Chapter 4

The Catchment to Coast Continuum

Wim Salomons, Hartwig H. Kremer and R. Kerry Turner
Contributors: *Elena N. Andreeva, Russell S. Arthurton, Horst Behrendt, Peter Burbridge,*
Chen-Tung Arthur Chen, Christopher J. Crossland, Jürgen Gandrass, Vjacheslav V. Gordeev, Nick Harvey,
G. H. Hong, Bjorn Kjerfve, L. D. de Lacerda, Janet I. Marshall Crossland, Nicole Morcom, Eric Odada,
Jozef Pacyna, Nancy N. Rabalais, Dennis Swaney, William J. Wiebe

4.1 Introduction

The policy and management challenge for coastal zones is to ensure the sustainable availability of coastal resources under intense pressure from environmental change. However, much of the environmental change pressures originate not from within the coastal zone but from the catchments, or river basins, that feed freshwater and materials into the coastal zone. Riverine inputs, along with oceanic forces, influence the geomorphology and availability of natural resources of the coastal zone. The linkages between catchment–coastal processes and systems, the influence of climatic change and the impacts on and feedback effects from socio-economic activity are still poorly understood.

One approach to better understanding of the catchment–coast linkage is to use retrospective information from the system in order to make predictions about its future behaviour. This requires an in-depth analysis of changes in processes and impacts that are the result of change in the biophysical system or its inherent variability and of those due to human impacts on the biophysical system (e.g., coastal engineering, conversion of wetlands, fishing) that have led to a significant loss of coastal ecosystems and resources. Less well-known are the indirect changes originating from the catchment basin that cause changes in flow of freshwater, sediments (Syvitski 2003, Syvitski et al. 2005), nutrients (Smith et al. 2003) and contaminants. The impacts of indirect changes are influenced by the source of the change, the time-scale over which it operates and the interaction of natural and socio-economic variables on the system (Fig. 4.1).

4.1.1 The LOICZ-Basins Approach

During the LOICZ-Basins study, not all the components of Fig. 4.1 could be considered within the available resources and time-frame. Attention was given to assessments across a time-frame of 20 to 30 years. The impact of differences in biophysical and socio-economic conditions on fluxes and their subsequent impact on the coastal zone were considered. In some cases, attention was paid to climate change. However, the challenge of identifying differences in culture and values was not met, (time-frames of hundreds of years) nor their effect on public policy and perceptions of coastal zone impacts.

Within LOICZ, a standardised framework of analysis was developed to assess the impact of land-based sources, in particular catchment basins, on coastal systems (see Chap. 1 and Text Box 4.1). About 100 catchment–coastal sea systems have been analysed through workshops and desk studies. In addition, individual assessments were scaled up to continental regions. The activities of LOICZ-Basins have also resulted in more detailed studies of catchments in Africa (AfriCat) and in Europe (EuroCat) (Fig. 4.2).

In the LOICZ-Basins assessments, the coastal sea and its associated catchment(s) are treated as one system and evaluated by consideration of the elements of the Driver–Pressure–State–Impact–Response (DPSIR) framework (Text Box 4.1; Fig. 4.3). The coastal response to land-based activities is determined against socio-economic activities so that results from natural and socio-economic sciences have to be combined (Turner et al. 1998, Salomons et al. 1999). For instance, impacts of socio-economic activities are modified by the biophysical settings of the catchment-coast-sea system. A similar level of socio-eco-

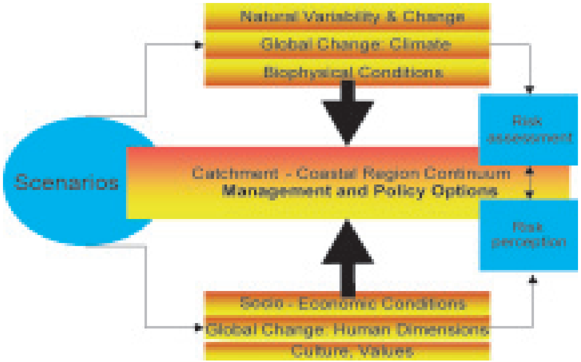


Fig. 4.1. LOICZ-Basins. Natural and socio-economic inter-linkage in the catchment–coast continuum

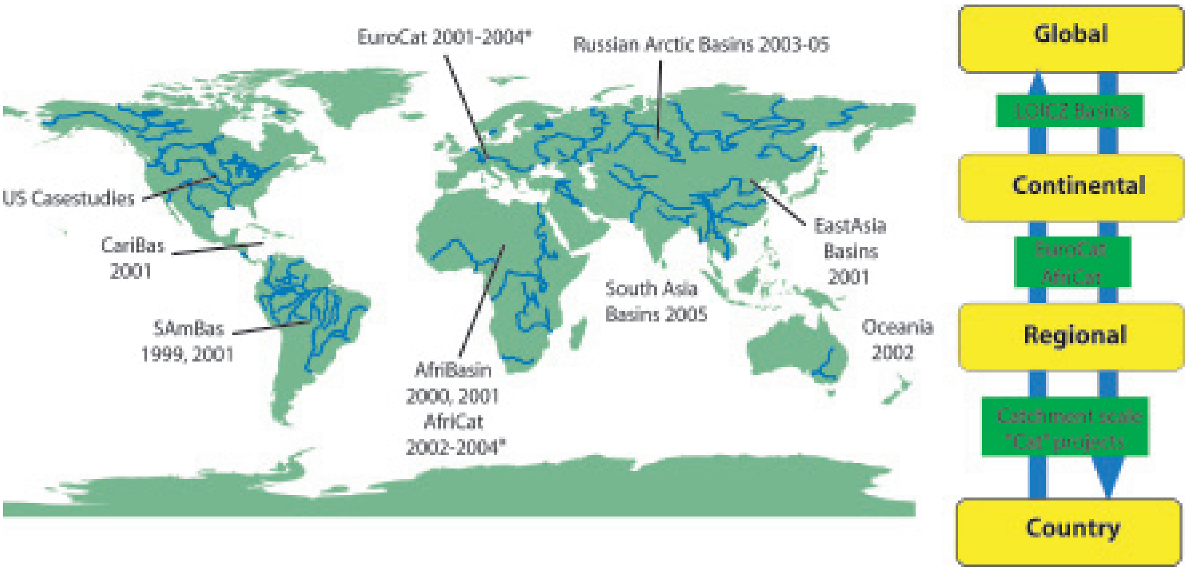
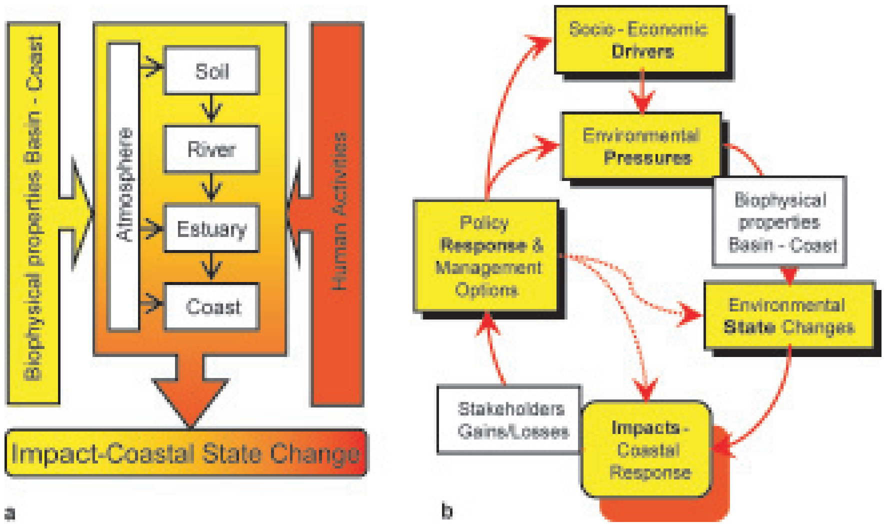


Fig. 4.2. LOICZ-Basins Catchments and coastal regions evaluated (* resulting research projects)

Fig. 4.3. LOICZ-Basins. **a** The catchment-coast continuum as one system; **b** the DPSIR framework



nomic activity in a small mountainous river system will have a different impact on the receiving coastal zone than a large lowland river system.

Large catchments would at first seem to be obvious examples to be addressed within a global LOICZ synthesising effort (e.g., Amazon, Nile, Yangtze, Orinoco). However, from the perspective of coastal change, the major influence from land-based flows is more often generated by small to medium catchments with high levels of socio-economic activity. In small to medium catchments, changes in land cover and use need much shorter time-frames to translate into coastal change, and for any given magnitude of change usually exhibit more visible impacts than changes within large catchments where the "buffer capacity" against land-based change is higher, simply as a function of basin size. Thus, small and medium catchments are a priority for the global LOICZ-Basins assessment. They dominate the global coastal zone (in Africa, for example, they characterise extensive parts of monsoon-driven runoff to the Indian Ocean).

The LOICZ-Basins assessment follows a hierarchy of scales which generate a composite regional picture. The scales range from:

- local catchments, to
- national or sub-regional or provincial levels, to
- full regional i.e., sub-continental or even continental.

The steps taken in an assessment are:

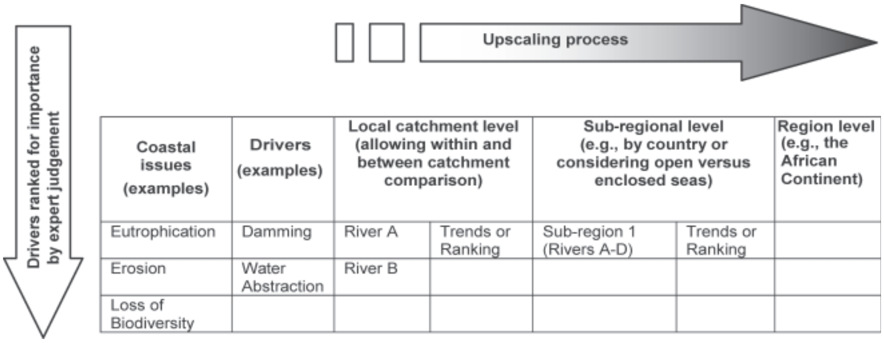
1. production of a list of coastal change issues and related drivers in the catchment.

Text Box 4.1. The Driver-Pressure-State-Impact-Response Framework

Wim Salomons, Hartwig H. Kremer, R. Kerry Turner

The Driver-Pressure-State-Impact-Response (DPSIR) scheme (Turner et al. 1998, Turner and Bower 1999) provides a standardised framework for site assessment and evaluation and adopts a systems approach. The elements of the framework are:

- *Drivers:* resulting from societal demands, these are the activities with consequences for the coastal zone and include: urbanisation, aquaculture, fisheries, oil production and pro-cessing, mining, agriculture and forestry, industrial development, ports and harbour development and other land-use changes.
- *Pressures:* processes affecting key ecosystem and social system functioning (i.e., natural and anthropogenic forcing affecting and changing the state of the coastal environment), including: damming and other constructions, river diversion, irrigation and water abstraction, industrial effluents (industrialisation), agricultural runoff, domestic wastes (urbanisation), navigation and dredging, sea-level rise induced by land-based activities or groundwater abstraction affecting the coastal zone (e.g., decrease of riverine sediment load leading to instability of coastal geomorphology) and other forcing functions, such as climate change.
- *State and state change:* the indicator functions and how they are affected, for example: water, nutrient and sediment transport (including contaminants where appropriate) observed in the coastal zone as key indicators for trans-boundary pressures within the water pathway. Indicators are designed to give an overview of the environmental status and its development over time and ultimately enable derivation of assimilative capacity limits, geomorphologic settings, erosion, sequestration of sediments, siltation and sedimentation, economic fluxes relating to changes in resource stocks and flows and changes in economic activity in monetary and other terms.
- *Impact:* effects on system characteristics and provision of goods and services, for example: habitat alteration, changes in biodiversity, social and economic functions, resource and services availability, use and sustainability and depreciation of the natural capital stock.
- *Response:* action taken at a political and/or management level that can include scientific responses (research efforts, monitoring programs) as well as policy and/or management response to either protect against changes, such as increased nutrient or contaminant input, secondary sea-level rise, or to ameliorate and/or rehabilitate adverse effects and ensure or re-establish the chance for sustainable use of the system's resources.



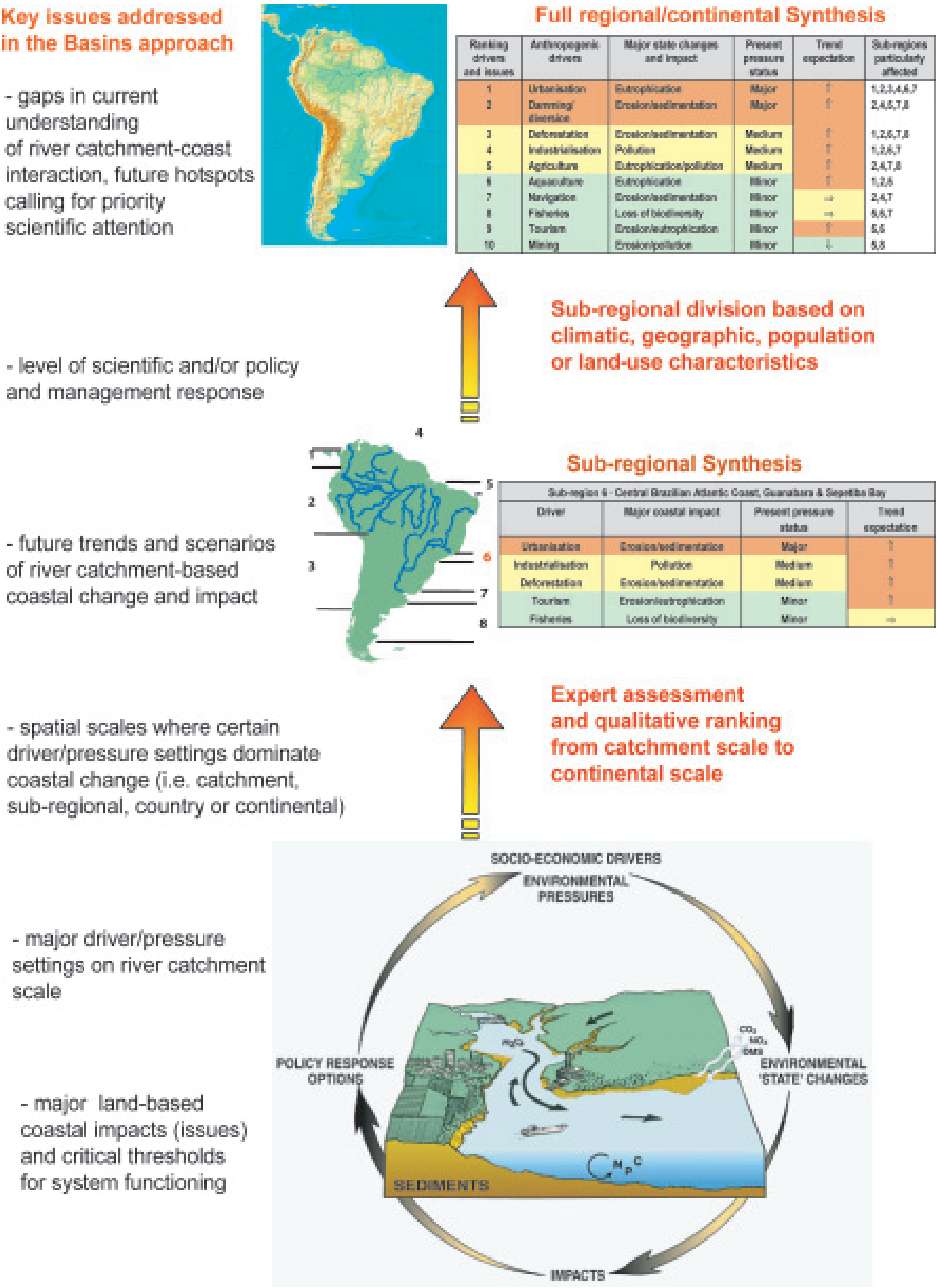
Coastal issues (examples)	Drivers (examples)	Local catchment level (allowing within and between catchment comparison)		Sub-regional level (e.g., by country or considering open versus enclosed seas)		Region level (e.g., the African Continent)
Eutrophication	Damming	River A	Trends or Ranking	Sub-region 1 (Rivers A-D)	Trends or Ranking	
Erosion	Water Abstraction	River B				
Loss of Biodiversity						

Fig. 4.4.
LOICZ-Basins. Schema of assessment tables

2. characterisation and ranking of the various issues of change, based on either qualitative (i.e., expert judgement) or quantitative (data) information. This step includes identification of critical load and threshold information for system functioning where available (e.g., Kjerfve et al. 2002, Lacerda et al. 2002, Gordeev et al. 2005).

Thus, LOICZ-Basins provides a typology of the current state and expected trends of coastal change under land-based human forcing and natural influences. The assessment follows a set of key questions that cover the various aspects and scales of the DPSIR analysis and utilises a sequence of assessment tables (Fig. 4.4). An example of the questions and upscaling procedure is presented in Fig. 4.5, using the results of the assessment of the South American sub-continent. The ranking of drivers, pressures, impacts and trends (synthesis tables in Fig. 4.5) is based on expert judgement but backed up by data from relevant literature. Detailed results (down to individual catchment scale) and the literature references can be found in the individual reports (see *www.loicz.org* and Appendix A.1).

In this chapter we summarise and focus on the regional and sub-regional scales. The regional-continental results are discussed in the main text; individual assessments of catchment basins can be found in the LOICZ-Basins reports (see Appendix A.1). The upscaling to subregions and sub-continental or continental scale is illustrated in partly coloured tables where green, yellow and red indicate the sequence of increased ranking of importance or decreasing, stable or increasing trend expectations respectively. The results from the relatively smaller (in terms of land area and population) and partly island dominated assessed areas of the Caribbean and Oceania regions are presented below in Text Boxes 4.2 and 4.3. For Europe the initial regional assessments were extended using a scenario-building approach to provide a set of considered options and outcomes of relevance to management interests.



Key issues addressed in the Basins approach

- gaps in current understanding of river catchment-coast interaction, future hotspots calling for priority scientific attention

- level of scientific and/or policy and management response

- future trends and scenarios of river catchment-based coastal change and impact

- spatial scales where certain driver/pressure settings dominate coastal change (i.e. catchment, sub-regional, country or continental)

- major driver/pressure settings on river catchment scale

- major land-based coastal impacts (issues) and critical thresholds for system functioning

Full regional/continental Synthesis

Ranking drivers and issues	Anthropogenic drivers	Major state changes and impact	Present pressure status	Trend expectation	Sub-regions particularly affected
1	Urbanisation	Eutrophication	Major	↑	1,2,3,4,6,7
2	Damming/ diversion	Erosion/sedimentation	Major	↑	2,4,5,7,8
3	Deforestation	Erosion/sedimentation	Medium	↑	1,2,6,7,8
4	Industrialisation	Pollution	Medium	↑	1,2,6,7
5	Agriculture	Eutrophication/pollution	Medium	↑	2,4,7,8
6	Aquaculture	Eutrophication	Minor	↑	1,2,6
7	Navigation	Erosion/sedimentation	Minor	→	2,4,7
8	Fisheries	Loss of biodiversity	Minor	→	5,6,7
9	Tourism	Erosion/eutrophication	Minor	↑	5,6
10	Mining	Erosion/pollution	Minor	↓	5,8

Sub-regional division based on climatic, geographic, population or land-use characteristics

Sub-regional Synthesis

Sub-region 6 - Central Brazilian Atlantic Coast, Guanabara & Sepetiba Bay

Driver	Major coastal impact	Present pressure status	Trend expectation
Urbanisation	Erosion/sedimentation	Major	↑
Industrialisation	Pollution	Medium	↑
Deforestation	Erosion/sedimentation	Medium	↑
Tourism	Erosion/eutrophication	Minor	↑
Fisheries	Loss of biodiversity	Minor	→

Expert assessment and qualitative ranking from catchment scale to continental scale

Fig. 4.5. LOICZ-Basins. Example of questions and upscaling assessment from South America (from Lacerda et al. 2002)

Text Box 4.2. The Caribbean

From Kjerfve et al. 2002

The Caribbean is an enclosed tropical sea covering 1 943 000 km^2 (Fig. TB4.2.1). The countries of the Caribbean region range from small, low islands to continental, mountainous lands with vast differences in rainfall patterns, climate, landform and land use. Humans have modified almost all of the Caribbean land for at least the past 500 years and only a few virgin forests remain. The coastal zone of the Caribbean supports more than 100 million people in more than 25 countries and territories with an anticipated population doubling time of 30 years at the current rate of growth. Intense housing, industrial and tourism developments compete for limited available space and attention from local governments and authorities.

The coastal environment consists of interlinked open marine and coastal ecosystems in a geographically diverse setting. Mangrove wetlands, seagrass beds and coral reefs are the dominant coastal habitats, each exhibiting high productivity and rich biological diversity. River drainage basins are relatively small for the most part because most of the countries are island states. However, the Magdalena River of Colombia, with a catchment of 257 000 km^2, drains directly into the western Caribbean at Barranquilla, delivering inputs of freshwater of 228 km^3 yr^{-1} and sediment of 144×10^6 t yr^{-1}. Generally, however, in contrast to the larger basins of South America, impacts are characterised by a short time response to changes in land use and cover, i.e., basin development activities to coastal state changes. The buffering capacity is less effective in small river catchment systems than in larger catchments.

Sedimentation/erosion is the most significant issue for the region followed by pollution, eutrophication and salinisation, and a broad-scale loss of biodiversity (Table TB4.2.1). For ex-

Table TB4.2.1. The Caribbean. Links between coastal issues/impacts and land-based drivers; overview and qualitative ranking. (* Categories based on accumulated local and sub-regional information: 1, low; 10, high. Trend: ⇒ stable, ⇑ increasing)

Coastal impact/issues	Anthropogenic drivers	Category*	Trend expectations	Sub-regions particularly affected
Sedimentation (salinisation – here a minor concern)	Damming/ diversion	10	⇒/⇑	Magdalena River and El Dique Canal; Delta and lagoon complex (Cienaga Grande de Santa Marta)
Sedimentation	Deforestation	8	⇑	Magdalena River, Colombia; Gulf of Paria, Trinidad, Eastern Caribbean; Aroa-Yaracuy River, Golfo Triste, Venezuela; Sibun, Belize; Sarstoon and Motagua Basins, Guatemala; Chamalecon, Ulua, and Aguan Rivers, Honduras
Pollution/ eutrophication	Tourism	8	⇒/⇑	Cancun, Cozumel, and East Coast of Yucatan, Mexico; Roatan, Honduras; El Rosario Islands, Caribbean Coast of Colombia and El Dique Delta
Pollution/ eutrophication	Urbanisation and industry	7–8	⇑	Magdalena River, Colombia; Kingston Harbor, Jamaica; Aroa-Yaracuy River, Golfo Triste, Venezuela; Chetumal Bay, Mexico; Belize City; Manabique, Guatemala; Roatan, Honduras
Eutrophication/ pollution	Agriculture	6 (locally up to 9)	⇑	Magdalena River, Colombia; Gulf of Paria, Trinidad, Eastern Caribbean; Rio Cobre, Jamaica; La Estrella River, Costa Rica; Aroa-Yaracuy River; Golfo Triste, Venezuela; Sibun, Stann and Monkey Basins, Belize; Sarstoon and Motagua Basins, Guatemala; Chamalecon, Ulua, and Aguan Rivers, Honduras
Sedimentation	Navigation	8	⇑	Magdalena River mouth (Bocas de Ceniza)
Biodiversity loss and/or decreasing biological productivity	Various drivers: (urbanisation, industry, damming/diversion	8 (locally 10)	⇒/⇑	Aroa-Yaracuy River; Golfo Triste, Venezuela; Magdalena delta and lagoon complex (Cienaga Grande de Santa Marta mangrove system); Magdalena River-El Dique Canal and El Rosario Islands (coral reefs)
	Various drivers: (tourism defores-tation, agriculture, fishing)	4	⇑	Gulf of Paria, Trinidad, Eastern Caribbean; Kingston Harbor, Jamaica; La Estrella River/Cahuita Reef, Costa Rica

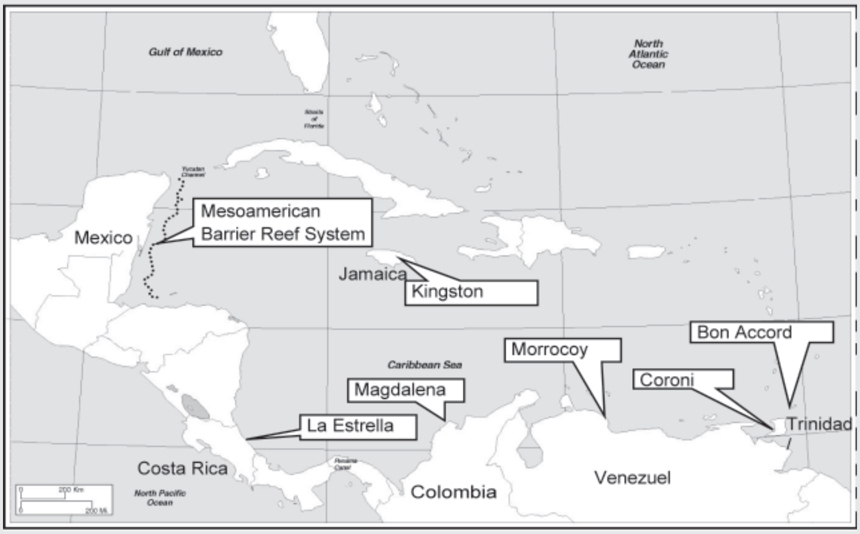
Text Box 4.2. *Continued*

ample, poor land-use practices, population growth and technological development have led to degradation of mangroves and coral reefs. Many drivers contribute to the generation of change and impacts, including (in order of importance): damming/diversion of rivers (particularly in the Magdalena subregion), deforestation, tourism (over a wide range of locations), urbanisation/industrialisation, agriculture and navigation. Land-use change and irrigation will generate growing pressure since many of the islands of the Caribbean suffer from low rainfall and thus lack of potable water. The response to coastal issues is usually hard engineering (coastal sea defences) rather than more environmentally sustainable soft engineering solutions.

Development is and will remain the major threat to river/island and coastal conservation and management in the Caribbean region. Biodiversity losses are a key concern. Similar to other tropical coastal ecosystems, the most important feature of the Caribbean is how interdependent the different components are, particularly in a downstream direction. For instance, mangrove forests generally benefit from increases in inorganic nutrients which the sediments have a high capacity to denitrify; one hectare of forest can probably process sustained inputs of 300 kg of N and 30 kg of P annually. In the Caribbean as elsewhere, mangrove forests are among the first coastal system to be destroyed. Seagrasses in the shallow sub-tidal zone are vulnerable to eutrophication; plankton-reducing light conditions and epiphytes covering the grass blades. The result is that seagrass beds decline, increasing nutrient flow to the reefs thereby stimulating massive algal growth that smothers the reefs. Virtually all of the coral reefs of the Caribbean region are either in critical condition (loss in 10–20 years) or threatened (loss in 20–40 years). Mangroves, seagrass beds and coral reefs, the three important and dominant coastal ecosystems in the Caribbean, need to be managed together in order to support efforts towards environmental and social sustainability in this fast growing economic region.

Numerous coastal and marine reserves and parks have been established, and many more are currently being created. These protected areas are likely to play a critical role in sustaining both productivity and marine biodiversity in the Caribbean, and thus contributing to the integrated coastal zone management of the region as a whole.

Fig. TB4.2.1. Caribbean. Case studies sites



Text Box 4.3. Oceania

From Morcom et al. 2002

Like other island-dominated regions, considerable parts of the broad area of Oceania (Fig. TB4.3.1) face serious environmental problems including widespread destruction of mangrove forests and coral reefs around population centres, urbanisation, overfishing, deforestation, soil erosion, misuse of pesticides, pollution of rivers and drinking water supplies, improper disposal of industrial and municipal wastes, and lack of sewage treatment facilities. The environmental and human impact of nuclear fallout from British, American, French and Soviet weapons testing programs still needs to be assessed. The paucity of published information, in particular on the cycling of water, sediment, nutrient, carbon and contaminant fluxes in the coastal zone of Oceania, has hampered attempts by LOICZ to assess nutrient fluxes in the region.

Polluted rivers and drinking water supplies are common in Oceania. Drivers/pressures are untreated municipal waste, urban sewage, agricultural runoff and mining (Table TB4.3.1). The last is most pronounced in the Fly River, Papua New Guinea, which carries levels of copper beyond threshold for sustained system functions; it was also impacted by several accidental spillages of toxins such as cyanide. In 1996 the extensive environmental damage resulted in US$ 320 million compensation in favour of the local communities to be used for pollution control and US$ 32 million to relocate whole villages. Other areas under mining pressure are New Caledonia and Guam.

Oceania has a chronic freshwater shortage; regionally water rationing has been imposed and locally water is routinely supplied for only one hour every second day. Urbanisation, domestic sewage and solid waste, agricultural wastes and industrial wastes all threaten the quality and supply of freshwater, in particular to low islands. These pressures are and will be exacerbated by climate change and future sea-level rise.

Coastal waters in the Oceania region are also polluted by industry. Industries such as fish canning, sugar milling, beer brewing and edible oils processing are significant regional pollutants of marine waters. Many hazardous and toxic wastes associated with

Text Box 4.3. *Continued*

medium-scale industrial bases in Fiji and Papua New Guinea are not well documented. However, a trend analysis expects industrial waste loading in Oceania to be increasing. These pressure/state change relationships raise substantial economic and public health issues in the region. For example, in Suva 95% of mangrove shellfish collected at eight sites was found to exceed World Health Organization limits of contamination for human consumption.

Another issue of high coastal relevance is sedimentation. Increased by intensifying land-use and cover change such as logging activities, urbanisation and rapid coastal development, mining, intensive agriculture and natural events, direct and indirect sediment effects on reefs and mangroves can be observed (e.g., around Suva, Fiji).

In summary, the amount of freshwater in Oceania is unlikely to increase and there is little evidence to suggest that the quality of polluted drinking water, rivers and coastal waters will be restored. There is potential for sewage, municipal and industrial wastes to be treated, which would directly affect fresh and coastal waters. However, the cost of building and maintaining such treatment facilities may be beyond many oceanic nations, dependencies and territories.

In response, pollution of fresh, coastal and marine waters is now recognised in Oceania, and the South Pacific Regional Environmental Programme (SPREP) Action Plan may provide an effective way forward with respect to environmental concerns.

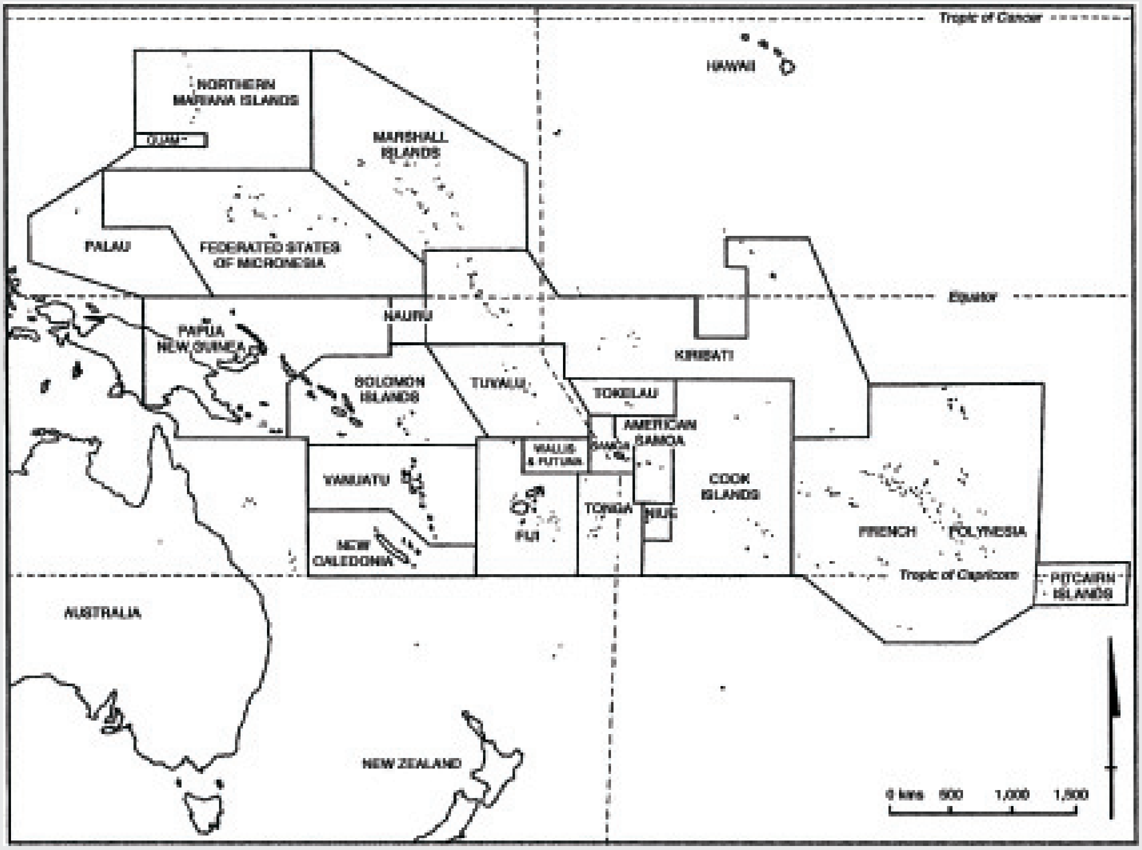


Fig. TB4.3.1. The Oceania region

4.2 South America

4.2.1 Overview of South American River Catchment-Coastal Zone Systems – Geography and Climate

The South American Atlantic coast is dominated by a few very large and many medium-sized river catchments and wetlands, all of which input nutrients that support the major part of the primary production and fisheries of the tropical and sub-tropical coasts of the sub-continent. These rivers discharge into the Atlantic to a relatively broad continental shelf (Kellogg and Mohriak 2001). Many of the medium-sized systems are visibly altered through human activities. Consequently, land-use and cover change, pollution and water diversion, which are drivers changing horizontal mass transport, are likely to cause stronger state changes and to generate acute coastal impacts when associated with these medium-sized catchments than, for instance, those associated with the Amazon. In contrast, along the Pacific coast of the sub-continent, characteristically small catchments discharge to a relatively narrow continental shelf with strong interac-

Text Box 4.3. *Continued*

Table TB4.3.1. Oceania. Links between coastal issues/impacts and land-based drivers; overview and qualitative ranking. (* Categories based on accumulated local and sub-regional information: 1, low; 10, high. Trend: ⇒ stable, ⇑ increasing)

Coastal impact/issues	Anthropogenic drivers	Category*	Trend expectations	Location
Pollution/ sedimentation/ erosion	Mining	10	?	Fly, Ok Tedi and Jaba Rivers, Papua Niew Guinea (PNG), Rivers in New Caledonia
Biodiversity loss/ decrease of biological productivity	Various drivers	10	⇑	Fly and Jaba Rivers, PNG; Rivers in southern New Caledonia; Suva-Fiji coastal waters
Sedimentation/ erosion Eutrophication	Deforestation	9	⇑	Rivers in Fiji; Rivers in southern New Caledonia and Solomon Islands
Eutrophication/ sedimentation/ Erosion/pollution	Urbanisation	8	⇑ ⇒	Rivers of Fiji, (Rewa, Vatuvaga River, Suva harbour – sewage); Tarawa lagoon, Kiribati –sewage, erosion; Nubukulou Creek – electricity and septic tanks); Oraniqio River – Fiji – sedimentation
Eutrophication/ pollution Sedimentation/ erosion	Agriculture	7	⇑	Rewa River, Fiji, other Streams in Fiji (pesticides); Waimanu River Fiji

tions with open ocean waters (Kellogg and Mohriak 2001). Therefore, the catchment basin effects on the receiving coastal waters differ between Pacific and Atlantic systems.

For both coasts a second sub-regional classification applies encompassing the wide range of climatic conditions from tropical to sub-Antarctic patterns. Desert-like regions along the Peruvian and Chilean coastline are replaced by humid areas with considerable annual rainfall further south in Chile, and north in Ecuador and Colombia. The northeast and central eastern parts of the Atlantic coast are tropical or sub-tropical, but arid in the northeast and humid in the east. The southern Atlantic coast exhibits more arid conditions with sparse vegetation.

Eight sub-regional divisions (Fig. 4.6a) and characteristic rivers (Fig. 4.6b) were selected as representative of South American catchments (Text Box 4.4).

4.2.2 Assessment of Land-based Drivers, Pressures and Coastal Impacts

4.2.2.1 *Drivers and Pressures*

Catchment basin activities have considerable influence on the environmental state of many South American coastal areas. Anthropogenic pressures are also characterised by two major features: urbanisation and megacities either affect the coastal waters and estuaries directly (e.g., Buenos Aires and Rio de Janeiro) or contribute to coastal change indirectly through the catchments that carry their urban waste-load (e.g., Caracas and São Paulo). Areas such as Patagonia and the northeast of Brazil have low population density and runoff, so that water quality is relatively un-impacted. Economically driven changes in land use affect large remote regions, for example, through deforestation that has a visible influence on the geomorphology of catchments as well as on the hydrological conditions. These pressures, although they appear insignificant in terms of immediate and visible coastal change (e.g., deforestation in the Amazon basin), may have strong potential for significant future impacts. There is an array of locally dominating drivers and pressures that tend to characterise the sub-regions.

4.2.2.2 *Coastal Issues – State Changes and Impacts*

The principal and most extensive coastal issues for South America are pollution, eutrophication, and the changing erosion/sedimentation equilibrium, although other issues may be more important at the site-specific level (Table 4.1). These pressures have already caused measurable impacts on South America's coastal zone, resulting in varying degrees of displacement from a baseline state in many ecosystems.

Fig. 4.6. South America. **a** The sub-regions identified in the South American Basins (SAmBas) study; **b** a selection of river catchment-coast systems evaluated (from Lacerda et al. 2002)

Pollution

Pollution is considered here as both the introduction of human-made substances into the aquatic environment that are harmful to human or animal life and health (e.g., pesticides, hydrocarbons, PCBs), and the increase to toxic levels of naturally-occurring elements (i.e., heavy metals). Continental inputs of trace metals, oil, oil derivatives and xenobiotics are rapidly increasing in parallel with economic development of most countries of the subcontinent. Diverse areas of the coastline, especially protected shores, are continually under pressure. Such areas in South America harbour over 2 million hectares of highly productive mangroves and wetlands that are nursery grounds for coastal fisheries. These key ecosystems are exposed to contaminants transported by rivers, and which can be conveyed through food chains to the human population.

Most pollutant inputs involve heavy metals from industrialisation and agriculture along river catchments. Copper contamination from pesticides used in agriculture is affecting the Negro River and southern Brazil. Even in relatively undisturbed environments, such as the rivers of Patagonia and north-eastern Brazil, heavy metal concentrations are generally much higher than local background values. As with nutrients, the high flushing rate to the open ocean due to coastal upwelling results in a large dilution of pollutant concentrations.

Atmospheric deposition of pollutants in basins transported by runoff also contributes significantly to increasing heavy metal concentrations in coastal seas. This is particularly important for metals such as lead and mercury, whose cycles include a significant atmospheric component; even relatively remote areas show abnormal concentrations of these two metals. Accelerated land-use changes in coastal basins also contribute to the re-mobilisation of deposited pollutants on soils.

Oil exploration and production in many river basins in South America is a key issue. Oil exploration in the Andes results in frequent oil spills introducing elevated levels of heavy metals that eventually affect the coastal zone.

Mining, although less important to catchment-coast interactions, may be significant in some regions. For example, in the Gallegos River, coal mining leads to increased lead concentration. Small-scale gold-mining is carried out in basin systems generally far from the coast close to the Andes Cordilleras, but mercury is transported from these inland sources to the coastal zone where it enters the food-chains.

Organic micro-pollutants are not significant contaminants of coastal waters in South America, but at some sites they show relatively high concentrations; for example, in the Esmeraldas River in Ecuador, the La Plata River estuary and some sites along the Patagonia coast.

Eutrophication

Urban and agricultural wastes released to the coast are raising special concerns in terms of impact on coastal waters. Eutrophication and coastal erosion rank as the

Text Box 4.4. South America: catchment sub-regions

From Lacerda et al. (2002)

Sub-region 1. North tropical Pacific coast, Columbia, Ecuador: the high rainfall Pacific coast of Colombia and Ecuador (latitudes 7° N to 0° S), rivers with small drainage basins but with large water and sediment discharges and high sediment yields. Typical rivers are the San Juan and Patia rivers in Colombia, with catchment areas of only 14 km^2 and sediment yields in the range of 1 000 t km^{-2} yr^{-1}, and the Esmeraldas and Chone rivers in Ecuador. Average annual rainfall for this sub-region is 5 900 mm. About 260 km^3 fresh-water is discharged annually into the Pacific Ocean, with a sediment load of nearly 31×10^6 t yr^{-1}).

Sub-region 2. Central Pacific coast, Ecuador, Peru, northern Chile: the driest coast of South America, from the Gulf of Guayaquil in Ecuador to northern Chile, including the entire Peruvian littoral (latitudes 0° S to 30° S). Most coastal features are dominated by open ocean phenomena and are greatly affected by El Niño events. Although river inputs may be important sources of nutrients to the coastal region, at least for the Gulf of Guayaquil, most of the coastal productivity and fisheries are dependent on oceanic upwelling. Typical rivers are the Guayas River in Ecuador, the Tumbes and Chira rivers in Peru and the BioBio River in Chile, all of which have small basins, large water and sediment discharges and high sediment yield. The Gulf of Guayaquil has the highest rates of mangrove deforestation and conversion to aquaculture in the world, having lost about 80% of its original area (3 973 ha to 785 ha between 1969 and 1991). This has caused large changes in geomorphology and basin land-use with direct effects on the coast.

Sub-region 3. Southern Pacific Coast, Chile: the southernmost area along the Pacific coast between latitudes 30° S and 42° S, the south-central Chilean littoral, with a temperate climate. Exposed sandy beaches with varying morphodynamics alternate with intertidal sand flats at the mouths of rivers. Small rivers with large sediment yields and strongly seasonal flows dominate water and sediment transport. Strong interaction between coastal and open ocean waters results in large dilution of continental material after it reaches the coast.

Sub-region 4. Caribbean to north-western Brazilian tropical Atlantic coast: the northernmost area including the Magdalena River delta, a complex lagoon-deltaic system (latitudes 10–12° N), which is the major contributor of fresh-water and continental sediments to the Caribbean Sea. The lower basin has witnessed great changes since colonial times, with major water diversion works and artificial canals changing the position of major river output to the Caribbean Sea. The Magdalena River discharges 228 km^3 of water and 144×10^6 tonnes of sediment annually into the Caribbean. Water and sediment discharges have great environmental and economic impacts on the adjacent coastal ecosystems, particularly from high sedimentation rates in Cartagena Bay and siltation on coral reefs of the El Rosario Islands to the south-east.

Sub-region 5. North-eastern Brazil sub-tropical Atlantic coast: the extensive oligotrophic north-eastern coast of Brazil (latitudes 3–12° S), where small to medium, highly seasonal rivers contribute almost all the nutrients for coastal primary production and fisheries. Most of the coastline runs parallel to the Equator, where constant strong winds drive immense amounts of sands to the coast, creating large dune-fields that continuously change the coastal geomorphology. The semi-arid nature of the regional climate has resulted in intense impoundment of waterways, mostly for irrigated agriculture and urban use. This has led to an extreme reduction of freshwater and fluvial sediment load to the ocean and generalised erosion along the coastal region.

Sub-region 6. Central Brazilian Atlantic coast, Guanabara and Sepitiba Bay: the south-eastern Brazilian coast (latitudes 20–30° S), the most industrialised and urbanised part of South America. The climate is tropical humid with abundant rains year-round and annual rainfall of 1 200 to 2 600 mm. Several small rivers with huge event-controlled discharges transport large volumes of sediments and pollutants to the coastal seas. Environmental pressures along this coast are enormous, mostly associated with unplanned urban and industrial development concentrated along very narrow coastal plains that house about 60 million people and the largest industrial parks and ports of the subcontinent.

Sub-region 7. Wider La Plata Atlantic coast, south-eastern Brazil, Uruguay, Argentina: the southern coast of Brazil (latitudes 30–38° S), and the region of influence of the Rio de la Plata estuary, mostly in a warm temperate climatic zone. This huge coastal plain is drained by three large rivers, the Uruguay, Paraná and Guaíba, that discharge into the Patos Lagoon, the largest coastal lagoon in the world. The Argentine and Uruguayan coasts of the Rio de la Plata contain the highest concentration of human population and industrial activities south of the São Paulo-Rio de Janeiro metropolitan areas. Agriculture and husbandry are the major activities of these large river basins. The coastal features and problems shared by the three countries pose a challenge for integrated coastal zone management on a multi-national level.

Sub-region 8. South-eastern Atlantic coast, Argentina, Patagonia: the Patagonia littoral in Argentina, (latitudes 38–52° S), with a temperate climate and an annual rainfall of less than 800 mm. The sub-region is characterised by long coastal-plain rivers that are still relatively undisturbed. Major rivers are the Negro, Chubut, Santa Cruz and Colorado with basin areas of 95, 30, 25 and 22×10^3 km^2, respectively. However, water discharge is relatively small, less than 2 000 m^3 per year. Extensive livestock breeding (particularly of sheep) and increasing agricultural activities are threatening many coastal sites of high ecological value to migrating species.

most important impacts on both coasts of South America. In most cases, direct links can be made to increasing population density and urbanisation of coastal catchments, even in regions of low population density, such as Patagonia and north-eastern Brazil.

The coasts of south-eastern Brazil and Buenos Aires Province are probably the regions most affected by eutrophication, reflecting the high concentrations of population and industries along major drainage rivers. Nutrient levels measured at nearly 200 stations along rivers draining to the metropolitan area of Rio de Janeiro showed concentrations one to three orders of magnitude higher than background. Elevated levels of coliforms (500 colis (Número Mais Provável (NMP)) 100 m l^{-1}) derived from river catchments can be measured in open oceanic waters off the beaches of the region. Even along the sparsely populated Uruguayan coast, low oxygen and high nitrogen concentrations have been observed.

Toxic algal blooms have increased in frequency along the eastern coast of Uruguay, the coastline of metropolitan Fortaleza in north-eastern Brazil and the Patagonian coast of Argentina, probably associated with an increase in freshwater inflow and sewage discharge. Along the Patagonian coast this may have increasing effects on important mussel banks and mariculture sites. In the spring of 1980, the human health dimension of increased riverine nutrient loads became apparent there when a large algal bloom caused human deaths from consumption of mussels contaminated by *Alexandrium* sp.

In Colombia, bacteria reaching coastal waters from sewage discharged into river basins has contaminated oyster banks. Non-toxic algal blooms have also been causing fish kills along the Caribbean coast of Colombia due to localized depletion of oxygen.

In some Venezuelan Caribbean islands, there is evidence of a growing frequency of *Ciguatera* blooms causing poisoning among humans, resulting from higher nutrient inputs to coastal areas. Periodic red tides contaminate mussels and oysters in the region. However, there is currently no evidence that these blooms are associated with inputs from catchment basins.

Along the Pacific coast of South America, eutrophication is an important issue. However, it seems to be more restricted and intense than on the Atlantic coast. Only in the Gulf of Guayaquil and along part of the northern Ecuadorian coast are nutrient levels high. To the south, the intense exchange between coastal and oceanic waters probably decreases the impact of augmented nutrient loads from rivers.

Coastal Geomorphology (Erosion, Siltation)

Diversions and damming of waterways are seriously affecting the erosion-accretion equilibrium of large stretches of the South American coastline. Examples can be found along the north-eastern Brazil coast and the Caribbean coast of Colombia and Venezuela.

Changing river sediment load alters the sedimentation-erosion equilibrium within an estuary or delta (also see Chap. 2). Coarse-grained bed load (> 60 µm) normally represents 10% or less of the total sediment discharge delivered to the coastal zone. Hence, it is assumed that a decrease of about 5% of the total sediment flux represents the critical threshold beyond which the coastal system is likely to show evidence of significant deterioration (coastal erosion). This level of change results in mangrove siltation (e.g., along the river estuaries in north-eastern Brazil), severe erosion of mangroves (e.g., in the Paraíba do Sul River delta, south-eastern Brazil) and sandy beaches (e.g., along the coasts of Buenos Aires Province in Argentina and in north-eastern Brazil).

Deforestation of river catchments facilitates soil erosion changing sediment quantity and quality resulting in increasing siltation of the coastal zone. The mouth of the Magdalena River in Colombia, where a major port is located, needs continuous dredging to prevent sedimentation. Disposal of dredged materials has affected adjacent sandy beaches, coral reefs and mangroves that cannot keep up with the increased sediment load. Evidence from deforestation-caused soil erosion has shown that long-lasting contaminants, such as heavy metals, may also be remobilised, increasing the contamination threat in coastal areas.

In semi-arid Argentinean Patagonia, scarce vegetation and increased livestock (sheep) pressure have resulted in considerable erosion and a heavy load of suspended matter carried to the ocean by the Chico River.

Biodiversity and Harvestable Resources

Loss of habitats and species is widespread along most of the sub-continent's coastline. These effects are mostly measured as significant losses of fisheries. Annual catches have been historically monitored at many sites and can provide reliable "critical threshold estimates" for this parameter. Extreme cases are the 90% reduction of commercial fisheries during the past 20 years at the Magdalena River delta and the 90% decline of viviparous shark catches at the Patos Lagoon estuary. Apart from fisheries, extensive mangrove areas in Ecuador and Colombia and salt marsh areas in southern Brazil have been lost.

4.2.3 State Changes, Impacts and Future Trends

Since impacts on the coastal zone promoted by the different forcing functions along the water continuum of the catchment may appear across different time scales, temporal change and variability represent crucial information for decision-making processes. Tables 4.1 and 4.2 show the ranked importance of impacts on coastal areas by catchment activities and their trend expectations.

The Atlantic coast of South America is more sensitive to impacts from catchment basin activities than the Pacific coast. The Atlantic border harbours the majority of the population and economic activities of South America, and over 90% of the South American drainage discharges into the Atlantic and Caribbean (Kellog and Mahiuk 2001). Oceanographic conditions and continental shelf geology also enhance longer residence times of sediments, water, and natural and anthropogenic substances from continental land sources whereas along the Pacific coast strong flushing results in rapid dilution of continental input into the open ocean.

Major impacts (ranking higher than 6) along the Atlantic coast include pollution due to industrialisation, eutrophication due to urbanisation, erosion and sedimentation due to deforestation and damming, and nutrient depletion due to damming. Along the Pacific coast, erosion due to deforestation and navigation and sedimentation due to deforestation are the major impacts and drivers. Trends indicate that future impacts are likely to increase in severity if economic growth continues and accelerates. It is important to note, however, that the local site-specific situation may differ from this longer term aggregate forecast. Therefore, reference should be made to the catchment level assessments (Lacerda et al. 2002) to gain a view of the relative importance of the impact/issue and associated driver at that local scale.

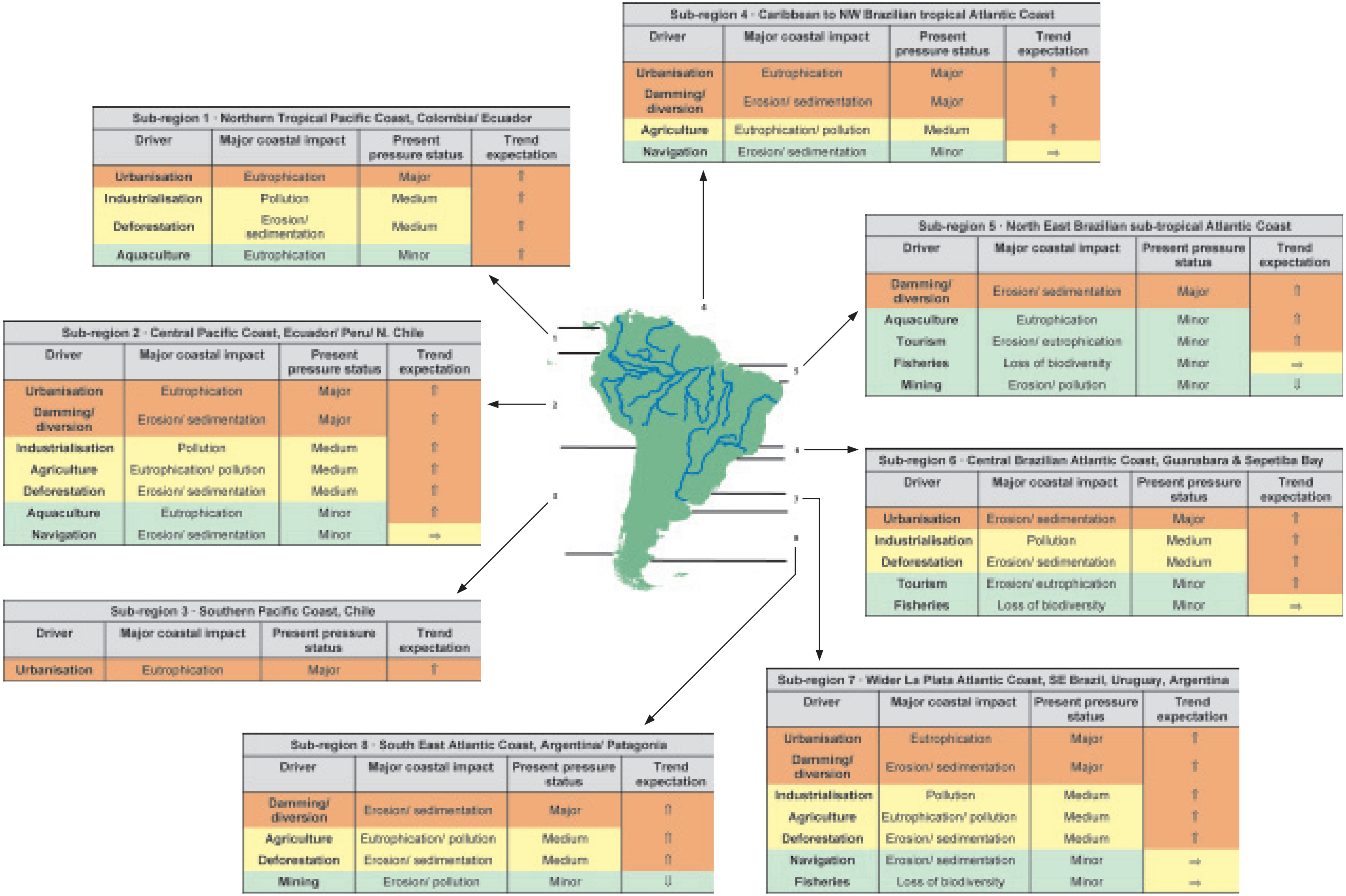
The qualitative ranking of major land-based activities, the present status of their effects on the coastal zone of South America and trend expectations derived by the group of experts are summarised in Table 4.2. On sub-continental scale eutrophication, pollution and changes in coastal geomorphology (erosion) were ascribed as the most important coastal impacts. Databases on nutrients and sediments are scarce or not easily accessible, a situation that needs improvement for management as well as assessment efforts. An overview on the biogeochemical characteristics of South American estuaries and lagoons has been produced based on available information and applying the LOICZ budgeting methods (Smith et al. 2000). A significant information gap exists for small rivers, in particular for those on the Pacific coast. An expert workshop elicited general agreement that small and medium-sized rivers are responsible for the majority of coastal waters' productivity, coastal amenities and coastal change especially along the Atlantic coast.

Table 4.1.
South America. Links between coastal issues/impacts and land-based drivers; overview and qualitative ranking at regional/sub-continental scale. (Category: 1 = low; 10 = high. Trend: ⇒ stable, ⇑ increasing, n.o. = not observed)

Atlantic Coast				Pacific Coast	
Coastal impact/issues	Driver	Category	Trend expectation	Category	Trend expectation
Pollution	Industrialisation	9	⇑	2	⇑
	Navigation	7	⇑	5	⇑
	Agriculture	5–6	⇑	?	⇑
	Urbanisation	6	⇑	5	⇑
Eutrophication	Urbanisation	8	⇑	5	⇑
	Agriculture	4–5	⇑	2	⇑
	Industrialisation	3	⇑	2	⇑
Sedimentation	Damming	8	⇑	n.o	n.o.
	Deforestation	7–8	⇑	6–7	⇒
	Navigation	6	⇑	n.o.	n.o
	Agriculture	4	⇒/⇑	2	⇒
Erosion	Deforestation	7	⇒/⇑	6	⇒
	Damming	6–7	⇒/⇑	1	⇒
	Navigation	1	⇒	7	⇑
Nutrient depletion	Damming	8	⇑	n.o.	n.o.
Salinisation	Damming	4	⇑	n.o	n.o.
Loss of biodiversity	Fisheries	4–6	?	2	⇑

Table 4.2. South America. Major activities, present status and trends affecting the coastal zone. (Trend: ⇒ stable, ⇑ increasing, ⇓ decreasing; *numerals* refer to sub-regions described in Text Box 4.4, Fig. 4.6a)

Anthropogenic drivers	Major state changes and impact	Present pressure status	Trend expectations	Sub-regions particularly affected
Urbanisation	Eutrophication	Major	⇑	1,2,3,4,6,7
Damming/diversion	Erosion/sedimentation	Major	⇑	2,4,5,7,8
Deforestation	Erosion/sedimentation	Medium	⇑	1,2,6,7,8
Industrialisation	Pollution	Medium	⇑	1,2,6,7
Agriculture	Eutrophication/pollution	Medium	⇑	2,4,7,8
Aquaculture	Eutrophication	Minor	⇑	1,2,5
Navigation	Erosion/sedimentation	Minor	⇒	2,4,7
Fisheries	Loss of biodiversity	Minor	⇒	5,6,7
Tourism	Erosion/eutrophication	Minor	⇑	5,6
Mining	Erosion/pollution	Minor	⇓	5,8



Sub-region 1 · Northern Tropical Pacific Coast, Colombia/ Ecuador

Driver	Major coastal impact	Present pressure status	Trend expectation
Urbanisation	Eutrophication	Major	↑
Industrialisation	Pollution	Medium	↑
Deforestation	Erosion/ sedimentation	Medium	↑
Aquaculture	Eutrophication	Minor	↑

Sub-region 2 · Central Pacific Coast, Ecuador/ Peru/ N. Chile

Driver	Major coastal impact	Present pressure status	Trend expectation
Urbanisation	Eutrophication	Major	↑
Damming/ diversion	Erosion/ sedimentation	Major	↑
Industrialisation	Pollution	Medium	↑
Agriculture	Eutrophication/ pollution	Medium	↑
Deforestation	Erosion/ sedimentation	Medium	↑
Aquaculture	Eutrophication	Minor	↑
Navigation	Erosion/ sedimentation	Minor	→

Sub-region 3 · Southern Pacific Coast, Chile

Driver	Major coastal impact	Present pressure status	Trend expectation
Urbanisation	Eutrophication	Major	↑

Sub-region 4 · Caribbean to NW Brazilian tropical Atlantic Coast

Driver	Major coastal impact	Present pressure status	Trend expectation
Urbanisation	Eutrophication	Major	↑
Damming/ diversion	Erosion/ sedimentation	Major	↑
Agriculture	Eutrophication/ pollution	Medium	↑
Navigation	Erosion/ sedimentation	Minor	→

Sub-region 5 · North East Brazilian sub-tropical Atlantic Coast

Driver	Major coastal impact	Present pressure status	Trend expectation
Damming/ diversion	Erosion/ sedimentation	Major	⇑
Aquaculture	Eutrophication	Minor	⇑
Tourism	Erosion/ eutrophication	Minor	⇑
Fisheries	Loss of biodiversity	Minor	→
Mining	Erosion/ pollution	Minor	⇓

Sub-region 6 · Central Brazilian Atlantic Coast, Guanabara & Sepetiba Bay

Driver	Major coastal impact	Present pressure status	Trend expectation
Urbanisation	Erosion/ sedimentation	Major	↑
Industrialisation	Pollution	Medium	↑
Deforestation	Erosion/ sedimentation	Medium	↑
Tourism	Erosion/ eutrophication	Minor	↑
Fisheries	Loss of biodiversity	Minor	→

Sub-region 7 · Wider La Plata Atlantic Coast, SE Brazil, Uruguay, Argentina

Driver	Major coastal impact	Present pressure status	Trend expectation
Urbanisation	Eutrophication	Major	↑
Damming/ diversion	Erosion/ sedimentation	Major	↑
Industrialisation	Pollution	Medium	↑
Agriculture	Eutrophication/ pollution	Medium	↑
Deforestation	Erosion/ sedimentation	Medium	↑
Navigation	Erosion/ sedimentation	Minor	→
Fisheries	Loss of biodiversity	Minor	→

Sub-region 8 · South East Atlantic Coast, Argentina/ Patagonia

Driver	Major coastal impact	Present pressure status	Trend expectation
Damming/ diversion	Erosion/ sedimentation	Major	⇑
Agriculture	Eutrophication/ pollution	Medium	⇑
Deforestation	Erosion/ sedimentation	Medium	⇑
Mining	Erosion/ pollution	Minor	⇓

Fig. 4.7. South America. Sub-regional synthesis and typology of river catchment–coast interactions

Table 4.3. South America. Priority driver/pressure features by country and corresponding "hot spots"

Country	Driver/Pressure	Hot spots	Available information
Colombia	Pollution (generated by urbanization industry, mining); Deforestation (generated by agriculture); Diversion of river discharges	Rio Magdalena; Cartagena Lagoon (to be opened to the Caribbean)	Nutrient and sediment discharges and concentrations are available for the Magdalena River back to the 1970s, but refer only to the delta and the river
Venezuela	Industrial liquid discharges; Oil exploration and extraction; Livestock land use; Sewage (prevention still possible); Agriculture	Orinoco Delta; Neveri River; Catatumbo River; Maracaibo Lake; Tuy River; Limon and Aroa rivers; Unare/ Chama rivers	Information available in comprehensive reviews, including nutrient and sediment discharges
Argentina	Pollution (generated by urbanisation and industry); Erosion or siltation (due to land use change); Oil spills (upstream)	Rosario and Buenos Aires Province (due to transboundary transport from Brazil through the Paraná River); Patagonia	Overview reports on the Parana-La Plata Rivers[a] Bibliography from various case studies in small Patagonian rivers
Brazil	Damming; Diversion; Irrigation; Agriculture (enhanced nutrient loads); Deforestation; Navigation	Jaguaribe River, NE coast, Ceará State; SE coast from the São Francisco River to Bay of Paranaguá; The Paraíba do Sul River-Sepetiba Bay, Rio de Janeiro	Major bibliography sources reviewed and published, addressing major issues on Integrated Coastal Zone Management. The national Water Agency (ANEEL), monitors water fluxes in major rivers. Historical data available on the internet
Uruguay	Navigation (timber transport); Agriculture (more irrigated rice paddies); Irrigation	Parana River[a]; Uruguay River; La Plata River	GEF project report[b]

[a] The Parana-La Plata Basin has been the subject of overviews promoted under the MERCOSUR agreement.
[b] Ongoing GEF project in the La Plata Basin.

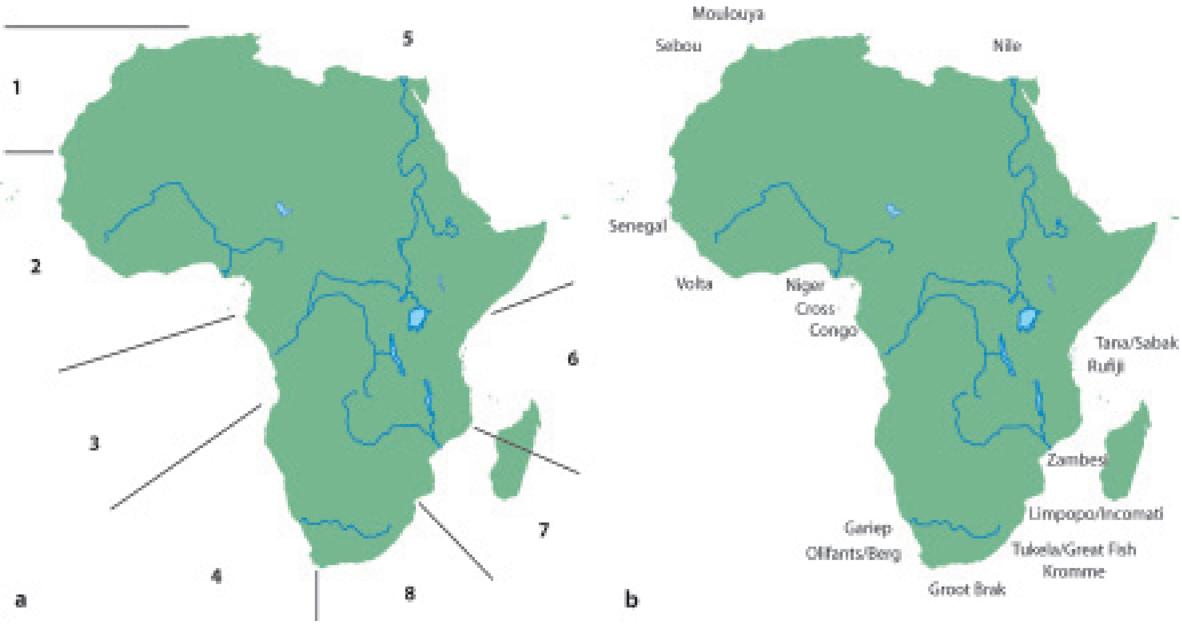


Fig. 4.8. Africa. **a** The sub-regions identified in the AfriBasins study; **b** a selection of river catchment-coast systems evaluated (from Arthurton et al. 2002)

4.2.4 Conclusions – South America

River basins of all sizes are, or are becoming, increasingly affected in particular by diversion of waters and/or damming for energy generation and/or irrigation purposes, basin deforestation and pollution from agriculture, urban and industrial effluents. Figure 4.7 is a sub-regional synthesis of main river catchment-coastal change issues, and provides an expert judgement-based ranking and trend analysis.

A number of case studies, from across the South American sub-continent are summarised in Table 4.3 and address key issues and scales that occur at the land-sea interface. An overall evaluation of the data in Table 4.3 supports the conclusion that across South America issues of water quality followed by a series of sediment-related issues and aspects driven by demands for water resource availability are the most important.

4.3 Africa

4.3.1 Overview of African River Catchment-Coastal Zone Systems – Geography and Climate

The environmental and socio-economic issues of Africa's coastal zone are influenced by both natural and anthropogenic marine-related pressures, such as relative sea-level rise which exacerbates coastal erosion and flooding around Lagos in Nigeria. The coastal zone is also directly influenced by the pressures of human activities, notably urban and industrial growth causing pollution (e.g., Alexandria in Egypt) and eutrophication (e.g., Saldanha Bay in the Western Cape). Around much of Africa, however, many of the coastal issues are linked to human activities and climatic variability that are far away in the continental hinterland. Such continental pressures have altered the nature of the drainage through the river systems – large and small – impeding the flow of freshwater, transported sediment and organic matter. They have also affected the quality of the water, mainly through the addition of nutrients and pollutants from domestic sewage and industrial and agricultural chemicals.

On the basis of geomorphic and climatic characteristics, eight sub-regions were evaluated (Fig. 4.8a, Text Box 4.5) within which representative catchments were chosen for assessment (Fig. 4.8b; Arthurton et al. 2002). The various sub-regions differ widely not only in the biophysical nature of their catchments but also in the availability and quality of existing data relating to their material fluxes. The catchments in South West and South East Africa have generally been well-studied especially over the last few decades and there exists an abundance of accessible high-quality monitoring data, both terrestrial and marine. Data for the Congo, by contrast, is sparse – a matter of concern in view of the obvious importance of such a large catchment in a regional synthesis of river catchment-to-coastal sea fluxes.

4.3.2 Assessment of Land-based Drivers, Pressures and Coastal Impacts

All of Africa's largest river basins – Niger, Congo, Nile and Zambezi – are included in the assessment, as are the important trans-boundary basins of the Senegal, Volta, Cross and Gariep rivers on the west coast and the Limpopo and Incomati on the east coast. Representative medium and small basins have also been assessed, including:

- the Sebou and Moulouya rivers in Morocco
- the Olifants and Berg rivers (west of the Cape of Good Hope) in South Africa,
- the Tana and Sabaki rivers in Kenya,
- the Rufiji in Tanzania, and
- the Thukela, Great Fish, Kromme and Groot Brak in South Africa east of the Cape.

4.3.2.1 *Drivers and Pressures*

Apart from climate change, the principal internal drivers of environmental change within African catchments are agricultural development, urbanisation, and their related activities – deforestation, damming and industrialisation (Table 4.4, Fig. 4.9; UNEP 2002a). Forest clearance and the general reduction in vegetation cover are consequences of agricultural expansion into marginal land, fuel-wood gathering and rapidly growing urban sprawl (e.g., around Nairobi and Johannesburg). Damming, water diversion and groundwater extraction are practices that have increased significantly in Africa during the last 50 years, particularly in South Africa, in response to development demands for agricultural irrigation, freshwater supply (particularly to fast-growing urban areas) and hydroelectric power (World Commission on Dams 2000).

All of these land-based human activities within Africa have produced substantial socio-economic benefits at local to regional scales. They have also resulted in considerable negative impacts, both socio-economic (e.g., the disruption of communities and their livelihoods) and environmental (e.g., the alteration of natural flooding regimes, the degradation of agricultural land by increased soil erosion, the destruction of habitats and the loss of biodiversity). The pressures exerted by these activities

Text Box 4.5. Africa: catchment sub-regions

From Arthurton et al. (2002)

Sub-region 1. North West Africa: relatively arid, medium basins with seasonal runoff. North West Africa is characterised by young mountains and numerous medium and small drainage basins with strong slopes, while the alluvial plains are few and of limited extent. River runoff and precipitation are irregular and may be high. Poorly vegetated steep slopes are prone to surface runoff resulting in soil erosion and high levels of fluvial suspended sediment transport – probably among the highest in Africa. The Sebou and Moulouya catchments (located in Morocco) are representative of the medium drainage basins that characterise the semi-arid Maghreb area. Many large dams have been built over recent decades. The resulting sediment entrapment has not only reduced the reservoir capacity, but has also become a principal cause of coastal erosion. The main sources of coastal eutrophication and pollution are untreated domestic and industrial wastewater and fertilisers. Most urban sewage is discharged without treatment. Human health issues also arise from the discharge of untreated sewage (related to urbanisation), while loss of biodiversity (or biological functioning) is seen as a complex interplay of all the principal drivers.

Sub-region 2. West Africa: featuring large trans-boundary basins (Niger, Volta, Senegal) including the medium-sized basin of the Cross River. Coastal erosion is a problem in all catchments, with critical thresholds exceeded in the Volta and Niger. Damming, deforestation and agriculture all contribute, with damming the prime cause in the Volta. Coastal sedimentation is a common issue, especially at the mouth of the Senegal River. Algal blooms are a manifestation of eutrophication, particularly in the Volta and Niger, with urbanisation (or human settlement) and, to a lesser extent, agriculture the principal drivers. Oil-related pollution is an important issue in the Cross River basin, while aquatic weeds, such as *Nypa* palm, infest all catchments. Critical thresholds for the loss of biological functioning have been exceeded in the Volta and Niger and especially in the Senegal. Human health issues, including the incidence of water-related diseases attributed to urbanisation, have been reported in all catchments, with critical thresholds being exceeded in the Volta and Senegal.

Sub-region 3. Congo: the second largest river in the world on the basis of annual flow, extending over a distance of 4 700 km from Lake Tanganyika to the Atlantic Ocean. The dominant characteristic of the Congo River is the remarkable regularity of its regime. The lower reaches of the basin (i.e., below Kinshasa and Brazzaville, some 300 km upstream) are free of major urban and industrial developments. Near the coast human activities involve fishing, gathering medicinal plants and subsistence cropping. The loss of habitat and biodiversity as a consequence of mangrove use for fuel wood is a major issue.

Sub-region 4. South West Africa (Namibia to Cape): mostly dominated by the upwelling system of the Benguela current; cool and temperate small (Berg) and medium (Olifants) catchments in the south and an arid large catchment (Gariep, formerly Orange) in the north. The major perennial river basins that influence the coastal zone include the Kunene, the Gariep, the Olifants and the Berg. Urban nodes, which also have a significant influence on the coastal zone, include Walvis Bay, Saldanha Bay, Table Bay and False Bay. The Gariep estuary is one of southern Africa's most important coastal wetlands; the dynamics of its deltaic mouth are affected by upstream impoundments and associated water-use practices. Human activities in the Olifants catchment appear to have a limited impact on its estuary and coastal zone, although damming and agriculture have led to a reduction of fresh-water inflow. In the Berg River, flow is very seasonal and the high concentration of dissolved inorganic nitrogen in the winter (wet season) is attributed largely to fertiliser from agricultural runoff. Urban and industrial nodes are associated with the progressive deterioration of water quality. Eutrophication attributed to industrial development around Saldanha Bay is of considerable concern. Of the urban node embayments, only False Bay receives significant basin drainage, with 11 small catchments discharging to the bay. Near the coast, human activities include fishing, gathering medicinal plants and subsistence cropping. The loss of habitat and biodiversity as a consequence of mangrove use for fuelwood is regarded as a major issue.

Sub-region 5. Nile: trans-boundary river system, the damming of which has led to profound changes in fluxes through the Nile delta and in the associated Mediterranean Sea. These changes are exacerbated by a rapid growth of urbanisation and industrialisation around Cairo and changes in agricultural practice in the Nile River valley and its delta region. All of these socio-economic drivers, together with the natural driver of climate change, have produced significant impacts at the coast. Notable among these has been the acute coastal erosion around the mouths of the Rosetta and Damietta distributaries of the delta, largely attributed to the almost complete cessation since the 1960s of coarse sediment flux below the Aswan dam. Damming is also responsible for the increasing salinisation of groundwater in the delta area. Other important coastal issues include eutrophication and pollution of the coastal waters from the discharge of urban and industrial wastewater (Mex Bay and Abu Qir Bay) and the loss of habitat resulting from the land-filling of coastal lagoons.

Sub-region 6. East Africa (Somalia to northern Mozambique): medium basins, seasonally flushed by rainfall principally occurring during the transitions between the north-east and south-east monsoons in April and October. All basins discharge on a coast that is characterised by fringing or patch coral reefs with an associated rich biodiversity. The Rufiji discharges through a delta dominated by mangrove forest into coastal waters that include the largely pristine Mafia Marine Park. Both the Sabaki and Tana rivers intermittently discharge sand and fines, the sand being transferred to beaches thence in part to dune systems that characterise the coast of northern Kenya. Coastal erosion and the discharge of sediment are two important issues on this coast. Fine sediment carried in suspension as plumes through the coastal waters may settle and smother growing coral. The contributions that damming, deforestation and changes in agricultural practice make to sediment input have been the subject of several studies in the Tana and Sabaki. The Tana headwaters are already dammed and additional dams are proposed, as they are for the Rufiji. Pollution is recognised as being a significant issue in the Tana and Sabaki basins with agriculture, industry and urbanisation all contributing. In the Rufiji, pesticides used in rice cultivation and the impacts of prawn farming are matters of concern, as are the impacts of population growth and the clearing of mangroves for agriculture. Pollutants and nutrients (untreated or partially treated sewage) delivered to coastal creeks from the urban-industrial centres of Mombasa and Dar es Salaam may be significant.

Sub-region 7. Central/south Mozambique: medium (Incomati) and large (Zambezi, Limpopo) catchments with high seasonality in runoff and subject to extreme cyclonic events; an estuarine/deltaic coast characterised by beach plains and mangrove-fringed creeks. The assessed catchments (Zambezi, Limpopo and Incomati) are trans-boundary systems. The rivers discharge on a predominantly alluvial coast formed mainly of older beach deposits and barrier bars and spits with associated creek systems, mangrove swamps and sand dunes. Most of the coastal issues and impacts are ascribed to damming and agricultural drivers/pressures, with reduction in stream flow a significant to acute and increasing problem. The middle course of the Zambezi River has been interrupted by two major artificial impoundments – Lake

◄

Kariba and Lake Cahora Bassa – which cover 5364 km^2 and 2739 km^2, respectively. Coastal erosion reported for the Zambezi delta and the Incomati River is attributed solely to damming. Loss of biological productivity, particularly in the Zambezi system, is partly a consequence of water abstraction for irrigation. The increasing salinisation of agricultural land flanking the Incomati estuary and the nutrient depletion in the coastal seas off the mouths of the Zambezi and Incomati are regarded as impacts of damming.

Sub-region 8. South-east Africa: ranging from sub-tropical in the north to warm temperate on the Cape coast and characterized by medium (Thukela, Great Fish) and small (Groot Brak, Kromme) catchments. The catchments assessed in this region comprise one medium basin (the Thukela, discharging on to the sediment-based, biologically significant Thukela Bank on the east coast) and three small basins (the Great Fish, Kromme, Groot Brak). The coast adjoining all these systems is dominated by oceanic processes being open and subject to strong wave action and longshore drift. The Thukela is the largest east coast system and is a source of water (via inter-basin transfer) for industries in the Johannesburg area and irrigation along the Vaal River, a tributary of the Gariep. The Great Fish lies in relatively arid areas and its flow has been enhanced and stabilised by the inter-basin transfer of water from the Gariep. This has significantly changed salinity gradient patterns in the estuary. The Kromme is a small system which, despite a greatly reduced freshwater input because of dam construction, retains an open mouth because of the local coastal morphology. The reduced freshwater supply has resulted in a marine-dominated, clear-water system totally different from the original estuarine community. The Groot Brak is a small system significantly impounded but also extensively investigated and manipulated to protect housing developments in the lower reaches.

on the hydrological regimes within river basins cause changes that are being translated through drainage systems into the coastal zone, including the adjacent seas.

4.3.2.2 *Coastal Issues – State Changes and Impacts*

Coastal Geomorphology (Erosion, Siltation)

Changes to the geomorphology of the coast in the vicinity of river mouths are common in the region. The processes may be erosion, as around the deltas of many of the major rivers (e.g., Volta, Nile, Zambezi) or, more unusually, accretionary (e.g., the Malindi shore in Kenya, adjoining the Sabaki). While human activities in the catchments, notably damming, water diversion and abstraction, undoubtedly play a major role, other drivers including extreme climatic events, climatic variability (e.g., monsoonal), sea-level rise and coastal engineering may also contribute. The case of the Nile is perhaps the best documented, with a clear demonstration of the linkage between the commissioning of the Aswan Dam in 1968 and rapid shoreline retreat at the mouths of the main distributaries to the Mediterranean Sea.

Reductions in river flow and discharge due to damming have caused sedimentation in many lower reaches and estuaries (e.g., Senegal and Southwest Africa). In some cases (Morocco, Southeast Africa) a lack of significant discharge has led to temporary closure or partial closure of estuary mouths by beach accretion. Reductions in river flow are held to be responsible for the growing problem of aquatic weeds (e.g., in Senegal and Volta deltas). They may also be the cause of increasing groundwater salinisation leading to losses in agricultural productivity in several estuarine situations (e.g., Moulouya in Morocco, Senegal, Incomati in Mozambique), though this effect might be exacerbated by sea-level rise.

The commonly twinned drivers/pressures of deforestation and agriculture generally have a medium though increasing impact at the coast. These activities tend to increase both the severity of flooding and the amount of sediment carried as river bed load and in suspension. The problem is acute in the small to medium catchments of Morocco (Sebou and Moulouya) and East Africa (Tana, Sabaki and Rufiji). Settling plumes of suspended sediment discharged from the Sabaki have threatened the health of the coral reef in the Watamu Marine Park at Malindi in Kenya.

The increased mobilisation of sediment resulting from agriculture and deforestation has an important bearing on the sustainability of damming in many parts of the region. In Morocco, particularly, some reservoirs are rapidly becoming operationally ineffective due to siltation.

Pollution and Eutrophication

Eutrophication at the coast as a consequence of agriculture is generally a medium-ranking, though increasing, issue for many rivers including the Moroccan rivers, the Niger and Cross rivers in Nigeria and the East African rivers. The Nile is considered to be a hotspot although such pollution is decreasing.

Eutrophication and contamination at the coast from urbanisation (or other human settlement) and industry are middle-ranking, though increasing. Acute areas are the Volta in Ghana where there are related human health issues, and the Cross River where there are serious issues of oil-related pollution. Some of the most acute problems of coastal pollution and eutrophication are derived from urban-industrial nodes within the coastline area itself, including the coastal strip at Casablanca in Morocco, Saldanha Bay and Cape Town in South Africa, the Alexandria coastal strip in Egypt and the industrial centres of Mombasa and Dar es Salaam in East Africa.

Salinisation

In the North West and West Africa, increasing salinisation is a serious issue caused variously by urbanisation and

Table 4.4. Africa. Links between coastal issues/impacts and land-based drivers; overview and qualitative ranking at regional/sub-continental scale. (Category: *1*, low;*10*, high. Trend: ⇒ stable, ⇑ increasing, ⇓ decreasing; numerals for sub-regions refer to Text Box 4.5, Fig. 4.8a)

Coastal impact/ issues	Anthropogenic drivers	West Coast			Nile Delta		East Coast		
		Category	Trend expectation	Sub-regions particularly affected	Category	Trend expectation	Category	Trend expectation	Sub-regions particularly affected
Erosion	Damming/ diversion	8	⇑	(2) Senegal, Volta, Niger	8	⇑	5	⇑	(7) Zambezi
	Deforestation	7	⇑	Most sub-regions (small and medium size catchments)			6	⇑	Most sub-regions (small and medium size catchments)
Sedimentation	Damming/ diversion	6	⇑	Major in (1, 2)	(local)		4	⇑	(6) Malindi coast, Kenya – major
	Deforestation	(4–5)	⇑	Most sub-regions (small and medium size catchments)			4–5 (7 local)	⇑	Most sub-regions (small and medium size catchments) locally major
	Agriculture	3–4	⇑	(2) Cross, (4) Gariep, Olifants, Berg			6	⇑	(6) Tana, Sabaki, Rufiji
Eutrophication	Agriculture	6–7	⇑	Major or medium ranking for most sub-regions, in particular in small and medium size catchments in 1	5–?	?	3–5	⇑	Minor most sub-regions, medium in particular in small and medium size catchments in (6)
	Urbanisation	8	⇑	Mostly in (1, 2)	8–?	?	3–5	⇑	
Pollution	Agriculture	2–7	⇑	Minor for most sub-regions, in particular in small and medium size catchments in 1, major in 2	7	⇓	6	⇑	Medium ranking for most sub-regions, in particular in small and medium size catchments in (6)
	Urbanisation/ industrialisation (incl. mining locally)	6	⇑	Mostly more coastal (1, 2, 4)	7	⇒	4	⇑	Mostly more coastal (6)
Salinisation	Damming/ diversion/ multiple drivers	6	⇑	(1) Moulouya, (2) Niger delta			7–8 (local)	⇑	(6) Tana, (7) Incomati
Nutrient depletion	Damming						5–8	⇑	(7) Southern Mozambique, (8). KwaZulu-Natal
Biodiversity loss	Various drivers	7	⇑	Almost all sub-regions	8	⇑	5–8	⇑	Almost all sub-regions
Human health issues	Various drivers	7	⇑		8	⇒/⇓	5	⇒/⇑	

agriculture (by over-abstraction of groundwater) and the natural drivers of climate change and sea-level rise. Salinisation is seen as a problem in the Niger and Cross, where the drivers are unclear, and the Senegal, where climate change (drought) is regarded as the cause. In South West Africa, during prolonged low-flow periods, salinisation in the lower reaches, particularly of the groundwater resources, has become a concern.

Biodiversity and Harvestable Resources

Loss of biodiversity and reduction in habitat are issues for all sub-regions. Generally, the linkages to drivers or pressures appear to be complex, with a wide range of contributions from land-based and coastal human activities as well as climate change. However, nutrient depletion has been identified as one key pressure associated with reduced fresh-water discharge. Damming and water abstraction result in serious reduction or depletion of land-sourced nutrients and organic matter in estuarine and coastal waters. The impacts of such depletion result in the increasing loss of biodiversity in the waters off Mozambique (Zambezi delta, Sofala bank) and KwaZulu, Natal.

4.3.3 State Changes, Impacts and Future Trends

Among the usual human activities that affect catchments, damming is the most significant driver/pressure through marked reductions in the volumes of fresh water discharged and by disruption of natural flooding regimes.

The main points from the regional synthesis are:

- Coastal erosion and sedimentation are significant and progressive impacts in nearly all sub-regions, the problems being acute on the Nile Delta and West African lagoon systems. Damming is the principal driver, with reductions in river flow and sediment flushing;
- Damming (with reductions in river flow) contributes to estuarine salinisation (sea water intrusion into groundwater; e.g., the Incomati river in Mozambique), and to nutrient depletion in the coastal sea with the consequent loss of biodiversity (e.g., off KwaZulu, Natal);
- In most sub-regions deforestation and agriculture are important drivers, particularly with respect to coastal sedimentation from medium and small catchments (e.g., the Tana and Sabaki rivers in Kenya);
- In the large West African catchments, human settlement is a major contributor to eutrophication and the proliferation of aquatic weeds;
- Serious levels of eutrophication and pollution are mostly restricted to coastal urban-industrial sources (e.g., Alexandria, Mombasa, Saldanha Bay and Cape Town); and
- Loss of biodiversity or biological functioning is a common issue, related to a complex interplay of human and natural drivers.

In ranking the coastal issues and impacts, it has proved difficult to achieve a consistency in standards between, and even within, sub-regions. Even in simple cases, the ranking of the issues and impacts and the state changes has largely been a process of expert judgement within the limitations of the often sparse data. This applies to scientific data and particularly to socio-economic infor-

Table 4.5. Africa. Major activities, present status and trends affecting the coastal zone. (Trend: ⇒ stable, ⇑ increasing, ⇓ decreasing; *numerals* refer to sub-regions described in Text Box 4.5, Fig. 4.8a)

Anthropogenic drivers	Major state changes and impact	Present pressure status	Trend expectations	Sub-regions particularly affected
Damming and diversion	Erosion sedimentation	Major	⇑	Almost all sub-regions, with (2) and (5) as particular "hot spots"
	Salinisation	Local	?	(1, 7)
	Nutrient depletion			(7, 8)
Various drivers	Biodiversity loss	Major	⇑	Almost all sub-regions
Deforestation	Erosion sedimentation	Medium		Medium ranking for most sub-regions, however, major for coastal impact generated in small and medium size catchments in (1) and (6)
Agriculture	Eutrophication pollution			
Urbanisation				Medium overall but major in 5
Industrialisation	Pollution			As above, but in most cases more coastal than catchment-based (more pronounced in 4, 5, 6)

Table 4.6.
Africa. Priority driver/pressure features by country and corresponding "hot spots" (*numerals* refer to sub-regions described in Text Box 4.5, Fig. 4.8a)

Country	Driver/pressure	Hot spots
Morocco (1)	Damming	Sedimentation through reduced flushing especially on Mediterranean coasts; salinisation of coastal plains
	Human settlement, agriculture and industrialisation	Eutrophication, pollution on Mediterranean and Atlantic coasts
Senegal (2)	Damming	Sedimentation, invasion by aquatic weeds and loss of biodiversity in Senegal River; estuarine ecosystem destroyed
	Human settlement	Human health issues
Ghana (2)	Damming	Erosion of Volta delta and invasion by aquatic weeds
	Human settlement	Eutrophication and human health issues in Volta
Nigeria (2)	Industrialisation	Oil-related pollution in Cross and Niger
South Africa (4, 8)	Damming and diversion	Nutrient depletion off southeast coast with resulting biodiversity loss; sedimentation and loss of habitat on southwest coast
	Urbanisation and industrialisation	Eutrophication and pollution at Saldanha Bay
Egypt (5)	Damming and diversion	Erosion of Nile delta
	Urbanisation and industrialisation	High levels of pollution and eutrophication in Abu Qir Bay, Mex Bay and on Alexandria city coast
Kenya (6)	Damming	Deterioration in Tana water quality
	Deforestation	Siltation at mouth of Sabaki
Tanzania (6)	Deforestation	Siltation at mouth of Rufiji
	Agriculture	Deterioration of Rufiji water quality
	Aquaculture	Pollution from prawn fisheries
Mozambique (6, 7)	Damming and abstraction	Biodiversity loss in Zambezi delta and on Sofala Bank
		Salinisation of Incomati
		Erosion of Zambezi delta

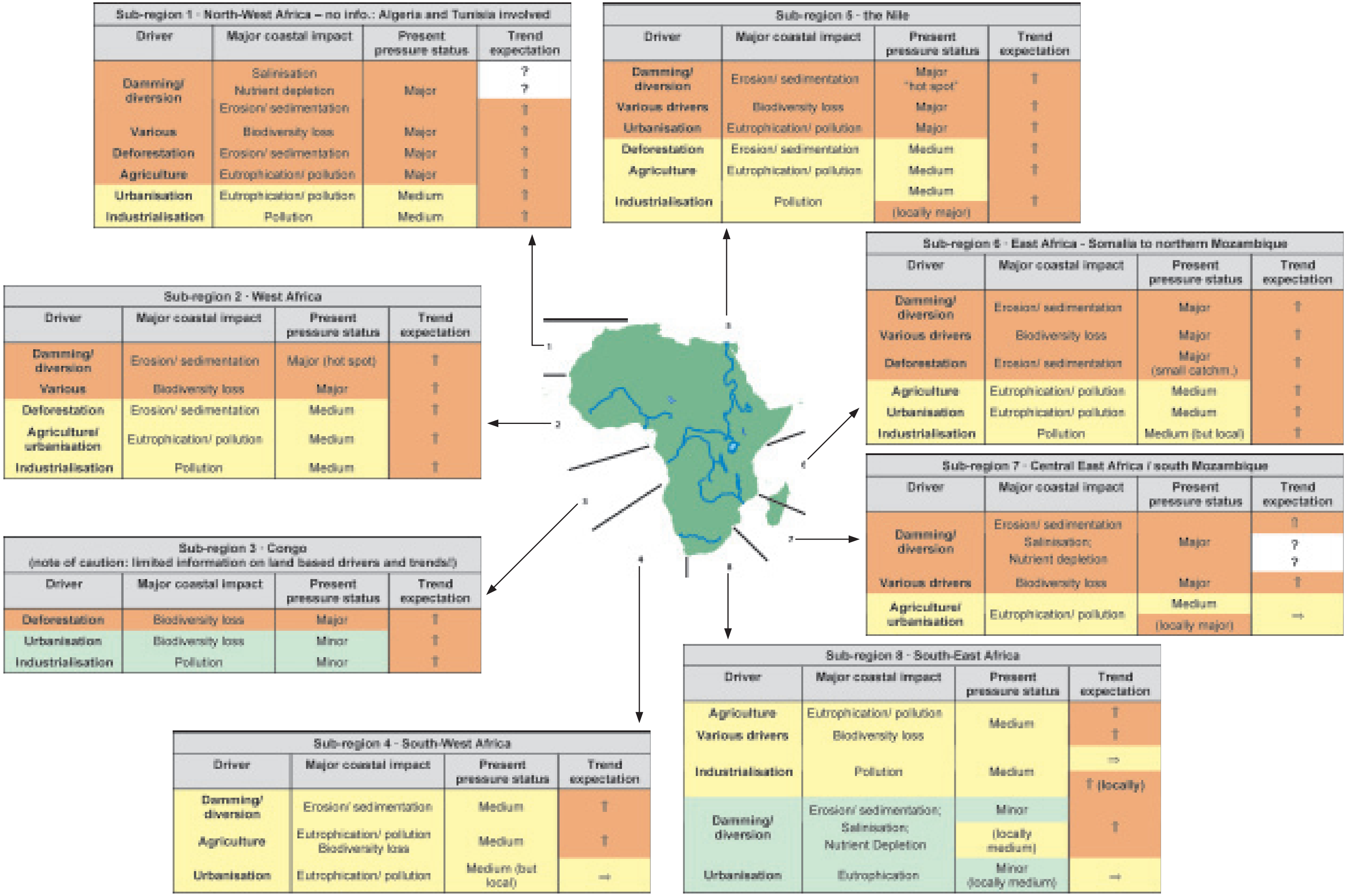
mation. Time-series data generated from routine monitoring programmes are rare. Information regarding the coastal environmental state within the region varies greatly in both its quality and availability. The scarcity of data, apart from South Africa, is a serious impediment to the understanding of the driver-impact linkages throughout much of the continent. This may have influenced the assessment output. However, for Africa a preliminary ranking order of the principal land-based drivers and pressures was drawn up together with expected future trends in impacts (Table 4.5).

Taking account of these limitations, the identification of areas calling for increased future scientific and/or management attention still seems appropriate, at least to inform future agendas. One needs to be aware of the risk that local, possibly short-term acute issues may have attracted higher rankings, while more spatially widespread and longer-term impacts that have been assigned lower rankings may turn out to be the more significant. With this in mind, a first-order list of future areas of concern has been developed, some of which are now foci for a new START/LOICZ "AfriCat" pilot project (*http://www.loicz.org*).

4.3.4 Conclusions – Africa

In general the AfriBasins data are typical of developing economy situations where economic growth and water use exceed the development of the necessary urban and industrial infrastructure. This finding parallels those for the South American and East Asian Basins assessments (Lacerda et al. 2002; Hong et al. 2002). However, heterogeneity of the sub-regions seems to be more pronounced in Africa than in other continents, making the ranking of issues and drivers in Africa a more complex challenge.

Within Africa, damming is the most significant driver/pressure resulting in marked reductions in the volumes of freshwater discharged and disruption of natural flooding regimes. During the last 50 years, damming, water diversion and water extraction have become common practices within the region, particularly in South Africa, principally for agricultural irrigation but also importantly for potable water supply and hydroelectric power generation. New dams and diversions are in their planning stages. In all the sub-regions, dam-related impacts at the coast were, with few exceptions, reported as show-



Sub-region 1 · North-West Africa – no info.: Algeria and Tunisia involved

Driver	Major coastal impact	Present pressure status	Trend expectation
Damming/ diversion	Salinisation Nutrient depletion Erosion/ sedimentation	Major	? ? ↑
Various	Biodiversity loss	Major	↑
Deforestation	Erosion/ sedimentation	Major	↑
Agriculture	Eutrophication/ pollution	Major	↑
Urbanisation	Eutrophication/ pollution	Medium	↑
Industrialisation	Pollution	Medium	↑

Sub-region 2 · West Africa

Driver	Major coastal impact	Present pressure status	Trend expectation
Damming/ diversion	Erosion/ sedimentation	Major (hot spot)	↑
Various	Biodiversity loss	Major	↑
Deforestation	Erosion/ sedimentation	Medium	↑
Agriculture/ urbanisation	Eutrophication/ pollution	Medium	↑
Industrialisation	Pollution	Medium	↑

Sub-region 3 · Congo
(note of caution: limited information on land based drivers and trends!)

Driver	Major coastal impact	Present pressure status	Trend expectation
Deforestation	Biodiversity loss	Major	↑
Urbanisation	Biodiversity loss	Minor	↑
Industrialisation	Pollution	Minor	↑

Sub-region 4 · South-West Africa

Driver	Major coastal impact	Present pressure status	Trend expectation
Damming/ diversion	Erosion/ sedimentation	Medium	↑
Agriculture	Eutrophication/ pollution Biodiversity loss	Medium	↑
Urbanisation	Eutrophication/ pollution	Medium (but local)	→

Sub-region 5 · the Nile

Driver	Major coastal impact	Present pressure status	Trend expectation
Damming/ diversion	Erosion/ sedimentation	Major "hot spot"	↑
Various drivers	Biodiversity loss	Major	↑
Urbanisation	Eutrophication/ pollution	Major	↑
Deforestation	Erosion/ sedimentation	Medium	↑
Agriculture	Eutrophication/ pollution	Medium	↑
Industrialisation	Pollution	Medium (locally major)	↑

Sub-region 6 · East Africa - Somalia to northern Mozambique

Driver	Major coastal impact	Present pressure status	Trend expectation
Damming/ diversion	Erosion/ sedimentation	Major	↑
Various drivers	Biodiversity loss	Major	↑
Deforestation	Erosion/ sedimentation	Major (small catchm.)	↑
Agriculture	Eutrophication/ pollution	Medium	↑
Urbanisation	Eutrophication/ pollution	Medium	↑
Industrialisation	Pollution	Medium (but local)	↑

Sub-region 7 · Central East Africa / south Mozambique

Driver	Major coastal impact	Present pressure status	Trend expectation
Damming/ diversion	Erosion/ sedimentation Salinisation; Nutrient depletion	Major	↑ ? ?
Various drivers	Biodiversity loss	Major	↑
Agriculture/ urbanisation	Eutrophication/ pollution	Medium (locally major)	→

Sub-region 8 · South-East Africa

Driver	Major coastal impact	Present pressure status	Trend expectation
Agriculture	Eutrophication/ pollution	Medium	↑
Various drivers	Biodiversity loss		↑
Industrialisation	Pollution	Medium	⇒ ↑ (locally)
Damming/ diversion	Erosion/ sedimentation; Salinisation; Nutrient Depletion	Minor (locally medium)	↑
Urbanisation	Eutrophication	Minor (locally medium)	→

Fig. 4.9. Africa. Sub-regional synthesis and typology of river catchment–coast interactions

ing increasing trends. This is supported by case studies and "hot spots" shown in Table 4.6.

Agriculture and deforestation are contributing to significant increases in soil erosion and consequently increased sediment flux and discharge. Agriculture, together with urbanisation and industrialisation, is contributing to the increasing degradation of water quality discharged to estuaries and coastal seas leading to growing problems of pollution and eutrophication and related human health issues.

All the socio-economic drivers referred to above play a part in the reported loss of biodiversity throughout the region, principally through the destruction of habitat and reduction in the volume and quality of freshwater discharged through the coastal zone to the coastal seas. Figure 4.9 is a sub-regional synthesis of main river catchment-coastal change issues, and provides an expert judgement-based ranking and trend analysis.

4.4 East Asia

4.4.1 Overview of East Asian River Catchment-Coastal Zone Systems – Geography and Climate

The East Asian region, comprising the eastern and southern side of the Euro-Asian continent, encompasses a wide range of climatic zones extending from tropics to Arctic tundra. A characteristic of this region is the East Asian Monsoon, with wet summers and dry winters; rainfall is generally higher in the south and lower in the north. East Asia is dominated by a number of large river catchments and wetlands to the east and south of the Himalayas, as well as eastward-flowing rivers traversing grasslands in the cold temperate far east of the Russian Federation. These rivers influence extended areas of the coastal zone in the southern and central region, but large parts of the coastline are also influenced by relatively small and medium-sized catchments. Riverine fresh water and nutrient supply dominate the biogeochemistry of the shelf regions in the marginal seas, determining most of the primary production and fisheries of the East Asian marginal seas – having a major role in the South China Sea, East China Sea, Yellow Sea, Bohai Sea and Sea of Japan and a lesser role in the Sea of Okhotsk and the Bering Sea.

While most coasts of East Asia are tectonically passive, the coasts of Taiwan and Japan are active and have small drainage basins that exhibit relatively high rates of water and sediment discharges. Smaller drainage basins have less area to store sediments so that their sediment yield increases by as much as 7-fold for each order of magnitude decrease in basin area.

A sub-regional classification, based on expert judgement, has delineated natural climatic and catchment characteristics and accounted for differences in the an-

Fig. 4.10.
East Asia. The sub-regions identified in the East Asia Basins study and a selection of river catchment-coast systems evaluated (from Hong et al. 2002)

thropogenic use pattern (Fig. 4.10, Text Box 4.6; Hong et al. 2002). There is extensive and intensive agriculture and aquaculture associated with a large population in the southern tropics, agriculture and industrial development linked to a large population in the temperate region, and terrestrial mining and offshore oil and gas exploitation allied to a sparse population in the cold temperate and Arctic regions.

Text Box 4.6. East Asia: catchment sub-regions

From Hong et al. (2002)

Sub-region 1. South China Sea: comprises the coast of Vietnam and South China from 7° N to the Tropic of Cancer, corresponding to the high rainfall region. On the Vietnamese coast, two large rivers (Mekong and Red), plus 114 smaller rivers discharge into the South China Sea while the Pearl River, China's third biggest system, marks the north-eastern boundary of the sub-region. The Mekong River (4880 km long, 0.795×10^6 km^2 catchment area) descends from the Tibetan plateau in China, crosses Myanmar, Laos, Thailand and Cambodia to Vietnam and deposits 1–3 cm of fertile silt each year on the lowland flood plains in Vietnam and Cambodia, sustaining these intensively farmed areas. In addition, river flow during the dry season is important for controlling salinity penetration into interior areas from the coast. The regional climate is humid tropical and dominated by monsoons. The Pearl River delta is in the subtropics and 80% of the annual discharge is in the wet season (April to September). Typhoons coincide with the wet season and flooding is common. The major drivers for the catchment changes are deforestation in the upper reaches of rivers, destruction of mangrove swamps, dike and dam building, channel dredging, agriculture, aquaculture, concentration of economic development and high population density. These drivers modify supply and distribution of water, sediments and nutrients.

In Vietnam some 42% of the total population of 77 million are resident in coastal areas Water is in great demand for rice production. Agriculture depends heavily upon chemical fertilisers and pesticides. Pesticide residues are transported by rivers to the coastal zone where they accumulate in the bottom sediments and aquatic organisms. Forest in the upper reaches of the Mekong River has been reduced from 43% in 1943 to 28% in 1995.

Further driver/pressure are urban waste, agriculture, aquaculture and transportation resulting in severe eutrophication. Man-made grow-out ponds that have replaced wetlands are highly enriched with fertilisers and serve as sources of dissolved and particulate nutrients. Demand for transportation and related traffic infrastructure lead to increased inputs of oil and other contaminants. In general, major drivers in the catchment and delta of the Pearl River are population growth, industrialisation and urbanisation leading to excess nutrient loads, organic contaminants and oil.

Sub-region 2. East China, Yellow and Bohai Seas, Taiwan Island: stretches from the Tropic of Cancer to 41° N and includes temperate coasts and the mouths of the Changjiang (Yangtze), Huanghe (Yellow), Hai and Liao rivers, with numerous medium and small rivers along the coasts of China and the Korean Peninsula. The Chinese continent dominates river discharge, is influenced by the East Asian monsoons but covers a wide climatic range from arid-temperate to humid tropics. The Changjiang (Yangtze) is the fourth largest river in the world in terms of water flow and sediment load. Construction of the Three Gorges dam will reduce the sediment discharged to the coast. The atmospheric pathway is a significant conduit of terrestrial materials to the ocean due to persistent westerly winds and the arid Gobi Desert areas and Loess Plateau region. The Korean rivers are steep, relatively short, with small drainage areas and relatively high sediment yields. Monsoonal Taiwan experiences typhoons and thunderstorms during the wet season which brings 80% of its annual precipitation.

While cultivated land area has decreased in China, the irrigated area has increased. Consequently, damming is a continuing activity affecting numerous Chinese river systems. Trapping efficiency is near 100% in some catchments, such as the Yellow (Huanghe). The application of chemical fertilisers caused the DIN concentration of the Changjiang and Huanghe to double in last two to three decades. Most industrial wastewater is pre-treated before discharge. Three large reservoirs in the Changjiang were built between 1968 and 2003 (including the Three Gorges dam) and the diversion of 1000 m^3 s^{-1} of water from the lower Changjiang to North China has been under consideration. The construction of the dams has reduced sediment transport downstream while deforestation in Sichuan has resulted in very high sediment loads due to serious soil erosion. The Yalujiang is dammed and the lower reaches receive a considerable amount of wastes from both non-point (e.g., agriculture) and point (e.g., domestic and industrial activities) sources.

The population density in Korea (471 persons km^{-2}) ranks as one of the highest in the world. Urbanisation, industrialisation and aquaculture has been rapid. Water resources in South Korea are fairly limited so there are large storage reservoirs around the country. Overuse of fertilisers, pesticides and insecticides in agriculture has led to pollution of rivers and streams.

Pressure from people on coastal zones of Taiwan is aggravated by the fact that most people live on the limited coastal plains. Pressure to move people inland has led to road construction and deforestation, both of which have contributed to an already high denudation rate of top soil. As a consequence of this, thirteen rivers in Taiwan are now ranked among the top 20 worldwide in terms of sediment yield. Together with agricultural fertiliser use this anthropogenic forcing may account for some 50% of the total particulate organic carbon and nitrogen fluxes from the Taiwanese islands.

Sub-region 3. The Sea of Japan, Sea of Okhotsk and Bering Sea: has a cold and relatively arid climate (33° N to the Arctic Circle, 66.33° N) containing the mouths of the Amur and Anadir rivers with medium and smaller rivers along the coasts of Siberia, Korea and Japan. The Tumen River (Tumenjiang) is frozen for 100–120 days yr^{-1} and experiences two flood periods; in April from the spring thaw and in July-August due to monsoonal rain. Peter the Great Bay has two inlets, Amursky and Ussurisky bays, with different types of drainage basin. The Amur is the world's ninth largest river, and its catchment contains significant agricultural areas as well as supporting biota of the taiga and subtropical forests. The basins in the Bering Sea are relatively pristine; the Anadyr River basin in north-eastern Siberia is an almost pristine watershed, lacking major industrial or agricultural activity, but mining activities pollute with heavy metals. The few river catchments emptying into the Sea of Japan, Sea of Okhotsk and Bering Sea are very different from the other regions in terms of human impacts since the region is scarcely populated, with human impact on the coastal zone localized to the few coastal cities. During the past decade, agricultural production in the Amur region has increased 3- to 4-fold and poor farming practices, such as burning straw and extensive use of herbicides and pesticides, have damaged soils, wildlife, human health and the economy. In the Tumen catchment, basically the only regional area of concern, industry within the watershed includes engineering, chemicals, materials processing, papermaking, rubber, textiles and printing, and further industrial development is planned.

4.4.2 Assessment of Land-based Drivers, Pressures and Coastal Impacts

Although anthropogenic pressures vary across East Asia, most rivers have been markedly altered by human activities or are subject to management plans affecting land and water use. The resultant drivers/pressures on the coastal zone are more pronounced than in other areas of the world. China alone supports more than 1 billion people, accounting for one-sixth of the world population. Consequently, changes in land use, pollution and water diversions have altered the horizontal mass transport of materials, and are likely to cause comparatively large coastal state-changes and generate zones of impact throughout the marginal seas of East Asia. The islands of Japan and Taiwan are also heavily populated, and human interference in the river catchments and flow regimes is extensive. There are pronounced differences among the sub-regions, particularly between the northern and southern groups highlighted in the sub-regional synthesis (Fig. 4.11).

4.4.2.1 *Drivers and Pressures*

The patterns of climate, including monsoons, and population distribution underpin the differences between the type and intensity of drivers and pressures across the three sub-regions of East Asia. In the southern sub-region, water extraction, diversion and damming usually in association with agriculture and locally intense urbanisation are principal drivers for coastal change. Increasing aquaculture ventures and industrial developments, coastal urbanisation and a high density coastal population add further pressures. Damming, mainly for hydroelectric power, and increasing urbanisation within an already high population density are the major drivers and pressures in the central region of East Asia. Deforestation in upper catchments is a continuing concern. By comparison, while the coastal zone of the sparsely populated northern sub-region sustains localised pressures from coastal urban areas, industrial development (including oil exploration) represents the major drivers and pressure elements (Table 4.7).

4.4.2.2 *Coastal Issues – State Changes and Impacts*

Sub-region 1: Vietnam and South China Sea

Coastal Geomorphology and Salinisation

In Vietnam, despite the building of dykes for coastal protection over the last millennium, the intensity and frequency of coastal flooding has increased in recent decades due to the combined effect of upstream deforestation, sea-level rise and blocking of waterways by the increased sedimentation at lagoon inlets and river mouths. Coastal erosion and accretion are rapid in the Mekong River delta (MRD) and Red River delta (RRD) posing major threats to the coastal development. The mean rate of coastal erosion increased along the Vanly coast after completion of large Hoa Binh Dam in the Red River catchment in 1989; a larger Son La dam is planned for the upper Hoa Binh River. By contrast, in the MRD coastal accretion has occurred on the Camau Peninsula. Also the RRD has expanded seaward 27 m yr^{-1} with a maximum rate of 120 m yr^{-1}, and 360 ha yr^{-1} have been added to the delta. Landward saltwater intrusion occurs as far as 50 km into the Red River and 70 km into the Mekong River due to decreased river flow in the dry season exacerbated by water abstraction for irrigation. Decreased river water discharge due to dams and irrigation in the upper reaches of the rivers and to sea-level rise will lead to enhanced saltwater intrusion.

Eutrophication

Eutrophication is widespread in southern Vietnam due to wastewater input from domestic activities, agriculture and aquaculture. The most significant impact derived from the rapid economic growth in the Red River basin is increased nitrogen loading to the coast. Pronounced state changes in the receiving marine environments of the Pearl River result from eutrophication yielding algal blooms, oxygen depletion and contamination of water resources. Red tides occur frequently in the western part of Hong Kong. The dinoflagellate bloom of *Gymnodinium mikimotoi* in 1998 resulted in massive fish kills and the loss of fish stocks.

Pollution

Oil is the most prominent contaminant in Vietnamese coastal waters, while pollution from the heavy metals occurs in some localised areas. Coastal mining for coal, sand, gravel and heavy minerals changes the morphology of the coastal landscape and subsequent dumping of solid and liquid waste degrades coastal water quality. Persistent organic pollutants (POPs) and chloro-pesticides have contaminated both the river water and sediment of the Pearl River delta. The urban wastewater discharges from the eight major cities of the region have reached almost 70% of the total Guangdong's Province discharges (Guangdong Province Environmental Protection Bureau 1996; Wong and Wong 2004). Chen (1994) estimates an annual regional generation of up to 2 billion and 560 million t industrial and domestic waste, respectively.

Table 4.7. East Asia. Links between coastal issues/impacts and land-based drivers; overview and qualitative ranking at regional/sub-continental scale. (Category: *1*, low; *10*, high. Trend: ⇒ stable, ⇑ increasing, ⇓ decreasing; numbers for sub-regions refer to Text Box 4.6, Figure 4.10)

Coastal impact/ issues	Anthropogenic drivers	Vietnam and South China (1)			Central China, Korea, Taiwan, Japan (2)			North East Asia (3)	
		Category	Trend expectation	Sub-regions particularly affected	Category	Trend expectation	Sub-regions particularly affected	Category	Trend expectation
Eutrophication/ red tides	Agriculture/ aquaculture	1–9	⇑	Locally	7–9	⇒	(Including Korea)	2	⇑
	Urbanisation/ industrialisation	1–9	⇑	(Major in Mekong, Red and Pearl River/Delta)	9–10	⇑	(Including Japan)		
Erosion/ sedimentation	Damming/diversion	2–10	⇒/⇑		10	⇑			
	Agriculture	2	⇒		8	⇒		2	⇒
	Deforestation	1–9	⇓		8	⇒		2	⇑
	Land reclamation	2–9	⇒						
	Sediment mining	1–9	⇒						
Coastal flooding	Deforestation	2–9	⇓					2–3	⇑
	Land reclamation	2–8	⇒/⇑		2–8	⇒/⇑			
Land subsidence	Groundwater pumping/erosion				4–10	⇒/⇑	(Central China and Taiwan)		
Salinisation	Agriculture/damming	1–8	⇒	Locally					
	Deforestation	2–5	⇓						
	Sediment mining	1–9	⇒	Locally					
Pollution	Mining and oil (on and off shore)	3–6	⇒					1–4	⇒
Biodiversity loss (modification)	Various drivers	4–10	⇒/⇑		3–5	⇑	(Central China and Taiwan)		

Table 4.8. East Asia. Major activities, present status and trends affecting the coastal zone. (Trend: ⇒ stable, ⇑ increasing, ⇓ decreasing; *numerals* refer to sub-regions described in Text Box 4.6, Fig. 4.10)

Anthropogenic drivers	Major state changes and impacts	Present pressure status	Trend expectations	Sub-regions particularly affected
Urbanisation/ industrialisation	Eutrophication/pollution/Harmful Algal Blooms (HABs) Water extraction	Major/medium	⇑	1, 2 incl. Japan, Taiwan, (locally 3)
Damming/diversion	Freshwater, nutrient, and sediment sequestration/coastal erosion	Major/medium	⇑	1 (locally), 2 incl. Japan, Taiwan
Agriculture/ aquaculture	Eutrophication, pesticide pollution/ diseases	Medium/major	⇒/⇑	1, 2
Deforestation	Habitat loss/modification Erosion/sedimentation Saltwater intrusion	Medium/major	⇒/⇓	1, 2,
Land reclamation	Sediment budget alteration	Medium (locally major)	⇑	1, 2
Mining (terrestrial and offshore)	Biodiversity loss	Medium/minor	⇒	1, 3

Biodiversity and Harvestable Resources

Recent natural and human-induced coastal land changes have led to the loss of tidal flats, mangroves, beaches, seagrass beds and coral reefs with > 30% of the mangrove forests converted to shrimp aquaculture ponds in the delta regions, significantly changing the coastline. Mangrove forest has been reduced from 400 000 ha in 1943 to 170 000 ha in 1993, and > 24 000 ha of the tidal flood plain including salt marshes was reclaimed for agriculture between 1958 and 1995; coastal land has accreted seaward. Beaches have been reduced by erosion and sand mining, coral reefs and seagrass beds have been destroyed by increased turbidity due to flood-originated silt and freshening of water and increased pollution has degraded living resources for coastal and offshore fisheries.

Sub-region 2: East China Sea, Yellow Sea and Bohai Sea; Taiwan and Japan

Coastal Geomorphology

The rate of sediment supply from the Huanghe (Yellow River) into the Yellow and Bohai seas has changed significantly due to human intervention throughout Chinese civilization. The Huanghe no longer flows into the sea for a large portion of the year due to increased water consumption by industry, agriculture and a growing population during the last 20 to 30 years. Consequently, the regime shift in the Huanghe delta from rapid accretion to coastal erosion is a dramatic change in the development of the regional coastal geomorphology. Increased water demand in East Asian continues to accelerate construction of dams along most of the river courses leading to decreased sediment discharge to the sea. More than 90% of the Huanghe sediment load is deposited in the lower reaches of the river and within the estuarine area. After construction of the Danjiangkou reservoir in the Changjiang (Yangtze) catchment in 1968, the annual suspended sediment discharge was reduced by 99%.

Sediment trapping and nutrient depletion are seen to originate from intense Taiwanese damming and have contributed to the erosion of many coastal deltas and beaches, and loss of fisheries resources (Chen et al. 2004). Such impacts are exacerbated by over-pumping of groundwater; 1 000 km^2 of the flat lands have subsided in Taiwan.

Eutrophication and Pollution

The amount of Chinese national waste drainage entering the seas exceeded 6.5×10^6 t yr^{-1} in the 1990s, of which 80–90% was carried by rivers. The ratios among nitrogen, phosphorus and silicon in the coastal ocean has changed due to human impacts in the watershed, affecting phytoplankton. The previous “nitrogen limitation” has switched to a phosphate and silica-limiting environment and the major phytoplankton species have shifted from diatoms to flagellates with harmful algal blooms (HABs) occurring more frequently in recent decades.

Biodiversity and Harvestable Resources

In combination with overfishing and pollution, reduction in nutrient supply from rivers and upwelling will further aggravate the problem of marine resource sustainability. A correlation can already be shown between the anomalies of the Changjiang outflow and the fisheries catch per unit effort (CPUE) in the East China Sea. Syvitski (2003) quotes an 85% reduction of shrimp fishery in the Bohai Sea when sediment discharge of the Huanghe was reduced along with water and nutrient discharge.

Sub-region 3: Sea of Japan, Okhotsk Sea and Bering Sea

Coastal Geomorphology

Annual precipitation has increased in recent decades along the southern coast of Korea and Cheju Island leading to increased erosion and an increase in the material export from the land to the sea.

Pollution

Minor contamination of heavy metals, petroleum hydrocarbons and chlorinated hydrocarbons was noted in the coastal waters north of the Tumen River. However coastal issues originate mainly from waste water discharge from large cities (e.g., Vladivostok and Ussurijisk) and from heavy industries concentrated along the banks of Amursky Bay. Mining activities are contaminating the Anadyr and Rudnaya rivers and impacting coastal waters of the Bering Sea and the middle of Sikote-Aline coast.

4.4.3 State Changes, Impacts and Future Trends

The extreme climatic conditions of the East Asian monsoon and a variety of anthropogenic drivers generate growing impacts on the coastal zones and the water continuum (Table 4.8). Damming of rivers has significantly distorted the erosion-accretion equilibrium of large stretches of the East Asian coastline. These effects are most apparent where water resources are both abundant seasonally (i.e., Vietnam and South China) and where water resources are scarce due to population growth in the catchment areas, in coastal metropolitan areas or in arid climates. Examples can be found along the Vietnamese coast and in the old Huanghe delta and current Huanghe delta. Diversion of water resources in the upper reaches of the rivers and especially in the Great Western Development area in China which influences upper and middle reaches of the Yangtze and Yellow rivers.

Numerous examples reveal that the oceanic environment is changing due to either natural or human-caused variations in climate and river runoff (Chen 2000) affecting water quality and changes in the flood storage and drainage capacities of landscapes. Rivers in Vietnam and South China are experiencing serious harmful algal blooms that result in fish kills; in particular the expanding aquaculture sector is affected. Red tides are frequent in the Bohai Sea off the Liao and Hai rivers (Yu et al. 1999) and coastal areas of Taiwan, the Korean Peninsula and Japan, probably due to an increased influx of nutrients and changing nutrient ratios (e.g., silicate becomes an issue when the N and P increase to a point that the ratios of Si : P and Si : N are altered). Many of the excess nutrients are coming from atmospheric deposition, not just human activities that result in changes in river runoff quality.

The most common contaminants in the coastal zone of East Asia are oil, polycyclic aromatic hydrocarbons (PAHs) and pesticides in Vietnam and South China (Sub-region 1), and heavy metals in the central area (Sub-region 2) and the northern area (Sub-region 3). Persistent organic pollutants (POPs) and heavy metals have been reported. DDT and HCH concentrations in oysters in the western waters of Hong Kong and in human breast milk were 2–10 times higher than those found in European and Canadian samples (Wong and Wong 2004, Wong et al. 2002). Oil pollution from offshore oil production has resulted in habitat loss in the coastal waters off Sakhalin Island. Most pollutant inputs are from agriculture and industrialisation along river catchments in Vietnam and South China (Sub-region 1) and the central sub-region (2), and from terrestrial and offshore mining (including oil exploration) in the northern sub-region (3). Atmospheric deposition is a major pathway for pollutants in northern East Asia.

Exploitation of living resources has resulted in habitat loss of mangroves, coral reefs and seagrass beds and led to decreases in the number of species and wetlands in Vietnam and South China. Fishery resources may decline with further contamination, overfishing or reduction of freshwater outflow of the Vietnamese and Taiwanese rivers, as well as the Yangtze River due to its damming and diversion. Overfishing and overcrowding of prawn cultivation affects about 1 000 km^2 offshore of the Hai and Liao rivers in the Bohai Sea. Coastal fisheries yields in the west of Taiwan have already been cut by half due to contamination and overfishing, an effect that exacerbates those pressures on the marine resources deriving from changing riverine material fluxes to the coastal waters.

In Vietnam and South China deltas (e.g., the Mekong, Red and Pearl rivers), saltwater intrusion affects rice agriculture and drinking water as well as spawning of prawns and fishes. In the central sub-region of China, inundation of deltaic lowlands by storm surges and high tides, and possible future sea-level rise, are concerns. Land subsidence in Shanghai and western Taiwan results from ground water extraction. In the Japanese islands, most sandy beaches are expected to be lost within the next 100 years due to sea-level rise.

4.4.4 Conclusions – East Asia

East Asia characterises the situation of developing economies and high population pressures, at least in the southern and central sub-regions, where economic growth frequently outpaces the necessary urban and industrial infrastructure. Hence, eutrophication, on the other hand

Sub-region 1 · Vietnam and South China: South China Sea

Driver	Major coastal impact	Present pressure status	Trend expectation
Aquaculture	Pollution/ diseases	Major	⇑
Urbanisation	Eutrophication/ siltation/ water shortage	Medium (Major locally)	⇑
Industrialisation	Pollution/ salinisation	Medium (Major locally)	⇑
Damming/ diversion	Erosion/ sedimentation; Nutrient depletion	Medium, (Major locally)	⇒ ⇑
Agriculture	Eutrophication/ pollution	Medium, (Major locally)	⇒ ⇑
Land reclamation	Erosion/ sedimentation/ flooding	Medium (Major locally)	⇒ ⇑
Various drivers	Biodiversity loss	Medium (Major locally)	⇒ ⇑
Mining/ oil extraction	Pollution	Medium	⇒
Deforestation	Erosion/ sedimentation	Medium (Minor locally)	⇓

Sub-region 2 · Central China: East China Sea/ Yellow Sea; Japan and Taiwan

Driver	Major coastal impact	Present pressure status	Trend expectation
Damming/ diversion	Erosion/ sedimentation; Nutrient Depletion	Major	⇑
Urbanisation	Eutrophication/ pollution	Major	⇑
Industrialisation	Pollution	Major	⇑
Agriculture	Eutrophication/ pollution (incl. red tides)	Major	⇒
Aquaculture	Pollution/ diseases	Major	⇒
Deforestation	Erosion/ sedimentation	Major	⇒
Groundwater pumping	Land subsidence	Medium (locally major)	⇒ ⇑
Land reclamation	Erosion/ sedimentation/ flooding	Medium	⇒
Various drivers	Biodiversity loss	Medium	⇑

Sub-region 3 · North East Asia: Korean East Coast, Okhotsk and Bering Sea (note of caution: limited information on land based drivers and trends!)

Driver	Major coastal impact	Present pressure status	Trend expectation
Urbanisation/ industrialisation	Eutrophication/ pollution	Minor (locally medium)	⇑ (locally)
Mining	Pollution	Minor (locally medium)	⇒
Deforestation	Erosion/ sedimentation/ flooding	Minor	⇑
Agriculture	Eutrophication/ pollution	Minor	⇑ ⇒

Fig. 4.11. East Asia. Sub-regional synthesis and typology of river catchment–coast interactions

nutrient depletion and pollution in the coastal zone are major consequences from catchment-based activities, linked to urbanisation and the rapidly increasing demand for water and energy. Increased efforts in damming and diversion of river courses are allied with erosion/sedimentation problems at the coast. Agriculture and deforestation affect some areas, in particular those in southern East Asia where tropical typhoons bring torrential rain and cause pulsed freshwater discharges to the coast. All the activities listed in Table 4.8 result in a variable degree of change in the trophic state and food webs of coastal ecosystems and loss of living resources.

The flood cycle, linked to the monsoon rains, is a critical factor in the life cycle of many of the region's aquatic species; even slight changes in peak river discharge could threaten fish production and food security. Impacts observed near dams constructed on the Mekong River tributaries illustrate that altering the annual flood cycle, reducing the silt load of the water or diverting the river flow can have serious impacts on agriculture in the Mekong delta. Figure 4.11 is a sub-regional synthesis of main river catchment-coastal change issues, and provides an expert judgement-based ranking and trend analysis.

4.5 Russian Arctic

4.5.1 Overview of Russian Arctic River Catchment-Coastal Zone Systems – Geography and Climate

The length of the Russian coastline exceeds 60 000 km accommodating a population of 17 × 10^6 people. More than 40 000 km are Arctic coast, 27 000 km of which belong to the continental shoreline. Nine large rivers – Northern (Russian: Svernaya) Dvina, Pechora, Ob and its tributaries, Yenisey, Lena, Khatanga, Jana, Indigirka and Kolyma – flow to the Arctic Ocean from large catchment basins (Fig. 4.12). In fact all northern rivers on their way to the Arctic deltas pass through several climatic zones each associated with different human activities.

Northern, western and eastern areas of the Russian coastal zone have industrial development (mining, refining, shipbuilding, construction including defence industries) and commercial fisheries. All types of settlements, from well-developed urban areas on the Baltic Sea to small rural settlements on the northern seas, are represented but there is much more limited use of the coastal

Fig. 4.12. Russian Arctic. The sub-regions identified in the Russian Arctic Basins study and a selection of river catchment-coast systems evaluated (from Gordeev et al. 2005): *Sub-region A*: White Sea: *A1* Onega River catchment basin, *A2* Northern Dvina (Ru: Severnaya Dvina) River catchment basin, *A3* Mezen and Kuloy River catchment basin. *Sub-region B*: Barents Sea: *B1* Kolsky Peninsula coast, *B2* Pechora River catchment basin. *Sub-region C*: Kara Sea: *C1* Yamal Peninsula coast, *C2* Ob River catchment basin, *C3* Yenisey River catchment basin. *Sub-region D*: Laptev Sea: *D1* Taymyr Peninsula coast, *D2* Khatanga River catchment basin, *D3* Olenek River catchment basin, *D4* Lena River catchment basin, *D5* Yana River catchment basin. *Sub-region E*: East Siberian Sea: *E1* Indigirka River catchment basin, *E2* Kolyma River catchment basin. *Sub-region F*: Chuckchee Sea: *F1* Chuckchee Sea coast

Text Box 4.7. Russian Arctic: catchment sub-regions

From Gordeev et al. (2005)

Sub-region A. White Sea: the Arkhangelsk region (A2 in Fig. 4.12), including the basin and mouth of the Northern (Severnaya) Dvina River and the coastal part of the White Sea. Ecologically, the White Sea is subdivided into two large parts:

- the eastern part with clean tidal waters but strong erosional impact with rates reaching 13–17 m yr^{-1} on the Tersky coast (eastern Kola Peninsula, B1 in Fig. 4.12) and the Kaninsky coast (north of A3 in Fig. 4.12);
- the western part (north west of A1 in Fig. 4.12), which has more internal bays and favourable conditions for accumulation of pollutants.

The surface water quality in the catchment of the Severnaya Dvina River is affected by timber processing, while the Arkhangelsk division contributes non-treated communal and industrial sewage into natural waters. Industrial development and commercial fisheries are impacting the traditional subsistence uses of biological resources carried out by the indigenous communities.

Sub-region B. Barents Sea: the far north-western part of the Russian coastal zone, the Murmansk region (B1 in Fig. 4.12) with 1730 km of diversified coastline including numerous fjords and bays. The large Kola Fjord is the most industrially-developed and populated part of the Russian north, receiving waters from the Kola River and other rivers of the Kola Peninsula, including: Patso-Yoki, Zapadnaya Litsa, Tuloma, Vorjema and Pechenga which together account for only 10% of the total sediment load to the Barents Sea. About 60% of the region's population is concentrated in the coastal zone. Biologically, the Barents Sea is the richest system of the Arctic Ocean due to advection of the warm Gulf Stream meeting with cold Arctic waters.

The south-eastern part of the Barents Sea is supplied by the Pechora River, the largest river of the lowland north-eastern part of Russia (B2 in Fig. 4.12). It supplies 70% of all river runoff into this coastal sea. The tundra zone in the catchment has relict islands of boreal forests. Some rivers are strongly impacted by mining, chemical, metallurgical and timber industries (e.g., Kola Peninsula and Murmansk regions), while other rivers experience little anthropogenic impact. In the Nenets Autonomous okrug or Pechora division (B2 in Fig. 4.12), industries, domestic and agricultural uses of floodplains are the main driving forces in changing the natural environment. Exploitation of oil and gas fields for chemical processing produces impacts though chronic environmental pollution and regular release of non-treated communal wastes and domestic sewage exacerbate the situation. A significant number of coastal and marine oil-fields will soon be accessed for further exploration and development.

Sub-region C. Kara Sea: Western Siberia (Tymen region, Khanty-Mansi and Yamal-Nenets Autonomous okrugs) with Russia's largest rivers: Ob, Pur, Taz, and Pjasina (C1, C2 in Fig. 4.12). They form a complex delta-estuarine areas and contribute 41% of the total runoff to the Arctic Ocean; the Ob River provides 37% of the runoff to the Kara Sea. Widespread bogs and marshes increase massively from north to south reflecting the growing thickness of the underlying permafrost in high latitudes. The catchment basin of the Ob River gathers water from the territories of seven administrative regions of Russia, which form the Western Siberia macro-region with a population 16.74 million people and is subject to industrial pressures and natural resource exploitation.

The Kara Sea subdivision (C3 in Fig. 4.12) in Eastern Siberia (Krasnoyarsky Kray, Evenkysky, Taymyr (Dolgano-Nenets) autonomous okrugs) has the largest river of Russia, the Yenisey River and its 190 000 tributaries which drain an area of 2.58×10^6 km^2 along a length of 3 500 km. Tributaries are concentrated in mountains to the east of the catchment. The river mouth is a dynamic estuarine delta with numerous channels; Yeniseyskaya Guba and the semi-enclosed Yenisey Bay cover some 20 000 km^2. The Ob River basin is highly industrialized, with oil and gas activities dominating. The central and southern regions of Western Siberia contain a diversity of industry, including materials processing, coal-mining, agriculture, transport, building materials manufacture, pipeline construction and military enterprises. Dams on the Ob River have had no significant impact on the volume of river flow, but coal-mining wastes and agricultural pollution have led to significant ecological impacts. Middle and northern reaches of the Ob River and its tributaries have pollution from crude oil and its products. The most prominent anthropogenic drivers in the Yenisey catchment are industry (mining, non-ferrous metallurgy, chemical plants, timber, pulp and paper production) agriculture, navigation, housing and communal holdings and the environmental state of the whole river is assessed as critical.

Sub-region D. Laptev Sea: receives runoff from four large rivers: Khatanga, Lena, the Olenek and Jana (D in Fig. 4.12). The 4 400 km-long Lena River has one of the largest catchment basins in Russia (2.49×10^6 km^2). Its delta is large, with a complex dynamic where strong flows of river sediments have formed some 6 089 channels, 58 728 lakes and 1 600 islands in a total area of 32 000 km^2. Permafrost is widespread and the coastal zone contains a narrow strip of tundra further south followed by forest-tundra and taiga forests.

Sub-region E. The East Siberian Sea: a shallow sea, where tidal activity is significant because of the very narrow strip of water free of ice. Annually the shoreline recedes at a rate of 4–30 m and some 10–50 km have been lost since the shoreline stabilised some 5–6 000 years ago. Two large rivers (Indigirka and Kolyma) drain the eastern part of Sakha-Yakutia (E in Fig. 4.12) and deliver up to 80% of the total runoff, but generally freshwater inflow has limited influence on the coastal sea. The Indigirka River in its lower reach passes through easily-eroded quaternary rocks, carrying high loads of sediments (11.2×10^6 t yr^{-1}). The Kolyma River drains lowland areas and carries 8.2×10^6 t yr^{-1} of sediment. The main changes in natural waters can be attributed to dam construction, industrial effluents (gold mines and other non-ferrous metal mining complexes), agricultural and domestic wastes.

zone in the Arctic than in the western (the Baltic Sea coast) and southern areas (the Black, Azov, and Caspian Sea coasts).

The break-up of the former Soviet Union in the 1990s transformed much of Russia. The northern coastal regions now represent > 64% of the Russian Federation and thus, the resources, environmental, social and economic state of these regions has great significance for the future development of the country. The notion of environmental safety is particularly relevant to the Arctic for several reasons. Among these are concerns relating to the fragility of northern ecosystems and their vulnerability to human disturbance. In addition, the area has a profound influence upon global (or at least hemispheric) environmental processes such as atmospheric and oceanic circulation, global warming and ozone layer depletion resulting from drivers that originate from within and outside the area (e.g., a warming climate, change in the ice sheets).

Table 4.9. Russian Arctic. Links between coastal issues/impacts and land-based drivers; overview and qualitative ranking at regional/sub-continental scale. (Category: 1, low; 10, high. Trend: ⇒ stable, ⇑ increasing, n.o. not observed; *letters* for sub-regions refer to Text Box 4.7, Fig. 4.12)

Coastal impact/ issues	Anthropogenic drivers	Western Russian Arctic (WRA) coast[a]			Eastern Russian Arctic (ERA) Coast	
		Category	Trend-expectation	Sub-regions particularly affected	Category	Trend-expectation
Pollution	Industrialisation	5–10	⇑	White Sea (A), locally major, Arkhangelsk, North. Dvina (A2)	4–5	⇒/⇑
	Navigation	3–6	⇑	Barents Sea (B), locally major Kola Penin. (B1), Pechora R. (B2)	2–3	⇑
	Urbanisation	8–9 (locally)	⇑	Kara Sea (C), locally major, Ob R. (C2), Yenisey (C3) partly Lena R. (D4)	2–3	⇑
Acidification	Industrialisation	8–10	⇒/⇑	Northern Dvina (A2), Kola Peninsula (B2) Yenisey R. (C3)	3–4	⇑
Radioactive pollution	Nuclear industry/ Navy/nuclear-power/engineering	5–10	⇒	Kola Bay (B1), Guba Chernaya (south of Novaya Zemlya B2) Yenisey Bay (C3)	3–4	⇒
Erosion	Damming	2–4	⇒	Ob R. (C2), Yenisey R. (C3)	1	⇒
	Thermoabrasion[b]	6	n.o.	Laptev Sea coast (D)	6	n.o.
Sedimentation	Navigation	2–3	⇒		2–3	⇒
Loss of biodiversity	Fisheries/damming/ pollution	1–3	⇒		n.o.	

[a] The Lena River divides the Western Russian Arctic (WRA) and the Eastern Russian Arctic (ERA); which comprises the whole area east of the Lena Basin. This boundary crosses the Laptev Sea and demarcates the junction of the Eurasian and North American tectonic plates.
[b] Thermoabrasion is climate driven thus mentioned here to showcase its much bigger role as a driver as compared to human influence.

The administrative regions of the Russian Federation correlate closely with the large catchment basins allowing a sub-regional division relevant to the Arctic seas and an assessment of management responses within the existing administrative framework (Fig. 4.12; Text Box 4.7).

4.5.2 Assessment of Land-based Drivers, Pressures and Coastal Impacts

The Russian Arctic has a long history of resource use and development, but concerted pressure on the coastal zone started in the 1930s. River and marine transport routes remain the most important part of the Arctic infrastructure. Catchment basin use is variable in the Russian Arctic. Fisheries, forestry and reindeer breeding are being supplemented by the development of industrial production sectors such as metallurgic plants (e.g., Severonickel, Pechenganickel, Norilsk), mining extractive and mining concentrating industries (e.g., Apatit, Pechora-coal), and high-capacity oil and gas output complexes.

4.5.2.1 *Drivers and Pressures*

Because of prevailing sea currents and atmospheric conditions, the Arctic Ocean acts as a sink for a wide range of pollutants, including heavy metals, toxic substances, hydrocarbons, PCBs and nuclear wastes (Griffiths and Young 1990). In recent years, various projects have been launched to extract vast quantities of natural resources.

Generally, the river basins are under considerable pressure from populated and industrial areas, particularly to the west of the Yenisey River (Table 4.9, Fig. 4.13). Airborne and waterborne pollutants find their way to the Arctic via long-range transport pathways. The traditional economy of indigenous people based on renewable natural resources remains a feature of the Arctic region. However, the main pillar of current economic development can be found in diversified industrial use of non-renewable resources such as oil, natural gas, coal, minerals, raw materials, and rare and precious metals. The Arctic coastal environment is under growing pressure from both local industrial centres and traditional economies and changing horizontal and atmospheric flows of pollutants, water and sediments in large catchments.

4.5.2.2 *Coastal Issues – State Changes and Impacts*

Pollution

Among the most important pollutants in the Russian Arctic are heavy metals, oil products, sulphur and nitrogen oxides, and organic micropollutants. Air-borne wastes produced by metallurgy smelters, cement plants and mining, strongly affect natural ecosystems within several industrial regions in the Kola Peninsula, Arkhangelsk, Vorkuta and Norilsk areas and in the Murmansk region. The great Siberian rivers remain among the most pristine big rivers in the world (especially the Lena River); however, in their upper and middle reaches heavy metals concentrations may still be quite high.

Rivers and lakes within gas and oil extracting regions (mainly in eastern European and north-western Siberia) are heavily polluted by crude oil leading to significant changes in the diversity of local fauna. Persistent organic pollutants (POPs) are among regularly-detected substances in the water, sediments and biota of the Arctic region; mainly organochlorine pesticides (e.g., HCH) and their metabolites, industrial chemicals (PCBs) and anthropogenic and natural combustion products (dioxin/furans and PAHs).

Acidification

Anthropogenic acidification of waters is occurring due to sulphur dioxide and oxides of nitrogen deposition from the atmosphere on the watershed areas (e.g., in the Murmansk region). At the same time, the trans-boundary transfer of sulphur from the Western Europe (and even from the American continent) is a significant source of sulphur input in the Russian Arctic.

Radioactive Pollution

Sources of artificial radionuclides in the Russian Arctic Seas include: the Novaya Zemlya nuclear weapon tests (1950s and 1960s), global background from other tests, the Chernobyl accident, mining-chemical plants in Russia, radiochemical plants in Western Europe, dumping of solid and liquid radioactive wastes in the Barents and the Kara Seas, and the northern military marine and atomic icebreaker fleet. Located in the river basins, Russian chemical plants of military-industrial complexes are powerful sources of radioactive pollution of the seas, for example, 1 100 TBq (30 000 Ci) were transferred to the Arctic Ocean through the Ob and Yenisey rivers between 1961 and 1989. However, the general degree of water radioactive contamination of the Arctic seas differs little from background (~6 Bq l^{-1}), except for several localized areas.

Coastal Geomorphology

Damming is seriously affecting the erosion-accretion equilibrium in the basins of some big Arctic rivers; there are 13 dams and reservoirs in the Ob River basin (total volume 75.2 km^3), 8 dams and reservoirs in the Yenisey River basin (473.9 km^3) and a few dams with reservoirs in the Lena and Kolyma basins. The most important changes in the suspen-ded matter discharge have occurred in the Yenisey basin.

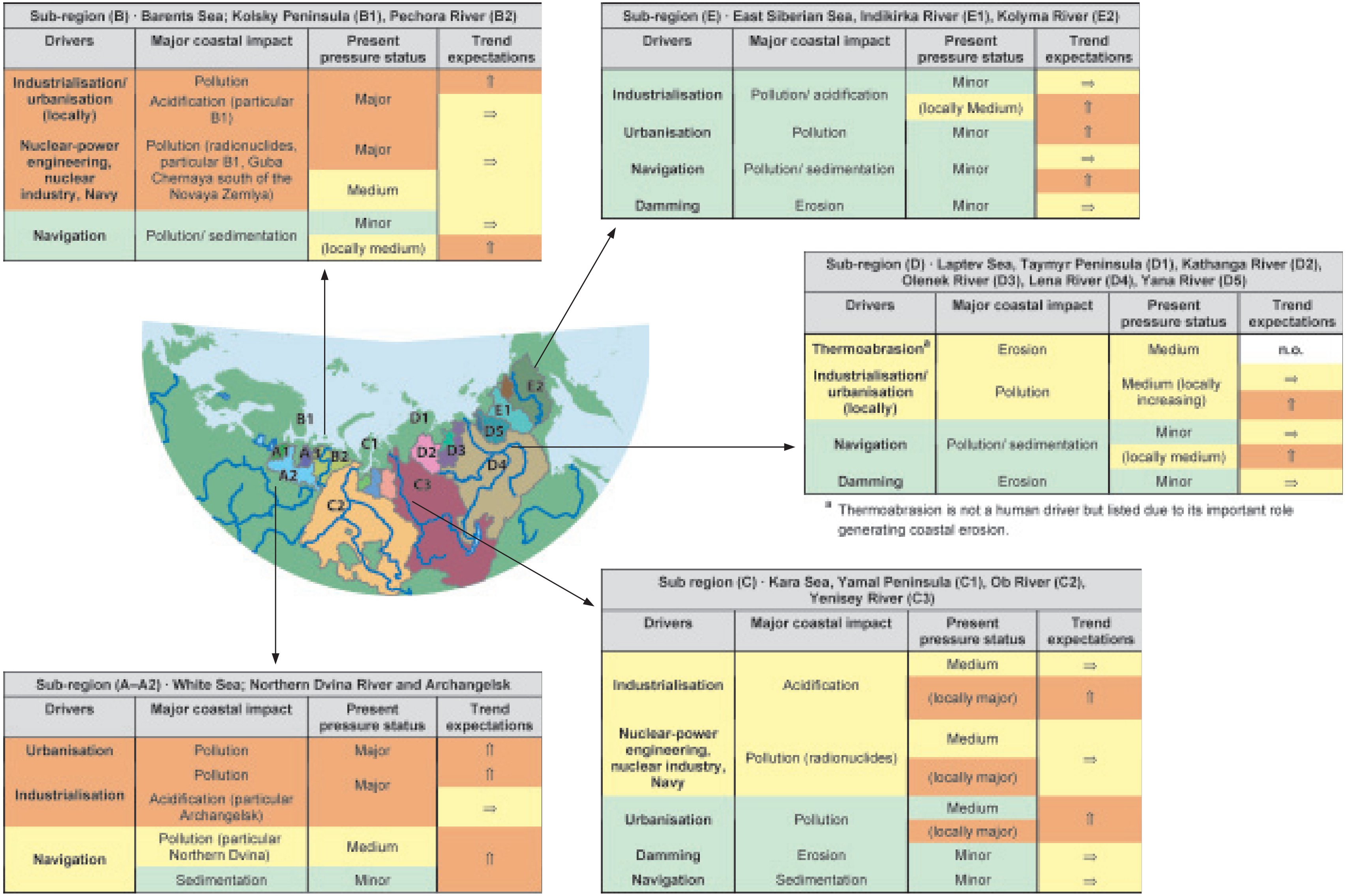
Coastal erosion due to thermo-abrasion is a significant source of sediment for the coastal zone (e.g., the total mass of abrasion material along 2 400 km of the Laptev Sea coastline is 2.4 times the discharge of riverine suspended sediment into the Laptev Sea). Erosion rates of high cliffs and seasonal ice melting causes shoreline retreat, and significant abrasion has been detected in the eastern White Sea and in the East Siberian Sea.

Eutrophication

Despite the existence of anthropogenic drivers for excess nutrient supply, the hydrological and biogeochemical system settings regulating water formation in the Arctic basin may diminish the development of eutrophication. Characteristic signals of eutrophication that can be detected locally are diminishing dissolved O_2 concentrations, increasing nutrient concentrations, intensive al-

Table 4.10. Russian Arctic. Major activities, present status and trends affecting the coastal zone. (Trend: ⇒ stable, ⇑ increasing; *letters* for sub-regions refer to Text Box 4.7, Fig. 4.12)

Anthropogenic drivers	Major state changes and impacts	Present pressure status	Trend expectation	Sub-regions particularly affected
Industrialisation incl. mining, oil and gas production	Pollution/acidification	Medium/major	⇒/⇑	A2, B1, B2, C2, C3, D4
Navigation	Pollution Sedimentation	Medium Minor	⇑ ⇒	A2, B2, D4, D5 (minor in all other areas)
Nuclear-power, engineering, nuclear industry, Navy	Radioactive pollution	Minor (major locally)	⇒	B1, B2, C3
Urbanisation	Pollution/partly eutrophication	Minor (medium to major locally)	⇑	A2, WRA Coast
Damming	Coastal erosion	Minor (locally more important)	⇒	C3, E2



Sub-region (B) · Barents Sea; Kolsky Peninsula (B1), Pechora River (B2)			
Drivers	Major coastal impact	Present pressure status	Trend expectations
Industrialisation/ urbanisation (locally)	Pollution Acidification (particular B1)	Major	⇑ ⇒
Nuclear-power engineering, nuclear industry, Navy	Pollution (radionuclides, particular B1, Guba Chernaya south of the Novaya Zemlya)	Major Medium	⇒
Navigation	Pollution/ sedimentation	Minor (locally medium)	⇒ ⇑

Sub-region (E) · East Siberian Sea, Indikirka River (E1), Kolyma River (E2)			
Drivers	Major coastal impact	Present pressure status	Trend expectations
Industrialisation	Pollution/ acidification	Minor (locally Medium)	⇒ ⇑
Urbanisation	Pollution	Minor	⇑
Navigation	Pollution/ sedimentation	Minor	⇒ ⇑
Damming	Erosion	Minor	⇒

Sub-region (D) · Laptev Sea, Taymyr Peninsula (D1), Kathanga River (D2), Olenek River (D3), Lena River (D4), Yana River (D5)			
Drivers	Major coastal impact	Present pressure status	Trend expectations
Thermoabrasion[a]	Erosion	Medium	n.o.
Industrialisation/ urbanisation (locally)	Pollution	Medium (locally increasing)	⇒ ⇑
Navigation	Pollution/ sedimentation	Minor (locally medium)	⇒ ⇑
Damming	Erosion	Minor	⇒

[a] Thermoabrasion is not a human driver but listed due to its important role generating coastal erosion.

Sub region (C) · Kara Sea, Yamal Peninsula (C1), Ob River (C2), Yenisey River (C3)			
Drivers	Major coastal impact	Present pressure status	Trend expectations
Industrialisation	Acidification	Medium (locally major)	⇒ ⇑
Nuclear-power engineering, nuclear industry, Navy	Pollution (radionuclides)	Medium (locally major)	⇒
Urbanisation	Pollution	Medium (locally major)	⇑
Damming	Erosion	Minor	⇒
Navigation	Sedimentation	Minor	⇒

Sub-region (A–A2) · White Sea; Northern Dvina River and Archangelsk			
Drivers	Major coastal impact	Present pressure status	Trend expectations
Urbanisation	Pollution	Major	⇑
Industrialisation	Pollution Acidification (particular Archangelsk)	Major	⇑ ⇒
Navigation	Pollution (particular Northern Dvina) Sedimentation	Medium Minor	⇑

Fig. 4.13. Russian Arctic. Sub-regional synthesis and typology of river catchment–coast interactions

gae bloom with prevailing blue-green and green phytoplankton species. However, the periodicity of appearance of low dissolved oxygen in waters of big Arctic river basins is very low. In general, eutrophication is significant in some small rivers and reservoirs but is not a major issue for the big Arctic rivers and their receiving water bodies.

Biodiversity and Harvestable Resources

Increasing pollution of lakes, rivers and the coastal zones of Arctic seas by oil products, heavy metals, pesticides and other pollutants is leading to loss of biodiversity including reduction of biomass and structural change in the planktonic community, loss of biomass and diversity of bottom fauna and, especially, loss of habitats and significant loss of fisheries. Overfishing exacerbates land-based pressures and significant decreases of fish populations results in a reduction of numbers of birds, seals and walruses.

4.5.3 State Changes, Impacts and Future Trends

Pollution by petroleum products, heavy metals and organic micro-pollutants remains the most significant problem in the Russian Arctic (Table 4.10). The economic recession of the 1990s in the Russian Federation interrupted further increases in pollution in the industrialised western Arctic. However, increasing activity by national and multinational oil, gas and coal companies will require extended infrastructure for land transport and growing navigation across the region. A significant increase in related pressures on the environment is anticipated.

Acidification is a major issue in some local areas of the Kola Peninsula, the Archangelsk and Norilsk areas; at present, there is stabilisation or even a decrease in sulphur deposition. Elsewhere, acidification is of minor importance.

Radionuclide pollution of the Arctic environment remains a major concern. Maximum pollution occurred in the 1960s and 1970s during and after the period of nuclear weapons tests. There are indications of a stabilisation of the situation, but due to the long life span of many nuclides the problem will persist into the future.

In the former Soviet Union many large dams were constructed in Arctic river basins. However, significant influences of damming on the annual hydrological regime and suspended matter discharge rates were observed only in the Yenisey River. For example, after construction of the Krasnoyarskaya dam in 1967, suspended matter discharge decreased by 2–3 times.

Generally, water withdrawal is not an issue in the Arctic, reflecting the high volumes of river water discharge and relatively low regional consumption of fresh water. Predictions to 2025 indicate that the total water withdrawal from Arctic river basins and loss by evaporation from reservoirs would not exceed 1–2% of the river runoff.

4.5.4 Conclusions – Russian Arctic

In the Russian Arctic the most important coastal issues relate to pollution originating mainly from industrialisation and navigation, acidification, radioactive pollution and erosion. In the Arctic basin there are many small rivers draining to the coastal seas and, due to the low density of population, the overwhelming majority of them, with the exception of small rivers of the Kola Peninsula and probably of the White and Barents seas, are relatively pristine. Figure 4.13 is a sub-regional synthesis of main river catchment-coastal change issues, and provides an expert judgement-based ranking and trend analysis.

4.6 Europe – Catchment-Coast Interactions

Regional assessment and synthesis efforts in Europe started in the late 1990s, incorporating both natural and social science aspects of catchment–coast interactions and in particular focused on policy and plausible scenarios of change. The EuroCat project provides primary information on the Vistula, Elbe, Rhine, Humber, Seine, Po, Idrija, Axios, and Provadijska catchment-coast systems (*http://www.iia-cnr.unical.it/EuroCat/project*) and the daNUbs project on the Danube–Black Sea interaction (*http://danubs.tuwein.ac.at*). A key consideration in these and related projects was to provide an appropriate coverage of the major European coastal sub-regions (Fig. 4.14) and in there to select catchments representative of a certain type of coast under typical driver–pressure settings. The increasing interest of the public sector on integrated catchment-coast studies is evident from the large-scale study on heavy metals and organic pollutants in the Rhine catchments and their impact on sediment quality in the coast (Text Box 4.8).

Both the "EuroCat" (*http://www.cs.iia.cnr.it/EUROCAT/project.htm*) and "daNUbs" (*http://danubs.tuwien.ac.at/*) project are part of the ELOISE (European Land-Ocean Interaction Studies; Cadée et al. 1994, *http://www2.nilu.no/eloise/* and for the digest: *http://www.eloisegroup.org/themes/*) research initiative of the European Union. Since the early 1990s the EC's ELOISE has developed into the biggest regional project cluster within LOICZ and accommodated around 60 individual multinational projects. As part of this initiative a major workshop in 2003 focused on DPSIR and scenarios for future developments of European coastal seas (Vermaat et al. 2005); the pertinent results of the workshop are incorporated in this section.

The work in EuroCat extended the DPSIR approach (see Text Box 4.1 above) with the development of scenarios highlighting potential catchment–coast interactions under different world views. Before addressing these scenarios and providing case applications (see Sect. 4.7), a

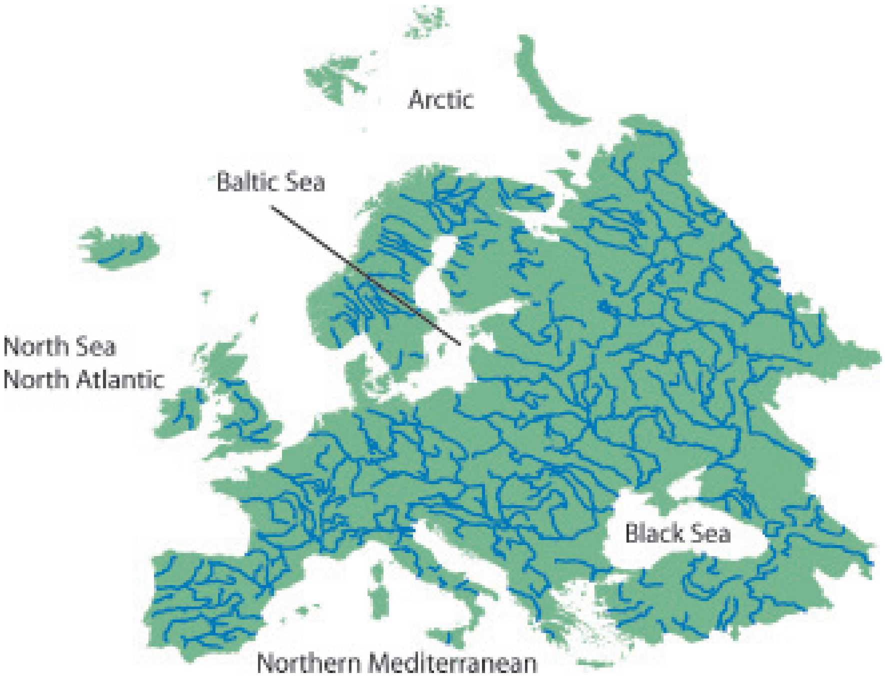


Fig. 4.14.
Europe. The sub-regions identified in the European Basins workshops

brief summary of the key findings from EuroCat is given to allow comparison with the regional assessments described earlier. Relatively rich data and information sources have underpinned this European assessment and yielded an extended coastal basin and catchment typology (Meybeck et al. 2004a).

4.6.1 Overview of the European Coastal Zone/Catchment Systems

Europe's coastal zone is to a considerable extent characterised by enclosed or semi-enclosed seas that largely trap the land-based inputs (e.g., Black Sea, Mediterranean Sea, Adriatic Sea, Baltic Sea, Fig. 4.14). In the North Sea, riparian influences affect the immediate near-shore coastal zone, but overall the system functioning is more ocean-dominated (Thomas et al. 2004). Other areas, such as the rocky and mountainous shores of the Atlantic coast of Scandinavian or the Iberian peninsula with its relatively small shelf, are even more ocean-dominated.

The median length of the river catchments in Europe is 600 km (ranging from 200 to 2 200 km) with the Danube, at 2 200 km, being rather modest in a global comparison. Processes in the catchment affect the coast with a certain delay time. Runoff per coastal catchment ranges from 20 and 715 mm yr^{-1} (Fekete et al. 1999, 2001, Vörösmarty et al. 2000a,b). Specific discharges range from 2 to 45 $\text{l s}^{-1}\,\text{km}^{-2}$, which is moderate compared to other global regions.

Seasonal runoff in Europe to a large extent is of the pluvial–oceanic type with peak flows during winter (e.g., the major rivers draining to the Atlantic coast), although some such as Rhine and Elbe have more complex cycles due to the influence of lakes and mountains. Northern European rivers have a minimum flow in late winter while Mediterranean rivers are more variable, ranging from minor or even zero net flow in summer to those (e.g., Rhone and Po) with mountain influences similar to the Rhine and Elbe.

Sediment yields differ markedly among sub-regions of Europe. Estimates from Meybeck et al. (2004b) show the lowest rate in the Baltic (12.5 $\text{t km}^{-2}\,\text{yr}^{-1}$) and the highest in the northern Mediterranean (300 $\text{t km}^{-2}\,\text{yr}^{-1}$), with relatively low to medium rates elsewhere (i.e., Atlantic 131 $\text{t km}^{-2}\,\text{yr}^{-1}$, northern Black Sea and Arctic 48 $\text{t km}^{-2}\,\text{yr}^{-1}$, North Sea 38 $\text{t km}^{-2}\,\text{yr}^{-1}$). However, sediment loads to the coastal seas are determined to a large extent by flow regimes modified by impoundments and irrigation (see below).

4.6.2 Assessment of Land-based Drivers, Pressures and Coastal Impacts

There are pronounced differences among the sub-regions of Europe in the type and intensity of drivers and pressures and the resultant impacts on coastal systems (Fig. 4.15).

4.6.2.1 *Population Pressure and Development (Urbanisation along River Catchments and in the Coastal Zone)*

Europe's population has grown by 100 million since 1972, totalling 818 million in 2000 (13.5% of the global total).

Text Box 4.8. Contaminated sediments in estuaries: the port of Rotterdam

J. Grandrass

Most of the river-borne sediment is deposited in the estuarine zone, and only a relatively small proportion of the fine sediment load eventually reaches the open coastal zone, where it eventually settles. In areas with limited tidal range and little or no off shore currents (such as the Mediterranean and Baltic seas) most of the sediment in the estuaries and deltas are of river origin. In estuaries with large tides this balance of sediments is reversed and there is a very little export of fluvial material but a net trapping of material originating from coastal and marine erosion. This net trapping of sediment from the marine environment results in major dredging activities to allow for continued access of waterways to shipping. It has been estimated that dredging activities to remove sediments in the North Sea region exceed sediment transport by the rivers.

Continuous maintenance dredging is essential in the Port of Rotterdam, the largest port in the world. Marine sediments accumulate through tidal action in the western port areas, while the eastern port sections receive fluvial sediments transported by the Rhine. The sediment transport of the Rhine is in the order of $3–4 \times 10^6$ tonnes dry weight per year, of which roughly half is deposited in the port and the remainder is transported to the North Sea. To maintain adequate port facilities, $15–20 \times 10^6$ m^3 of sediments are dredged per year. The relocation of this dredged material to the North Sea, the preferred disposal option, is regulated by a set of so-called Sea/Slufter limit values. Dredged material exceeding these limits, mainly sediments from the eastern port areas, has to be disposed of in a confined site, the Slufter (Fig. TB4.8.1).

This storage area has a limited life and the Port Authority of Rotterdam posed the question of how the contamination of dredged material will develop in the future and whether it will reach levels that allow again its relocation to the North Sea. This required (*a*) the development of an integrated modelling tool for contaminant (heavy metals and organic micro-pollutants) transport at the catchment level linked to the quality of sediments in the Port of Rotterdam and point and diffuse sources in the transboundary Rhine catchment and (*b*) the development of scenarios. Two types of scenarios were modelled, taking the present state as a starting point, for the time-period until 2015. The "business as usual" (BAU) scenarios take measures into account which are already agreed on or are "in the pipeline", i.e., the implementation can most probably be expected. The "Green" scenarios include additional reduction measures that might be realised but largely depend on future policies. Taking the present state as a starting point, the changes in modelled future inputs in the Rhine basin were extrapolated on the development of the quality of sediments in the eastern parts of the Port of Rotterdam and were compared with Dutch quality criteria (2002) for relocation of dredged material to the North Sea.

Measures accounted for in the BAU scenarios are not expected to result in a substantial decrease in contamination of sediments/dredged material for most of the investigated substances. Additional measures (Green scenarios) could achieve more satisfying results. However, even in the Green scenarios, defined target values will still be exceeded for the investigated compounds until 2015, with the exception of lead (Fig. TB4.8.2). Pathways incorporating the highest reduction potentials for copper, zinc and cadmium are inputs from urban areas, from wastewater treatment plants and to a lesser extent erosion from agricultural ar-

Fig. TB4.8.1.
The Slufter (Rotterdam) – a confined disposal site for contaminated dredged material (from Gandrass and Salomons 2001)

The most significant demographic trends that bear on changes in the coastal zone include the increasing number of households and the increasing mobility of people. While the coastal zone of Europe has areas (particularly in highly industrialised Western Europe) with medium to high population densities (> 500 people km^{-2}), there are also remote areas in the Arctic and northern Baltic with low population densities (0–5 people km^{-2}). The population densities (people km^{-2}) in European sub-regions has been estimated as: North Sea (183), northern Mediterranean Sea (121), Atlantic (88), northern Black Sea (78), Baltic (48), Arctic (6.6) (Meybeck et al. 2004a). Population density changes seasonally; during the summer tourist season population more than doubles in parts of the northern Mediterranean coast.

The expansion of buildings and infrastructure has multiple causes, but two factors are especially relevant for coastal areas - transportation and tourism. Europe's coasts host 66% of the total tourist trade and in the Mediterranean, for example, arrivals are expected to grow from 135 million per annum in 1990 to as many as 353 million by 2025. Tourism's main environmental impacts are also generated via transport requirements, together with use of water and land, energy demands and waste generaeas. Additional related measures, which would bring the highest net reductions, are substitution of building materials as uncoated galvanised steel and copper, decoupling of paved urban areas from sewer systems, enlargement of rainwater storage basins and erosion reduction measures in agricultural areas.

PAHs are mainly released by combustion of fossil fuels and related processes resulting in elevated atmospheric deposition rates in urban areas. This pathway and related additional measures, especially towards reduced emissions from residential combustion, incorporates the highest reduction potential. PCBs have been banned in many countries and are restricted in marketing and use by the European Council Directive 76/769/EEC. New PCB inputs are mainly driven by atmospheric deposition; re-emissions from soils becoming more important. Major pathways are paved urban areas and direct atmospheric deposition on surface waters. Additional reduction measures are decoupling of paved urban areas from sewer systems and enlargement of rainwater storage basins.

An issue of special importance is the "historic" contamination of sediments in the Rhine basin. Contaminated sediments ("legacy" of past pollution) are stored behind dams in the Rhine catchment. They are already eroded by high discharge episodes and affect the quality of the sediments in the Rhine estuary. Not only in the Rhine but also in other catchments with past industrialisation, this process which might become more important in the future (i.e., with climate change).

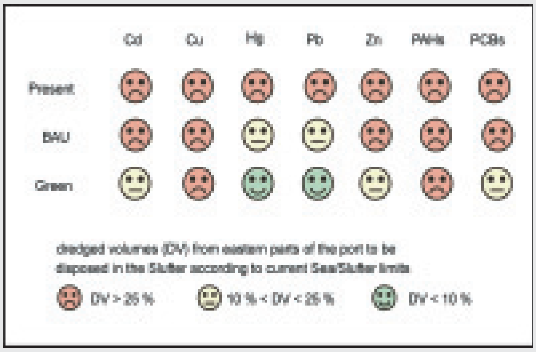


Fig. TB4.8.2. Present and estimated future quality of dredged material in the eastern parts of the Port of Rotterdam according to Dutch Sea and Slufter limit values

tion. The environmental impacts are highly concentrated and seasonal within or close to resort areas, but lateral expansion along coastlines is also a common phenomenon. Road transport is the dominant mode in Western Europe, with rail networks somewhat better developed; the balance of central investments continue to favour road transport; for example, between 1992–2000 the European Investment Bank gave 50% of its loans to road projects and only 14% to rail (EEA 2003). Transport infrastructure and trade are strongly linked, and coastal habitats and ecosystems face fragmentation along with other areas close to main arterial transport routes.

All European countries are engaged in growing and extensive trade activities placing pressure on coastal localities. Maritime transport accounts for 10–15% of total SO_2 emissions and in the Mediterranean, oil spills and related risks are high reflecting that 30% of all merchant shipping and 20% of global oil shipping crosses that sea each year. Ports and associated industrial development are responsible for land conversion/reclamation, loss of intertidal and other habitats, dredging and contaminated sediment disposal.

4.6.2.2 *Changes in Flow Patterns*

The increasing physical growth of European economies manifests itself, among other ways, in massive new construction of buildings and infrastructure that has profound effects on catchment processes, leading to increased flood risk, changes in sediment fluxes (and contamination risks) as well as habitat and biodiversity loss in the catchment-coast continuum. Direct physical alteration and destruction of habitats because of development pressure is, along with nutrient pollution, probably the most important threat to the coastal environment both for Europe and worldwide (GESAMP 2001).

Changes in flow regimes of European rivers are a key pressure on the systems and affect substantially the interaction with the receiving coastal waters. In particular in the northern Mediterranean basins, sediment and nutrient flows to the coastal zone have largely been altered by damming and water diversion and use. Rivers and deltaic areas such as the Po, Rhone and Ebro, have suffered from sediment starvation in response to significant hydrologic changes in the catchments.

In addition, irrigated cropland is a large proportion of the agricultural areas in Western, Central and Eastern Europe, (see *http://countries.eea.eu.int/SERIS/NavigateCurr*, for border of these regions) ranging from 11% to 18%, and continues to expand in some Western European and Mediterranean areas. This type of production affects water resources and wetlands in particular because 31% of Europe's population already lives in countries that use more than 20% of their annual water resource (EEA 2003).

Meybeck et al. (2004b) estimated that the overall freshwater riverine discharge to the Mediterranean Sea has diminished by almost 50% since the beginning of the 20th century, from 600 $km^3 yr^{-1}$ to 330 $km^3 yr^{-1}$; the outstanding example is the Nile with almost 95% reduction of flow (see also Sect. 4.3, above). Effects of flow change are evident in the horizontal transport of organic carbon and pollutants. The Mediterranean shows a slower increase in nutrient loads than expected from the population pressure, but the delivery of population-driven nutrient loads to the coastal zone below the Aswan dam now equals the loads before damming in the early 1960s (Nixon 2003).

4.6.2.3 *Nutrients*

Europe's semi-enclosed and enclosed seas, with their limited water exchange, are particularly sensitive to pollution threats. Marine and coastal eutrophication from elevated nitrogen and phosphorus levels quickly emerged as a worrying trend, the impacts of which were exacerbated by the loss of natural interceptors such as coastal wetlands. Severe eutrophication has occurred in the Black Sea and in more enclosed areas in the Baltic and Mediterranean seas.

Meybeck at al. (2004a), based on the modelling data of Green et al. (2004), calculated between 0.5 and 4.5 mg l^{-1} total nitrogen for remote riverine areas such as the Norwegian basin (principal rivers: Trondheims Fjord, Soge Fjord, Alta R.) and the North Sea basin (principal rivers: Rhine, Elbe, Gota, Glama, Weser, Meuse, Thames and Humber) respectively. Average total N (i.e., NO_3^-, NO_2^-, NH_4^+ and organic N) calculated per coastal catchment contained in the 5-degree grid cell database, yielded values ranging between 2 437 and 178 kg N km^{-2} yr^{-1} in the western parts of the UK and Sweden, respectively. This represents a 10- to 20-fold difference across Europe.

In summary, there is a northwest to south-central axis of high nitrogen yields, covering the UK, Western and Central Europe (i.e., the North Sea catchment basin) including parts of Scandinavia, Benelux, Germany and Italy wherein values ranged between 1 445 and 2 437 kg N km^{-2} yr^{-1}. Countries bordering the Atlantic basin, the southern Baltic, the Black Sea and eastern Mediterranean yielded an order of magnitude less, with values between 500 and 900 kg N km^{-2} yr^{-1}.

Obviously differences exist in the effects on water quality and ecosystem functioning along this north-south axis. Usually dissolved organic nitrogen (DON) originating from more remote and low-populated areas, such as the Arctic, has little effect on the phytoplankton system in comparison to the dissolved inorganic nitrogen (DIN)-rich loads – essentially ammonium and nitrate – from highly-populated and agricultural areas. Nitrate represents > 90% of the total N load in Western European rivers, such as the Scheldt. Meybeck et al. (2004b) consider Europe to be at the upper end of the nitrogen yield values for global regions (also see Text Box 3.1, Chap. 3).

Over the last 20 years, nutrient yields (especially phosphorus) have greatly decreased for both the Rhine and Elbe and today, the main sources of nutrient discharge follow diffuse pathways mainly nourished by agriculture. These intensive measures to control point source discharges have helped towards achieving the targets that were defined by the conference of Environmental Ministers in the early 1980s (to accomplish a 50% reduction of nutrient inputs to the North and Baltic Sea between 1985/87 and 1995; Behrendt et al. 2002) for phosphorus but not for nitrogen, where the reduction in specific yields is between 36% and 48% on a catchment scale. At the coastal interface the total load reduction to the three major coastal seas ranges between 12% and 26% (Table 4.11).

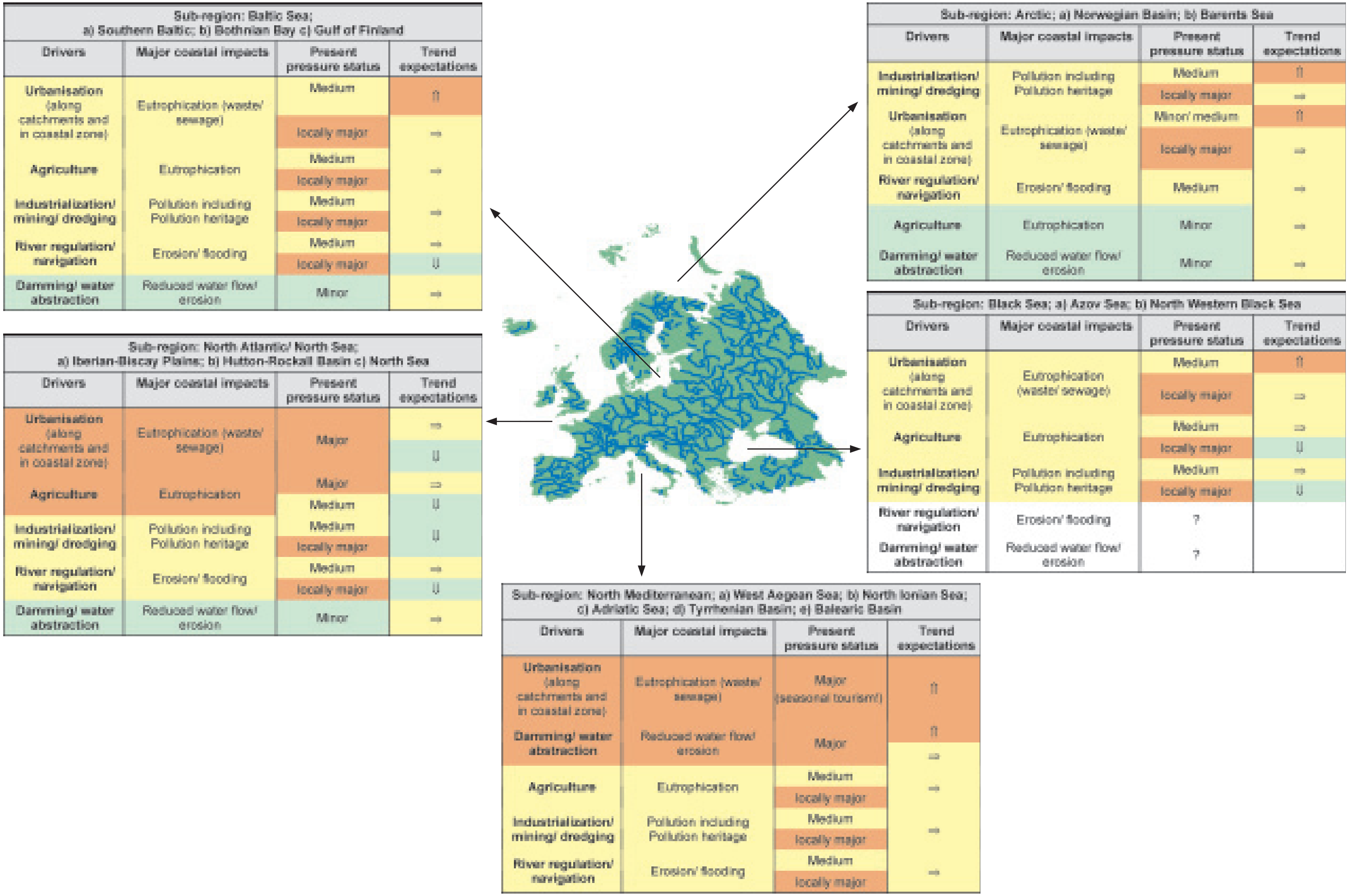
The importance of diffuse rather than point sources was apparent even in the early 1990s in the Vistula and other Eastern European rivers such that their status compares with that currently of the Rhine and Elbe after management action has been taken. Different hydrologic conditions, lower population density in the catchment and limited access to waste water treatment facilities all result in a higher proportion of nutrient input from diffuse sources. As a consequence of agricultural pressure and limited water treatment, the nutrient loads of the Po into the Adriatic Sea also are clearly dominated by diffuse sources. Waste-water treatment levels and discharges are still problematic in the Mediterranean, Adriatic and Black seas.

Irrespective of the fact that LOICZ Basins (as a work in progress) in its first years did not generate a comprehensive assessment and synthesis of the situation in North America which makes it somewhat difficult to compare the European situation at least two case studies from North America are provided. The Hudson River system (Text Box 4.9) and the Mississippi River system (Text Box 4.10) may help putting the European findings

Table 4.11. Europe. Total nitrogen and phosphorus inputs to three European coastal seas and the changes between 1983–87 and 1993–97 (after Behrendt et al. 2002)

Coastal sea	Period	Total N inputs (kt yr^{-1})	Diffuse sources (%)	Change in total N between the two periods (%)	Total P inputs (t yr^{-1})	Diffuse sources (%)	Change in total P between the two periods (%)
Black Sea	1983–1987	150.4	75.0		10 640	36.7	
	1993–1997	131.7	80.5	–12.5	5 310	71.6	–50.1
North Sea	1983–1987	873.1	56.6		78 770	31.0	
	1993–1997	642.1	69.1	–26.5	30 320	65.0	–61.5
Baltic Sea	1983–1987	61.1	74.8		4 130	30.3	
	1993–1997	44.9	81.1	–26.6	1 620	71.0	–60.8

[a] Station Bimmen/Lobith at the German-Dutch Border.



Sub-region: Baltic Sea;
a) Southern Baltic; b) Bothnian Bay c) Gulf of Finland

Drivers	Major coastal impacts	Present pressure status	Trend expectations
Urbanisation (along catchments and in coastal zone)	Eutrophication (waste/ sewage)	Medium locally major	⇑ →
Agriculture	Eutrophication	Medium locally major	→
Industrialization/ mining/ dredging	Pollution including Pollution heritage	Medium locally major	→
River regulation/ navigation	Erosion/ flooding	Medium locally major	→ ⇓
Damming/ water abstraction	Reduced water flow/ erosion	Minor	→

Sub-region: North Atlantic/ North Sea;
a) Iberian-Biscay Plains; b) Hutton-Rockall Basin c) North Sea

Drivers	Major coastal impacts	Present pressure status	Trend expectations
Urbanisation (along catchments and in coastal zone)	Eutrophication (waste/ sewage)	Major	⇒ ⇓
Agriculture	Eutrophication	Major Medium	⇒ ⇓
Industrialization/ mining/ dredging	Pollution including Pollution heritage	Medium locally major	⇓
River regulation/ navigation	Erosion/ flooding	Medium locally major	→ ⇓
Damming/ water abstraction	Reduced water flow/ erosion	Minor	→

Sub-region: Arctic; a) Norwegian Basin; b) Barents Sea

Drivers	Major coastal impacts	Present pressure status	Trend expectations
Industrialization/ mining/ dredging	Pollution including Pollution heritage	Medium locally major	⇑ →
Urbanisation (along catchments and in coastal zone)	Eutrophication (waste/ sewage)	Minor/ medium locally major	⇑ →
River regulation/ navigation	Erosion/ flooding	Medium	→
Agriculture	Eutrophication	Minor	→
Damming/ water abstraction	Reduced water flow/ erosion	Minor	→

Sub-region: Black Sea; a) Azov Sea; b) North Western Black Sea

Drivers	Major coastal impacts	Present pressure status	Trend expectations
Urbanisation (along catchments and in coastal zone)	Eutrophication (waste/ sewage)	Medium locally major	⇑ ⇒
Agriculture	Eutrophication	Medium locally major	⇒ ⇓
Industrialization/ mining/ dredging	Pollution including Pollution heritage	Medium locally major	→ ⇓
River regulation/ navigation	Erosion/ flooding	?	
Damming/ water abstraction	Reduced water flow/ erosion	?	

Sub-region: North Mediterranean; a) West Aegean Sea; b) North Ionian Sea;
c) Adriatic Sea; d) Tyrrhenian Basin; e) Balearic Basin

Drivers	Major coastal impacts	Present pressure status	Trend expectations
Urbanisation (along catchments and in coastal zone)	Eutrophication (waste/ sewage)	Major (seasonal tourism!)	⇑
Damming/ water abstraction	Reduced water flow/ erosion	Major	⇑ ⇒
Agriculture	Eutrophication	Medium locally major	→
Industrialization/ mining/ dredging	Pollution including Pollution heritage	Medium locally major	→
River regulation/ navigation	Erosion/ flooding	Medium locally major	→

Fig. 4.15. Europe. Sub-regional synthesis and typology of the river catchment–coast interactions

Text Box 4.9. The Hudson River estuary: a history of expanding and changing human pressures

Dennis P. Swaney and Karin E. Limburg

The Hudson River, whose 35 000 km^2 watershed occupies most of northeastern region of New York state as well as areas of adjoining states, spans a range of land cover from the forested Adirondack mountains to urban Manhattan (Fig. TB.4.9.1). The watershed is conveniently divided into 3 or 4 subregions, including the relatively heavily forested Upper Hudson, the agricultural Mohawk, the rural but increasingly suburban Middle Hudson, and the urban/suburban Lower Hudson. The river is dammed below its confluence with the Mohawk at Troy, just above Albany, and the dam serves as the upper boundary of tidal influence. Since the arrival of Henry Hudson (the first European to explore the Hudson) in 1609, the region has seen first gradual, and then in the 19th and 20th century, explosive population growth. This has brought significant and multifaceted aspects of human accelerated environmental changes to the estuary.

As the region was settled, vast areas of the Hudson basin were cleared of forest and replaced with crop and pastureland. Agricultural land use peaked early in this century. Some simulation results suggest that soil erosion, and the associated sediment and organic carbon flux to the river, may have peaked around the same time, possibly driving the metabolism of the river to its greatest level of heterotrophy (Swaney et al., 1996; Howarth et al., 2000a). Much of the agricultural land of that time has since been abandoned, returning to forest, or has been developed as the population expands outward from village and city centers.

In modern times, the regional population, especially that of the greater metropolitan area of New York City at the mouth of the Hudson, and the Hudson Valley extending up the river to Albany, has represented a major source of sewage and nutrient loads to the estuary, though the time series of individual constituents has varied depending upon the goals of waste treatment. Estimated BOD load peaked in the 1930s at about 600 metric tons d^{-1}, declining since then in response to improvements in sewage treatment to the present 100 metric tons d^{-1} (Hetling et al., in press). Total nitrogen load climbed steadily from the turn of the century to the 1930s to about 120 metric tons N d^{-1}, but has fluctuated at relatively high levels since that time, to the recent estimates of greater than 100 metric tons d^{-1} (Hetling et al., in press). Until recently, nitrogen removal has not been a priority sewage treatment practice. Total phosphorus load, on the other hand, peaked in the 1970s at about 35 metric tons d^{-1}, falling dramatically thereafter in response to sewage treatment and especially as phosphates were removed from detergent formulations as mandated by increasingly stringent environmental legislation regarding phosphorus (Hetling et al. 2003).

Over the years, the Hudson has felt other human impacts as well, including many forms of industrial pollution. Though most of these sources have been cleaned up in response to environmental legislation, there is still a legacy of PCB contamination in the sediments of the upper Hudson. Recent (and controversial) action by the EPA has mandated that these sediments be dredged from the river bottom and removed. Heavy metal and organic chemical contaminants also remain in the many of the coastal marshes and sediments of the lower Hudson and New York Harbor.

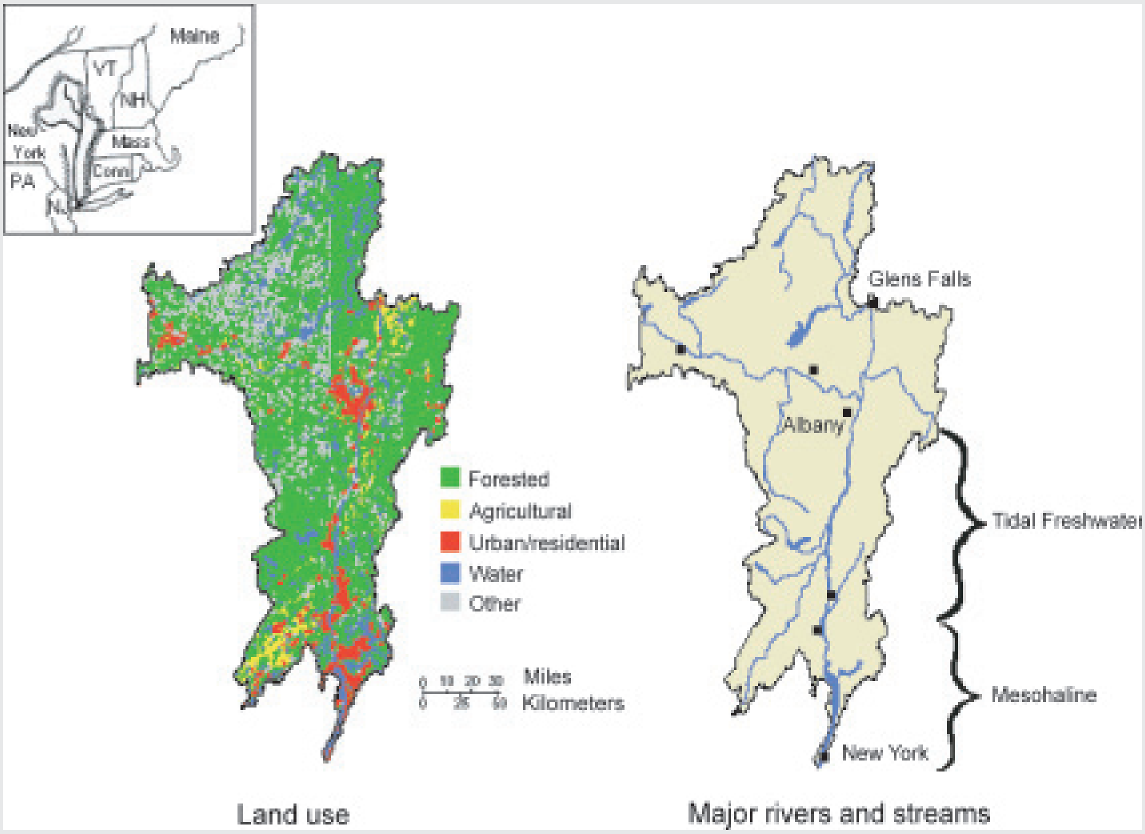


Fig. TB4.9.1. Land use and major rivers of the Hudson basin (after Wall et al. 1998). The Hudson remains tidal in its freshwater reaches up to the Troy dam above Albany

◀

The Hudson has also seen its share of harmful invasive species – on average, a new one per year has been observed over the last century (Mills et al., 1997) – including the devilishly-spiked water chestnut, *Trapa natans*, which now infests the marshes of the tidal freshwater Hudson, and perhaps most significant, the zebra mussel, (*Dreissena polymorpha*), which seems to have dramatically altered the carbon budget of large reaches of the freshwater estuary (Fig. TB.4.9.2).

While salinity eliminates the direct effect of *Dreissena* on the mesohaline Hudson, the interaction of high nutrient loads and physical circulation suggest that it is a highly eutrophic system in which productivity will continue to depend on upstream sources, local waste loads, and climate change-induced fluctuations of flow and stratification (Howarth et al. 2000b). Thus, the combined effects of human activities, waste loads, invasive species, and climate change will play a role in the nutrient loads of the Hudson system to the coastal zone.

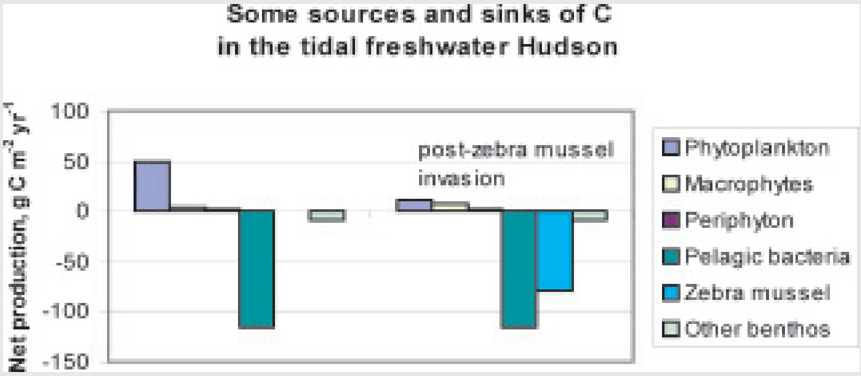


Fig. TB4.9.2.
Effects of the invasion of zebra mussel (*Dreissena polymorpha*) on the carbon dynamics of the tidal freshwater Hudson (Cole and Caraco, in press)

of river catchment-coast interactions, their history and drivers into a broader geographical context. These cases together cover already more than 40% of the whole US drainage basin area affecting the Atlantic and Gulf of Mexico coastal waters.

4.6.3 Conclusions – Europe

The population pressure in the catchment basins connected to the North Sea/Atlantic sub-region dominates compared with the rest of Europe. Representing only 23.4% of the total area, this sub-region accommodates almost 41% of the population and contributes 48% of the total nitrogen emissions (5.5 times higher than in the Arctic and with a much higher bioavailability to coastal metabolic systems). The key drivers are urbanisation (not only coastal) and agricultural land use that employs large amounts of industrial fertilisers. The population density in this sub-region and in the northern Mediterranean is among the highest globally, ranging from 131 people km^{-2} to 120 people km^{-2} respectively. The Baltic (48) and the northern Black Sea (78) have lower population densities, and the Arctic (6.6) sub-region is sparsely populated. However, the assessment of current driver/pressure settings and trend expectations in the north-western Arctic (see Sect. 4.5 above) indicates that pressures due to urbanisation and raw material exploitation are likely to increase. Table 4.12 shows a summary of the key catchment-based driver/pressure interlinks with coastal impact and change. The trends, based on expert judgement, reflect the current expectations and in the nutrient case, they are substantiated by the quantitative findings of the ELOISE projects: EuroCat and DaNUbs.

In the Mediterranean sub-region, water abstraction and damming have had the most pronounced effect on coastal systems due to flow reduction. Around 50% reduction in water flow has diminished the expected acceleration of nutrient loads to the coastal zone and greatly diminished the sediment supply to the coastal systems.

In Europe significant progress has been made in combating point-source pollution of rivers, streams, estuaries and coasts (e.g., from sewage treatment plants and industrial facilities). As such, there has been a significant reduction in heavy metals, phosphorus and organic micro-pollutants discharges from rivers into the European coastal seas. However, with regard to nutrients (and in particular nitrogen), the issue of eutrophication remains and in some cases toxic algal blooms occur in Europe. From assessment of most coast systems in Europe, the EuroCat project concluded that eutrophication and in one case pollution (metals) were the major issues for the coastal zone. The results showed that even for the most stringent and plausible environmental protection scenarios, eutrophication will remain a problem affecting the ecosystem and economic resources (e.g., tourism, mussel farming). Strategies to combat eutrophication – managed retreat and/or wetland creation schemes, improved water treatment programmes, agricultural zoning – were much more effective in the UK and the Netherlands. An additional benefit of coastal realignment,

Text Box 4.10. Watershed alterations and coastal ocean response: the Mississippi River

Nancy N. Rabalais

The linked Mississippi/Atchafalaya River and northern Gulf of Mexico system is a prime example of the worldwide trend of changing river-borne fluxes and resulting diminution of coastal water quality. The Mississippi River system ranks among the world's top ten rivers in length, freshwater discharge, and sediment delivery and drains 41% of the contiguous United States (Milliman and Meade 1983; Fig. TB4.10.1).

One third of the flow from the Mississippi River main stem is diverted into the Atchafalaya River where it joins the Red River for eventual delivery through a delta 210 km west of the main Mississippi River birdfoot delta. Prevailing currents from east to west move most of the freshwater, suspended sediments and dissolved and particulate nutrients onto the Louisiana and Texas continental shelf (Rabalais et al. 1996). At the terminus of this river system is the largest zone of oxygen-depleted coastal waters in the western Atlantic Ocean (Rabalais et al. 2002).

The Mississippi River system delivers an average of 580 km^3 of freshwater to the Gulf of Mexico yearly along with sediment yields of 210×10^6 t yr^{-1}, 1.6×10^6 t yr^{-1} nitrate, 0.1×10^6 t yr^{-1} phosphorus and 2.1×10^6 t yr^{-1} silica (Turner and Rabalais 1991). The 1820–1992 average discharge rate (decadal time scale) for the Mississippi River is remarkably stable near 14000 $m^3 s^{-1}$ despite significant interannual variability and some decadal trends (Fig. TB4.10.2). The discharge of the Atchafalaya increased during the period 1900–1992, primarily as a result of the tendency for the Atchafalaya to capture more of the flow of the Mississippi (until stabilized at 30% in 1977) (Bratkovich et al. 1994). A slight increase in Mississippi River discharge for 1900–1992 is accounted for by an increased discharge in September through December.

Mississippi River nutrient concentrations and loading to the adjacent continental shelf changed dramatically during the last half of the 20th century. The mean annual concentration of nitrate was approximately the same in 1905–1906 and 1933–1934 as in the 1950s, but it has doubled since the 1950s (Fig. TB4.10.2; Turner and Rabalais 1991). The increase in total nitrogen is almost entirely due to changes in nitrate concentration (Turner and Rabalais 1991, Goolsby et al. 1999). Prior to the 1960s, nitrogen flux closely paralleled river discharge, a pattern that still holds, but the load of nitrogen per volume discharge is greater than historically.

It follows, and is supported with evidence from long-term datasets and the sedimentary record, that increases in riverine dissolved inorganic nitrogen concentration and loads are highly correlated with indicators of increased productivity in the overlying water column and subsequent worsening of oxygen stress in the bottom waters. Evidence comes from changes in diatom production, increased accumulation of diatom remains in the sediments, increased marine-sourced carbon accumulation in the sediments, decreased diversity of benthic fauna, and relative changes in benthic fauna that indicate a worsening oxygen environment (Fig. TB4.10.2; Turner and Rabalais 1994a,b; Eadie et al. 1994, Nelsen et al. 1994, Rabalais et al. 1996, Sen Gupta et al. 1996).

In addition to a steady population increase within the Mississippi basin since the mid-1800s with related inputs of nitrogen through municipal wastewater systems, human activities have changed the natural functioning of the Mississippi River system (Rabalais et al. 1999). Flood control and navigation channelisation restructured the Mississippi River's flow through the early part of the 20th century. The suspended sediment loads carried by the Mississippi River to the Gulf of Mexico decreased by one-half since the Mississippi valley was first settled by European colonists. This decrease occurred mostly since 1950, however, when the largest natural sources of sediments in the drainage basin were cut off from the Mississippi River main stem by the construction of large reservoirs on the Missouri and Arkansas Rivers (Meade 1995). This large decrease in sediments from the western tributaries was counterbalanced somewhat by a 5-to 10-fold increase in sediment loads in the Ohio River as a result of deforestation and row crop farming. Other significant alterations in landscape (deforestation, conversion of wetlands to cropland, loss of riparian zones, expansion of artificial agricultural drainage) removed most of the natural buffering capacity for removing nutrients from runoff into the Mississippi tributaries and main stem. There was an increase in the area of land artificially drained between 1900 and 1920, and another significant burst in drainage during 1945–1960 (Fig. TB4.10.2). In addition to physical re-

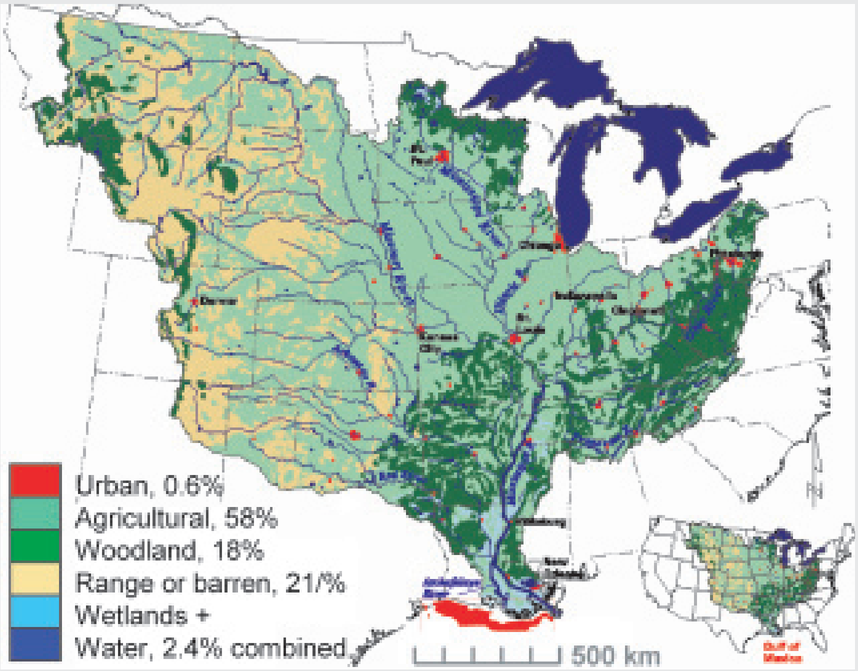


Fig. TB4.10.1. Mississippi River drainage basin and major tributaries, and general location of the 1999 midsummer hypoxic zone (Rabalais et al. 1999; from Goolsby 2000)

◀

structuring, there was a dramatic increase in nitrogen input into the Mississippi River drainage basin, primarily from fertiliser application, between the 1950s and 1980s (Fig. TB4.10.2). While the increase in drainage and fertiliser application was accompanied by an equally dramatic increase in crop production, these important alterations led to significant increases in riverine nitrate concentrations and flux to the Gulf (Turner and Rabalais 1991, Goolsby et al. 1999). The annual flux of nitrogen to the Gulf tripled between 1955–1970 and 1980–1996 to the present average of 1.6×10^6 t yr^{-1}, with 61% of that flux in the form of nitrate. Ninety percent of the nitrate inputs to the basin are from non-point sources, of which 74% is agricultural in origin. In addition, 56% of the nitrate enters the Mississippi River system north of the Ohio River. Organic nitrogen measurements were not regularly made before 1973, but they show no trend since then.

Evidence associates increased coastal ocean productivity and worsening oxygen depletion with changes in landscape use and nutrient management which resulted in nutrient enrichment of receiving waters. Nutrient flux to coastal systems, while essential to the overall productivity of those systems, has increased over time due to anthropogenic activities and has led to broad-scale degradation of the marine environment. The fact that the most dramatic changes in the continental shelf ecosystem adjacent to the Mississippi River have occurred since the 1950s and are coincident with an increase in nitrate load, points to that aspect of human ecology for future management scenarios.

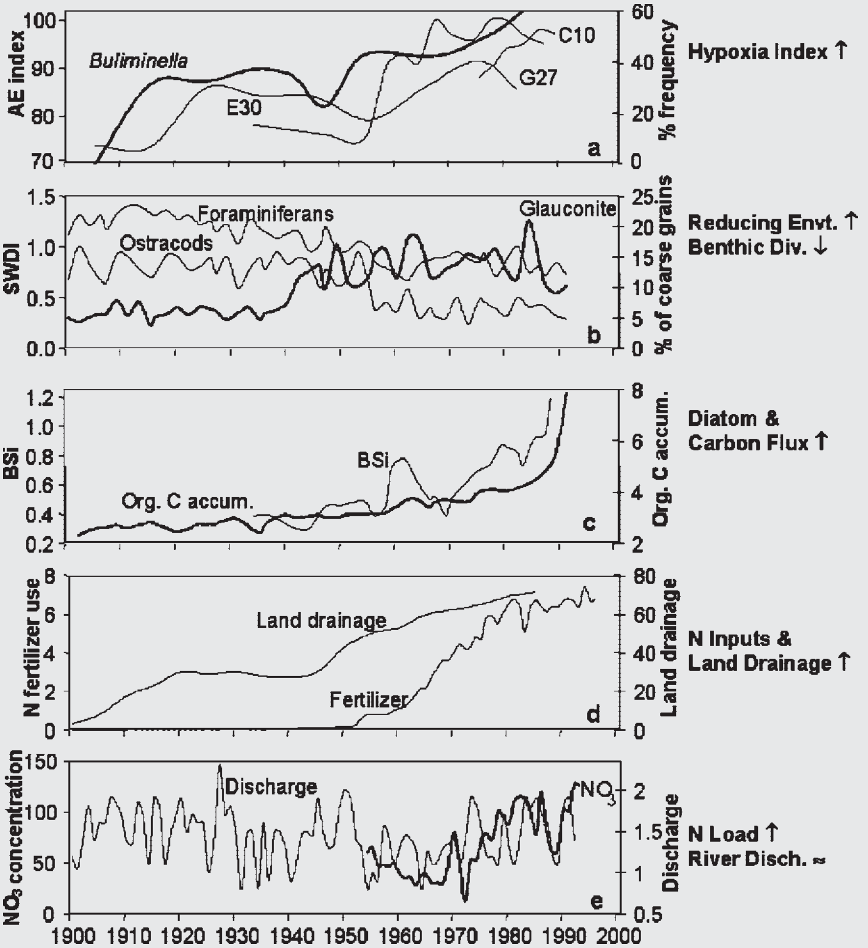


Fig. TB4.10.2. **a** A-E index for cores C10 (3-yr running average), E30, and G27 (Sen Gupta et al. 1996); percent frequency of *Buliminella* in core G27 (Rabalais et al. 1996). **b** SWDI (Shannon-Wiener Diversity Index) for foraminiferans and ostracods (Nelsen et al. 1994, TA Nelsen,National Oceanic and Atmospheric Administration, Miami, Florida, unpublished data); percent glauconite in coarse grain sediment (Nelsen et al. 1994). **c** BSi (biologically bound silica, frequency) for core E30 (Turner and Rabalais 1994b); organic carbon accumulation (mg C m^{-2} yr^{-1}) (Eadie et al. 1994). **d** Nitrogen fertiliser use in the Mississippi River basin (10^6 mt yr^{-1}) (Goolsby et al. 1999); land drainage (millions of acres) (Mitsch et al. 2001). **e** Nitrate concentration (µM) in the lower Mississippi River (Turner et al. 1998); lower Mississippi River discharge (10^4 m^3 s^{-1}) (Bratkovich et al. 1994) (from Rabalais et al. 2002)

creation of wetlands and soft defences, apart from increasing the estuarine filtering capacity for nutrients, is the creation of additional areas for carbon sequestration (Cave et al. 2003).

As far as industrial pollution is concerned, there is a residual of pollutants in the European catchments predating environmental legislation. Large-scale mining was started during Roman times (Settle and Paterson 1980) and intensified during the industrial revolution in the 19th century. Hence, many polluted sites exist in catchments across Europe, and pollutants are also stored in sediments (Salomons and Stigliani 1995). Consideration of the entire catchment becomes extremely relevant where the environmental quality of sediments in the coastal strip is affected (Text Box 4.8 above). Figure 4.15 is a sub-regional synthesis of main river catchment-coastal change issues, and provides an expert judgement-based ranking and trend analysis.

Table 4.12. Europe. Major activities, present status and trends affecting the coastal zone. (Trend: ⇒ stable, ⇑ increasing, ⇓ decreasing, sub-regions as shown in Fig. 4.14)

Anthropogenic drivers	Major state changes and impacts	Present pressure status	Trend expectations	Sub-region and main catchment basins
Urbanisation (along catchments and in coastal zone)	Eutrophication (waste/sewage)	Major	⇒/⇓ (successful point source treatment)	**North Atlantic/North Sea** a) Iberian-Biscay Plains Loire, Douro, Seine, Tejo, Guadiana, Garonne, Guadalquivir, Dordogne, Tamar b) Hutton-Rockall Basin Thjorsa, Olfusa, Shannon, Severn c) North Sea Rhine, Elbe, Gota, Glama, Weser, Meuse, Thames, Humber
Agriculture	Eutrophication	Major/medium	⇒/⇓	
Industrialization/mining/ dredging	Pollution including pollution heritage	Medium/locally major	⇓	
River regulation/navigation	Erosion/flooding	Medium/locally major, e.g., Humber	⇒/⇓ (in response to predicted climate and sea level change)	
Damming/water abstraction	Reduced water flow/erosion	Minor	⇒	
Urbanisation (along catchments and in coastal zone)	Eutrophication (waste/sewage)	Medium/locally major in the south	⇒/⇑	**Baltic Sea** a) Southern Baltic Vistula, Odra, Nemanus, Daugava b) Bothnian Bay Kemijoki, Tornionjoki, Amgerman, Dalalven c) Gulf of Finland Neva, Narva, Kymijoki, Luga
Agriculture	Eutrophication	Medium/locally major	⇒	
Industrialization/mining/ dredging	Pollution including pollution heritage	Medium/locally major	⇒	
River regulation/navigation	Erosion/flooding	Medium/locally major	⇒/⇓ (in response to climate and sea level change)	
Damming/water abstraction	Reduced water flow/erosion	Minor	⇒	
Industrialisation/mining/ dredging	Pollution including pollution heritage	Medium/locally major (see also Sect. 4.5)	⇒/⇑ likely to increase in Russia (see also Sect. 4.5)	**Arctic** a) Norwegian Basin Trondheims Fjord, Soge Fjord, Alta River b) Barents Sea Dvina, Pechora, Mezen, Onega
Urbanisation (along catchments and in coastal zone)	Eutrophication (waste/sewage)	Minor/locally major (see also Sect. 4.5)	⇒/⇑ likely to increase in Russia (see also Sect. 4.5)	
River regulation/navigation	Erosion/flooding	Medium	⇒	
Agriculture	Eutrophication	Minor	⇒	
Water abstraction/damming	Reduced water flow/erosion	Minor	⇒	

Table 4.12. *Continued*

Anthropogenic drivers	Major state changes and impacts	Present pressure status	Trend expectations	Sub-region and main catchment basins
Urbanisation (along catchments and in coastal zone)	Eutrophication (waste/sewage)	Medium/locally major	⇒/⇑ increasing locally/temporarily (also due to tourism)	**Black Sea** a) Azov Sea Don, Kuban b) NW Black Sea Danube, Dnepr, Dnestr, Bug, Provadijska c) NE Black Sea (not considered as no major rivers)
Agriculture	Eutrophication	Medium/locally major	⇒/⇓ decreasing (in the course of recent socio-political changes)	
Industrialization/mining/dredging	Pollution including pollution heritage	Medium/locally major	⇒/⇓ decreasing (in the course of recent socio-political changes)	
Damming/water abstraction	Reduced water flow/erosion	?		
River regulation/navigation	Erosion/flooding	?		
Urbanisation (along catchments and in coastal zone)	Eutrophication (waste/sewage)	Major	⇑ (seasonal doubling due to tourism!)	**North Mediterranean Sea** a) West Aegean Sea Evros, Strymon, Axios, Aliakmon, Pinios b) North Ionian Sea Bradano, Salso, Smeto, Acheloos, Alfias c) Adriatic Sea Po, Brenta, Adige, Piave, Tagliamento, Idrija-Isonzo, Neretva, Drina, Semani, Vijose d) Tyrrhenian Basin Arno, Tevere e) Balearic Basin Rhone, Ebro, Segura, Jucar
Damming/water abstraction	Reduced water flow/erosion	Major	⇒/⇑	
Agriculture	Eutrophication	Medium/locally major, e.g., Po	⇒	
Industrialization/mining/dredging	Pollution including pollution heritage	Medium/locally major, e.g., Idrijca	⇒	
River regulation/navigation	Erosion/flooding	Medium/locally major	⇒	

4.7 Towards Coupled Coastal and River Catchment Management: DPSIR Application into Scenarios for Europe

4.7.1 Introduction

The coastal region is subject to drivers and pressures exerting their influence across global scales. Interrelated global driving pressures, such as, urbanisation, industrial development and mass tourism together with human-induced climate change, impact on regional and local resource systems with consequent local (yet generalised) management problems. Such problems require co-coordinated responses by policy makers at the national or supra-national scale (e.g., EU and beyond).

A number of general problems with implications on policy and management can be highlighted:

- the future impacts of trade and economic development, including increased dredging activities with their geomorphologic and biogeochemical impacts, the welfare consequences for natural and social systems, and the spread of invasive exotic species into local ecosystems.
- the consequences of environmental change on fisheries and the implications of more extensive and intensive aquaculture developments.
- the selection of future strategies for coastal protection and the consequences of sea defence systems (both immediately at the coast and within estuarine/fresh-water fluvial catchment areas).
- water quality deterioration, future monitoring and evaluation.
- degradation and/or destruction of a range of natural habitats and ecosystems.

Three particular characteristics of coastal zones complicate the management task: the extreme variability present in coastal systems, the highly diverse nature of such systems, and their multi-functionality and consequent high economic value. In addition, coastal areas are socio-cultural entities, with specific historical conditions and symbolic significances (Turner et al. 2001). This adds to their "value" but is also problematic because these institutional domains can have trans-national boundaries that cross national jurisdictions and require international agreements and legislation. Institutions face a problem because they are often not coincident with the spatial and temporal scales or with the susceptibility of biogeochemical and physical processes - the so-called "scaling mismatch problem" (von Bodungen and Turner 2001). The resource management task is further compounded by the existence of multiple stakeholder interests and competing resource uses and values typically of coastal zones.

4.7.2 Scenarios and Coastal Futures

The rapidly changing record of the last half century highlights the difficulties involved in forecasting future decades. The underlying context for any "futures" thinking for Europe must include an appreciation of the globalisation process and the implications of an expanding European Union and Single Market. Globalisation has brought a growing interdependence between financial markets and institutions, economies, culture, technology, politics and governance. So far, market forces and related social systems have become the increasingly dominant paradigm. In Europe, there is the additional dimension of change involving the inclusion of the countries of Central and Eastern Europe into the EU, together with their own internal transitions from centrally-planned to market-based economies and societies.

If we follow the advice of scenario analysts, then we need to foster a process by which alternative world views (eco-centrism, techno-centrism, weak sustainability or strong sustainability) and conventional wisdom are challenged and clarified, in order to focus on critical issues (Gallopin and Raskin 1998). We can envisage a future in which globalisation and liberal market conditions and values continue to evolve, or one in which coordinated and concerted collective actions are agreed upon by national governments and implemented by increasingly influential international agencies. Alternatively, self-interest and protectionism may become the dominant characteristics of a future society, with Europe gradually fragmenting rather than unifying. But even more radical change is a plausible future and the strong sustainability and "deep green" visions may also become realities.

There is no shortage of candidate scenarios to choose from and the following consideration is based on a hybrid approach that borrows from a set of scenarios previously formulated to investigate the impact of climate change, technological advances and environmental consequences in a range of contexts (Parry 2000, Lorenzoni et al. 2000, OST 1999, EEA 2000). The aim is to first provide a set of basic contextual narratives within which to set four somewhat more specific scenarios (UNEP 2002b) with relevance for coastal-catchment areas.

The narrative contexts and the scenarios are framed by two orthogonal axes, representing characteristics grouped around the concepts of societal values and forms of governance (Fig. 4.16). The values axis provides a spectrum from individualistic, self-interested, consumerist, market-based preferences through to collectivist, citizen-based communitarian preferences, often with a conservationist bias. The vertical axis spans levels of effective governance from local to global. The four quadrants are not sharply differentiated but rather are bounded by overlapping transitional zones. Change occurs as certain trends and characteristics become more

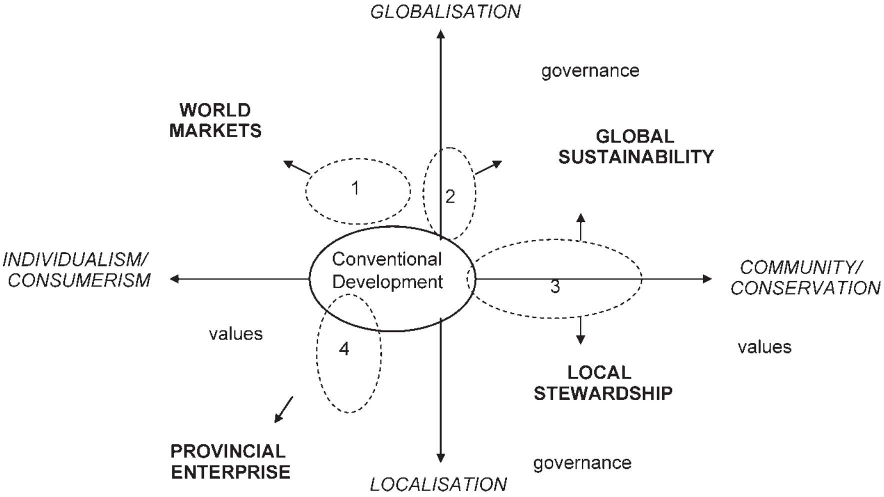


Fig. 4.16.
Europe. Environmental futures scenarios

or less dominant across the different spheres of modern life – government, business, social, cultural and environmental.

Taking the four contextual background conditions first, *World Markets* is dominated by globalisation, which fosters techno-centric and often short-term societal views. Expectations about an expanding EU and Single Market are born out and economic growth remains the prime policy objective. Environmental concerns are assumed to be tackled by a combination of market-incentive measures, voluntary agreements between business and government and technological innovation. Decoupling of the growth process from environmental degradation is assumed to be feasible, not least because ecosystems are often resilient. Weak sustainability thinking is favoured and "no-regret" and "win-win" options are the only ones pushed hard by regulators. Rapid technological change, sometimes unplanned, will be the norm, as will trade and population migration. Private healthcare, information technology, biotechnology and pharmaceutical sectors of the economy, for example, will thrive, while "sunset" industries will rapidly disintegrate (e.g., heavy engineering, mining and some basic manufacturing). The internal and external boundaries of state will retreat producing a more hollowed-out structure (Jordan et al. 2000). National governments will struggle to impose macroeconomic controls as trans-national corporate power and influence escalates. Multilateral environmental agreements will prove problematic and prone to enforcement failures.

Under *Global Sustainability*, there would be a strong emphasis on international/global agreements and solutions. The process would be by and large "top down" governance. Trade and population migration would still increase but within limits often tempered by environmental considerations. EU expansion would be realised but social inequities would receive specific policy attention via technology transfer, financial compensation and debt-for-nature swaps/agri-environmental programmes.

Provincial Enterprise would be a much more heterogeneous world, EU expansion might stall and a slow process of fragmentation (economically and politically) might be fostered. A protectionist mentality would prove popular and economic growth, trade and international agreement-making prospects would all suffer.

Local Stewardship would put environmental conservation (eco-centrism) as a high priority. A very strong sustainability strategy would be seen as the only long-term option. This strategy would emphasise the need for a re-orientation of society's values and forms of governance, down to the local community scale. Decentralisation of economic and social systems would be enforced, so that over time local needs and circumstances become the prime focus for policy. Economic growth, trade, tourism (international) and population migration trends would be slowed and in some cases reversed.

4.7.3 Application of Scenarios: an Example for Europe

The use of scenario's will be illustrated for coastal futures in Europe. The four scenarios (1, 2, 3 and 4) can be broadly located in Fig. 4.16, with the arrows indicating the general direction of change over decadal time. Scenario 1 is almost a trend/baseline scenario. The policy goal of maximise GDP growth is achieved via an extended single market system stretching into central Asia. New accession states are given transitional status to ease their progress into market-based systems. The relatively weak enforcement of environmental standards in these countries fosters short-term profitability but may hinder long-term resource use efficiencies. Rapidly growing volumes of trade and travel increase the level of economic interdependence in Europe, but social cohesion remains weak, as people strive to satisfy individual consumerist preferences. Scenario 2 imposes sustainability constraints via a "top down" governance process but also encourages citizens to “think globally and act locally.” Scenario 3 allows for a much more radical paradigm shift in societal values and organisations, environmental conservation and social equity rise up the political priority agenda. In Scenario 4, protectionism breeds growing disparities across the sub-regions of Europe. Inequality and possible conflicts spawn a relative isolationist response at the nation-state level. So now we turn to the implications for the future coastal zones in Europe, given the different scenarios.

Under all scenario conditions, pressures on coastal ecosystems increase, either through direct exploitation of coastal resources, including local-use changes and an increase in the built-environment at the coast; or through changes in related catchments associated with the spatial planning of development and transportation policies, changes in agriculture policy, especially trade regimes and reform of the Common Agricultural Policy (CAP). Another striking feature of the scenario analysis is that the impact of climate change does not vary significantly across scenarios until around 2030–2050 because of delays in the response of the climate system.

If *Scenario 1* conditions prevail then trade, economic development and the migration of people across Europe all increase significantly. This increase in general economic activity will outweigh improvements in energy efficiency stimulated by carbon taxes and technological change. Public transport will remain under-developed as car transport remains the dominant mode of transport. Air traffic also grows due to trade activities and international tourism. Emissions of air pollutants and greenhouse gases (GHGs) continue to rise because of the dominant effect of the energy and transport sectors of the European economies. It is also the case that effective policies to reduce CO_2 and other GHGs are slow to evolve or remain dormant. By 2030, sea-level rises (average 10 cm) will have occurred with increased flooding risks and defence costs. The extent of the built environment at the coast and across adjacent catchments expands rapidly in Western Europe but is more stable in Central and Eastern Europe if population declines continue. The number of people living in areas of increased fresh-water stress also rises as already vulnerable areas in the south of Europe face a deteriorating situation and other areas become newly stressed.

The Mediterranean coast is a particular pressure and stress problem through a combination of urban growth with inadequate wastewater treatment facilities, tourism growth and increases in intensively farmed croplands close to estuaries. While the CAP is reformed this is achieved via a stronger imposition of international market pricing regimes. Some funds are made available to provide short-run support for farmers, particularly in the new entrant countries of Central and Eastern Europe but land is still abandoned in these regions. Elsewhere land abandonment is restricted to small areas, for example, in upland areas. Overall, only the most efficient farmers survive by intensifying production and embracing genetic modification technology, with consequent diffuse pollution and other environmental risk increases.

To sum up the coastal zone consequences under *Scenario 1*, tourism impacts escalate leading to local environmental problems such as salinisation and eutrophication of coastal waters. Second homes expand in almost all areas but are particularly problematic in the Baltic and Mediterranean areas. Sea-level rise exacerbated by climate change begins to pose major difficulties and other catchment flooding events are exacerbated by the expansion of the built-environment, from the 2030s onwards. Policy responses are somewhat restricted. At the international level environmental agreements prove to be difficult to negotiate and only partially effective if and when implemented. Coastal areas are therefore by and large left in the hands of local authorities and local regulators. This forum of governance offers unpredictable results and falls well short of integrated coastal management principles and practice.

Under *Scenario 2* conditions, Europe begins to resemble more of a federal state and is characterised by strong environmental and other regulatory agencies (e.g., European Environment Agency) which promote sustainability. Transport and energy sector growth is constrained by a range of intervention policies. Internationally the World Trade Organisation adopts an environmental mandate to complement its existing remit. Nationally, green belt policies and designations, such as Natura 2000, are strengthened and ecotourism principles are supported. CAP reform is dominated by switches to funding for a range of agri-environment schemes. The more proactive “environmental” strategy succeeds in stabilising air pollution and GHGs emissions, largely because of energy-efficiency gains and extensive switching to non-fossil fuels, and declines are possible from 2030 onwards. Sea-level rise difficulties remain to be solved but policy responses are more flexible e.g., managed realignment schemes.

Areas under severe water stress remain more or less constant or fall slightly in some regions as irrigated agriculture is abandoned. Overall, Western European coasts are moved closer to integrated coastal management regimes, elsewhere basic coastal management measures are put in place and historical zoning plans revitalised. The EU Water Framework Directive (see Text Box 5.1) is fully implemented as are Regional Seas Agreements.

Under *Scenario 3*, a combination of strong framework policies designed to ensure sustainability principles can be put into practice. Most significantly, attitudinal and lifestyle changes in society generate significant falls in air pollution and GHGs emissions, beginning in the 2020s. Climate-induced sea-level rise is still a problem but is tackled almost exclusively via “soft engineering” measures and relocation schemes with compensation for sufferers. Public transport networks are encouraged and succeed in reducing the dominance of the motor car (which itself becomes significantly "cleaner" and "more efficient"). Local tourism activities flourish at the expense of international tourism and "package" holidays. The built-environment expansion is halted, except for some areas in Western Europe where development pressures remain particularly strong and a major re-conversion of lost habitats is stimulated (by more designated sites, agri-environmental schemes, managed realignment) to ensure increases in biodiversity. The total area under severe water stress is constant or declining as demands (especially from agriculture and mass tourism) are blunted by pricing policies and changing consumption patterns i.e., a decline in meat eating. Policy responses at the coast embrace integrated coastal management principles but are more effectively enabled because of the existence of voluntary partnerships across stakeholders and other participatory arrangements at the local level. This "bottom up" activity serves to complement the full imposition of the EU Water Framework Directive and Regional Seas Agreements.

Under *Scenario 4*, the expanded EU itself may fail to materialise. A fall in overall economic activity, trading activity and tourism is likely. Because of this relative economic stagnation at the micro-level (most severe in Central and Eastern Europe), overall air pollution and GHGs emissions remain stable. Sea-level rise remains a problem and there is a lack of resources to invest in both mitigation and adaptation measures. The number of people living in water stress areas increases as new areas join the vulnerable category. Less than full implementation of legislation like the EU Water Framework Directive bring forth the risk of water resource conflicts and more extensive water contamination problems. Coastal zones in Western Europe remain under built-environment/economic development, tourism, port expansion and other infrastructure growth pressures. In Central Europe, conditions are more stable but do not improve, while in Eastern Europe coastal zones could become militarised zones with restricted areas, except for port facilities.

4.8 Summary and Conclusions

Within LOICZ-Basins, a standardised framework of analysis was developed to assess the impact of land-based activities and sources on coastal systems (Kremer et al. 2002). Close to 100 catchment-coastal sea systems have been analysed and the individual assessments were scaled-up to coherent continental regions.

Large catchments, the obvious examples to be addressed within a global LOICZ synthesising effort (e.g., Nile, Yangtze, Orinoco), were part of the evaluation. However, from the perspective of coastal change, the immediate influence from land-based flows is more often generated in small to medium catchments with high levels of socio-economic activity. In smaller systems, changes in land cover and use need much shorter timeframes to translate into coastal change and may exhibit more visible impacts than in large catchments where the "buffer capacity" against land-based change is higher simply as a function of catchment size. Thus, small and medium catchments were a priority for the global LOICZ-Basins assessment. They dominate the global coastal zone (in Africa, for example, they characterise extensive parts of monsoon-driven runoff to the Indian Ocean). In island-dominated regions, such as the South Pacific or the Caribbean, frequently a whole island is a catchment affecting the islands coastal zone.

4.8.1 Catchments and Changes

The results from the continental upscaling are summarised in Table 4.13 and global trends were derived for some of the pressures and drivers; these are summarised below.

Eutrophication

The negative impacts of eutrophication are reported for all continents. In Europe and North America, nutrient run-off from agriculture is considered as the main source for excess nitrogen and phosphorus in the coastal zone. However, in South America, Africa and East Asia urbanisation (sewage) is considered a significant source. The effects of eutrophication are oxygen deficiency, harmful algal blooms, disappearing macroalgal and seagrass beds as well as potential effects on biodiversity and loss of harvestable resources. A recent compilation of global oxygen depletion (Fig. 4.17; Diaz et al. 2004) indicates a broad global incidence, but evidence from LOICZ-Basins suggests that oxygen deficiency is more widespread in South America, East Asia and Africa.

The use of mineral fertilisers in agriculture is well-documented and three periods of fertiliser nutrient consumption can be distinguished: a period of continuous rise (1950 to 1989); a period when the consumption fell (1989 to 1994), due to the decline in fertiliser use in Central Europe, the former Soviet Union and to a lesser extent in Western Europe; and a period (1994 to 2001) in which the consumption in Western Europe stabilised but increased in Asia and Latin America. Fertiliser consumption is expected to grow globally by an average 1% per year (FAO 2000b) over the next three decades (somewhat faster in developing countries than in developed). Figure 4.18 shows the values of one example year in each of these periods, respectively. However, the fastest growth rates are expected in sub-Saharan Africa where fertiliser use is currently very low, so that even fast growth rates in use will likely translate into relatively small absolute increases. The relatively slow increase after 2000 implies a

Table 4.13. LOICZ Basins. Summary tables from the regional assessments – full regional continental/sub-continental scale (ranking by expert judgment, flux and threshold data and number of sub-regions affected)

South America

Ranking	Anthropogenic drivers	Major state changes and impact	Present pressure status	Trend expectations
1	Urbanisation	Eutrophication	Major	⇑
2	Damming/diversion	Changed material fluxes/erosion/ sedimentation	Major	⇑
3	Deforestation	Erosion/sedimentation	Medium	⇑
4	Industrialisation	Pollution	Medium	⇑
5	Agriculture	Eutrophication/pollution	Medium	⇑
6	Aquaculture	Eutrophication	Minor	⇑
7	Navigation	Erosion/sedimentation	Minor	⇒
8	Fisheries	Loss of biodiversity	Minor	⇒
9	Tourism	Erosion/eutrophication	Minor	⇑
10	Mining	Erosion/pollution	Minor	⇓

Africa

Ranking	Anthropogenic drivers	Major state changes and impact	Present pressure status	Trend expectations
1	Damming/diversion	Changed material fluxes/erosion/sedimentation (locally salinisation/nutrient depletion)	Major	⇑
2	Various drivers	Biodiversity loss	Major	⇑
3	Deforestation	Erosion/sedimentation	Medium	⇑
4	Agriculture	Eutrophication/pollution	Medium	⇑
5	Urbanisation	Eutrophication/pollution	Medium	⇑
6	Industrialisation	Pollution	Medium	⇑

East Asia

Ranking	Anthropogenic drivers	Major state changes and impact	Present pressure status	Trend expectations
1	Urbanisation/industrialisation	Eutrophication/pollution/harmful algal blooms (HABs)	Major/	⇑
		Water extraction	Medium	
2	Damming/diversion	Changed material fluxes/coastal erosion	Major/	⇑
			Medium	
3	Agriculture/aquaculture	Eutrophication, pesticide pollution/diseases	Medium/	⇒
			Major	⇑
4	Deforestation	Habitat loss/modification/erosion/sedimentation/saltwater intrusion	Medium/	⇓
			Major	⇒
5	Land reclamation	Sediment budget alteration	Medium (locally major)	⇑
6	Mining (terrestrial and offshore)	Biodiversity loss	Medium/	⇒
			Minor	

Russian Arctic[a]

Ranking	Anthropogenic drivers	Major state changes and impact	Present pressure status	Trend expectations
1	Industrialisation (incl. mining/ oil and gas production)	Pollution/acidification	Medium/	⇒
			Major	⇑
2	Navigation	Pollution/sedimentation	Medium/	⇑
			Minor	⇒
3	Nuclear-power, engineering, nuclear industry, navy	Radioactive pollution	Minor	⇒
			(locally major)	
4	Urbanisation	Pollution/partly eutrophication	Minor	⇑
			(locally medium to major)	

Table 4.13. *Continued*

Russian Arctic[a] (*Continued*)

Ranking	Anthropogenic drivers	Major state changes and impact	Present pressure status	Trend expectations
5	Damming	Changed material fluxes/coastal erosion	Minor	⇒
			locally up to medium	

Europe[b]

Ranking	Anthropogenic drivers	Major state changes and impact	Present pressure status	Trend expectations
1	Urbanisation (incl. tourism in sub-regions)	Eutrophication/pollution	Major	⇒
				⇑
2	Agriculture	Eutrophication/pollution	Medium	⇒
				⇓ (in sub-regions)
3	Industrialisation (incl. mining/dredging)	Pollution (incl. pollution heritage)	Medium	⇒
				⇓ (in sub-regions)
4	River regulation/navigation	Erosion/flooding	Medium	⇒
				⇓
5	Damming/water abstraction	Changed material fluxes/coastal erosion	Medium/minor	⇒
			(but major in the Mediterranean)	

Caribbean

Ranking	Anthropogenic drivers	Major state changes and impact	Present pressure status	Trend expectations
1	Damming/diversion	Erosion/sedimentation	Major (locally)	⇑
				⇒
2	Deforestation	Sedimentation	Major	⇑
3	Tourism (land and sea-based)	Pollution/eutrophication	Major	⇑
				⇒
4	Urbanisation	Pollution/eutrophication	Major (locally)	⇑
5	Industrialisation	Pollution/eutrophication	Major (locally)	⇑
6	Agriculture	Eutrophication	Medium	⇑
			locally major	
7	All drivers	Biodiversity loss/modification	Medium	⇒
			locally major	⇑

Oceania

Ranking	Anthropogenic drivers	Major state changes and impact	Present pressure status	Trend expectations
1	All drivers	Biodiversity loss/modification	Major	⇑
2[c]	Mining	Pollution/sedimentation/erosion	Major (locally)	?
3	Deforestation	Sedimentation/erosion	Major	⇑
4	Urbanisation	Eutrophication/pollution/sedimentation/ erosion	Major (locally)	⇒
				⇑
5	Agriculture	Eutrophication/erosion/sedimentation	Medium	⇑
			locally major	

[a] in the Russian Arctic sub-table indicates that this ranking largely applies to the Western Russian Arctic (i.e. west of the Lena River) and that it can also be argued (to some extent) since it reflects a "broad brush" view again that neglects the partly substantial pressures deriving from drivers such as urbanization and drilling on local scales.

[b] in the European sub-table indicates that the ranking expresses a rather subjective interpolation across extremely heterogeneous sub-regions (see Fig. 4.15) where driver/pressure settings cover a broad range. For example position 5 for" Damming/water abstraction" is quite arguable since in one of the most populated sub-regions such as the Northern Mediterranean it is substantial as in other cases elsewhere such as the Vistula system. This table tries to provide the "broad brush" European Synthesis – for higher detail please refer to Fig. 4.15 and the text.

[c] in the Oceania sub-table indicates that due to the fact this area is very heterogeneous "Mining" in certain regions certainly may represent a 1 priority. However it seems to the sum of drivers/pressures that over a full regional scale the impact on the sustainability of the coastal life support ecosystems in form of biodiversity loss justifies a higher rank allocation.

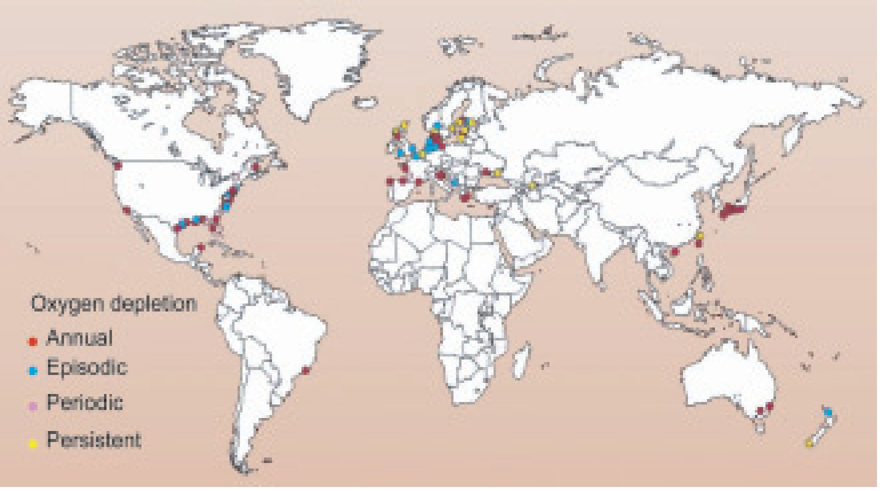


Fig. 4.17. Occurrences of oxygen depletion in coastal areas (Diaz et al. 2004)

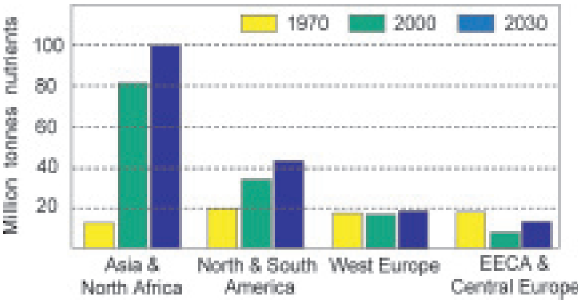


Fig. 4.18. Fertiliser consumption (1970 to 2000) and projected consumption for 2030 (IFA 2003)

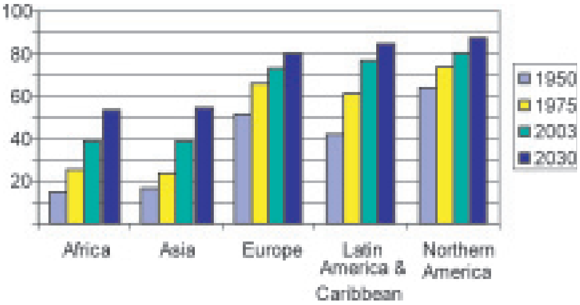


Fig. 4.19. Regional populations residing in urban areas (adapted from Urban and Rural areas 2003, United Nations Population Division 2004)

lower rate of increase of nutrient supply to the coastal zone through rivers. Hence the current situation regarding oxygen deficiency, harmful algal blooms and habitat loss may remain static and is expected not to show an improvement. Also aquaculture, an expanding coastal economic activity, will cause an additional increase of nutrient inputs into the coastal zone.

People Pressure and Urbanisation

The world urban population is growing faster than the global population as a whole. In 2003 3 billion people or 48% of humankind were living in urban settlements. The urban population is expected to increase to 5 billion by 2030; the rural population is anticipated to decline slightly from 3.3 billion in 2003 to 3.2 billion in 2030.

Following recent estimates (Small and Nicholls 2003) the coastal strip defined by a 100 km horizontal distance band and up to 100 m above sea level currently accommodates around 1.2 billion people, i.e. around 23% of the 1990 global population which translates to an average population density nearly 3 times higher than global average. Most of this near-coastal population live in relatively densely-populated rural areas and small to medium size coastal cities rather than in mega-cities. These estimates are considerably lower than earlier ones, which go up to even 60% in a comparable (see comprehensive compilation by Shi and Singh 2003). However,much more significant than absolute figures is that the continuous sprawl of coastal urbanisation is accelerating on virtually all continents at faster rates than further inland. As a consequence this demographic pressure may become increasingly more important as a source of nutrient inputs to the coastal zone reflecting for instance in the strong rise in urbanisation in Africa, Asia and Latin America (Fig. 4.19).

Erosion-Sedimentation Issues

The geomorphology of the coast is strongly affected by changes in hydrology and sediment supply. These changes are caused by the building of dams and causeways, creating reservoirs, establishing large-scale irrigation schemes and changing land use patterns. These developments change the flow of rivers and diminish the amount of sediment being carried, which, in turn, can alter coastlines. The consequence of reduced sediment can extend to long stretches of coastline where the erosive effect of waves is no longer replaced by sediment inputs from rivers. Deforestation, by contrast, can increase sediment supply and damage wetlands, submerged vegetation, deltas and coral reefs.

The LOICZ-Basins assessments contain many examples of coastal impacts from changes in hydrologic and sediment regimes at the catchment level. The commonly twinned drivers/pressures of deforestation and agriculture generally have a moderate though increasing impact at the coast. Both activities tend to result in reduced water retention in the catchment and increased soil erosion, thus increasing both the severity of flooding and the amount of sediment carried as river bedload and in suspension. The problem is acute in the small to medium-sized African catchments.

Diversions and damming of waterways are seriously affecting the erosion-accretion equilibrium of large stretches of the South American coastline. These effects are most apparent where water resources are scarce, or where there is rapid population growth in coastal metropolitan areas, or where arid climates prevail. Examples can be found along the north-eastern Brazilian coast and the Caribbean coasts of Colombia and Venezuela.

In many estuaries, changing river sediment load alters the sedimentation-erosion equilibrium within the estuary or delta. Recognising that coarse-grained bedload normally represents 10% or less of the total sediment discharge delivered to the coastal zone, we assumed that a decrease of 5% of the total sediment flux represented a critical threshold, beyond which the coastal system is likely to show evidence of significant deterioration (coastal erosion). In South America, this level of change results in mangrove siltation in estuaries of north-eastern Brazil, in severe erosion of mangroves in south-eastern Brazil, and in sandy beach erosion on the coasts of Buenos Aires Province in Argentina and in north-eastern Brazil. Damming and water abstraction in the Indus River have led to major changes in the morphology of the Indus delta (see Text Box 4.11).

The drivers and pressures causing a changing sediment flux to the coast are manifold but, reservoirs and irrigation channels can retain a large proportion of the fluvial sediment discharge (Syvitski 2003, Syvitski et al. 2005). According to Vörösmarty et al. (1997, 2003), 663 dams with large reservoirs (greater than 0.5 km^3 maximum storage capacity) store about 5 000 km^3 of water, or approximately 15% of the global river water discharge. These large reservoirs intercept more than 40% of global water discharge with 25 to 30% (4–5 Gt yr^{-1}) of the sediment flux being trapped behind dams.

Text Box 4.11. Change in the morphology of the Indus delta resulting from damming and water abstraction in the Indus River system

Peter R. Burbridge

Entrapment of sediments in the river course and water abstraction can lead to subsidence of deltas, with consequent loss of biodiversity and fisheries. One example is the Indus delta, where major water impoundments have resulted in a decrease in water flow and the delivery of mineral sediments and organic matter to the delta. With the reduction in the annual supply of these materials, the subsidence of the sediments forming the delta is no longer offset by their replenishment. With greatly restricted river flow, the functions of the estuary are reduced and both primary and secondary production has fallen. With subsidence, the biodiversity of mangroves has decreased and with it, the shrimp fishery has declined.

4.8.2 Information Gaps

Issues of Scale

LOICZ-Basins has shown that humans play a powerful role in altering hydrology and material fluxes and fate and transformation in the coastal realm (Meybeck 2003, 2004c, Salomons 2004, Syvitski et al. 2003, 2005, Vermaat et al. 2005). This influence has greatly changed in rate and scale through the past two centuries, but a thorough understanding of the causal linkages between these drivers/pressures and the coastal state changes at multiple scales remains a major challenge.

Global Scale Science

The common nature of the many drivers/pressures globally, such as intensification of agriculture, expansion of construction and infrastructure in the coastal zone and effects of impoundments, requires greater analysis (Meybeck 2004c). Coastal signals are frequently masked by a complex interplay of land-based processes, e.g., the effects of increased erosion due to land-use and cover change being concealed by the enormous trapping efficiency of worldwide damming activities. In addition, climate change affects the hydrology of catchments and land use in catchments with direct implications for erosion, sediment supply and nutrient loads. It is expected that low-lying areas, such as deltas and large estuaries, will be particularly sensitive to changes in sediment supply. A global assessment focusing on past and future changes in coastal morphology in response to the multitude of changes in catchments is needed.

A major challenge is measuring and understanding the temporal interplay between changes at the catchment level and their (often delayed) impact at the coast. The issue of delayed and non-linear responses has been described for pollutants. Stored chemicals/pollutants from past pollution events (e.g., mining, industry, intensive agriculture) may take several years before they reach the coast due to the buffering capacity of soils and sediments (Salomons and Stigliani 1995). However, while the phenomenon of temporal delay in sediment supply and its effect on coastal morphology and ecosystems has been identified, it has not yet been sufficiently addressed at the global scale.

Regional Scale Science

Supporting the findings of the LOICZ global investigation on estuarine metabolism (see Chap. 3), LOICZ-Basins consolidated the view that science must look beyond the confines of a coastal area ascribed by narrow shoreline boundaries and take a "source-to-sink" approach when considering the coastal zone. Management of coastal systems to ensure the continuity of coastal goods and services for human society in the context of river catchment-coastal sea interaction needs to be addressed at predominantly regional scales.

The EuroCat study showed that the use of socio-economic scenarios to couple models can be helpful. One of its major outcomes was a clear demonstration that wetland creation (e.g., restoring former coastal features) provided major benefits, including restoration of habitats, recreational areas, enhanced environmental services (i.e., denitrification and trapping of phosphorus) and sequestering of carbon. In addition, calculations for the Humber (UK) catchment showed that coastal realignment is more effective than hard engineering structures in defense against sea-level rise. These single measure approaches at local and sub-regional scales provide effective resolution to a number coastal issues (e.g., nutrient reduction, sustainability by maintenance of environmental goods and services in the coastal zone, impacts of sea-level and CO_2 rises). Importantly, the studies demonstrated benefits based on economic data as well as on ecological grounds. Elsewhere in the world, the need for habitat restoration has generally been argued mostly on ecological principles.

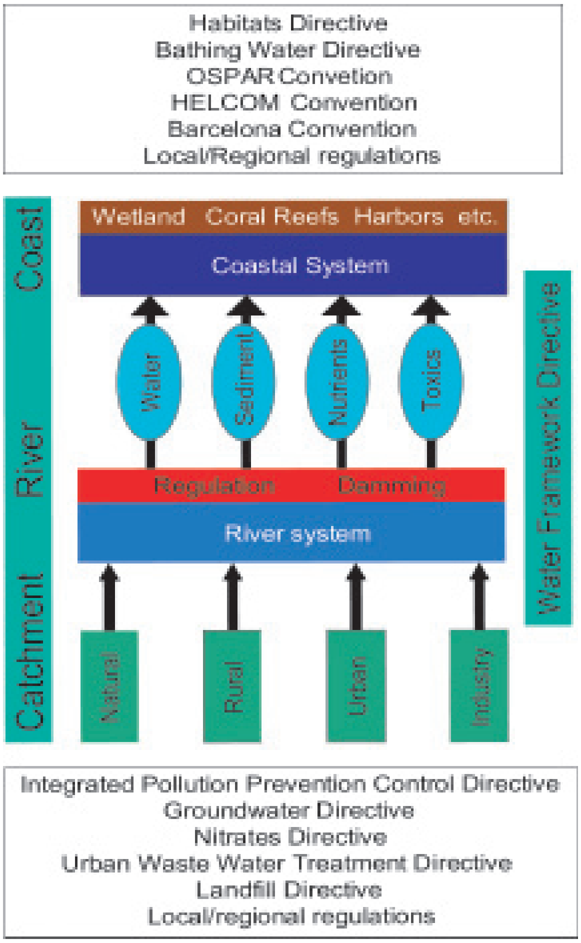


Fig. 4.20. Europe. Mismatch between regulation in catchments and in the coastal region (based on Ledoux and Turner 2003)

Integration of Policy and Management with the Catchment-Coastal Continuum

Effective management and sustainable use of the coastal zone requires not only detailed integrated scientific assessment of the catchment-coast continuum, but an analysis and understanding of the policy framework for the region. Generally, as with the science, there is a lack of integration between policies for the catchment and those for the coastal region. In Europe, for instance, there is not a lack of policies and directives (Fig. 4.20), rather the policies refer either to the catchment or to the coastal region; they are not integrated across the catchment-coast continuum that constitutes the coastal zone. However, the recent European Union Water Framework Directive provides an enlightened and more holistic approach, which should make the integrated scientific results from projects such as EuroCat more accessible and amenable for management and for policy applications.

The success in meeting all these challenges will continue to be constrained by the paucity of data and information, and disciplinary and interdisciplinary capacity in particular in the socio-economic fields. In principle, the quantification of the findings, prediction and risk/vulnerability analysis at the catchment basin scale and at full regional and global scales, remain major challenges for the future LOICZ.

References

Arthurton RS, Kremer HH, Odada E, SalomonsW, Marshall Crossland JI (eds) (2002) African Basins: LOICZ global change assessment and synthesis of river catchment–coastal sea interaction and human dimensions. LOICZ Reports and Studies. LOICZ, Texel, The Netherlands, No. 25

Behrendt H, Kornmilch H, Opitz D, Schmoll O, Scholz G (2002) Estimation of the nutrient inputs into river systems – experiences from German rivers. In: Kremer H (ed) (2002) Regimes of Regional and Global Coastal Change. Special Issue, Reg Environ Change 3:107–117

Bratkovich A, Dinnel SP, Goolsby DA (1994) Variability and prediction of freshwater and nitrate fluxes for the Louisiana-Texas shelf: Mississippi and Atchafalaya River source functions. Estuaries 17:766–778

Cadee N, Dronkers J, Heip C, Martin J-M, Nolan C (1994) ELOISE. European Land-Ocean Interaction Studies science plan. EUR 15608, European Commission, Luxembourg

Cave R, Brouwer R, Coombes E, Hadley D, Turner K, Lorenzoni I (2003) Futures scenarios and cost effectiveness analysis of alternative policy options to improve water quality in the Humber catchment in the United Kingdom. EuroCat Report

Chen JT (1994) Study on the environmental protection countermeasures of Pearl River coast zones. In: Wong CK, Chu KH, Chen QC, Ma XL (eds) Environmental research in the Pearl River and coastal area. Guangdong Higher Education Press, Guangzhou, pp 153–161

Chen C-TA (2000) The Three Gorges dam: reducing the upwelling and thus productivity in the East China Sea. Geophysical Research Letters 27:381–383

Chen C-TA, Liu JT, Tsuang B-J (2004) Island-based catchment – The Taiwan example. Reg Environ Change 4:39–48

Cole, J.J. and N. F. Caraco. In Press. Primary production and its regulation in the tidal-freshwater Hudson River. In: Levinton J, Waldman J (eds). The Hudson River Ecosystem

Diaz RJ, Nestlerode J, Diaz ML (2004) A global perspective on the effects of eutrophication and hypoxia on aquatic biota. In: Rupp GL, White MD (eds) Proceedings of the 7th international symposium on fish physiology, toxicology and water quality, Tallinn, Estonia, May 12–15, 2003, pp 1–33. EPA 600/R-04/049, US Environmental Protection Agency, Ecosystems Research Division, Athens, Georgia

Eadie BJ, McKee BA, Lansing MB, Robbins JA, Metz S, Trefry JH (1994) Records of nutrient-enhanced coastal productivity in sediments from the Louisiana continental shelf. Estuaries 17:754–765

EEA (2000) Cloudy crystal balls: an assessment of recent European and global scenario studies and models. Environmental Issues, European Environmental Agency, Series No17, Copenhagen

EEA (2003) Europe's environment: the third assessment. Environmental Assessment, European Environmental Agency, Report No. 10, Copenhagen

FAO (2000a) Fertilizer requirements in 2015 and 2030. FAO, Rome, Italy

FAO (2000b) FAOSTAT database collections, Food and Agriculture Organization of the United Nations (FAO), Rome (*http://www.apps.fao.org*)

Fekete BM, Vörösmarty CJ, Grabs W (1999) Global, composite runoff fields based on observed river discharge and simulated water balances. World Meteorological Organization-Global Runoff Data Center, Report 22, Koblenz, Germany

Gallopin GC, Raskin P (1998) Windows on the future: global scenarios and sustainability. Environment 40(3):7–11, 26–31

Gandrass J, Salomons W (2001) PORII. Dredged material in the Port of Rotterdam– Interface between Rhine catchment area and North Sea. GKSS Research Center Report

GESAMP (2001). A sea of troubles. GESAMP (IMO/FAO/UNESCO/IOC/WMO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection) Reports and Studies. FAO, Rome, No. 70 and No. 71

Goolsby DA (2000) Mississippi Basin nitrogen flux believed to cause Gulf hypoxia, EOS Transactions of the American Geophysical Union 81:325–327

Goolsby DA, Battaglin WA, Lawrence GB, Artz RS, Aulenbach BT, Hooper RP (1999) Flux and sources of nutrients in the Mississippi-Atchafalaya River Basin: topic 3 report for the integrated assessment of hypoxia in the Gulf of Mexico. NOAA Coastal Ocean Program Decision Analysis Series. NOAA Coastal Ocean Program, Silver Spring, MD, No. 17Humphrey S, Burbridge P, Blatch C (2000) US lessons for coastal management in the European Union. Marine Policy 24:275–286

Gordeev VV, Andreeva E, Lisitzin AP, Kremer HH, Salomons W, Marshall Crossland JI (2005): 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 & Studies No. 29, ii+xxx pages, LOICZ, Texel, The Netherlands

Green P, Vörösmarty C, Meybeck M (in press) Global distribution of river nitrogen fluxes in pristine and impacted basins. Biogeochem

Griffiths F, Young OR (1990) Protecting the Arctic's environment: impressions of the co-chairs. Working Group on Arctic International Relations, Reports and Papers 1990-1, Hanover, New Hampshire

Hetling LJ, Stoddard A, Brosnan TM, Hammerman DA, Norris TM (2003) Effect of water quality management efforts on wastewater loadings over the past century. Water Environ Res 75:30

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

Howarth RW, Jaworski N, Swaney DP, Townsend A, Billen G (2000a). Some approaches for assessing human influences on fluxes of nitrogen and organic carbon to estuaries, In: Hobbie JE (ed) Estuarine Science. A synthetic approach to research and practice. Island Press, Washington DC

Howarth RW, Swaney DP, Butler TJ, Marino RM (2000b) Climatic control on eutrophication of the Hudson River estuary. Ecosystems. 3:210–215

Jordan AJ, Lorenzoni I, O'Riordan T, Turner RK (2000) Europe in the new millennium. In: Parry, ML (ed) Assessment of the potential effects of climate change in Europe: The Europe ACACIA Project. University of East Anglia, Norwich, pp 35–45

Kellogg JN, Mohriak WU (2001) The tectonic and geological environment of coastal South America. In: Seeliger U, Kjerfve B (eds) Coastal marine ecosystems of Latin America, Springer-Verlag, Berlin, pp 1–16

Kjerfve B, Wiebe WJ, Kremer HH, Salomons W, Marshall Crossland JI (eds) (2002) Caribbean basins: LOICZ global change assessment and synthesis of river catchment/island–coastal sea interaction and human dimensions. LOICZ Reports and Studies. LOICZ, Texel, The Netherlands, No. 27 (part)

Kremer HH, Salomons W, Crossland CJ (2002) Human dimensions of land-based fluxes to the coastal zone: the LOICZ-Basins approach. In: de Lacerda LD, Kremer HH, Kjerfve B, Salomons W, Marshall Crossland JI, Crossland CJ (eds) South American basins: LOICZ global change assessment and synthesis of river catchment–coastal sea interaction and human dimensions. LOICZ Reports and Studies. LOICZ, Texel, The Netherlands, No. 21, pp 61–72

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

Ledoux L, Turner RK. (2003), Report on the Institutions, stakeholders and potential/actual conflicts of interest and value within a given catchment, *EUROCAT WD, 33. http://www.cs.iia.cnr.it/EUROCAT/project.htm*

Lorenzoni I, Jordan A, Hulme M, Turner RK, O'Riordan T (2000) A coevolutionary approach to climate change impact assessment: Part I. Integrating socio-economic and climate change scenarios. Global Environmental Change – Human policy dimensions 10:57–68

Meade RH (ed) (1995) Contaminants in the Mississippi River, 1987–1992. US Geological Survey Circular 1133, US Dept of the Interior, US Geological Survey, Denver, Colorado

Meybeck M, Laroche L, Durr HH, Syvitski JPM (2003) Global variability of daily total suspended solids and their fluxes in rivers. Global and Planetary Change 39:65–93

Meybeck M, Dürr H, Vogler J, Lacharte L, Gueguen Y (2004a) Space analysis of catchment/coast relationships. Synthesis report: European catchments, catchment changes and their impact on the coast, "EuroCat", European Commission, DG Research, 5th Framework Programme, Contribution No. EVK1-CT-2000-00044

Meybeck M, Vogler J, Moatar F, Durr H, Laroche L, Lachartre L (2004b) Analysis of temporal variability in river systems. Synthesis report: European catchments, catchment changes and their impact on the coast, "EuroCat", European Commission, DG Research, 5th Framework Programme, Contribution No. EVK1-CT-2000-00044

Meybeck M, Vogler J, Turner K, Hisschemöller M, van Tilburg, M (2004c). River-coast integration in European regional seas. Part I: Improving basin-coast integration (Meybeck and Vogler). Part II: Scenario analysis (Turner). Part III: Institutional analysis (Hisschemöller and van Tilburg). Synthesis report: European catchments, catchment changes and their impact on the coast, "EuroCat", European Commission, DG Research, 5th Framework Programme, Contribution No. EVK1-CT-2000-00044

Mills EL, Scheuerell MD, Carlton JT, Strayer DL (1997) Biological invasions in the Hudson River basin: an inventory and historical analysis. New York State Museum Circular 57

Mitsch WJ, Day JR, Gilliam JW, Groffman PM, Hey DL, Randall GW, Wang N (2001) Reducing nitrogen loading to the Gulf of Mexico from the Mississippi River basin: strategies to counter a persistent ecological problem. BioScience 15:373–388

Morcom N, Harvey N, Marshall Crossland JI (2002) Oceania basins. LOICZ global change assessment and synthesis of river catchment–coastal sea interaction and human dimensions. LOICZ Reports and Studies. LOICZ, Texel, The Netherlands, No. 27 (part)

Nelsen TA, Blackwelder P, Hood T, McKee B, Romer N, Alvarez-Zarikian C, Metz S (1994) Time-based correlation of biogenic, lithogenic and authigenic sediment components with anthropogenic inputs in the Gulf of Mexico NECOP study area. Estuaries 17:873–885

Nixon SW (2003) Replacing the Nile: are anthropogenic nutrients providing the fertility once brought to the Mediterranean by a great river? Ambio 32(1):30–39

OST (1999) Environmental futures. Report for the UK National Technology Foresight Programme. Office of Science & Technology, DTI/Pub 4015/IK 399 NP, VRN 99647, London, UK

Parry M (ed) (2000) Assessment of potential effects and adaptations for climate change in Europe The Europe Acacia Project, Jackson Institute, University of East Anglia, Norwich

Rabalais, NN, Turner RE, Justic D, Dortch Q, Wiseman WJ Jr. (1999) Characterization of hypoxia: topic 1 report for the integrated assessment of hypoxia in the Gulf of Mexico. NOAA Coastal Ocean Program Decision Analysis Series No. 15. NOAA Coastal Ocean Program, Silver Spring, MD, 167 pp

Rabalais NN, Turner RE, Justic D, Dortch Q, Wiseman WJ, Sen Gupta BK (1996) Nutrient changes in the Mississippi River and system responses on the adjacent continental shelf. Estuaries19:386–407

Rabalais NN, Turner RE, Justic D, Dortch Q, Wiseman WJ (1999) Characterization of hypoxia: topic 1 report for the integrated assessment of hypoxia in the Gulf of Mexico. NOAA Coastal Ocean Program Decision Analysis Series. NOAA Coastal Ocean Program, Silver Spring MD, No. 15

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

Salomons W (2004) European catchments: catchment changes and their impact on the coast. Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands

Salomons W, Stigliani WM (1995) Biogeodynamics of pollutants in soils and sediments. Springer, Berlin

Salomons W, Turner RK, de Lacerda LD, Ramachandran S (eds) (1999) Perspectives on integrated coastal zone management. Springer-Verlag, Berlin, Heidelberg

Sen Gupta BK, Turner RE, Rabalais NN (1996) Seasonal oxygen depletion in continental-shelf waters of Louisiana: historical record of benthic foraminifers. Geology 24:227–230

Settle DM, Patterson CC (1980) Lead in Albacore: guide to lead pollution. American Science 207:1167–1176

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

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

Smith SV, Dupra V, Marshall Crossland JI, Crossland CJ (2000) Estuarine systems of the South American region: carbon, nitrogen and phosphorus fluxes. LOICZ Reports and Studies. LOICZ, Texel, The Netherlands, No. 15

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

Swaney, D.P., D. Sherman, and R. W. Howarth. 1996. Modeling water, sediment, and organic carbon discharges in the Hudson-Mohawk Basin: coupling to terrestrial sources. Estuaries. 19:833–847

Syvitski JMP (ed) (2003) Supply and flux of sediment along hydrological pathways: anthropogenic influences at the global scale. Global and Planetary Change, Special Issue 39:1–199

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

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

Turner RE, Rabalais NN (1991) Changes in Mississippi River water quality this century. Implications for coastal food webs. BioScience 41:140–148

Turner RE, Rabalais NN (1994a) Coastal eutrophication near the Mississippi River delta. Nature 368:619–621

Turner RE, Rabalais NN (1994b) Changes in the Mississippi River nutrient supply and offshore silicate-based phytoplankton community responses. In Dyer KR, Orth RJ (eds) Changes in fluxes in estuaries: implications from science to management. Proceedings of ECSA22/ERF Symposium, International Symposium Series, Olsen & Olsen, Fredensborg, Denmark, pp 147–150

Turner RE, Qureshi N, Rabalais NN, Dortch Q, Justic D, Shaw RF, Cope J (1998a) Fluctuating silicate:nitrate ratios and coastal plankton food webs. Proceedings of the National Academy of Science, USA 95:13048–13051

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

Turner RK, Bateman IJ, Adger WN (eds) (2001) Economics of coastal and water resources: valuing environmental functions. IT Week, Kluwer, Dordrecht

UNEP (2002a) Africa environment outlook – past, present and future perspectives. Earthprint Limited, Stevenage, England

UNEP (2002b) Integrating environment and development, 1992–2002. UNEP, Nairobi

UNPD (2004) Urban and rural areas, 2003. United Nations Population Division *http://www.un.org/esa/population/publications/wup2003/2003urban_rural.htm*

Vermaat JE, Ledoux LC, Salomons W, Turner RK (eds) (2005) Managing European coasts; past, present and future. Springer, Berlin, Heidelberg, New York

Von Bodungen B, Turner RK (eds) (2001) Science and integrated coastal management. Report of the 85th Dahlem Workshop Berlin December 12–17 1999. Dahlem University Press, Berlin

Vörösmarty CJ, Sharma KP, Fekete BM, Copeland AH, Holden J, Marble J, Lough JA (1997) The storage and aging of continental runoff in large reservoir systems of the world. Ambio 26: 210–219

Vörösmarty CJ, Fekete BM, Meybeck M, Lammers RB (2000a) The global system of rivers: its role in organizing continental land mass and defining land-to-ocean linkages. Global Biogeochemical Cycles 14(2):599–621

Vörösmarty CJ, Fekete BM, Meybeck M, Lammers RB (2000b) Geomorphometric attributes of the global system of rivers at 30-minute spatial resolution. Journal of Hydrology 237:17–39

Vörösmarty C, Meybeck M, Fekete B, Sharma K, Green P, Syvitski JPM (2003) Anthropogenic sediment retention: Major global-scale impact from the population of registered impoundments. Global and Planetary Change 39(1/2):169–190

Wall, GR., Riva-Murray, K, Phillips, PJ (1998) Water Quality in the Hudson River Basin, New York and Adjacent States, 1992–95. U.S. Geological Survey circular 1165.

Wong CKC, Leung CKM, Poon BHT, Lan CY, Wong MH (2002) Organochlorine hydrocarbons in human breast milk collected in Hong Kong and Guangzhou. Arch Environ Contam Toxicol 43:364–372

Wong AMW, Wong MH (2004) Recent socio-economic changes in relation to environmental quality of the Pearl River delta. In: Kremer H (ed) (2004) River catchment-coastal sea interaction and human dimensions. Reg Environ Change 4:28–38

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

Yu Z, Zhang J, Yao Q, Mi T (1999) Nutrients in the Bohai Sea. In: Hong GH, Zhang J, Chung CS (eds) Biogeochemical processes in the Bohai and Yellow Sea, Dongjin Publication Association, Seoul, pp 11–20