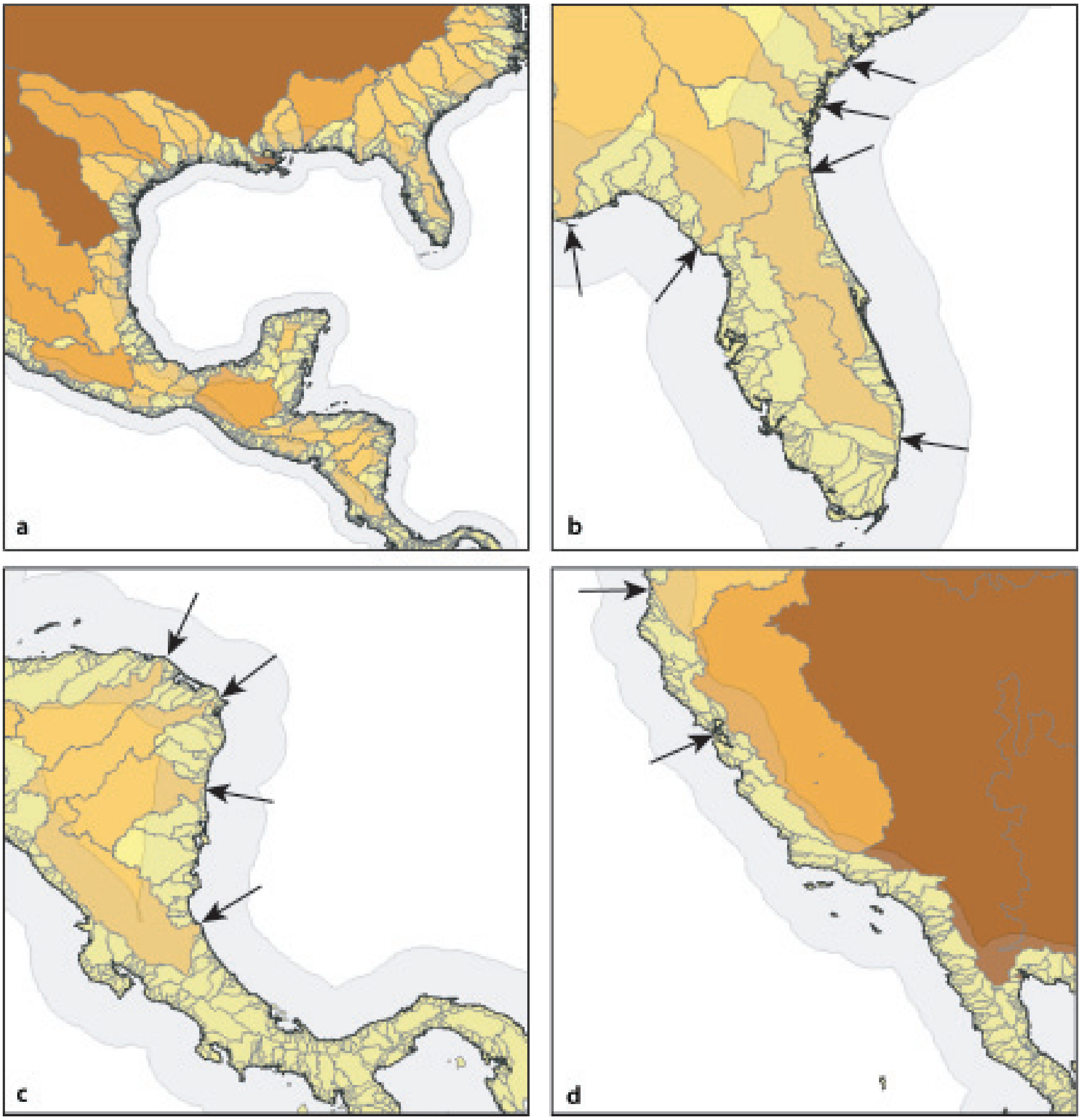

Fig. 5.2. River basins from the coasts of the US and Central America. The transparent grey is a 100 km buffer around the coastline, indicating the approximate extent of the coastal zone. Yellow basins represent those less than 10 000 km^2 in area – the approximate dividing line between "small" and "large" basins. In (**a**), small coastal basins appear numerous, but far from continuous. A close-up view in (**b**) brings the smallest coastal basins into view, and shows how much of the coastline is without the large basin discharges indicated by arrows (e.g., three in all of peninsular Florida). Similarly, in (**c**), it can be seen that the isthmus of Central America contains only small basins – a feature common to many islands and peninsulas. (**d**) shows part of the west coast of Mexico and the US; there are only two large basin discharge points between the tip of Baja California (not shown) and southern Oregon. Many extensive reaches of coastline are dominated completely by inputs from the functionally distinctive smaller basins

tems (terrestrial, estuarine or marine), coastal zone managers will need to consider management of water levels and fluxes through controls on withdrawal or alterations in recharge patterns, as well as groundwater quality management (e.g., through controls on land use and waste disposal). Such major interventions require a sound scientific justification and technical understanding that does not currently exist.

5.4.3 Biogeochemical Budgets

A major challenge in enhancing scientific knowledge and its use for informing management is the issue of spatial heterogeneity and the choice of appropriate scales to use in analysing biogeochemical processes and budgets. It is obvious that with decreasing system size comes increasing heterogeneity among systems. The ocean as a whole is a large system in which most metabolism is accomplished by plankton with relatively rapid biotic turnover rates. Smaller systems in the coastal zone are locally dominated by plankton, benthic micro- and macroalgae, seagrasses, coral reefs and mangroves. These systems differ greatly between one another, and they respond very differently to perturbations. Generalising globally therefore demands that each system type be adequately represented at an appropriate scale for data analysis.

Several other challenges are associated with methodological issues. The first issue involves scaling. Because large systems tend to have longer water exchange times, this can be considered a scaling issue in both space and time. Any budget or inventory approach to assessing the function of aquatic ecosystems needs to deal with two broad classes of material transfer: physical transfer and biotic cycling. As a generality, the physical transfers have a wide dynamic range at small scales. For example, water flow can vary from near stagnant to meters per second (a range of orders of magnitude). As scales get larger, the accumulated physical transfers are smaller – large transfers in one direction tend to be balanced by transfers in the other direction. This balance is required to conserve mass. At small scales, biotic transfers tend to have a much lower dynamic range and these processes also tend to balance at larger scales. However, with an increase in scale, the ability to see small effects of biotic processes grows. More information is needed for small, active systems with short water exchange times while recognising that these systems tend not to yield robust estimates of fluxes.

A second methodological issue concerns the use of ΔDIP as a proxy for organic carbon metabolism. This clearly works in some – but not all – systems. In particular, other reaction pathways, notably sorption and desorption of DIP with respect to sediment particles, interfere with the proxy. This is a particular problem for systems with high mineral turbidity. Yet reliable data simply do not exist to develop a large number of budgets or inventories based on carbon. Either an alternative approach must be found or methods must be developed to modify the DIP budgets.

A third methodological issue involves extrapolation from a relatively small number of budget sites to the global coastal zone. We have used a powerful geo-statistical clustering tool (LOICZView) and data available at a grid scale of 0.5 degrees (areas > 2 000 km^2 for much of the globe). This grid scale is largely dictated by the available spatial data. On land, because most features are both spatially fixed and readily visible, global resolution to 1 km is available for many variables. In the ocean, resolution of geo-spatial data is hampered by the more rapid dynamics of water movement, the limited ability to see and thus describe subsurface features, and the importance of largely invisible chemical characteristics of the water. Most available spatially distributed information is at scales well in excess of 1 degree and interpolated to smaller scales. It is therefore impossible to use such coarsely defined data to extrapolate the characteristics of small coastal features. Some alternative approach must be found.

Successful extrapolation from the LOICZ biogeochemical budget data to the global coastal zone requires three classes of globally available data:

- data for that portion of the land delivering materials to a particular location (system or biogeochemical budget site) in the coastal zone,
- oceanic data adjacent to the system, and
- oceanic data for that system.

For land, data can be obtained from highly resolved remote sensing data. These data can be re-sampled at the scale of the budget system watershed, or catchment, i.e., at a more natural or functional scale than the 0.5 degree grid. Process-based regression models of material fluxes could then be developed for the budget catchments and then extrapolated to the generally coarser and more artificial catchments defined by the 0.5 degree grid. Both the lack of an objective oceanic functional unit equivalent to catchment basins and the crudeness of the oceanic data have so far precluded an equivalent analysis for either the budget systems themselves or the ocean region exchanging with any particular system.

It is clear that there are subject areas that deserve further research and assessment based on collective experience gained by LOICZ. The first area concerns themes and methodological issues, which represent possible revisions or expansions of the LOICZ fundamentals. Additional issues concern the refinement of LOICZ software tools and support. Other possible gaps are (*1*) lack of large river budgets, treatments and actual determination of proportional influence, and (*2*) geographic coverage gaps, such as the North American continent including Arctic, the European Arctic and Central America.

5.5 The LOICZ Contribution

Drawing the outcomes of the LOICZ themes together, and considering the questions they raise, highlights some broad key outcomes from the first phase of LOICZ regarding impacts along the catchment–coast continuum:

1. Land use and cover change, directly or in adaptation to global forcing and related changing societal demands for space, food and water, are driving changes of material fluxes through river catchments to the coastal seas and cause state changes and system impacts.
2. Priorities of drivers and trends that can be expected to generate key coastal issues are urbanisation and increasing demand for water (river regulation) and food (agriculture/fertilizer use).

3. Advancement in mitigating riverine nutrient and contaminant loads to the coastal zone is being accomplished in certain areas such as Europe in time-scales of two decades following policy implementation that targets specific goals for point-source treatment.
4. Costs of "no-response" scenarios that exceed critical thresholds of system function and lead to habitat impact are evident in some sites and are likely to increase.
5. Most of the global coastal zones affected by river input from small and medium-sized catchments are lacking the scientific understanding of catchment coast interaction dynamics and scales as well as the institutional underpinning to cope with increasing pressures.
6. Small and medium-sized catchments and in particular small and low lying island-dominated areas frequently feature the extreme end of DPSI scenarios (e.g., population-density driven water demand and pollution), and there is little evidence for operational mechanisms to take scientifically based management action.
7. Tools and mechanisms to utilize the scientific understanding are available in some areas and are lacking in others. In particular the institutional dimensions of either scientific and management response have proven to be rather ineffective in many regional assessments. However, the key prerequisite to improving this situation is to apply a broad, full-catchment scale to the scientific, assessment and management aspects to adequately address the temporal and spatial complexity of the issues.
8. The overall trend expectation of the driver development affecting coastal seas indicates an accelerated catchment based influence on coastal zones and their functioning.

The key issues identified from the LOICZ work and the scientific framework that has been developed support evolving concepts of integrated management for terrestrial, coastal and marine systems. For example, the UN sponsored Global Environment Facility (GEF) Operational Programme No. 2 gives priority to "the sustainable use of the biological resources in coastal, marine and freshwater ecosystems." The European Union developed the Water Framework Directive that required integrated management strategies to be developed for river basin systems. This has been followed by a Recommendation to all Member States to develop integrated policies, management strategies and plans for the implementation of integrated coastal zone management. These examples illustrate the movement towards more integrated development planning and resources management and the corresponding need for enhanced scientific knowledge and frameworks of the kind LOICZ has been developing to help inform policy, management strategies and planning decisions.

The LOICZ programme also provides an ongoing, adaptive global synthesis that represents an evolving new approach to linking science and management. It has several features that allow it to function in this way, including:

- an adaptive approach to science and management,
- evolving questions,
- long term (ongoing) projects,
- a unique global network of participating scientists and others who have adopted the LOICZ methodologies, and
- ongoing, participatory synthesis to help prioritise future research needs and goals.

5.6 Implications for Management

The first phase of the LOICZ programme provided a valuable scientific framework for studying and integrating a broad range of factors that influence the dynamics of coastal systems and the human use of the resources derived from the functions of those systems. The individual thematic studies presented in the previous chapters have expanded our understanding of the transformation and fate of materials discharged into different coastal environments. While there are constraints imposed by limited understanding of natural variability in climatic conditions and the full impact of human-induced changes on water and material fluxes, *there is now sufficient understanding of these factors to develop new and more holistic frameworks for understanding how coastal ecosystems are responding to human pressures and how we can improve coastal management to respond to these changes.*

The key findings of the thematic studies and their implications for management are:

- *Coastal systems are important to the functioning of the Earth system.*

  Although the coastal zone is only 12% of the surface area of the Earth, coastal systems have been shown to be disproportionately important in the global cycles of nitrogen, phosphorus, and carbon. At local to regional scales, waste and load estimates have been derived, system metabolism has been estimated and tools and a data base of more than 200 coastal sites have been developed and made accessible through a dedicated public website (*http://data.ecology.su.se/MNODE*). Estimates of human pressures on material fluxes and changes in river catchments affecting the coastal seas have been derived at the continental scale for Africa and South America, at the sub-continental scale for Europe and Asia, and for small-island areas of the Caribbean and Oceania. Data and the resulting information and synthesis have been made publicly available (*http://w3g.gkss.de/projects/loicz_basins*). The improved management of human activities affecting material fluxes to and within coastal systems could therefore play a significant role in managing global material cycles and moderating the influence of climate change.

- *Investing in science and management of the coastal zone is highly worthwhile.*
  Coastal ecosystems are complex, productive and critical to human society, and are impacted differentially by human activities. LOICZ identified and quantified the vulnerability of coastal systems to global change impacts. Differences between un-impacted and impacted coastal ecosystems can be significant and can dramatically affect the provision of ecosystem services that support human welfare. The value of ecosystem services derived from the coastal zone is estimated to be large (US$ 17.5 trillion yr^{-1}) and under significant threat. A more certain scientific understanding of coastal processes can help to improve the management of coastal systems, reduce the vulnerability of human activities and enhance the sustainability of public and private investments. Therefore, investing in science and management of the coastal zone makes good economic sense.
- *A broad systems approach is necessary to effectively manage human activities in the coastal zone.*
  The coastal zone is dynamic at multiple time and space scales, but it is possible (at least to some degree) to separate the background "natural" dynamics from changes due to human activities. Resilience and adaptability to change at various rates in the biological and social components of the system are critical to their sustainability. To understand these impacts and to manage effectively the human activities in these systems, we need to adopt a broader "systems" perspective that integrates the interacting biophysical and social dynamics and the multiple temporal and spatial scales involved. To meet some of these needs, a typology system of the coastal zone was developed. Application of this approach also allowed us to understand the previously under-estimated influence of groundwater discharge on coastal systems.
- *Complex scientific information can be synthesized to inform and improve the management of coastal systems.*
  Synthesising the large and complex amount of data available about the coastal zone to address management issues is a daunting task that often hinders effective management. The DPSIR approach is a useful framework for enhancing stakeholder participation and organizing and synthesising knowledge about land-based fluxes and other information important to management of the coastal zone at regional and local scales. Regional/continental scale assessments are a useful complement to the DPSIR approach. The regional river-basin studies have identified a common list of drivers for river basins and have identified key differences in the relative importance of these drivers among regions. For example, the major influence (driver) in temperate climatic zones characterized by industrial development and urbanisation is eutrophication of estuarine and nearshore marine waters. For tropical river basins the main driver for coastal change is change in sediment budgets. For polar climatic zones, the main driver of change is change in climatic conditions. Therefore, the focus of management in each area needs to correspond to what are found to be the major drivers and influences. The DPSIR approach is also iterative, so that as the relative importance of specific drivers changes with time, these "new" conditions can be fed back into the cycle for re-analysis.
  Although there are major river systems discharging into the coastal zone, most of Earth's coastline is characterized by small heterogeneous systems that contribute disproportionately to carbon and nutrient budgets and have high potential to be influenced by human activities. Therefore, management to mitigate the impacts of human activities on small, semi-enclosed systems, as well as on large catchment systems, is an important objective.

5.7 The Future of LOICZ

The science of LOICZ has focussed on the measurement of biogeochemical fluxes into and within the coastal zone and shown these fluxes to be important and relevant to global environmental change (GEC) science because:

- biogeochemical fluxes of CO_2 and trace gases are the key variables for scaling up to global climate change,
- biogeochemical variables are the key constituents for connections across coastal boundaries i.e. from catchment to coast, from coast to ocean and from coast to atmosphere,
- biogeochemical fluxes include primary production, which underpins ecosystems and renewable resources,
- water and sediment quality determine distribution of key habitats and affect human amenity and use, and
- biogeochemical processes and cycles include key positive and negative feedbacks in coupled coastal systems, which determine thresholds and boundaries for system resilience.

5.7.1 The Future Challenges for LOICZ

From an initial investigation of process and of specific marine and terrestrial systems, LOICZ has arrived at a point of improved systematic understanding of the controls and influences on coastal fluxes. We can now look forward to the next steps to inter-calibrate and combine the results of the converging threads of understanding developed during the first phase of LOICZ. The recommendations below reflect the need and opportunities for advancing the process, recognising the multiplicity of processes, changes and forces (natural and human-driven) across the dynamic and heterogeneous global coastal zone.

1. *Integrated and multidisciplinary team approaches*. While often stated, there is imperative for *genuine* research collaboration among natural, social and economic disciplines. Existing global examples show clear knowledge benefits from such team interactions. New approaches are needed to assist team actions, such as the DPSIR framework, and "wiring diagrams" used in IGBP for the development of cross-cutting projects.
2. *Targeted research*. Thematic and programmatic research approaches as practised in "*post-Normal*" *science* (Funtowicz and Ravetz 1992, 1993, Ravetz and Funtowicz 1999) address the management of complex science-related issues by focusing on aspects of problem-solving that tend to be neglected in traditional accounts of scientific practice: uncertainty, value-loading and a plurality of legitimate perspectives. It provides a coherent explanation of the need for greater participation in science-policy processes, based on the new tasks of quality assurance in these problem-areas, and is an alternative approach to coastal zone research compared with the traditional, fragmented approach of task-based, disciplinary or sectoral efforts. Questions of different temporal and spatial scales need urgent consideration along with new tools for assessment and measurement across scales and within socio-economic research. A focus should be placed on understanding whole ecosystem functioning and forcing, vulnerability and risk, changing pressures, feedbacks and integration of forcings. Improved models (conceptual, numeric, deterministic, probabilistic) for top-down and bottom-up approaches are required. Efforts on socio-economic research need to be greatly increased.
3. *Synthesis and integration of information*. New scientific enterprise is always welcome but better use needs to be made of existing data, information and knowledge; bodies funding research need to shift policies in this regard. New tools, approaches and efforts should be exerted for the synthesis of scientific data into information and knowledge, and outcomes need to be made accessible to users and the community. Along with further concerted effort to engage with users, science programmes should include a clear strategy for communication and delivery of information.
4. *Regionality*. Thematic projects, synthesis and integration should be directed to assessment at regional scales to more fully understand the tapestry of the coastal zone and to resolve response and management options that address the vital transboundary elements. The application of common methodologies will increase regional integration of information and options.
5. *Non-linearity of processes (feedbacks and thresholds)*. The non-linear relationships of forcing and function are apparent in the coastal zone. New concepts, tools and approaches are required, to encompass non-linearity in modelling and predictions, scenario-building and vulnerability-risk assessments.
6. *Monitoring and indicators of functions and changes*. Proxies for measurement of 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.
7. *Improved databases and access*. There is need for concerted efforts to develop stronger datasets, to fill critical data gaps and to improve cross-referencing of datasets so that stronger integration can be achieved. Improved access to existing data and wider accessible to datasets would reduce duplication in coastal assessments.
8. *Capacity building*. Underpinning future research enterprise is the need for continuing and enhanced capacity-building in both science and management training and awareness.

Therefore, the challenges for future GEC research on the coastal zone are 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, future research goals for LOICZ are aimed to overcome traditional disciplinary fragmentation, in particular between natural and human-dimension sciences, in order to focus on the primary issues of sustainable human use of coastal systems in respect to vulnerability of coasts and risks for human uses.

5.7.2 The Potential for LOICZ to Contribute to Future Coastal Management Challenges

The coastal regions of the globe will form the focus of future growth of population, development of settlements, and expansion and diversification of economic activities. Coastal regions already provide a significant proportion of the goods and services that support the livelihoods of coastal communities and national economies. These development pressures will bring major changes to coastal ecosystems and the role they play in global environmental change. There will also be increased risks to human societies from natural and man-induced natural hazards. These risks can be minimised through sound planning and management of development processes.

The LOICZ programme has provided a wealth of information that could be used to strengthen the conceptual basis for integrated coastal management and associated development and spatial planning. For example, the work on material fluxes and river basins has demonstrated strong linkages between the management of small to medium sized catchments and impacts on coastal and nearshore marine systems, the supply of natural resources they sustain, and functions such as buffering of storm surges. The DPSIR framework has demonstrated how such complex information from the natural and social sciences can be integrated to identify the core drivers that influence the management of river systems and the response of coastal systems. This work could be used to expand the conceptual basis of existing policy instruments, for instance, the EU Water Framework Directive, to encompass material fluxes, surface and ground water flows, and energy and other factors that will influence sustainable human use of coastal areas. This would strengthen such policy and management instruments by supporting the development of integrated river basin management and their effectiveness in supporting the management of coastal and marine areas.

The challenge is to make available the results of the LOICZ science in a format and constitution that provides a means and route to contribute to the formulation and implementation of policies, management strategies and implementation arrangements that are appropriate to the different regions of the world. Although further research is needed to refine the results of the thematic studies and to strengthen their utility, there is sufficient understanding of the role of coastal systems in global environmental change to develop a constructive dialogue with policy ma-kers, planners and managers. That is a question of effective communication of science and one that the next phase of the LOICZ programme will address with great vigour.

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