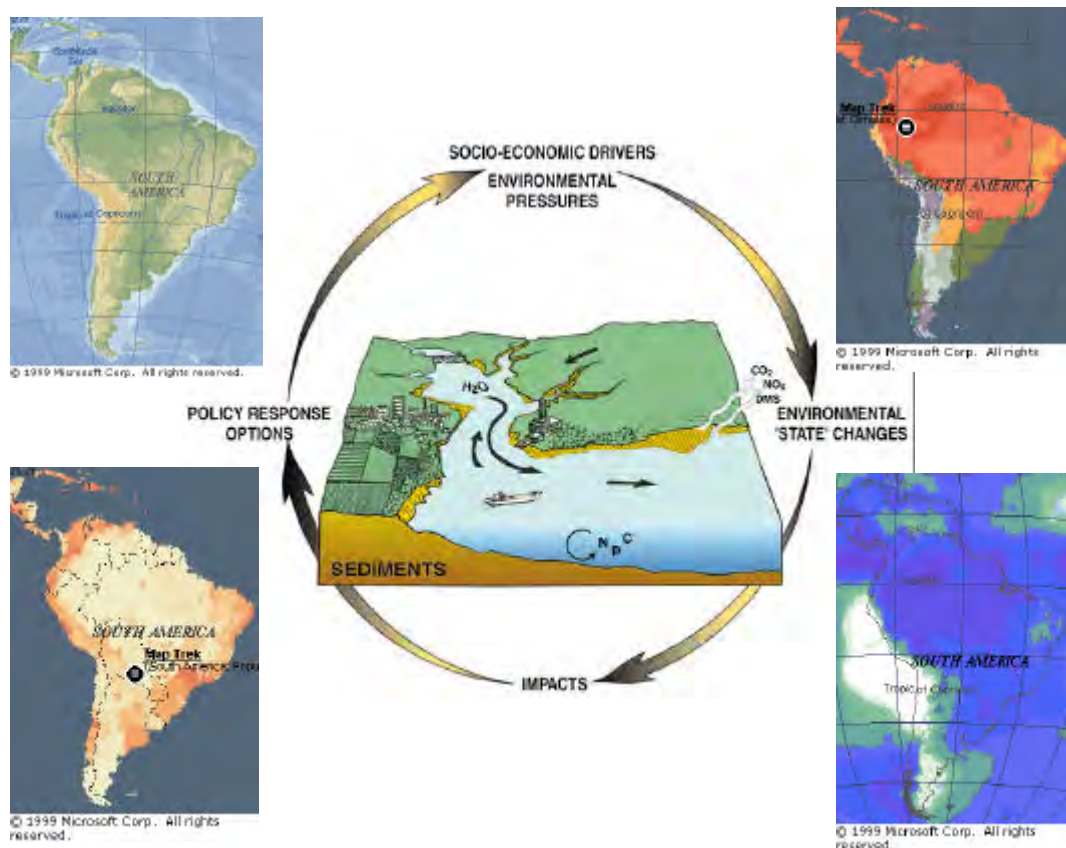


LAND-OCEAN INTERACTIONS IN THE COASTAL ZONE (LOICZ)
Core Project of the
International Geosphere-Biosphere Programme: A Study of Global Change
(IGBP)

with

**INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION (UNESCO/IOC) and the
NATIONAL RESEARCH COUNCIL OF BRAZIL (CNPq)**



SOUTH AMERICAN BASINS
LOICZ Global Change Assessment and Synthesis of
River Catchment – Coastal Sea Interaction and Human Dimensions

*Compiled and edited by L.D. de Lacerda, H.H. Kremer, B. Kjerfve, W. Salomons,
J.I. Marshall Crossland and C.J. Crossland*



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by

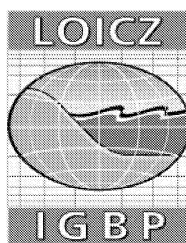
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This report and allied workshops are contributions to the global LOICZ Basins assessment and synthesis core project: The Biogeochemical and Human Dimensions of Land-Based Fluxes to the Coastal Zone.

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Cover: The cover shows various images of South America and the DPSIR framework cycle as shown in LOICZ R&S No 11 (from Turner *et al.* 1998).

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Workshops Structure

This report provides a synthesis of the contributed papers and regional investigations of the two-phase LOICZ South American Basins assessment process conducted in November 1999 and May 2001.

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1. Executive summary

by L.D. Lacerda, H.H. Kremer and Wim Salomons

The LOICZ Core Project

Coastal zones world-wide are subject to many pressures which are not constant but change over time. Management practices in Europe and North America over recent decades have drastically decreased the impact of “classical” contaminants such as heavy metals, PCB’s and partly nutrients, in particular in emerging economies, however, these latter substances still have a high or even increasing priority. In addition, new classes of chemicals have entered the priority lists of international organisations and will require coastal zone impact and monitoring studies. Increasingly the coastal zone is subject to a “competition for space” - urban and industrial development pressures, tourism and the increase in traffic demand physical space and cause a decrease in the size and functioning of coastal ecosystems. Past and planned physical changes in river catchments (e.g., damming, diversion) influence the natural flow of water, nutrients, sediments and pollutants to the coast. Numerous studies have addressed these issues and produced large amounts of data but only rarely have these been integrated, assessed and synthesised. Nor has the interaction between the biogeochemical environment and the human historical evolution of a given site been considered.

The *Land Ocean Interactions in the Coastal Zone* (LOICZ) core project of the International Geosphere Biosphere Project, IGBP, is evaluating the biogeochemical and human interactions influencing coastal change. Coastal zones are an integral part of the water cascade including river catchments and their response to external forcing from both anthropogenic and natural changes. The LOICZ key questions addressing these issues are:

- How are humans altering the mass balances of water, sediment, nutrient and contaminant fluxes, and what are the consequences?
- How do changes in land use, climate and sea level alter fluxes and retention of water and particulate matter in coastal zones, and affect morphodynamics?
- How can we apply knowledge of processes and impacts of biogeochemical and socio-economic changes to improve integrated coastal management?

Within LOICZ, the **Basins** core project is working *inter alia* to develop a global assessment of the importance of changes in river catchments and impacts on coastal seas by applying a systems approach. The river catchment (or island) and its associated coastal zone are treated as one system (Figure 1.1). Changes in the coastal zone result from both local human activities and biophysical properties. Thus, on a global scale, regional coastal zones will show differences in their response to a similar human activity. The regional systems are subject to outside (long-term) pressures and drivers including climate change and global socio-economic trends and changes. To elucidate these intricate relationships, **LOICZ-Basins** focuses on the horizontal flux of substances within the catchment (island) coastal zone system. This systems approach, integrating the natural and social sciences, addresses issues such as critical concentrations and loads, resilience and carrying capacity. The DPSIR framework, developed by the OECD, is adapted for this purpose.

To generate a global picture, a set of standardised (and thus comparable) regional assessment workshops has been implemented, aiming to scale up information from single river catchment/coastal sea systems to sub-regional and finally regional scales. Characteristic types or classes of coastal issues and changes are identified, prioritised and linked to their major natural and anthropogenic drivers on a river catchment or island scale. Numeric or qualitative indices are developed to allow this prioritisation and to compare the scenarios of land-driven coastal change in a qualitative or semi-quantitative way within and across regions. This will enable the visualisation/mapping and up-scaling of the issues and scenario simulation on various spatial and temporal scales. It is expected, ultimately, to use the LOICZ typology approach for global up-scaling (<http://www.kgs.ukans.edu/Hexacoral/Workshops> and in general www.nioz.nl/loicz/), which is under continued development in co-operation with IGBP-BAHC – (Biospheric Aspects of the Hydrological Cycle core project).

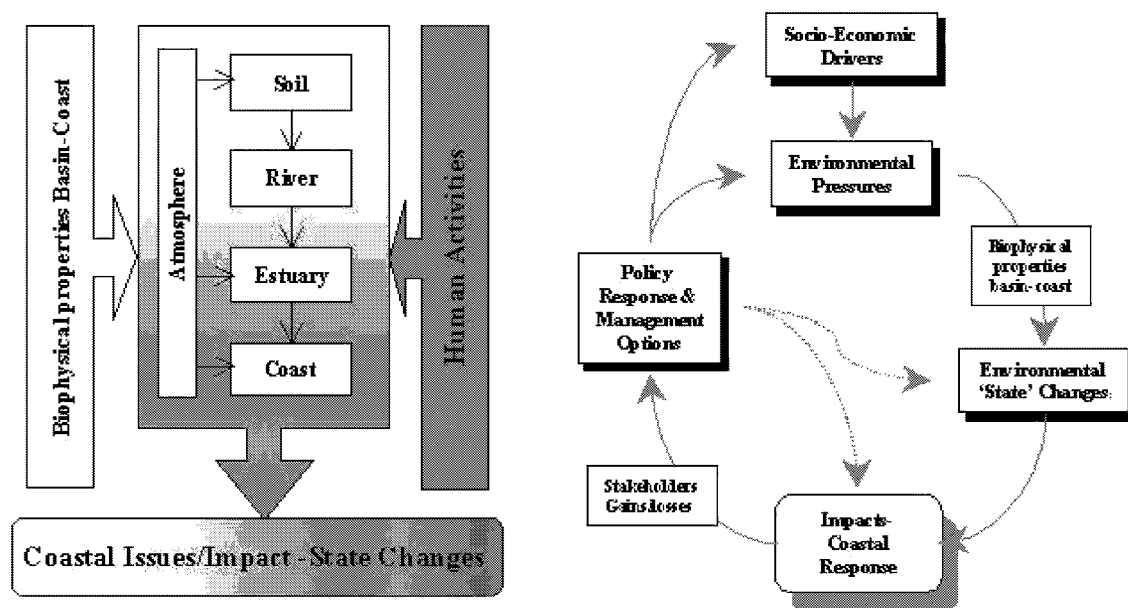


Figure 1.1 The catchment (island)-coastal zone system and the DPSIR framework.

The South American Basins (SAMBas) Workshops

Two workshops were held in South America to address LOICZ-Basin issues. The first, more general, one was held in Bahia Blanca, Argentina in 1999. The second workshop (Fortaleza, Brazil, 2001) refined the regional assessments and focused on the human dimension, seeking a sound scientific basis on which to develop project proposals for holistic (i.e., interdisciplinary) studies on the human dimensions of land-based coastal change, with a clear focus on the implications for coastal monitoring and management. For this purpose “hot spots” important for future research evaluation and a project design applicable to various spatial and temporal scales had to be identified.

Overview of the South American coastal zone-catchment system

The first SAMBas workshop developed a catchment classification and an initial assessment of the drivers-pressure-state of the South American coastal zone catchment system at a large scale. The South American sub-continent is dominated by a number of very large river catchments and wetlands east of the Andes interacting with wide areas of the coastal zone. Considerable parts of the coastline are also influenced by relatively small and medium size catchments. Their nutrient supply supports the major part of the primary production and fisheries of the Western Atlantic tropical and sub-tropical coast of South America. Those rivers however, are often visibly altered through human activities (e.g., pollutant loads draining into Sepetiba Bay) and their pressures on the coastal zone are more pronounced than in areas where pressure is diffused across larger catchments such as the Amazon. Consequently, land use and cover change, pollution and water diversion, which are examples of drivers changing horizontal mass transport, are likely to cause stronger ecosystem state changes and to generate “hot issues” of coastal impact if they occur in smaller catchments. The Pacific coast of South America is characterised by small catchments in a tectonically active geology, with pronounced seasonality in runoff and a coastal system dominated by a strong upwelling over wide spatial scales. The effects of change in the receiving coastal waters are expected to differ between the two coasts.

For both coasts a second sub-regional classification applies, encompassing the wide range of climatic conditions in South America, from tropical to Sub-Antarctic along the north-south axis. Humid areas with considerable annual rainfall and lush tropical vegetation are replaced further south by arid regions with sparse vegetation along the Peruvian and Chilean coasts.

The LOICZ South American Basins workshops, **SAmBas** I and II, identified coastal change and catchment-based drivers of change by considering the following:

- Coastal geomorphology
- Coastal habitats/biodiversity
- Climatic conditions
- People relationships (demography and drivers)
- Catchment size and seasonal runoff
- Land use and cover

Using these criteria, eight sub-regions (Figure 1.2) were identified:

Pacific coast

Area 1 corresponds to the high rainfall coast, including important rivers with high sediment yield such as the San Juan and Patia rivers in Colombia and the Esmeraldas River in Ecuador.

Area 2 covers the driest coast of South America, from the Gulf of Guayaquil in Ecuador across the entire Peruvian littoral to northern Chile, where most coastal features are dominated by open ocean phenomena (upwelling).

Area 3 is represented by the Chilean littoral with temperate to sub-antarctic climate.

Atlantic coast

Area 4 includes the Magdalena River Delta, a complex lagoon-deltaic systems which is the major contributor of freshwater and continental sediments to the Caribbean Sea.

Area 5 typifies the extensive oligotrophic north-eastern coast of Brazil, where small to medium sized highly seasonal rivers contribute almost all the nutrients which support coastal primary production and fisheries.

Area 6 comprises the south-eastern Brazilian coast, the most industrialised and urbanised part of the South American coast, housing about 60 million people and containing the largest industrial park and navigation park of the sub-continent .

Area 7 includes the southern coast of Brazil and the La Plata River estuary. Coastal features and problems shared by three countries pose a challenging environment for ICZM on a multi-national level.

Area 8 comprises the Patagonian littoral in Argentina, with long coastal plain rivers still in a relatively undisturbed condition.

Recent assessment work in the area between sub-region 5 and 6, including the São Francisco River, will be made available to **SAmBas** electronically at a later stage (Knoppers pers. comm.)



Figure 1.2 Sub regions for the assessment of river catchment – coastal sea interaction classes determined in the first LOICZ South American Basins Workshop (SAmBas 1).

Anthropogenic pressures exhibit many features. For the continent a ranking order was drawn up together with expected future trends in impact (Table 1.1).

Table 1.1 Major activities and present status and trends affecting the coastal zone.

Anthropogenic drivers	Major state changes and impact	Present status	Trend expectations	Major areas affected (as for Figure 1.2)
Urbanization	Eutrophication	Major	Increasing	1,2,3,4,6,7
Damming/diversion	Erosion/sedimentation	Major	Increasing	2,4,5,7,8
Industrialization	Pollution	Medium	Increasing	1,2,6,7
Agriculture	Eutrophication/pollution	Medium	Increasing	2,4,7,8
Deforestation	Erosion/sedimentation	Medium	Increasing	1,2,6,7,8
Navigation	Erosion/sedimentation	Low	Stable	2,4,7
Aquaculture	Eutrophication	Low	Increasing	1,2,5
Fisheries	Loss of biodiversity	Low	Stable	5,6,7
Mining	Erosion/pollution	Low	Decreasing	5,8
Tourism	Erosion/eutrophication	Low	Increasing	5,6

The tabulated data are characteristic of a typical developing economy situation, in which economic growth exceeds development of necessary urban and industrial infrastructure. As a result, the major impacts on the coastal zone caused by catchment-based activities are eutrophication and pollution, linked to urbanization and the increasing necessity for water and energy that result in increased damming and diversion of river courses and associated erosion/sedimentation problems at the coast. Agriculture and deforestation also affect certain areas, in particular along steep slopes of mountainous country e.g., south-eastern Brazil and on the tectonically active coasts of the Pacific and the Caribbean. A major local issue is aquaculture. Ecuador is a large producer of farmed shrimps and this has resulted in environmental problems at the coast. This activity is spreading through the sub-continent's coastal catchments, in particular in north-eastern Brazil.

The regional catchment-coastal sea systems

In the second workshop, the standardized **Basins** assessment tables (see Chapter 2, Chapter 8) were used to guide a detailed sequence of assessment steps. Key case studies were considered and priority elements and locations identified for future research effort. The following questions were addressed:

1. Assessing coastal **Issues/Impacts (critical thresholds)** based on coastal change in the region:
 - What are the major impacts (coastal issues) on/in the coastal zone?
 - How close are these impacts to a critical threshold of system functioning?
2. Assessment and ranking of major catchment-based **Drivers/Pressures** generating the coastal **Issues/Impacts**:
 - What are the major (up to 10) driver/pressure settings at catchment level causing coastal change?
 - Can we identify spatial scales on which certain driver/pressure settings dominate coastal issues?
3. Upscaling from catchment to **regional Driver/Pressure** settings generating the coastal **Issues/Impact** and expected **trends**:
 - What are the major driver/pressure settings causing observed coastal impact?
 - What are the future trends at catchment level; at sub-regional/island or country level; at regional level?
4. Assessment and synthesis of **scientific, policy and/or management responses**:

- What is the current status of response taken on scientific, policy or management levels to address major coastal issues in the region?
5. Assessment and synthesis of **gaps in understanding, “hot spots” and research needs:**
- What are the major gaps in our understanding of river catchment – coastal sea interactions in the region of concern and which “hot spots” should be addressed with priority in a future integrated scientific work proposal (natural and socio economic disciplines)?

The issues were evaluated for the river systems shown in Figure 1.3. These rivers represent all classes of catchment-coastal systems in South America, as determined in the first **LOICZ SAmBas** workshop. The variability of coastal drainage of South America was taken into account during the development of **SAmBas**, in particular when selecting case study sites.

The tectonically passive Atlantic coast has larger drainage basins (e.g., the Uruguay and São Francisco rivers), variably with high and low water and sediment discharges, mostly dependent on climate. They have lower sediment yields than the Pacific coast systems. For example, the Jaguaribe River, a highly seasonal catchment in north-eastern Brazil, with a basin area of about 72,000 km², has a sediment yield of only 30 t.km⁻².yr⁻¹; the Negro River in Patagonia with similar basin area (100,000 km²) also has relatively low water and sediment yields (860 m³.s⁻¹ and 140 t.km².yr⁻¹), compared with the much greater sediment yields of Pacific and Caribbean coastal catchments in Colombia, with basin areas 10 times smaller.

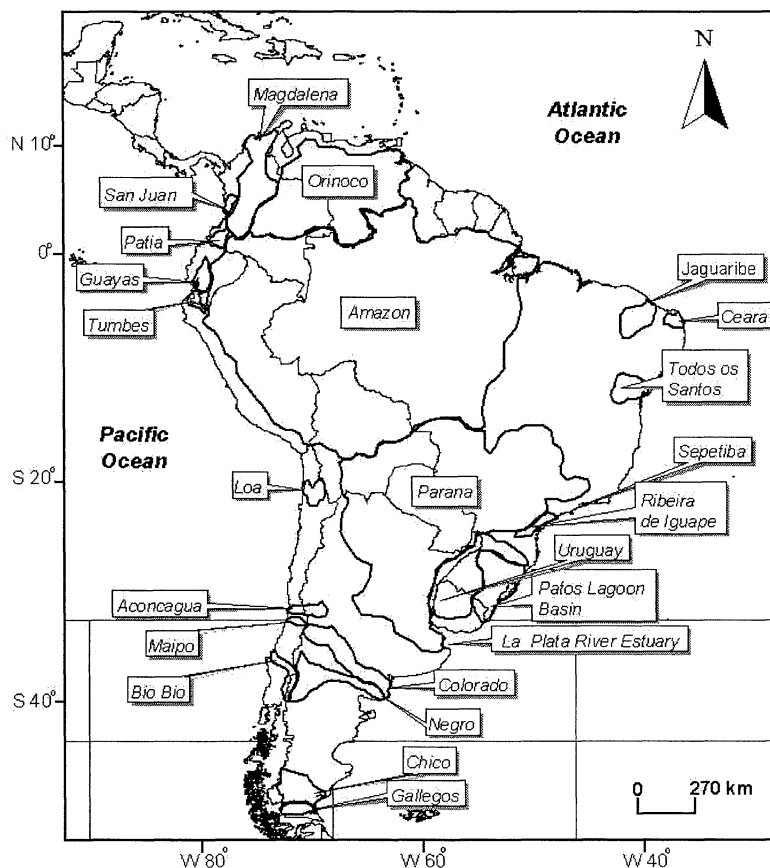


Figure 1.3. Rivers evaluated for issues, pressures, drivers and land-based activities in SAmBas Workshop 2.

Demonstration sites

After analysis and discussion of the various drivers, pressures, issues and impacts affecting changes in the catchment-coastal systems of South America, demonstration sites for key case studies were identified (Table 1.2).

Table 1.2 Demonstration sites for key case studies of catchment–coastal systems in South America.

Area location/ sub-region	Major rivers	Major coastal issues	Major drivers	Contact person
1 (7°N to 0°S)	San Juan River and Patia River , Colombia; Esmeraldas River, Ecuador	Erosion/ sedimentation	Agriculture	J.D. Restrepo, Colombia
2 (0°S to 42°S)	Guayas River and Chaira River, Ecuador; Tumbes River, Peru; Loa River, Aconcagua River and Bio Bio River , Chile	Eutrophication/ pollution/ sedimentation	Urbanisation/ aquaculture/ deforestation	R. Martinez G., Ecuador and G. Daneri, Chile
3 (42°S to 56°S)	Calle River , Chile	Eutrophication	Urbanization	G. Daneri, Chile
4 (10°N to 12°N)	Magdalena River , Colombia	Sedimentation/ eutrophication	Diversión/ urbanization	J.D. Restrepo, Colombia
5 (3°S to 12°S)	Ceará River , Pacoti River, Jaguaribe River and São Francisco River, Brazil	Erosion/ eutrophication	Damming/ urbanization	R.V. Marins and G.S.S. Freire, Brazil
6 (20°S to 30°S)	Doce River, Paraíba do Sul River, Guanabara Bay and Sepetiba Bay , Iguape River, Brazil	Eutrophication/ pollution	Urbanization/ industrialisation	E.D. Bidone and R. Sales, Brazil
7 (30°S to 38°S)	Patos Lagoon estuary , Brazil; La Plata River Estuary , Uruguay; Buenos Aires coast rivers, Argentina	Eutrophication/ pollution/ sedimentation	Urbanization/ industrialisation/ agriculture	U. Seeliger, Brazil, J. Cantera, Uruguay and P. DePetris, Argentina
8 (38°S to 52°S)	Negro River , Gallegos River and Colorado River, Patagonia, Argentina	Erosion/ eutrophication	Damming/ urbanization	P. DePetris, Argentina

The selection of demonstration sites provides coverage of key issues and representation of sub-regional river-coast classes. However, it was considered critical in determining the human dimensions of land-based coastal change and environmental impact to address not only the “hot spots”. There should be at least one companion baseline study carried out in the same sub-region at a relatively “undisturbed” site. This was given high priority for testing and providing the ground truth for indicators expected to be developed and applied in the interdisciplinary science. Another aspect was the availability of data; a **SAmBas** work proposal should have foundation in existing data as is expected to be the case for the catchments listed.

Within the **SAmBas** network the key contact persons identified for each of the case study sites agreed to assist in further developing specific research proposals and to investigate the options for potential funding on national and international levels. The group reiterated that regardless whether national or international financial support was targeted, the initiative and detailed networking needs at site level would need to come from the regional scientific community. LOICZ could provide a framework and assist in sustaining the necessary links.

2. Regional assessment and synthesis: South America

by L.D. Lacerda, Bjorn Kjerfve, Wim Salomons and H.H. Kremer

2.1 Introduction

Most studies of environmental impacts on coastal ecosystems deal with the coastal sites themselves. Less attention has been paid to those activities occurring within catchment basins and their potential to impact on coastal areas. Study of these impacts and a need to cope with their adverse ecological effects has resulted in a multidisciplinary approach to assessment, analysis and trend modelling of the pressures, state changes and impacts (Lacerda *et al.* 1999).

Most legislation regarding environmental conservation, management and the sustainable use of coastal natural resources fails to consider human activities in catchment basins; activities that are sometimes far from the coast. As well, many socio-economic driving forces acting on river catchments may be completely different from those acting on coastal areas. A general problem is a scaling mismatch between legal instruments and coastal issues as well as with drivers of change and legislation, rather than low quality environmental laws (Kremer and Köhn 2000). As a result, despite a strengthening of environmental regulations for many coastal areas around the world, potential beneficial effects of these regulations on the quality of coastal environments are being overtaken by detrimental impacts generated in catchment basins (Salomons *et al.* 1999).

The **LOICZ Basins** project assesses coastal change from a system perspective, and considers observed effects as a reflection of pressures within the whole catchment basin. However, it is recognised that coastal change is forced both by land-based processes and global forces affecting the material cycles and thus the horizontal fluxes reaching the coast. The priority focus in **LOICZ Basins** is the transport of water and sediments and the cycling of carbon, nitrogen and phosphorus. Of particular interest is the residual transport of these materials generated by sectoral activities such as agriculture, urbanisation, industrial production and damming. This information will be used to derive critical fluxes, loads and concentrations to enable scenario and carrying capacity analyses based on current status and expected pressure trends. This report is the outcome of the **SAmBas** assessment and synthesis workshops held in Bahia Blanca, Argentina, 11-13 November, 1999 and Fortaleza, Brazil, 2-5 May, 2001 dealing with catchment basin/coastal sea interactions in South America. It includes

- 2.2 Indicators of coastal change
- 2.3 Biophysical sub-regions and catchment size classes
- 2.4 Coastal issues, state changes, critical loads and ranking
- 2.5 Driver-Pressure-State change relationships
- 2.6 Assessment of land-based drivers

The guiding questions were:

- What is the present state of the South American coastal zone with regard to environmental impacts caused by basin activities?
- What is the scientific and management response to the situation?
- What do we know about horizontal material transport and cycles in the coastal zone?
- To what extent do these activities and cycles indicate changes in environmental functioning and sustainable provision of goods and services under the various natural and anthropogenic forcing functions within the catchment systems?
- What are the trends expected for land-based coastal change based on expert judgement?

The DPSIR framework

LOICZ Basins requires integrated work by natural, social and economic scientists and a framework facilitating multidisciplinary analyses. **SAmBas** and other regional **LOICZ Basins** efforts follow the Driver-Pressure-State-Impact-Response or DPSIR scheme (Turner *et al.* 1998; Turner and Bower 1999). By enabling calculation and modeling of the impacts of change on the delivery and use of environmental goods and services expressed in scientific and monetary terms, the scheme provides a standardized platform for independent review of political and managerial response and options. This report sets the

stage for a standardized evaluation and first synthesis of interacting South American catchment - coastal systems, taking into account natural science and socio-economic features and applying a whole-catchment scale. The elements of this framework are:

Drivers: catchment-based sectoral activities

with consequences for the coastal zone such as:

- urbanisation
- aquaculture
- fisheries
- oil production and processing
- mining
- agriculture and forestry
- industrial development
- land use change

Pressures: processes affecting key ecosystem and social system functioning

(i.e., natural and anthropogenic forcing affecting and changing the state of the coastal environment)

- damming and other constructions;
- river diversion, irrigation and water abstraction;
- influence of industrial effluents (industrialisation), agricultural and domestic wastes (urbanisation);
- navigation and dredging;
- sea-level rise induced by land based activities and affecting the coastal zone (e.g., decrease of riverine sediment load leading to instability of coastal geomorphology);
- other forcing functions (not primarily anthropogenic) such as climate change.

State and State change: the indicator functions and how they are affected

- 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 enable ultimately derivation of critical load information);
- geomorphologic settings, erosion, sequestration of sediments, siltation and sedimentation;
- economic fluxes relating to changes in resource flows from coastal systems, their value, and changes in economic activity including the valuation of natural resources, goods and services.

Impact: effects on system characteristics and provision of goods and services

- habitat alteration;
- changes in biodiversity;
- social and economic functions;
- resource and services availability, use and sustainability;
- depreciation of the natural capital.

Response: action taken

- scientific response (research efforts, monitoring programs);
- 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.

2.2. Indicators of coastal change

LOICZ South American Basins (SAmBas) aims to develop at least a qualitative or semi-quantitative set of environmental indicators (OECD 1993) of drivers, pressures and corresponding state changes (biogeochemical and biological) in the coastal zone. Major functions of these indicators are to reduce the number of measurements and parameters needed to characterize a given environmental change and to

simplify the communication process between technicians and decision makers. Table 2.1 presents a set of potential environmental indicators which could be used in a demonstration project that takes into consideration the major drivers and pressures identified during the first **SAmBas** workshop.

All the indicators can be quantitatively measured and linked, at least qualitatively, to a specific societal response. This will enable future derivation of “indices” of coastal change in response to basin-derived activities. Such indices should eventually incorporate societal and economic elements to better characterize the human dimension of the change. See Bidone and Lacerda this report, Volume 2.

Table 2.1. Summary of environmental indicators of drivers, pressures and state change applied to the South America context (based on OECD 1993).

Environmental pressure	Environmental conditions	Response	Indicators (examples)
Emissions of nutrients (C,N,P)	Concentrations of nutrients C,N,P in coastal waters	Maximum allowed concentrations (MAC)	<ul style="list-style-type: none"> • Percentage of urban houses attended by treated sewage • Urban <i>vs</i> rural area • Dissolved oxygen concentrations. • Primary productivity rates
Emission of heavy metals	Concentrations of heavy metals in coastal waters, sediments and biota	MAC	<ul style="list-style-type: none"> • Frequency of occurrence of surpassing the MAC
Mangrove and salt marsh loss	Mangrove and salt marsh area	Replanting Conservation	<ul style="list-style-type: none"> • Historical changes in mangrove and salt marsh areas • Ratio of replanted mangrove and salt marsh areas to natural area
Sediment load increase (siltation)	Total suspended solids concentrations (TSS) TSS mineralogy Sedimentation rates	MAC	<ul style="list-style-type: none"> • Frequency of occurrence of exceeding the MAC • Historical variation in sedimentation rates • Clay type ratio in TSS
Sediment load decrease (erosion)	Coastal erosion rates	Integrated Coastal Zone Management	<ul style="list-style-type: none"> • Beach loss rates • Dune loss rates • Mangrove and salt marsh erosion
Freshwater withdrawal	Ground water salinity	MAC	<ul style="list-style-type: none"> • Groundwater conductivity variation along gradients • Soil salinity
Fisheries losses	Fish stocks	Fisheries management legislation. Maximum capture Temporary bans	<ul style="list-style-type: none"> • Change in fisheries stocks • Population parameters • Catches diversity

Impacts on various habitats, including those resulting in changing options for human use such as increased sediment load affecting coastal aquaculture fisheries, also need to be categorized. The sets of categories and indices are expected to provide input into a wider global typology assessment (see: www.nioz.nl/loicz/ or <http://www.kgs.ukans.edu/Hexacoral/>).

As the LOICZ coastal typology activities progress, it should become possible to better integrate catchment scale processes. The DPSIR scheme (see Figure 4.1, page 62) applied to **SAmBas** should provide typological information useful also for management. Comparison of state change scenarios representing various types of political and management responses to drivers and pressures upstream may than also be scaled up and compared.

2.3. Biophysical sub-regions and catchment size-classes

To permit comparison of South American regional catchment–coastal sea interactions, compilation of a river database by **SAMBas** has just begun. The database includes topological parameters and summarised data on water discharge and sediment load. Water quality data such as nutrients, heavy metals, pesticides concentrations need to be added. In a further step, indices of data quality and uncertainty need to be included (Costanza 1992). This will allow testing of the validity of the typological assumptions adopted: e.g., variability of data used to estimate average values of parameters, measurements and errors.

In South America, river basins have an array of dimensions (Figure 2.1) and a drainage basin topology is a convenient way to organise their environmental issues. Usually the size of the basin dictates the severity of coastal impacts. For example, agriculture in a large basin has relatively little impact on coastal zone ecosystems whereas a similar level of activities in a smaller basin might cause severe siltation and eutrophication in the delta and adjacent coastal areas. On the other hand, water diversion in a large basin might have a tremendous downstream impact, whereas diversion in a small system might be relatively insignificant regionally.

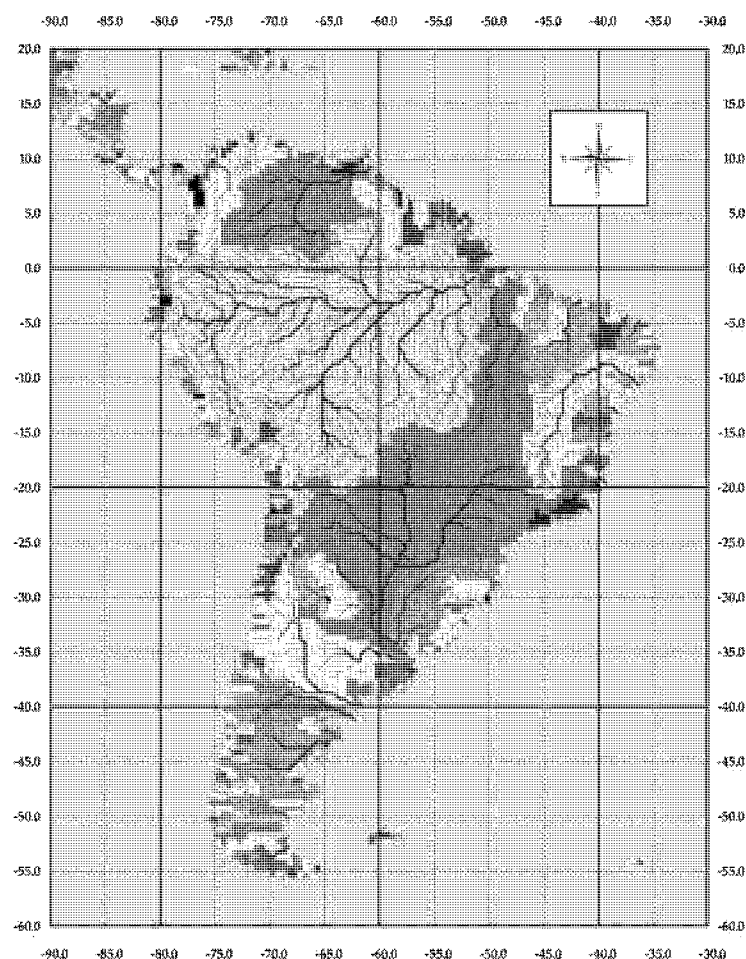


Figure 2.1. Major and minor river catchments in South America. Note the predominance of small river basins along the tectonically active Pacific coast, the Caribbean and a large stretch of the Brazilian coast (from: South American Drainage Basins: <http://r-hydronet.sr.unh.edu>).

To enable an appropriate ranking of Driver/Pressure influence, we have chosen to evaluate the effects in coastal areas from activities in the drainage basins separated according to three size classes:

- small basins, <10,000 km² in area

- medium basins, 10,000-200,000 km² in area
- large basins, >200,000 km² in area

Examples of different rivers, and their major hydrographic characteristics, representing the different type classes used in this study and which have been identified as generating impacts on coastal areas, are listed in Table 2.2 and shown in Figure 2.2.



Figure 2.2. Major catchments in South America addressed in the regional SAMBas assessment.

The Caribbean and Pacific coasts of South America have geological similarities and are quite different from the Atlantic coast. The Pacific and the Caribbean coasts are tectonically active, characterised by high topographic relief with many short rivers and relatively small drainage basins. High water and sediment discharges result in high coastal yields (Kellogg and Mohriak 2001). Venezuela, for example, has many small catchment basins (Table 2.2) including the Aroa, Catatumbo, Chama, Limon and Tuy rivers, with basin areas of less than 8,000 km², but with sediment yields in excess of 1,000 t km⁻¹ year⁻¹.

The Atlantic coast presents a low topographic relief bordering a broad continental shelf. It is a tectonically passive coast along a trailing plate margin typically with large drainage basins (e.g., the Uruguay and São Francisco rivers), with variable water and sediment discharges, mostly determined by climate. In general they have low sediment yields. For example, the Jaguaribe River, a highly seasonal catchment in north-eastern Brazil, with a basin area of about 72,000 km², has a sediment yield of about 30 t km⁻² yr⁻¹. Approximately 93% of the South America drainage is to the Caribbean and the Atlantic away from the Andes, an example of continental-scale drainage control by plate tectonics (Kellogg and Mohriak 2001).

The variability of coastal drainage of South America must be taken into account during the development of SAMBas, in particular when selecting case study sites.

Table 2.2. Examples of South American drainage basin types (data from Barcellos *et al.* 1997; Goniadzki 1999; Milliman and Meade 1983; Milliman and Syvitski 1992; Restrepo and Kjerfve 2000; Freire 1989; Salomão *et al.* 2001, ANEEL 2000, * Knoppers pers. com.)

River (Basin classes) – L = Large, M = Medium, S = Small;	Basin Size Class	Basin Area (10 ³ km ²)	Water Discharge (m ³ s ⁻¹)	Sediment Load (10 ⁶ t yr ⁻¹)	Sediment Yield (t km ⁻² yr ⁻¹)	Receiving. Coastal Sea
R. Magdalena, Colombia	L	250	7,200	144	560	Caribbean
R. Orinoco, Venezuela	L	990	34,500	150	150	N. Atlantic
R. Amazon, Brazil	L	6,150	150,000	1,200	190	N. Atlantic
R. S. Francisco, Brazil	L	640	2,000*	6	10	S. Atlantic
R. Uruguay, Uruguay	L	244	4,670	11	45	S. Atlantic
R. Paraná, Argentina	L	2,600	13,940	79	30	S. Atlantic
R. Atrato, Colombia	M	35	4,500	11	315	Caribbean
R. Unare, Venezuela	M	23	50	11	500	N. Atlantic
R. Tocuyo, Venezuela	M	18	55	53	3,000	N. Atlantic
R. Negro, Argentina	M	100	860	13	140	S. Atlantic
R. Chira, Peru	M	20	3,850	20	1,000	S. Pacific
R. San Juan, Colombia	M	14	2,550	16	1,150	N. Pacific
R. Patía, Colombia	M	14	7,690	14	972	N. Pacific
R. Jaguaribe, Brazil	M	72	130	2	28	S. Atlantic
R. Paraíba do Sul, Brazil	M	55	886*	2	20	S. Atlantic
R. Aroa, Venezuela	S	0.9	5	1.1	1,250	N. Atlantic
R. Catacumbo, Venezuela	S	7.2	420	10.7	1,500	N. Atlantic
R. Chama, Venezuela	S	1.3	20	1.1	1,000	N. Atlantic
R. Limon, Venezuela	S	1.8	54	2.6	1,500	N. Atlantic
R. Neveri, Venezuela	S	0.9	20	0.3	300	N. Atlantic
R. Tuy, Venezuela	S	6.6	65	6.6	1,000	N. Atlantic
Canal S. Francisco, Brazil	S	2.5	180	0.3	120	S. Atlantic
R. Pacoti, Brazil	S	3.0	7	0.1	35	S. Atlantic

Sub-regional division

A sub-regional division was used to select hot spots and test sites for **SAmBas**, based on the geological and climatic characteristics of the coast and of the typical coastal catchments (Figure 2.3). South America is dominated by a number of very large river catchments and wetlands east of the Andes which input nutrients that support the major part of the primary production and fisheries of the Western Atlantic tropical and sub-tropical coasts of the sub-continent. These systems however, are often visibly altered through human activities (e.g., pollutant loads draining into Sepetiba Bay); their pressures on the coastal zone are more pronounced than in areas where pressure is diffused over larger catchments, such as the Amazon. Consequently, land use and cover change, pollution or water diversion, which are drivers changing horizontal mass transport, are likely to cause stronger state changes and to generate “hot issues” of coastal impact when associated with smaller catchments. In addition, the characteristically small catchments of the Pacific coast discharge into a relatively narrow continental shelf with strong interaction with open ocean waters; the discharge into the Atlantic is to a relatively broad continental shelf (Kellogg

and Mohriak 2001). Therefore, the basin effects on the receiving coastal waters will quite probably be different between Pacific and Atlantic systems.

For both coasts a second sub-regional classification applies, encompassing the wide range of climatic conditions in South America, from tropical to sub-Antarctic patterns. Here, desert-like regions along the Peruvian and Chilean coastline are replaced by quite humid areas with considerable annual rainfall further south. The north-east and central eastern parts are tropical or sub-tropical while the south-east shows more arid conditions with sparse vegetation.

Anthropogenic pressures also exhibit two major features. Mega-cities either affect the coastal waters or estuaries directly (Buenos Aires and Rio de Janeiro) or contribute to coastal change indirectly through the catchments which carry their urban waste load (Caracas and São Paulo). Areas such as Patagonia have low population density and runoff, so water quality is relatively unimpacted. Perhaps rather surprisingly, these characteristics also apply within much of the large Orinoco system. Economically driven changes in land use affects large remote regions through, for example, continued deforestation which has visible influence on the geomorphology of catchments as well as on the hydrological conditions. These pressures, although manifested by relatively small coastal effects e.g., deforestation in the Amazon basin, may have strong potential for significant impacts.



Figure 2.3. Sub-regional typology of South American river catchment-coastal sea interaction.

The eight sub-regional divisions (Figure 2.3) were selected as representative of South American catchments. (The area between 5 and 6 incl. the São Francisco River, was subject to extensive assessment work during the time of the report preparation, information of which will be made available to SAMBas, at least electronically, at a later stage, Knoppers pers. com.)

Area 1: 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 km² but large water and sediment discharges and sediment yields on the range of 1,000 t.km⁻².yr⁻¹ (Restrepo and Kjerfve 2000b), and the Esmeraldas and Chone rivers in Ecuador (PMRC 1993a). Average annual rainfall for this sub-region is 5,900 mm. About 260 km³ of freshwater is discharged annually into the Pacific Ocean, with a sediment load of nearly 31x10⁶ t yr⁻¹ (Restrepo and Kjerfve 2000b).

Area 2: 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 (Echevaria and Sarbaia 1993). 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. 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) (PMRC 1993b). This has caused enormous changes in geomorphology and basin land use with direct effects on the coast. Typical rivers are the Guayas River in Ecuador, the Tumbes and Chira rivers in

Peru and the BioBio River in Chile. They have small basins, large water and sediment discharges and high sediment yield. For example, the Chira River has a very small basin area of only 20,000 km² but shows a sediment yield of about 1,000 t k⁻² yr⁻¹.

- Area 3: 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 of different morphodynamics alternate with intertidal sand flats at the mouth of rivers (Jaramillo 2001). 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.
- Area 4: The northernmost Atlantic coast area includes the Magdalena River delta, a complex lagoon-deltaic system (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 km³ of water and 144x10⁶ tonnes of sediment annually into the Caribbean. These 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 (Restrepo and Kjerfve 2000a).
- Area 5: 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 (Medeiros *et al.* 1999; Ekau and Knoppers 1999a). 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 which continuously change the coastal geomorphology (Jimenez *et al.* 1999). The semi-arid nature of the region's climate has resulted in intense impoundment of waterways, mostly for irrigated agriculture and urban use (Campos *et al.* 1997). This has led to an extreme reduction of fresh water and fluvial sediment load to the ocean and generalised erosion along the coastal region (Valentini 1996).
- Area 6: The south-eastern Brazilian coast (20-30°S), the most industrialised and urbanised part of the South American coast, houses about 60 million people and the largest industrial parks and ports of the sub-continent. The climate is tropical humid with abundant rains year-round and annual rainfall of 1,200 to 2,600 mm (Ekau and Knoppers 1999a). Environmental pressure along this coast is enormous, mostly associated with unplanned urban and industrial development concentrated along very narrow coastal plains. Several small rivers with huge event-controlled discharges transport large volumes of sediments and pollutants to the coastal seas (Bidone *et al.* 1999; Lacerda *et al.* 2001).
- Area 7: The southern coast of Brazil (30-38°S) and the region of influence of the La Plata River estuary, is mostly in a warm temperate climatic zone. This huge coastal plain is drained by three large rivers, the Uruguay, Paraná and Guaíba, which drain 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 ICZM on a multi-national level.
- Area 8: The Patagonia littoral in Argentina, (38-52°S), has a temperate climate and an annual rainfall of less than 800 mm. The sub-region is characterised by long coastal plain rivers still relatively undisturbed. However, extensive livestock breeding (particularly of sheep) and increasing agricultural activities are threatening many coastal sites of high ecological value to migrating species. Major rivers are the Negro, Chubut, Santa Cruz and Colorado with basin areas of 95, 30, 25 and 22x10³ km², respectively. However, water discharge is relatively small, less than 2,000 m³ per year (Gaiero *et al.* 2001).

2.4. Coastal issues, state changes, critical loads and ranking

Catchment basin activities have considerable influence on the environmental state of many South American coastal areas. A number of case studies, from across the South American continent, were discussed during SAmBas 1. These are summarized below (Table 2.3) and address key issues and scales rather than expressing the entire dimension of the continent's land-based problems which occur at the land-sea interface.

Table 2.3 Summary of priority driver/pressure features by country, corresponding “hot spots” and information available in South America.

Country	Driver/Pressure	Hot spots	Available information
Colombia	<ul style="list-style-type: none"> • Pollution (generated by urbanization, industry, mining) • Deforestation (generated by agriculture) • Diversion of river discharges 	<ul style="list-style-type: none"> • Rio Magdalena • Cartagena Lagoon (to be opened to the Caribbean) 	<ul style="list-style-type: none"> • Nutrient and sediment discharges and concentrations available for the Magdalena River back to the 1970's, but refers only to the delta and the river.
Venezuela	<ul style="list-style-type: none"> • Industrial liquid discharges • Oil exploration and extraction • Livestock land use • Sewage (prevention still possible) • Agriculture 	<ul style="list-style-type: none"> • Orinoco Delta • Neveri River • Catatumbo River • Maracaibo Lake • Tuy River • Limon and Aroa rivers • Unare/ Chama rivers 	<ul style="list-style-type: none"> • Available information in comprehensive reviews, including nutrient and sediment discharges, have been published by MARNR and other government agencies.
Argentina	<ul style="list-style-type: none"> • Pollution (generated by urbanization and industry) • Erosion, siltation due to land use change • Oil spills (upstream) 	<ul style="list-style-type: none"> • Rosario and Buenos Aires Province (due to transboundary transport from Brazil through the Paraná River) • Patagonia 	<ul style="list-style-type: none"> • Overview reports on the Parana-La Plata rivers* • Bibliography from various case studies in small Patagonian rivers
Brazil	<ul style="list-style-type: none"> • Damming • Diversion • Irrigation • Agriculture (nutrient loads) • Deforestation • Navigation 	<ul style="list-style-type: none"> • 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 	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Navigation (timber transport) • Agriculture (more irrigated rice paddies) • Irrigation 	<ul style="list-style-type: none"> • Parana River* • Uruguay River • La Plata River 	<ul style="list-style-type: none"> • GEF project report**

* = The Parana-La Plata basin has been the subject of overviews promoted under the MERCOSUR agreement.

** = On-going GEF project in the La Plata Basin.

A preliminary critical load approach was applied for catchments during the workshops. Critical loads represent quantitative estimates of ecosystem sensitivity to a given impact and may be compared to the present-day status of the ecosystems regarding a given parameter and/or pressure. Although initially determined for pollutant loads (in particular of acidity), critical load approaches may provide values for assessing basin-derived impacts on the coastal zone (Kuylenstierna *et al.* 2001).

Coastal impacts and issues in the coastal zone of South America were characterized and ranked according to their degree of importance, based on a quantitative or qualitative evaluation of the present-day distance to the critical threshold of a given parameter for system functioning (Table 2.4).

Generally, coastal issues are eutrophication, pollution and changing erosion/sedimentation equilibrium, although other issues may be even more important at the site-specific level (see individual sub-regional tables in the appendices). These pressures have already caused measurable impacts on the sub-continent's

coastal zone, resulting in varying degrees of displacement from baseline background state in many ecosystems.

Eutrophication

Urban and agricultural waste released to the coast are raising special concerns regarding toxicological impacts on coastal waters. Together with erosion, this impact ranked the most important on both coasts of South America. In most cases eutrophication is directly linked to increasing population density and urbanization of coastal catchments, even in low density regions such as Patagonia and north-eastern Brazil.

The coasts of SE Brazil and Buenos Aires Province are probably the regions in South America most affected by eutrophication, due to the enormous concentration of population and industries along major rivers draining to these coasts. Anoxia or low oxygen levels ($<3 \text{ mg l}^{-1}$) occur in lowland watersheds, estuaries and coastal lagoons and significantly affect coastal embayments. Nutrient concentrations measured at nearly 200 stations along rivers draining to the metropolitan area of Rio de Janeiro, SE Brazil, showed concentrations one to three orders of magnitude higher than background (Knoppers *et al.* 1999; Bidone *et al.* 1999; Kjerfve *et al.* 2001a). Elevated levels of coliforms (500 colis NMP 100 ml⁻¹) derived from river catchments can be measured in open oceanic waters off beaches of the region. Even along the sparsely populated Uruguayan coast, low oxygen and high nitrogen concentrations are occurring.

Toxic algae blooms have increased in frequency along the eastern coast of Uruguay, probably associated with the increase in freshwater inflow to the La Plata River estuarine area. Algal blooms are also becoming frequent in coastal waters off Buenos Aires and along the Patagonian coast of Argentina. These are also presumed to be associated with sewage discharge in the Parana River basin, upstream of the La Plata estuary, and from Patagonian rivers. Along the Patagonian coast, this may have increasing effects on important mussel banks and sea farms. In the spring of 1980, the human health dimension of increased riverine nutrient loads became apparent when a big algal bloom caused human deaths from consumption of mussels contaminated by *Alexandrium* sp. Since then a research program (NICOTEA) has been established, monitoring algal blooms at several sites along that coast. Data series from this program show a significant increase in blooms over the last 20 years, related to human activities in the coastal zone. Non-toxic algal blooms have also been causing fish kills along the Caribbean coast of Colombia, due to localized depletion of oxygen (Mancera-Pineda and Vidal 1994).

Along the coastline of metropolitan Fortaleza, NE Brazil, seasonal algal blooms occur due to the flushing of eutrophic river waters during heavy rains in summer, when the normally oligotrophic coastal waters are submitted to sudden high inputs of nutrients. The alga involved has not yet been identified.

In Colombia, bacteria reaching coastal waters from sewage discharged into river basins contaminate oyster banks (Escobar-Nieves 1988). These effects may be aggravated by the dredging of Barranquilla Harbour at the Magdalena River mouth, which will increase mobilisation and discharges of basin-borne pollutants to the coastal zone. These dredging activities may also increase siltation on the offshore reefs of Caribbean Colombia to a level critical for the sustainability of the biodiversity and structure of benthic ecosystems.

In some Venezuelan Caribbean islands, there is evidence of a growing frequency of ciguatera, associated with an increasing frequency of algal blooms due to 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 also an important issue. However, it seems to be more restricted and intense than along 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. For most of this coast, little information exists (Hajek *et al.* 1990; Parra and Habit 1998; Espinoza *et al.* 1995).

Pollution

Pollution is considered here as the introduction into the aquatic environment of man-made substances which are harmful to life and to human or animal 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 due to economic development of most countries of the continent. Diverse areas of the coastline, especially protected shores, are continually under pressure (Seeliger *et al.* 1988; Peters *et al.* 1997). Such areas harbor over 2 million hectares of highly productive mangroves and wetlands, which are nursery grounds for coastal fisheries (Seeliger 1997; Kjerfve *et al.* 1997; Lacerda *et al.* in press). These key ecosystems are exposed to contaminants transported by rivers and can convey contaminants through food chains to the human population (Lacerda 1998).

Most pollutant inputs are from industrialisation and agriculture along river catchments and involve heavy metals. Copper contamination from pesticides used in agriculture is affecting the Negro River (Gaiero *et al.* this report). A similar situation occurs in southern Brazil (MMA 1996a). Even in relatively undisturbed environments such as the rivers of Patagonia and north-eastern Brazil, heavy metal concentrations are in general much higher than local background values. Monitoring suggests that bottom sediments and filter-feeding organisms are the best indicators of pollution. As with nutrients, the high flushing rate to the open ocean due to coastal upwelling results in large dilution of pollutant concentrations.

Apart from direct inputs to rivers, atmospheric deposition of pollutants on basins and transport 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 shows 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 in coastal areas of the region. Hydrocarbons are occasionally delivered to the coastal zone through rivers, in particular in Colombia and western Venezuela. In the Colorado River, in northern Patagonia, oil exploration in the Andes results in frequent oil spills that eventually affect the coastal zone, as occurs also along part of the Ecuadorian coast. This activity also contributes heavy metals.

Mining, although less important to coastal watersheds, may be significant in certain regions. In the Gallegos River, coal mining is responsible for increasing lead concentration. Small-scale gold-mining, the most important source of mercury in South America, is carried out in basin systems generally far from the coast. However, evidence from the Paraíba do Sul River, SE Brazil; the Gurupi River, NE Brazil; and probably the Magdalena River, Colombia, reveals mercury transport from these inland areas to the coastal zone, where this highly toxic pollutant enters coastal food chains (Lacerda *et al.* 1993; Veiga 1997; Lacerda and Salomons 1998). Migrating sea birds may transport mercury and thus contaminate mangrove areas far from any gold-mining sites (Fulano 1995).

Transposition of waters from adjacent basins can increase pollutant load and potential toxicity in coastal areas. Between 30 and 45% of the total mercury input reaching Sepetiba Bay, SE Brazil, comes with diverted water from the Paraíba do Sul River (Molisani *et al.* this report). In the river, mercury is not a significant environmental issue, since small fisheries, based on low trophic level fluvial species, do not allow significant mercury biomagnification along food chains. However, in Sepetiba Bay, with optimum conditions for mercury methylation (Marins *et al.* 1998), large fisheries, including top carnivores, may convey highly toxic methyl-Hg to the local population which depends on fish as its major protein source (Lacerda *et al.* 2001).

Organic micropollutants are not significant contaminants of coastal waters in South America, but at some sites they show relatively high concentrations. This is the case for the Esmeraldas River in Ecuador, the La Plata River estuary and some sites along the Patagonia coast.

Coastal geomorphology

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, due to population growth in coastal metropolitan areas, or under arid climates. Examples can be found along the north-eastern Brazil coast and the Caribbean coast of Colombia and Venezuela (Lacerda 1993; Lacerda *et al.* in press; Kjerfve *et al.* 2001b).

In many estuaries, changing river sediment load alters the sedimentation-erosion equilibrium within the estuary or delta. Coarse-grained bed load ($>60\ \mu\text{m}$) is normally taken to represent 10% or less of the total sediment discharge delivered to the coastal zone. Hence, it was assumed that a decrease of approximately 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 such as along the Pacoti River estuary, NE Brazil (Freire 1989) and in severe erosion of mangroves, such as in the Paraíba do Sul River delta, SE Brazil (Salomão *et al.* 2001) and sandy beaches the coasts of Buenos Aires Province in Argentina and in NE Brazil.

In Brazil, transposition of water and materials across catchment basins is altering major stretches of the densely populated south-east coast. In Sepetiba Bay, diversion of the adjacent Paraíba do Sul catchment basin to the Rio de Janeiro metropolitan area has resulted in a ten-fold increase in the freshwater discharge to that bay, and increased sedimentation from about $60\ \text{mg cm}^{-2}\cdot\text{yr}^{-1}$ in the early 1970's to $>320\ \text{mg cm}^{-2}\ \text{yr}^{-1}$ in the 1990's (Forte 1996; Barcellos and Lacerda 1994; Barcelos *et al.* 1997). At the mouth of the Paraíba do Sul River, on the north coast of Rio de Janeiro State and about 300 km from Sepetiba Bay, extensive erosion of the coastline is destroying fringes of mangrove forests, dunes and small villages in the area, due to lack of sediment transport (Dias and Silva 1984). Similarly, at the Jaguaribe River in NE Brazil, where semi-arid conditions make water supply a key development issue, construction of large reservoirs and irrigation networks has decreased sediment transport to the coast. It is now only $2\times 10^6\ \text{t yr}^{-1}$, with a sediment yield of about $28\ \text{t km}^{-2}\cdot\text{yr}^{-1}$. This sediment load is presently only 10%-50% of the necessary continental supply to maintain the stability of the coastline, so that there is severe erosion and degradation of mangrove ecosystems (Cavalcante 2000).

Deforestation of river catchments facilitates soil erosion, resulting in increasing siltation of the coastal zone. Sediment quality change may also be significant, although this is not well assessed in the region. The mouth of the Magdalena River in Colombia, where a major port is sited, needs continuous dredging to prevent sedimentation. Disposal of dredged materials has affected adjacent sandy beaches and mangroves, which cannot keep up with the increased sediment load. Coral reefs, mainly around the Archipelago de Islas del Rosario and in the Santa Marta area, which are subjected to higher annual sediment load discharged through the Magdalena River during a 3-4 month period, are showing increasing signs of deterioration (Garzón-Ferreira and Kielman 1993). Recently, evidence from deforestation-caused soil erosion has shown that long-lasting contaminants such as heavy metals may also be remobilized, increasing the contamination threat in coastal areas (Watras and Huckabee 1994).

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. Guanabara Bay, in SE Brazil, experienced very rapid sedimentation in the 1990's as a result of deforestation in the drainage basin (Kjerfve *et al.* 1998), resulting in suspended solid concentrations in excess of $100\ \text{mg l}^{-1}$ in its tributary rivers (Knoppers *et al.* 1999). Many other examples attest the growing importance of river basin-generated activities upon coastal waters. It becomes apparent that different drivers can cause similar pressures and thus comparable inverse state changes of catchment processes affecting the coastal zone.

Biodiversity

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 a reliable "critical loads" for this parameter. Extreme cases are the 90% reduction of commercial fisheries during the past 20 years at the Magdalena River delta (Botero 2001) and the 90% decline of viviparous shark catches at the Patos Lagoon estuary (Haimovici *et al.* 1997). Apart from fisheries, loss of extensive mangrove areas in Ecuador and Colombia and salt marsh areas in southern Brazil have been reported (Cardona and Botero 1998; PMRC 1993a,b; Seeliger and Costa 1997).

Table 2.4. Major coastal impacts/issues and critical thresholds along the coast of South America; overview and qualitative ranking of impacts.
Impact scale: 10 = maximum; 0 = none.

Coastal impact/issue	Local site/region (contributing river basins)	Critical threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category	References/ data source
Erosion (coastal geomorphology)	a. Rivers of northern Patagonia (Negro, Chubut, Colorado) including estuaries and adjacent beaches.	a. Several dams affects river basins. Critical bedload is about 10^5 t yr^{-1} .	a. Critical load already passed. Present delivery of sediments estimated as 70-80% only of the critical load of material transport for sustained coastal stability.	a. 8	a. Violante <i>et al.</i> (2001); Isla (1997); Lopez and Marcomini (1998); Cionchi <i>et al.</i> (1993); Pasquine <i>et al.</i> (1997)
	b. Paraíba do Sul River delta and small rivers with steep slopes and high relief (1,000-1,500 m) with emphasis on the Rio de Janeiro metropolitan area, SE Brazil	b. Not known, for the Paraíba do Sul River. For small steep watersheds critical loads are surpassed with rain of 80 mm or more.	b. Critical threshold passed. Present sediment delivery reaches about $60 \times 10^3 \text{ ton.yr}^{-1}$, probably well below the critical load needed for coastal stability, since strong erosion of beaches and urban structures is presently occurring. Potential erosive precipitation events occurring between December and March.	b. 8	b. Salomão <i>et al.</i> (2001); Bidone <i>et al.</i> (1999)
	c. Northeastern coast of Brazil: Jaguaribe River, Pacoti River, São Francisco River	c. $0.02\text{-}0.1 \text{ } 10^6 \text{ t yr}^{-1}$ (5%).	c. Present delivery of sediments is about 10% to 50% of the critical load. Erosion of adjacent beaches already evident.	c. 9	c. Jimenez <i>et al.</i> (1999); Freire (1989); Valentini (1996); Bezerra (1996)

Coastal impact/issue	Local site/region (contributing river basins)	Critical threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category	References/data source
Erosion cont.	d. Magdalena River delta	d. Not known	d. Observed coastal erosion of 17 m ³ yr ⁻¹ due to jetty construction at the river mouth.	d. 8	d. Correa (1996); Martinez and Molina (1992)
	e. Uruguayan coast of the la Plata River estuary	e. Not known	e. Dune and beach loss observed.	e. 6	e. ECOPLATA (1999)
	f. Esmeraldas and Chone rivers, Ecuador	f. Lack of vegetation protecting the coastline. In the Chone River estuary, mangrove cover was reduced by 80% from 1969 to 1991.	f. Esmeraldas River estuary records 210 mg l ⁻¹ of suspended solids, suspected to be well over background concentrations. In the Chone River estuary, high sedimentation rates and bank erosion due to clear-cutting of mangroves have been observed.	f. 7-8	f. PMRC (1993a,b)
	g. Gulf of Guayaquil, Ecuador	g. Mangrove cover reduced by 23.6% from 1969 to 1996.	g. In the Gulf of Guayaquil, suspended solids are also thought to be far above background, reaching maximum concentrations of up to 3.04 g l ⁻¹ and 4.13 g l ⁻¹ during the rainy and dry season respectively.	g. 7	g. INOCAR (1998a,b)
	h. Baudó, San Juan, Patía and Mira Rivers, Colombia	h. Areas of high sediment dynamics that maximises impacts	h. Erosion of coastline and associated barrier islands observed.	h. 6-10	h. Restrepo and Kjerfve (2000b)
	i. Chañaral, Bío Bío and Aconcagua rivers, Chile	i. Areas of low sediment dynamics	i. Sedimentation occurring in estuaries.	i. 3-5	i. Hajek <i>et al.</i> (1990)

Coastal impact/issue	Local site/region (contributing river basins)	Critical threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category	References/ data source
Eutrophication	a. Small rivers in the Buenos Aires Province	For all sites C:N:P ratios compared to Redfield ratio can be used as a first approximation of natural levels. Dissolved oxygen levels should be > 5.0 mg l ⁻¹ , taking into consideration the existence of natural sub-oxic environments such as mangroves and some coastal lagoons. Chl-a concentration at background levels.	a. C:N ratios mostly unknown. Occurrence of low oxygen in estuaries of the region (<4 mg.l ⁻¹).	a. 4-5	a. Bilos <i>et al.</i> (1998); Manassero <i>et al.</i> (1998, 2000); Ronco <i>et al.</i> (1995)
	b. Rio de la Plata, along the Buenos Aires Province, Rio Uruguay, Montevideo Bay, Samboronbon Bay at the Buenos Aires coast, Rio Paraná		b. In the Rio de La Plata estuarine region, increased nutrient load is changing the ecosystem. Along the Uruguayan coast, freshwater inflow is increasing in recent years as has the frequency of algal blooms. Low oxygen and very high nitrogen concentrations occur in estuaries and lagoons. Fish mortality near beaches is also common.	b. 9	b. Kurucz <i>et al.</i> (1997)
	c. Sepetiba Bay and Guanabara basins, to Rio Ribeira de Iguape, SE Brazil		c. Extreme cases occur at the Guanabara Bay and basin and local areas of the Buenos Aires Province coast where complete anoxia dominates extensive areas. Redfield ratios are over 1,000. In the Rio de Janeiro metropolitan rivers, concentrations are well above critical thresholds and Redfield relationships are changed: (NO ₃ = 0.11–0.76 mg.l ⁻¹ ; NH ₃ = 1.49–4.0 mg.l ⁻¹ ; PO ₄ = 0.34–1.3 mg.l ⁻¹).	c. 10	c. Bidone <i>et al.</i> (1999); Knoppers <i>et al.</i> (1999); Bidone (2000)

Coastal impact/issue	Local site/region (contributing river basins)	Critical threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category	References/data source
Eutrophication cont.	d. Rio Cocó and Rio Ceará, NE Brazil		d. Oxygen levels below 2 mg l ⁻¹ in the Cocó River estuary. Algal blooms on beaches adjacent to most rivers. High concentrations of nitrogen and phosphorus.	d. 6	d. Marins <i>et al.</i> (2004); Almeida <i>et al.</i> (2000); Mavignier (1992).
	e. Magdalena River Delta/Lagoon complex and sectors of the Caribbean coast of Colombia		e. Biological communities at the Magdalena River delta show signs of mortality. Declining fisheries from 63,700 t in 1978 to 7,850 t in 1998, suggest decreasing water quality of the region.	e. 9	e. INVEMAR (1997, 2000), Beltran <i>et al.</i> (2000)
	f. Patos Lagoon Estuary, Brazil		f. 0.6-76.8 µg Chl-a l ⁻¹ , 0.73-8.55 mg kg ⁻¹ P-Tot; up to 12 µM P-PO ₄ and up to 45 µM N-NH ₄ in the water column.	f. 6	f. Baisch (1997); Almeida <i>et al.</i> (1993) Baumgarten <i>et al.</i> (1995)
	g. Esmeraldas and Chone rivers, Ecuador		g. In the Esmeraldas River estuary, OD= 0.9-6.7 mg.l ⁻¹ , BOD/N=10.35 µg at l ⁻¹ ; NO ₃ = 0.36µgat l ⁻¹ ; NO ₂ = 2.35 µgat l ⁻¹ PO ₄ Faecal coliforms in 1980 210-240x10 ³ NMP 100 ml ⁻¹ . In the Chone River estuary, DO= 1.6-7.5 mg l ⁻¹ N=12.1 µgat l ⁻¹ NO ₃ , 1.35 µgat l ⁻¹ NO ₂ ; 0.34 µgat l ⁻¹ PO ₄ Faecal coliforms =~93,000 NMP 100 ml ⁻¹ .	g. 7-8	g. PMRC (1993a,b)
	h. Gulf of Guayaquil, Ecuador		h. Gulf of Guayaquil: Estero Salado: DO = 3.4- 8 mg l ⁻¹ ; N= 0.1-1.4 µg-at l ⁻¹ NO ₂ ; 10-33 µg- at l ⁻¹ NO ₃ ; 1.2-4.4 µg-at l ⁻¹ PO ₄ Faecal coliforms = 0-240 NMP 100 ml ⁻¹ . In organisms total coliforms >2400 NMP 100 ml ⁻¹ .	h. 6	h. INOCAR (1998a,b)
	i. Aconcagua, Bio Bio and Calle Calle rivers in Chile		i. Unknown	i = ?	i. Hajek <i>et al.</i> (1990); Espinoza <i>et al.</i> (1995), Univ. de Concepción (1999); Parra and Habit (1998)

Coastal impact/Issue	Local site/region (contributing river basins)	Critical threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category	References/ data source
Pollution*	<p>a. Northern Patagonia rivers (Chubut; Negro, Colorado) and Gallegos River.</p> <p>b. Rio de la Plata: Rio Parana, Rio Uruguay, Montevideo Bay, tributaries of the Uruguayan coast, Buenos Aires coast, Riachuelo, Santa Lucia Stream, Reconquista and Carrasco streams</p> <p>c. Patos Lagoon basin.</p> <p>d. Iguape River to Sepetiba/ Guanabara basin</p> <p>e. Todos os Santos Bay, Coco/ Ceara rivers, CE</p>	<p>Some ubiquitous trace metals such as Hg may be used as a good indicator of general pollution, as tracer of industrial and urban sources. Baseline concentrations of Hg are relatively constant throughout the Atlantic coast of South America (<20 ng.l⁻¹), and can be used as a threshold. Similarly, background concentrations of most trace metals are available for coastal sediments all over the continent. For biota, maximum allowed concentrations from national ministries of health or environment should be adopted.</p> <p>Organic micro-pollutants should be absent.</p>	<p>a. Pb and pesticides at anomalous concentrations occurring along the Patagonian coast. Increasing background levels by a factor of 2 in most areas. Human impact already discernible.</p> <p>b. Pollutants reaching threshold values along many areas of the La Plata River Estuary. Heavy Metals in mg.kg⁻¹: Cr: 0.75-57, Pb: 0.7-141, Cd: 0.04-0.23, Cu: up to 109. Pesticides: 10-250 ng DDT/L. High concentration of trace metals present in biota in µg.kg⁻¹: Hg: 11-254, Pb: 34; Cd: 0.5-3.7. Also of hydrocarbons: 0.1-50 µg.kg⁻¹.</p> <p>c. High concentrations of certain trace metals in the water column well above background levels. Pb up to 20 µg l⁻¹; Cd up to 6.5 µg l⁻¹, phenol up to 30 µg l⁻¹, oil up to 30mg l⁻¹.</p> <p>d. Cd, Cu and Zn concentrations in bivalves are extremely high in Sepetiba Bay, more than 20 times the maximum allowed for human consumption.</p> <p>e. Present Hg concentrations reach about 2-5 times baseline levels in "hot spots" along the SE Brazilian coast.</p>	<p>a. 4-5</p> <p>b. 10</p> <p>c. 5</p> <p>d. 10</p> <p>e. 4</p>	<p>a. Gaiero <i>et al.</i> (2001); Gil <i>et al.</i> (1999); Harvey and Gil (1988); Amin <i>et al.</i> (1996)</p> <p>b. Moyano <i>et al.</i> (1992, 1993); AGOSBA-OSN-SIHN, (1994); Moyano (1991); CARU (1993); ECOPLATA (1999); Marcovecchio and Moreno (1992, 1993); Segneur <i>et al.</i> (1991); Lacerda <i>et al.</i> (1998); Seeliger <i>et al.</i> (1988)</p> <p>c. Niencheski and Baumgarten (1997)</p> <p>d. Barcellos and Lacerda (1994), Lacerda <i>et al.</i> (1993); Seeliger <i>et al.</i> (1988);</p> <p>e. Marins <i>et al.</i> (2001); Muller <i>et al.</i> (1999).</p>

Coastal Impact/ Issue	Local site/Region (contributing river basins)	Critical Threshold (for system functioning)	Distance to Critical Threshold (qualitative or quantitative)	Impact category	References/ Data source
Pollution cont.	f. Magdalena River delta-Lagoon complex g. Esmeraldas and Chone Rivers, Ecuador h. Acocagua and Loa Rivers		f. Cd, Cu and Zn concentrations in bivalves are extremely high in Cienaga Grande de Santa Marta, Colombia. g. Esmeraldas River shows high levels of Cu in waters (0.1-7.2 µg l ⁻¹) and some organic micro-pollutants: Heptachloro = 0.005 ppb and DDT = 0.017 ppb. Heavy metals (ppm) in sediments: Zn= 87.4, Cd=2.31, Cu=43.75. In organisms: Cu and Cd ingested in 250 g oysters and mussels reach 6.5 mg l ⁻¹ and 0.384 mg l ⁻¹ . h. High flushing to open ocean due to coastal upwelling results in large dilution and low pollutants concentrations.	f. 3 g. 7-8 h. 1	f. INVEMAR (1997, 2000) g. PMRC (1993b) h. Hajek <i>et al.</i> (1990); Espinoza <i>et al.</i> (1995); Universidad de Concepción (1999); Parra and Habit (1998)

Coastal impact/issue	Local site/region (contributing river basins)	Critical threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category	References/ data source
Biodiversity loss and/or decreasing biological productivity	a. Sepetiba Basin	Fishery stocks and biological productivity characterize threshold levels. In Sepetiba Bay, sustainable annual catches reach 2,000 t and 64,000 t at the Magdalena River mouth. High biodiversity typical of most coastal areas still under study.	a. Fisheries stocks in Sepetiba Bay decreased about 20% during the last decade. General decrease in some fisheries (e.g., sardine) and loss of habitats along the SE Brazilian coast.	a.7	a. Lacerda (1993); Biodiversity inventories of the REVIZEE Program of Brazil; Magro <i>et al.</i> (2000).
	b. Magdalena River	Increasing introduction of exotic species such as <i>Vibrio cholerae</i> , bivalves and other groups.	b. In the Magdalena River fisheries decrease reached 90% during the last two decades. Mangrove area losses. Coral reefs loss.	b.8	b. Botero (2001). Global Mangrove Database and Information System (GLOMIS) (HYPERLINK "http://www.gloemis.com").
	c. La Plata River Estuary		c. Various reports of loss of fisheries. Mortality of mammals and fish, quantitatively unknown.	c. 8	c. Graña and Pinciro (1997); Acuña <i>et al.</i> (1997); INAPE reports; INIDEP reports
	d. Patos Lagoon estuary		d. Changes in zooplankton community structure; anatomic anomalies. Overexploited <i>Netuma</i> spp. stocks. Decline of up to 90% in abundance of viviparous sharks (<i>Rhinobathus horkelii</i> ; <i>Galeorhinus galeus</i>).	d. 5	d. Montu and Gloeden, (1982); Haimovici <i>et al.</i> (1997)

Coastal impact/ issue	Local site/region (contributing river basins)	Critical threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category	References/ data source
Sedimentation	a. Iguape River, Sepetiba Bay and Guanabara Bay basin	Pre-urban sediment accumulation rates may be used as a good indicator of critical threshold. For example, it is about 30 mg m ⁻² yr ⁻¹ in Sepetiba Bay.	a. Threshold overtaken by 10 times in Sepetiba Bay. Present sedimentation rates are about 360 mg.m ⁻² .yr ⁻¹ . Similarly, sedimentation rates are over 30 times the critical threshold in Guanabara Bay. Suspended solids load of small rivers in the Rio de Janeiro metropolitan areas is >100 mg l ⁻¹ ; sedimentation rates of coastal lagoons is >0.1 cm yr ⁻¹ .	a. 6	a. Lacerda <i>et al.</i> (2001); Barcelos <i>et al.</i> (1999); Lacerda <i>et al.</i> (2001); Forte (1996); Knoppers <i>et al.</i> (1999)
	b. Rivers of the NE Brazil coast: Jaguaribe and Pacoti		b. Mangroves are being buried in sectors of the NE Brazil coast due to large intrusion of marine sands.	b. 7	b. Freire (1989); Maia (1992)
	c. Magdalena River and partial diversion of the river flow.		c. Channelization of the lower Magdalena River and partial diversion of the river flow. Observed coral reef mortality at El Rosario Island, Caribbean coast.	c. 10	c. Vernet (1985); Restrepo and Kjerfve (2000 a)
	d. Parana and Uruguay rivers: turbidity-saline front. Rio de la Plata		d. Present load at the la Plata River Estuary 79x10 ⁶ t yr ⁻¹ and 11x10 ⁶ t yr ⁻¹ in the zone of maximal sedimentation. Sedimentation affects navigation channels necessitating dredging.	d. 10	d. Lopez (1997)
	e. Patos Lagoon estuary		e. Natural sediment removal to coastal nearshore waters. Dredge material disposal in nearshore waters. Annual sediment removal of about 2,500,000 m ³ . Over 60 dredging sites between 1980-95; means per location in the estuary ranged from 1,200 to 1,800,000 m ³ .	e.5	e. SUPRG (1996); Calliari (1980)

Coastal impact/issue	Local site/region (contributing river basins)	Critical threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category	References/data source
Salinization	a. Magdalena River/Lagoon delta Santa Marta	a. Seawater salinity (30-38).	a. Mortality of mangroves due to salinization reaches 272 km ² over a 39-year period.	a. 6	a. Cordona and Botero (1998)
Nutrient depletion	a. Rivers of the Northern Brazilian coast b. Northern Patagonian rivers (Colorado, Negro and Neuquén)	a. Oligotrophic coastal area: Chl- <i>a</i> (0.05-0.5 mg.m ⁻³). b. Current total POC flux is about 4.1 x 10 ⁴ tyr ⁻¹ , total N is 1.1 x 10 ⁴ tyr ⁻¹ and total P of 2.0 x 10 ⁴ tyr ⁻¹ .	a. Not known b. Historical evolution of nutrient fluxes is unknown. However, there is evidence of nutrients being trapped in reservoirs.	a. 3 b. 5	a. Ekau and Knoppers (1999); Medeiros <i>et al.</i> (1999) b. Depetris <i>et al.</i> (1999); Gaiero <i>et al.</i> (2001)

2.5. Driver-pressures-state change relationships

The Caribbean and Pacific coasts of South America have geological similarities but are quite different from the Atlantic coast.

The variability of coastal drainage of South America must be taken into account during the development of **SAmBas**, in particular when selecting case study sites.

As a starting point for description of the regional DPSIR scenarios, a matrix of causes and effects (Table 2.5) was created to provide an overview of the major drivers affecting drainage basins of different sizes, the mechanisms whereby the resulting pressures affect the coast, the specific effects observed, and timing of these state changes.

Coastal state changes can be quite different on tectonically active coasts from those on passive coasts, Particularly in association with small basins. Therefore, a sub-category was introduced to address differences in coastal responses between active and passive margins.

Since impact on the coastal zone promoted by the different forcing functions along the water continuum may appear on different time scales, the temporal parameter to the decision-making process. Discrete effects, which occur nearly immediately after the pressure is established, and more progressive effects, which only manifest over a decade or an even larger time period, both have to be considered.

Larger basin rivers are the least affected by human pressure, as expected. However, diversion of waters for energy generation and/or irrigation purposes is becoming a major issue, and may be already affecting large rivers. Typical cases are the São Francisco River in NE Brazil and some Amazonian rivers. Medium-size river basins have been strongly affected by water diversion, damming and basin deforestation, and these rivers also suffer pollution problems due to agriculture, urban and industrial effluents. Tectonically passive coastal basins are more seriously affected by these changes. This class of rivers, due to their significance as water resources and apparently sensitive to human driver pressures, is a key issue within the **SAmBas** objectives. Finally, small basin rivers are mostly affected by eutrophication and pollution due to effluent discharge from urbanization and industrialization within their catchments and deforestation in their basins.

Another important aspect is the timing of the related changes in the coastal zone. With the exception of damming and diversion of waters, most environmental changes occurring in the coastal zone will be progressive, calling for medium to long-term monitoring programs to be established in order to fully understand those changes and eventually to propose alternatives options for management.

Table 2.5. DPSIR matrix characterizing major catchment based drivers/pressures and a qualitative ranking of related state changes impacting the coastal zone of South America versus catchment size class.

State change dimension: major; medium ; minor ; no impact; ? insufficient information; time scale: p = progressive ; d = discrete

Driver	Pressures	State change (qualitative index)				Impact on the coastal system	Time scale
		Large basins	Medium basins	Small basins: active coast	Small basins: passive coast		
Urbanization	Increase of nutrient- and metal- rich and BOD-rich waste effluents. Increasing sediment runoff. Increasing water extraction.	minor	medium	medium	major	<ul style="list-style-type: none"> Eutrophication Pollution (mostly heavy metals) Accelerated rates of biodiversity loss in the coastal region and adjacent continental platform 	d/p
Agriculture	Waste/nutrient (excess fertilizer), BOD effluent increase. Sediment load and water extraction increase. Poor agricultural practices results in poor soil conservation. Increasing pesticide input to the environment. Freshwater diversion, land fill and canalization.	?	medium	major	major	<ul style="list-style-type: none"> Eutrophication Pollution with heavy metals (e.g., Cu) and pesticides Sedimentation and loss of habitat and coastal biodiversity due to accelerating upland erosion rates Habitat loss, in particular of wetlands Shallow water infilling Salinization Algae blooms Decreasing light penetration for photosynthesis Increasing anoxia Introduction of exotic species 	p/d

Driver	Pressures	State change (qualitative index)				Impact on the coastal system	Time scale
		Large basins	Medium basins	Small basins: active coast	Small basins: passive coast		
Damming	Nutrient and sediment sequestration. Changing hydrological cycle. Decreasing runoff.	?	major	no impact	medium	<ul style="list-style-type: none"> Coastal erosion, but sedimentation with marine sands may occur Nutrient depletion Salinization Continuity of net. water flux Loss in amenity value Stratification of the water column 	d
Industries	Waste and heat effluent. Water extraction. Pollutant and BOD loads increase.	minor	major	minor	major	<ul style="list-style-type: none"> Pollution, heavy metals and organic micopollutants Increasing anoxia 	p
Deforestation	Sediment budget alteration. Increasing loads of suspended sediments to the coastal zone. Changes in soil quality, habitat loss and ecosystems alteration. Biodiversity loss.	minor	major	major	major	<ul style="list-style-type: none"> Sedimentation. Mangroves and coral reefs siltation Loss of biodiversity Impacts on artisanal fisheries. Catastrophic slope erosion 	P
Navigation	Waste effluent. Dredging. Increasing demand for coastal engineering works (e.g. jetties and channels. Riverbed diversion.	medium	major	no impact	no impact	<ul style="list-style-type: none"> Pollution Sedimentation 	p
Aquaculture	Increase of nutrient-rich and DBO-rich waste effluents. Deforestation. Water extraction.	no impact	minor	major	major	<ul style="list-style-type: none"> Eutrophication Erosion, when mangroves are affected Introduction of exotic species Wetland losses 	p

2.6 Assessment of land-based drivers

Assessment of land-based drivers and their related coastal impacts considered different scales (catchment, sub-regional and full regional) and ranked according to a relative category (Table 2.6). The ranking takes into consideration the present dimensions of the impacts and their probable evolution under future scenarios constructed on existing data and statistics. This evaluation is incomplete, since only seven countries contributed (Argentina, Brazil, Chile, Colombia, Ecuador, Uruguay and Venezuela), although these countries together cover nearly 75% of South America and harbor about 80% of its population. Generally in South America, water resource issues are most important followed by a series of sediment-related issues and finally aspects of water quality.

2.6.1 Catchment scale

Table 2.6 shows the ranked importance of impacts on coastal areas by basin activities and their trend expectations at a catchment scale.

Some issues were agreed to be of only minor importance, with scenarios of decreasing or stabilizing pressure on the coastal zone. For example, a coastal fishery may be affected by harvesting of species with part of their life cycle occurring upriver. This has only been reported for the Magdalena River, Colombia, and since it involves a limited number of generalist species, its importance in the future will most probably remain the same. Similarly, catchment-based tourism causes little impact on the coastal zone and tends to increase its self-regulation due to better public environmental awareness.

On the other hand, navigation, which is presently restricted to a few large rivers, shows a reported trend of accelerated increase in the next years, as corroborated by the many navigation projects presently under evaluation in many countries. This is the case for the Orinoco, which otherwise can be considered as being in a relatively unimpacted condition. Other issues (e.g., damming of rivers, diversion of discharges, irrigation, agriculture and deforestation of watersheds) are widespread and serious throughout the sub-continent, and their impact on the coastal zone is already significant and will tend to increase in the near future, due to increasing demands for fresh water and hydroelectric power to meet a growing economic scenario. Typological up-scaling using indices for the expected trends would prove valuable for the identification of future “hot spots”.

Another class of drivers including urbanization and industrialisation, which have an important effect on the coastal zone due to increasing nutrient and contaminant discharges, will probably decrease significantly in the near future. This is mainly due to improved enforcement of control regulations and decreasing demographic pressure within many catchments. Apparently this is only true for the more distant river catchment zones and not for the “classical” coastlines themselves, where pressure may still increase. The modelling efforts will need to attribute observed coastal state changes in biogeochemical cycling to these spatially contradictory pressure developments in the catchment. This mixture of varying point and diffuse source influences can be dealt with by using the SARCS/WOTRO/LOICZ model, which employs sectoral residual production of materials such as C, N and P to derive the economically-driven share of ambient concentrations and enable the allocation of socio-economic figures (McManus *et al.* 2001 and in prep).

Table 2.6. The link between coastal issues/impacts and land based drivers in the Atlantic Zones of South America – Overview and qualitative ranking on local or catchment scale: Category: 1 = low; 10 = high

Coastal impact/ issues	Drivers	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ data sources
		River	Category		
Eutrophication	Agriculture	a. Negro and Chubut Rivers, Patagonia	a. 3	↑↑	a. Depetris <i>et al.</i> (in prep.); Gaiero <i>et al.</i> (2001)
		b. Jaguaribe River, NE Brazil	b. 3	↑	b. Maia (1992)
		c. Magdalena River, Colombia	c. 8	↑	c. COLCIENCIAS-FEN (1989)
		d. Patos Lagoon estuary, Brazil	d. 7	↑	d. Baish (1997); Baumgarten <i>et al.</i> (1995)
		e. Aconcagua River, Chile	e. 4	↑	e. Daneri <i>pers. comm.</i>
		f. Maipo River, Chile	f. 4	↑	f. Daneri <i>pers. Comm.</i>
		g. Rio de La Plata, Uruguay	g. 9	↑	g. Kurucz <i>et al.</i> (1997)
	Urbanisation	a. Chubut River, Patagonia	a. 7	↑	a. Gaiero <i>et al.</i> (2001)
		b. Rivers of the SE coast of Brazil	b. 10	↑	b. Bidone <i>et al.</i> (1999); Bidone (2000)
		c. Rivers of the Buenos Aires coast	c. 8	=	c. ECOPLATA (1999)
		d. Magdalena River, Colombia	d. 10	↑	d. HIMAT-INGEOMINAS (1991); Cardona and Botero (1998)
		e. Ceará and Cocó rivers, NE Brazil	e. 6	↑	e. Mavignier (1992); Almeida <i>et al.</i> (2001)
		f. La Plata River, Uruguay	f. 10	↑	f. ECOPLATA (1999)
		g. Patos Lagoon estuary	g. 3	↑	g. Baish (1997); Baumgarten <i>et al.</i> (1995); Almeida <i>et al.</i> (1993)
		h. Esmeraldas and Chone rivers, Ecuador	h. 9	↑	h. PMRC (1993a,b)
		i. Guayas River/Guayaquil Gulf, Ecuador	i. 8	↑	i. INOCAR (1998a,b)
		j. Maipo River, Chile	j. 7	↑	j. Daneri <i>pers. comm.</i>
		k. Bio Bio River, Chile	k. 7	↑	k. Daneri <i>pers. comm.</i>
	Industrialisation	a. Rivers of the SE coast of Brazil	a. 5	↑	a. Bidone <i>et al.</i> (1999); Lacerda <i>et al.</i> (2001)
		b. Rivers of the Buenos Aires coast	b. 2	↑	b. ECOPLATA (1999)
		c. Patos Lagoon estuary	c. 3	↑	c. Baish (1997); Baumgarten <i>et al.</i> (1995); Almeida <i>et al.</i> (1993)
		d. Chubut River, Patagonia	d. 2	↑	d. Depetris <i>et al.</i> (in prep.); Gaiero <i>et al.</i> (2001)
	Aquaculture	a. Esmeraldas and Chone rivers, Ecuador	a. 7-10		a. PMRC (1993a,b)
		b. Guayaquil Gulf, Ecuador	b. 8		b. INOCAR (1998a,b)

Coastal impact/ issues	Drivers	(allowing within and between catchment comparison)	Trend expectations	References/ Data sources
Local catchment RIVER		CATEGORY		
Erosion	Damming	a. Negro, Colorado and Chubut rivers, Patagonia, southern Argentina	=	a. Isla and Bujalevsky (1995); Pasquini <i>et al.</i> (1997)
		b. Jaguaribe River, NE Brazil	↑	b. Cavalcante (2000)
		c. Paraíba do Sul River, SE Brazil	↑	c. Dias and Silva (1984); Salomão (2001)
		d. Guayaquil Gulf, Ecuador	↑	d. CAAM (1996)
		e. La Plata River estuary, Uruguay	=	e. ECOPLATA (1999)
		f. Patia River, Colombia	=	f. Restrepo and Kjerfve (2000b)
		g. Buenos Aires Province rivers	↑	g. Gionchi <i>et al.</i> (1993); Isla (1997); Lopez and Marcomini (1998); Violante <i>et al.</i> (2001)
	Deforestation	a. Patagonia Rivers	↑	a. Passovani <i>et al.</i> (1992)
		b. Rivers of the SE coast of Brazil	=	b. Lacerda <i>et al.</i> (2001)
		c. Magdalena River, Colombia	↑	c. COLCIENCIAS-FEN (1989)
		d. La Plata River Estuary, Uruguay	↑	d. ECOPLATA (1999)
		e. Esmeralds and Chone rivers, Ecuador	↑	e. PMRC (1993a,b)
		f. Guayas River/Guayaquil Gulf, Ecuador	↑	f. INOCAR (1998a,b)
	Navigation	a. Magdalena River, Colombia	↑	a. Correa (1991); Martínez (1993)
		b. Guayaquil Gulf, Ecuador	↑	b. CAAM (1996)

Coastal impact/ issues	Drivers	Local catchment (allowing within and between catchment comparison)	Trend expectations	References/ Data sources
Pollution	Industrialisation	a. Rivers of the SE coast of Brazil	↑	a. Esteves and Lacerda (2000); Bidone <i>et al.</i> (1999); Barcellos and Lacerda (1994)
		b. Rivers of the Buenos Aires coast	↑	b. Seeliger <i>et al.</i> (1988); Moyano (1991)
		c. Patos Lagoon Estuary	=	c. Niencheski and Baumgarten (1997)
		d. Esmeraldas and Chone rivers, Ecuador	↑	d. PMRC (1993a)
		e. Guayaquil Gulf, Ecuador	↑	e. PMRC (1993a)
		f. Tumbes and Chira rivers, Peru	?	f. Daneri <i>pers. comm.</i>
		g. Loa and Bio Bio rivers, Chile	?	g. Daneri <i>pers. comm.</i>
		h. Aconcagua and Maipo rivers, Chile		h. Daneri <i>pers. comm.</i>
	Navigation	a. Rivers of SE Brazil	↑	a. Barcellos and Lacerda (1994)
		b. Rivers of the Buenos Aires coast	↑	b. Wells and Daborn (1997); ECOPLATA (1999)
		c. Patos Lagoon estuary, Brazil	=	c. SUPRG (1996)
	Agriculture	a. Patagonia rivers	↑	a. Gaiero <i>et al.</i> (2001)
		b. Rivers of the Buenos Aires coast	↑	b. ECOPLATA (1999)
		c. Jaguaribe River, NE Brazil	↑	c. Bezerra (1996)
		d. Patos Lagoon estuary, Brazil	↑	d. Niencheski and Baumgarten (1997)
		e. Guayaquil Gulf, Ecuador	↑	e. CAAM (1996)
		f. Aconcagua River, Chile	↑	f. Hajek <i>et al.</i> (1990)
		g. Maipo River, Chile	↑	g. Parra and Habit (1998)
	Urbanization	a. Patagonia rivers	↑	a. Gaiero <i>et al.</i> (2001)
		b. Rivers of the SE coast of Brazil	↑	b. Bidone <i>et al.</i> (1999); Knoppers <i>et al.</i> (1999), Esteves and Lacerda (2000)
		c. Cocó and Ceará rivers, Fortaleza metropolitan area, NE Brazil	↑	c. Martins <i>et al.</i> (2001)
		d. Patos Lagoon estuary	=	d. Almeida <i>et al.</i> (1993); Baisch (1997)
		e. Maipo River, Chile	↑	e. Hajek <i>et al.</i> (1990)
		f. Biobio River, Chile	↑	f. Parra and Habit (1998)

Coastal IMPACT/ ISSUES	DRIVERS	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ Data sources
Sedimentation	Agriculture	a. Patagonia rivers, Argentina	a. 6	↑	a. Gaiero <i>et al.</i> (2001)
		b. Jaguaribe and Pacoti rivers, NE Brazil	b. 3	=	b. Freire (1989); Bezerra (1996), Maia (1992)
		c. Rivers of SE Brazil	c. 3	↑	c. Salomão <i>et al.</i> (2001), Knoppers <i>et al.</i> (1999)
		d. Patos Lagoon estuary	d. 3	↑	d. Caliani (1980)
		e. Esmeraldas and Chone rivers, Ecuador	e. 7-10	↑	e. PMRC (1993a,b)
		f. Guayaquil Gulf, Ecuador	f. 8	↑	f. INOCAR (1998a,b)
	Navigation	a. Rivers of the SE coast of Brazil	a. 6	↑	a. MMA (1996)
		b. Rivers of the Buenos Aires Coast	b. 6	↑	b. ECOPLATA (1999)
		c. Magdalena River delta, Colombia	c. 8	↑	c. Correa (1991); Martinez (1993)
		d. Patos Lagoon estuary, Brazil	d. 5	=	d. SUPRG (1996)
		e. Patia River, Colombia	e. 9	=	e. Daneri <i>pers. comm.</i>
	Damming/ Diversion	a. Jaguaribe River, NE Brazil	a. 8	↑	a. Bezerra (1996); ANEEL (1999)
		b. Magdalena River, Colombia	b. 10	=	b. Vernet (1985); Restrepo and Kjerfve (2000)
		c. Sepetiba Bay, SE Brazil	c. 10	↑	c. Lacerda <i>et al.</i> (2001)
	Deforestation	a. Patagonia Rivers, Argentina	a. 8	↑	a. Gaiero <i>et al.</i> (2001)
		b. Rivers of SE Brazil	b. 10	↑	b. Salomão <i>et al.</i> (2001); Knoppers <i>et al.</i> (1999)
		c. Jaguaribe River, NE Brazil	c. 4	↑	c. Freire (1989); Bezerra (1996), Maia (1992)
		d. Esmeraldas and Chone rivers, Ecuador	d. 9	↑	d. PMRC (1993a,b)
		e. Guayas River/Guayaquil Gulf, Ecuador	e. 8	↑	e. INOCAR (1998a,b)
		f. Patia River, Colombia	f. 8	=	f. Daneri <i>pers. comm.</i>
		g. Itata and Bio Bio rivers, Chile	g. 8	=	g. Daneri <i>pers. comm.</i>
	Urbanization	a. Maipo River, Chile	a. 3	↑	h. Daneri <i>pers. comm.</i>
	Sand Mining	a. Negro River, Patagonia	a. 4	=	a. Cionchi <i>et al.</i> (1993); Pasquini <i>et al.</i> (1997)

Coastal impact/ issues	Drivers	Local catchment (allowing within and between catchment comparison)	Trend expectations	References/ data sources
		River catchment	Category	
Nutrient depletion	Damming	a. Chubut, Colorado and Negro rivers, Patagonia, Argentina	a. 8	a. Gaiero <i>et al.</i> (2001); Depetris <i>et al.</i> (in prep.)
		b. Rivers of SE Brazil	b. 6	b. Salomão <i>et al.</i> (2001); Knoppers <i>et al.</i> (1999)
		c. Jaguaribe River, NE Brazil	c. 9	c. Freire (1989); Bezerra (1996); Maia (1992)
Salinization	Damming/ Diversion	a. Jaguaribe River, NE Brazil	a. 4	a. Freire (1989)
		b. Magdalena River lagoon-delta complex, Colombia	b. 9	b. Cardona and Botero (1998)
		c. Patos Lagoon estuary	c. 3	c. Costa <i>et al.</i> (1988); Fernandes and Niencheski (1998)
Loss of biodiversity	Fisheries	a. Patagonia rivers, Argentina	a. ?	a. Gaiero <i>et al.</i> (2001)
		b. Rivers of SE Brazil	b. 6	b. MMA (1996); Knoppers <i>et al.</i> (1999)
		c. Cocó and Ceará rivers, Fortaleza metropolitan area, NE Brazil	c. 4	c. Marins <i>et al.</i> (2001)
		d. Rivers of the Buenos Aires coast	d. ?	d. ECOPLATA (1999)
		e. Patos Lagoon estuary	e. 5	e. Montu and Gloeden (1982); Haimovici <i>et al.</i> (1997)
		f. Guayaquil Gulf, Ecuador	f. 7	f. PMRC (1993a)

2.6.2. Sub-regional and regional (sub-continental) scales

Table 2.7 shows the ranked importance of impacts on coastal areas by catchment activities and their trend expectations at sub-continental scale. The Atlantic coast of South America seems more sensitive to impacts from river 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 results in longer residence times of sediments, water, and natural and anthropogenic substances from continental land sources whereas along the Pacific coast, strong peak flushing result 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 urbanization, 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. Trend expectation are of increasing impact, since the impacts are linked to the improving economy of the countries involved. It is important to note however, that the local specific site situation may differ from this longer scale integration when looked at in isolation. Therefore, reference should be made to the catchment tables in Chapter 8 (Volume 2) to gain a view of the relative importance of the impact/issue and associated driver at that local scale.

Table 2.7. The link between coastal issues/impacts and land-based drivers in South American coastal zones – Overview and qualitative ranking on full regional/sub-continental scale.

Category: 1 = low; 10 = high; trend: \Rightarrow = stable; \Uparrow = increasing; n.o. = not observed

Coastal impact/ issues	Driver	Full regional		Trend- expectation	Reference/ data source
		Coast	Category		
Erosion	Damming	Atlantic coast	6-7	\Rightarrow/\Uparrow	Annex tables 1, 2, 3, 4 and 5
		Pacific coast	1	\Rightarrow	Annex table 6
	Deforestation	Atlantic coast	7	\Rightarrow/\Uparrow	Annex tables 1, 2 and 3
		Pacific coast	6	\Rightarrow	Annex table 6
	Navigation	Atlantic coast	1	\Rightarrow	Annex table 4
		Pacific coast	7	\Uparrow	Annex table 6
	Agriculture	Atlantic coast	4-5	\Uparrow	Annex tables 3, 4 and 5
		Pacific coast	2	\Uparrow	Annex table 6
Eutrophication	Urbanisation	Atlantic coast	8	\Uparrow	Annex tables 1, 2, 4 and 5
		Pacific coast	5	\Uparrow	Annex tables 6
	Industrialisation	Atlantic coast	3	\Uparrow	Annex tables 2, 4 and 5
		Pacific coast	2	\Uparrow	Annex tables 6
Pollution	Industrialisation	Atlantic coast	9	\Uparrow	Annex tables 1, 2 and 5
		Pacific coast	2	\Uparrow	Annex tables 6
	Navigation	Atlantic coast	7	\Uparrow	Annex tables 1, 2 and 5
		Pacific coast	5	\Uparrow	
	Agriculture	Atlantic coast	5-6	\Uparrow	Annex tables 1, 4 and 5
		Pacific coast		\Uparrow	Annex tables 6
	Urbanization	Atlantic coast	6	\Uparrow	Annex tables 2, 4 and 5
		Pacific coast	5	\Uparrow	Annex tables 6
Sedimentation	Agriculture	Atlantic coast	4	\Rightarrow/\Uparrow	Annex tables 2, 4 and 5
		Pacific coast	2	\Rightarrow	Annex tables 6
	Navigation	Atlantic coast	6	\Uparrow	Annex tables 2, 3 and 4
		Pacific coast	n.o.	n.o.	n.o.
	Damming	Atlantic coast	8	\Uparrow	Annex tables 3 and 5
		Pacific coast	n.o.	n.o.	n.o.
	Deforestation	Atlantic coast	7-8	\Uparrow	Annex tables 2 and 5
		Pacific coast	6-7	\Rightarrow	Annex tables 6
Nutrient depletion	Damming	Atlantic coast	8	\Uparrow	Annex tables 2 and 5
		Pacific coast	n.o.	n.o.	n.o.
Salinization	Damming	Atlantic coast	4	\Uparrow	Annex tables 3, 4 and 5
		Pacific coast	n.o.	n.o.	n.o.
Loss of biodiversity	Fisheries	Atlantic coast	4-6	?-6	Annex tables 1, 2, 4 and 5
		Pacific coast	2	\Uparrow	Annex tables 6

2.7. Policy and management response

A general summary of the scientific and management responses to coastal issues in South America is presented in Table 2.8.

Monitoring and research efforts differ in nature and intensity according to country. There is a general absence of long-term data and inter-regional comparisons. Determining changes in loads and derivation of the “critical loads” to the coastal zone is thus not a trivial effort, and evaluation will be based on very limited information. Most monitoring programs began in the 1980’s and have at best been going for 20 years (e.g., in Argentina and Brazil). From the LOICZ workshop on estuarine systems of the South American Region (Smith *et al.* 2000), fluxes of carbon, nitrogen and phosphorus estimated for a variety of rivers in Brazil, Uruguay, Argentina, Ecuador and Chile can be compared. Although very restricted geographically, this exercise may be a key step in developing a typology of the South American coasts. An overview of the national efforts is presented below.

Colombia

The main rivers in Colombia flowing into the Caribbean are the Magdalena, Atrato and Sinú. Most monitoring and research efforts have been carried out in the Magdalena River and its deltaic estuarine-lagoon complex (Ciénaga Grande de Santa Marta-CGSM), as well as in the deltaic-estuarine areas of the Sinú and Atrato rivers. In the Magdalena River, water discharge, sediment load, nutrient and heavy metals concentrations have been monitored at downstream stations. However, for nutrients, contaminants and pathogenic bacteria, data coverage is neither continuous nor systematic but has been gathered through specific studies or during limited time periods by institutions such as INGEOMINAS (Instituto Nacional de Geología y Minería) of the Ministry of the Environment: Quality (HIMAT-INGEOMINAS 1999), INVEMAR (Instituto de Investigaciones Marinas), IDEAM (Instituto de Hidrología, Meteorología y Estudios Ambientales) and Laboratorio Las Flores. Management response criteria for the Magdalena catchment are from the Ministry of the Environment.

Water discharge and sediment loads in the Magdalena, Atrato and Sinú rivers have been monitored continuously since 1972 [Magdalena River Water discharge data 1940-2000; sediment load data 1972-2000; HIMAT-INGEOMIN (1999); and heavy metals levels from 1980 to 1990 (Bustus 1999)]. Scientific analyses have recently been published on the water and sediment loads of the rivers in Colombia (Restrepo and Kjerfve 2000a, 2000b), and university and research institutions continue to develop nutrient budgets, especially for the Magdalena River and its deltaic area. Training and the use of LOICZ tools and models would assist the synthesis of monitoring information.

The Magdalena River is among of the 20 major rivers in the world in terms of sediments loads to the ocean relative to water discharge, and can be considered as the river catchment in Colombia with greatest impact on the coastal zone. It drains most of the urban, industrial and agricultural land of the country and most rivers from the Colombian Andes region flow into the Magdalena River. This leads to an important pollution issue. Deforestation is an important driver within the Magdalena River basin, resulting in areas of erosion as well as increased sediment load and siltation, which often causes interruption of water flow to deltaic lagoons and mangrove swamps. Deforestation results mainly from agricultural development, livestock and timber production. The Canal del Dique, an artificial arm of the Magdalena River, discharges freshwater and sediments to a coastal area with extensive coral reefs which are now heavily degraded.

Extensive ecological research has been carried out in the Ciénaga Grande de Santa Marta since 1978 and information on physical, chemical and biological variables of water bodies and mangrove sediments is available in databases, technical reports and publications prepared mainly by INVEMAR. For Ciénaga de la Virgen, a coastal lagoon located close to the city of Cartagena, information on physical, chemical and biological variables is available in several universities and government institutions. This lagoon receives a high sewage and industrial load from the city and is also the recipient of large amounts of solid waste. An artificial inlet connecting this lagoon to the Caribbean Sea will soon be opened. While this may assist the state of the lagoon, there are concerns about the potential impacts on the adjacent coastal zone, where tourism is a very important economic activity.

Venezuela

A large amount of data exists for the Lake Maracaibo basin on the north-western Caribbean coast, where tremendous amounts of industrial and sewage wastewater, as well as sediments, are discharged into the lake. Dredging of a canal has allowed better freshwater exchange with the Caribbean Sea year-round and enables adequate oxygenation of the lake. The risk of impacts on the coastal sea such as oxygen depletion, however, is not yet fully resolved and there is evidence elsewhere of low oxygen levels in coastal waters due to increasing BOD from riverine inputs, e.g., in the Mississippi delta (Rabalais, this report). Rapid sedimentation is already occurring in some estuaries and in Lake Maracaibo.

Along the northern coast, draining to the Caribbean, several small creeks have a great impact due to their loads of animal waste products (hogs), agricultural activities in the mountains and especially municipal sewage. Caracas city effluents are diverted to the Guaire River and the Tuy River system, which finally collects most of the sewage of the larger cities. It is discharged east of Caracas and the inshore east-west current brings the contaminants and nutrients back to the littoral area of Caracas. Most of the beaches are closed to recreational use. Less information exists for central coastal areas including the Guaire-Tuy and Neveri rivers.

Most of the Venezuelan population (65%-70%) inhabits the western and northern mountainous range, resulting in a large impact on this part of the country, while leaving the huge Orinoco River basin and coast relatively untouched. As shown in Table 2.2, large amounts of sediments (and probably of nutrients) are brought to the coast by small rivers with very high yields. Future development plans for the Orinoco River basin include oil exploration in the delta and a navigation waterway through the main river and the Apure River, the largest of the Orinoco tributaries in Venezuela. Recent research in the Orinoco River basin has resulted in a comprehensive database dating back 80 years (Weibezahn *et al.* 1990, Lopez *et al.* 1998).

Brazil

Water discharges have been monitored for many Brazilian rivers from the early 1900's. The National Electricity Agency (ANEEL) is responsible for discharge and water quality measurements. In the Jaguaribe River in NE Brazil, for example, there are 11 pluviometric stations with 80 years of monitoring plus 13 river discharge monitoring stations with 25 years of data (ANEEL 2000). Although the historical monitoring of fluxes dates back to the 1950's, data on sediment and nutrient loads are scarce or very recent. Monitoring of sediment flux, nutrients and marine-borne sediments (Marins *et al.* 2001) has recently started with the support of the National Research Council (CNPq). Water balance models have been applied to this basin but need testing for robustness (SRH 1998). Surveys of soil, geology and groundwater resources (CPRM 1996) also exist at a regional level. Efforts to collect such data are underway through the LOICZ regional program on nutrient fluxes (Smith *et al.* 2000). A whole-country coastal management program developed during the past 20 years by the Ministry of the Environment has provided extensive information on the driving forces and major aspects of the environment in the coastal zone of the country (MMA 1996). Local catchment management plans associated with dam development, water diversion and agriculture are carried out under PRODETUR-CE (Tourism Development Program) and PROURB-CE (Urban Development Plan). The National Environmental Council (CONAMA) establishes baseline and maximum concentrations for pollutants. The quality of biological resources for human consumption are permanently monitored and should meet the CONAMA Guidelines. The National Forest Code controls mangrove conservation and regulates aquaculture activities.

The 32-year program Marine Geology and Geophysics Program (PGGM) of the Brazilian-German Joint Oceanographic Cruises started in 1990 is assessing coastal productivity, trophic status, fisheries and sedimentology. The recently initiated REVIZEE Program (Living Resources from the Economic Exclusive Zone) has addressed many issues regarding coastal impacts derived from basin activities, in particular coastal erosion and living and non-living resources contamination (Ekau and Knoppers 1999a,b; Freire and Hazin 2000; MMA 1996a). The establishment of nine sites under the Brazilian Long Term Ecological Studies (PELD), including at least two sites of significance to **SAmBas**, Patos Lagoon estuary and the SE Brazil coast, will provide historical data sets and long-term monitoring of coastal issues and impacts.

Major drivers affecting the coastal zone include river damming and industrial effluent releases. River damming is particularly important along the north-eastern and south-eastern coasts of Brazil. Intensive erosion of the coastline is presently occurring at the São Francisco River estuary, in Todos os Santos Bay, in the Paraíba do Sul River estuary and along the coast of Ceará State, NE Brazil. Although monitoring is in place, no steps to minimize impacts have been taken. Inventories of nutrients, carbon and trace metals are available for most of the south-eastern and southern coasts, but little for the north-eastern and northern coasts. Budgets of carbon, nitrogen and phosphorus for some small-catchment river systems in Brazil have been recently published (Smith *et al.* 2000).

At catchment scale, local policies are also in effect. In the Patos Lagoon estuary, the Rio Grande Harbor Authority monitors dredging and dumping of navigation wastes. Monitoring of physico-chemical parameters, regulation of estuarine fisheries and regulation of water use in the estuary are also locally managed. Over 500 scientific papers published on structural/functional aspects of the Patos Lagoon estuary and adjacent coast have been recently reviewed (Seeliger and Kjerfve 2001).

In the Paraíba do Sul-Sepetiba Bay basin, permanent monitoring of water quality by local environmental authorities (FEEMA and CETESB) takes place. Emission inventories and permanent monitoring of water, sediments and biota for pollutants are also carried out at the local level. An Interstate Committee on Water Uses and Basin Management of the Paraíba do Sul watershed controls industrial and urban expansion. More than 800 scientific papers on eutrophication, heavy metal pollution and oil pollution for the area have been recently reviewed (Knoppers *et al.* 1999; Bidone 2000).

Uruguay

The Río de la Plata estuary is the mouth of the second largest fluvial basin system in South America, covering an area of 3.1×10^6 km². The three major rivers that flow into the Río de la Plata are the Paraná, the Uruguay and the Santa Lucia rivers. The Río de la Plata estuary covers 35,500 km² and its mouth at the Atlantic Ocean is 230 km wide. The Paraná and Uruguay rivers, which drain two separate basins, supply more than 97% of the water input.

The Uruguay River has a catchment area of 244,000 km² and is 1,780 km long, draining portions of Argentina, Brazil and Uruguay. Its geology is complex, a mix of volcanic (basaltic overflows) sedimentary rocks and alluvial sediments. It is managed bilaterally by an Uruguay/Argentinean Commission, the Administrative Commission of the Uruguay River (CARU), from the Uruguayan border to its mouth. Since 1989, CARU has coordinated an annual survey with Uruguayan and Argentinean researchers, looking at nutrient loads, sediments and water pollution (CARU 1997, 1998). The mean discharge at El Hervidero (1916-1975) is $4,700 \text{ m}^3 \text{ s}^{-1}$, with a range from 800 to $14,300 \text{ m}^3 \text{ s}^{-1}$. The river floods in winter, with a secondary maximum in October and minimum flow from summer to autumn (November-May). Its seasonal variability is always greater than 11%, with a mean of 17%. The carbon, nitrogen and phosphorus fluxes for the frontal zone of the Río de la Plata were recently budgeted (Nagy 2000).

Since 1953, the Uruguay River discharge has increased: from $5,200 \text{ m}^3 \text{ s}^{-1}$ for a 30-year running mean, $5,450 \text{ m}^3 \text{ s}^{-1}$ for a 20-year running mean, and up to $6,000 \text{ m}^3 \text{ s}^{-1}$ for a 10-year mean (Monestier and Miguez 1993). The increment has been very sharp since 1971. Since 1979, the Salto Grande dam has also modified the Uruguay River flow.

El Niño events are sometimes well correlated with the Uruguay River floods while La Niña events are slightly associated with its droughts (Mechoso and Pérez Iribarren 1992). Weak negative signals between November 1993 and February 1994 may be correlated with the relatively small river flow (for most recent short-time mean) during the first half of 1994. Recent wet months seem to be correlated with very strong SIO signals (1992, summer and spring of 1993, February-May of 1995). The percentage of the suspended matter load of the Uruguay River transferred to the Río de la Plata is 25%, totalling 52 mg l^{-1} (Nagy 1989).

The Santa Lucía River flow is comparatively negligible with respect to the whole system, but is important locally on the Uruguayan coast. Its mean depth is 10 m and its average flow to the Atlantic Ocean is $22,000 \text{ m}^3$. It has high concentrations of suspended sediments that range between 50 to 300 mg l^{-1} . The basin of the Santa Lucia River, in the south-central zone of Uruguay, encompasses an area of 13,681 km²

(55°00' W to 57°10' W; 33°40' S to 34°50' S). Most of the basin is urbanized and provides considerable resources for the Uruguayan economy. It supplies drinking water for 60% of the total population of the country and constitutes one of the principal agricultural production areas with associated agricultural industries. The natural hydrological cycle is significantly altered by a number of dams (e.g., Aguas Corrientes, Canelón Grande, Paso Severino). These dams and the high population pressure on the catchment basin have a significant impact on the environmental quality of the Río de la Plata.

The estuarine zone of the Santa Lucía River was an important fishing region for a number of riverine and marine species. The health of the river basin and the river mouth have changed greatly in the last century. Human and industrial impacts have degraded the natural environment; however, quantitative data records of changes and impacts are not available, limiting the possibility for detailed comparisons. Presently, the region is monitored by the Water Quality Program (SOHMA/DINAMA).

The Río de la Plata is of great social and economic importance for the whole region, including its Maritime Front (subjected to special technical commission of the Maritime Front 2000-2004 for its management), since it is a part of the main world shipping routes. International sea-cargo passing through this area was 47.2x10⁶ tons in 1996 (this figure sums overseas transport data from Argentinean and Uruguayan river ports). To this figure should be added national and regional shipping movements. The system is a major access route to the MERCOSUR, an emerging common market covering more than 13x10⁶ km² and with a population of about 200 million inhabitants in the four member countries: Argentina, Brazil, Paraguay and Uruguay. The integration of the Río de la Plata basin and the MERCOSUR is expected to promote regional economic development and lead to increased river and maritime shipping in the area.

Argentina

Organic loading and nutrient input from untreated sewage effluents originating in urban areas appears as the priority pressure in Argentina, in particular in the Paraná River drainage basin. Point-source pollution of industrial origin is of moderate importance, particularly in Buenos Aires Province, where the Buenos Aires metropolitan area (more than 12 million inhabitants) directly affects the Río de la Plata. Small polluted streams such as the Riachuelo and the Reconquista rivers are extreme examples.

Monitoring continues along the Buenos Aires Province coast, to assess the inputs of nutrients and heavy metals, in particular by specific multidisciplinary programs such as the Environmental Monitoring of Sanborobon Bay and the Environmental Management of Matanza and Riachuelo Basins. It is mostly carried out by IADO (Instituto Argentino de Oceanografía), INIDEP (Instituto Nacional de Investigaciones y Desarrollo Pesquero) and other governmental and academic institutions. No significant long-term changes in nutrient flux states have been identified, but some short-term localized changes are obvious. Most of the transfer takes place as a diffuse input, since Buenos Aires Province is drained by small streams and rivers. Further coastal environmental problems may arise from more distant and thus transboundary human-induced actions along the Paraná River due to deforestation and planned dredging of the Brazilian portion of the basin for navigation purposes.

By comparison, the Patagonian coastline is not heavily affected by industries, although specific activities such as oil production and coal mining may be of significance in specific areas (e.g., oil drilling in the Colorado River drainage basin, coal extraction in the Gallegos River headwaters). Research projects such as PARAT, carried out over the last four years with support from the European Commission, have been significant in gathering relevant information concerning the contribution of Patagonian rivers to the coastal zone. Gil and Esteves (2000) developed a budget of carbon, nitrogen and phosphorus fluxes for Bahía Nueva, Golfo Nuevo, under the program "Patagonian Coastal Zone Management Plan", supported by GEF/UNEP and the national CONICET. Monitoring of nutrients and heavy metal fluvial fluxes to the ocean have started (Gaiero *et al.* 2001; in press) and some preliminary results were published under LOICZ initiative (Pasquini *et al.* 1997).

These recent achievements need to be evaluated and trend analysis performed to establish baseline conditions. Biological resources along the Patagonian coastline are still abundant and significant, not only as a source of fisheries but also as a tourist attraction. It is expected that typologically the Patagonian catchments may finally form one cluster of relatively comparable systems.

Chile

Surveys of environmental status of river catchments for the Loa, Aconcagua, Maipo, Itata, Bio Bio and Calle rivers are in progress. Some preliminary flux estimates are available for the south coast fjord region of Chile (Silva *et al.* 2000). Monitoring and discrete studies are being carried on in northern coastal catchments by the Universidad de Concepción and EULA Center. Environmental guidelines are promulgated under the National Environmental Policy.

Ecuador

Ecuador has responded to the land based environmental pressures through various programs: In the Gulf of Guayaquil, the Water Quality Monitoring run by INOCAR, the Navy Institute of Oceanography, has been set up as a scientific response. In parallel the Marine coastal Environmental Education and Management of Coastal Resources Program, PMRC and the Marine Coastal Environmental Education Program are active, covering areas such as the Esmeraldas and Chone rivers. The gulf and rivers have also been declared a "Priority region for the application of the National Policy on Biodiversity of Ecuador". The "Strategic regional program for the protection of the coastal-marine and freshwater associated with activities developed inland-CPPS" is a broader scale national protection initiative dealing with issues of the integrated management of the coastal area of the southeast Pacific. Ecuador also participated in the recent LOICZ biogeochemical flux assessment experiment; thus nutrient budgets and a typological analysis of some of its coastal regions have recently published, in particular for the Gulf of Guayaquil (Tutivén 2000).

Regional

On an international South American scale, specific research projects and management programs have studied some of the larger rivers of South America over the past 20 years, in particular the Amazon (CAMREX and AMASEDS, Lacerda and Howarth 1991) and São Francisco (Paredes *et al.* 1983a) in Brazil, the Parana River in Argentina-Uruguay (GEF and BID Projects) and the Orinoco River in Venezuela (Paolini *et al.* 1983; Richey *et al.* 1985; Lopez *et al.* 1998; Weibezahn *et al.* 1990). Medium-sized basins scattered through South America are being monitored, but either on an irregular basis or during specific programs (e.g., the Magdalena, Sinu and Atrato rivers in Colombia; the Gallegos, Negro and Chico rivers in Argentina, the Jaguaribe and the Paraíba do Sul Rivers in Brazil).

A recent initiative collecting information of mangrove-containing coastal areas (about 75% of the South American coast) has been launched through the Global Mangrove Database and Information Systems (GLOMIS) from the International Society for Mangrove Ecosystems and International Tropical Timber Organization, with its Regional Center at Fortaleza, CE, north-eastern Brazil (www.glomis.com). The GIWA program of UNEP-GEF is currently involved in scaling and scoping its focus sub-regions in South America (<http://www.giwa.net>).

Table 2.8 Scientific and/or management response to coastal impact/issues in South America Coastal Zones on catchment, sub regional and regional scale.

River catchment	RESPONSE Catchment scale		RESPONSE Sub regional/Country scale		RESPONSE Regional scale	
	Scientific	Management	Scientific	Management	Scientific	Management
BRAZIL Jaguaribe River	11 pluviometric stations within the basin with 80 years of monitoring plus 13 river discharge stations with 25 years of monitoring (ANEEL, 2000). Monitoring of sediment flux, nutrients and marine-borne sediments (Marins <i>et al.</i> 2001). Water balance model developed but needs testing for robustness (SRH, 1998). Survey of soil, geology and ground water resources (CPRM 1996).	ICZM at the national (Brazil) level. Local catchment management plan associated with dam development, water diversion and agriculture. PRODETUR program.	Survey of major drivers and impacts in the coastal zone (MMA 1996a,b). Brazil-German Joint Oceanographic Programs on coastal productivity, trophic status, fisheries and sedimentology. REVIZEE Northeast Program. Survey of Economic Resources of the Exclusive Zone (Freire and Hazin 2000). Rio Grande Harbor Authority monitors dredging and dumping of navigation wastes. PGGM – National Programme on Marine Geology. ANEEL monitors river fluxes, sediment quality and rainfall.	ICZM plan in place. PRODETUR-CE Tourism development program PROURB-CE. Urban development plan. State Environmental Authorities run local ICZM. National Environmental Council (CONAMA) determines baseline and maximum concentrations of pollutants. Quality of biological resources for human consumption permanently monitored. National Forest Code controls mangrove conservation. National Institute of Renewable Resources controls aquaculture enterprises.	Global Mangrove Database and Information Systems (GLOMIS) by International Society for Mangrove Ecosystems and International Tropical Timber Organization.	Global Mangrove Database and Information Systems (GLOMIS) by International Society for Mangrove Ecosystems and International Tropical Timber Organization. Regional Center at Fortaleza, CE. MERCOSUR Agreement.
Ceará River	Monitoring of water quality including trace metals and Hg (Marins <i>et al.</i> 2001).	Maranguapinho Ecological Corridor, a joint preservation and reforestation program by the four municipalities of the basin. PROURB-CE Program.				

Table 2.8 continued

BRAZIL <i>Cont.</i>	Scientific				Management			
	Scientific	Management	Scientific	Management	Scientific	Management	Scientific	Management
Pacoti River	Monitoring of water quality including trace metals and Hg (Lacerda <i>et al.</i> 2001). Monitoring of sediment flux, nutrients and marine-borne sediments Freire (1989).	Creation of an Environmental Protection Area, including the mangrove forests of the river PROURB-CE Program.						
Patos Lagoon estuary	Over 500 scientific papers published on structural/functional aspects of Patos Lagoon estuary and adjacent coast. Monitoring of physico-chemical parameters. Establishment of Brazilian LTER site.	Regulation of estuarine fisheries. Regulation of water use in estuary; Rio Grande. Estuary Management Program supported by Interamerican Bank for Development.						
Paraíba do Sul-Sepetiba Bay Basin	Over 800 scientific papers on eutrophication, heavy metal pollution and oil pollution. Permanent monitoring of water quality by local environmental authorities (FEEMA and CETESB). Emission inventorying and permanent monitoring.	Interstate Committee on Water Uses and Basin Management. PDBG – Guanbara Bay Depollution Program. Regulation of estuarine fisheries. Management of Industrial Residues. ICZM at Sepetiba Bay basin.						

Table 2.8 continued

URUGUAY	Scientific	Management	Scientific	Management	Scientific	Management
Uruguay River	CARU studies in 1997 and 1998. Data sources: INAPE, INIDEP, and SOHMA.	Administrative Commission of the Uruguay River (CARU). Water Quality Program (SOHMA/DINAMA).	CARU studies in 1997 and 1998. Data sources: INAPE, INIDEP, and SOHMA.	Fisheries Research Plan. ECOPLATA Project. Coastal Sensitivity Atlas of Argentina.	GEF Program: Environmental Protection of the La Plata River.	Strategic Action Plan of the Administrative Commission on the Rio de La Plata.
Parana River	Environmental Stress of the Paraná River Project. River-Flood Plain Interactions in The Parana River Project.	-	Monitoring of water fluxes of the Parana and Uruguay rivers.		Transboundary Diagnostic Analysis. Monitoring GOOS Monitoring of <i>Vibrio colera</i> .	Technical commission of the Maritime Front 2000-2004.
La Plata River	ECOPLATA (GEF)	Integrated Coastal Zone Management of the Uruguayan coast of the La Plata River (DINAMA, INAPE, Universidad de la Republica.	National Environmental Systems (Argentina).		Meso-scale Atmospheric Modeling.	
Small coastal streams	ECOPLATA (GEF)	IMM, MVOITMA				
COLOMBIA						
Magdalena River	Water discharge data (1940-2000). Sediment load data (1972-2000). IDEAM (Colombia) Heavy metal levels (1980-1990) Bustus (1999); HIMAT-INGEOMIN (1999).	Ministry of the Environment: Quality criteria for wastewaters in tributary basins.	Water discharge data (1940-2000). Sediment load data (1972-2000). IDEAM (Colombia). Heavy metal levels (1980-1990) Bustus (1999); HIMAT-INGEOMIN (1999).	Ministry of the Environment: Quality criteria for waste waters in tributary basins.	Monitoring programs through hydrological and geological institutes (IDEAM, HIMAT, INGEOMIN).	Water Quality Criteria for the Magdalena Basin, Ministry of the Environment.

Table 2.8 continued

ECUADOR	Scientific	Management	Scientific	Management	Scientific	Management
Gulf of Guayaquil	Water Quality Monitoring (INOCAR)	Marine coastal Environmental Education Program Management of Coastal Resources Program.		Marine coastal Environmental Education Program. Priority region for the application of the National Policy on Biodiversity of Ecuador.		Strategic Regional Program for the Protection of the coastal-Marine and Freshwater Associated with Activities Developed Inland CPPS – Integrated management of the Coastal Area of the southeast Pacific.
Chone River		Marine coastal Environmental Education Program Management of Coastal Resources Program.				
Esmeraldas River		Marine coastal Environmental Education Program Management of Coastal Resources Program.				
ARGENTINA						
Argentinian coast and small stream of Río de la Plata	Environmental Monitoring of Sanborobon Bay	Environmental management of Matanza and Riachuelo basins.				The Parana-La Plata basin has been the subject of overviews promoted under the MERCOSUR Agreement
Patagonian rivers	Monitoring of nutrients and heavy metal fluvial fluxes to the ocean, preliminary results published under LOICZ initiative.					
CHILE						
Loa, Aconcagua, Maipo, Itata, Bio Bio and Calle rivers	Survey of environmental status of river catchments. Monitoring and discrete studies by Universidad de Concepción and EULA Center.	Under national environmental policy.				

2.8. Key areas for research projects

Based on the assessment of issues, loads and current response presented the group derived a list of current and/or future “hot spots” which are suggested as demonstration sites for future research (Table 2.9). This information is provided at local or catchment scales, sub-regional scales and finally at the full regional or continental scale (see Chapter 3).

The potential pilot studies to be developed from this assessment step will aim to synthesize the physical, biogeochemical and human interaction processes relevant to land-sea interactions and human dimension of change. The goal is a higher order understanding of the natural and anthropogenic forcing of coastal processes, including the development of the necessary tools for regional and global comparison and up-scaling. Close coupling of “classical” natural sciences with the socio-economic disciplines will be a key for making the results useful to the coastal stakeholders. Further details and suggestions for a future South American Basins project are outlined in Chapter 3.

TABLE 2.9. “Hot spots” of land based coastal impact and gaps in understanding as well as a first overview of issues to be addressed in future research. (Identifying the appropriate scale for the design of a new scientific effort)

River catchment	“Hot spot” catchment scale		“Hot spot” Sub regional / Country scale – Brazil		“Hot spot” Regional – South American scale	
	Key issue, trend and gaps	Scientific approach	Key issue, trend and gaps	Scientific approach	Key issue, trend and gaps	Scientific approach
River Jaguaribe, NE Brazil)	Erosion due to sediment retention in dams. New dams planned and new irrigated agriculture shall increase these problems. Major gap is long-term monitoring to measure high seasonality of river flow.	Long-term monitoring of water and sediment fluxes. Due to increasing agriculture and urbanization of the watershed flux studies of C, N and P to the ocean are necessary. Water balance and critical flux investigation of sediments.	The Brazilian Atlantic coast is most affected by eutrophication and pollution. Excess nutrients and heavy metals are the major agents. Loss of biodiversity and habitat degradation needs better monitoring. Erosion due to decreasing sediment load, although site specific, is very significant.	Nutrient flux studies along river catchments. Long term monitoring of biological communities and land use change.	Eutrophication and pollution, in particular by heavy metals are the major issues of river-derived impacts in the coastal zone of South America. Loss of biodiversity, mostly due to urbanization and degradation of habitats is also widespread. These issues are increasing or stable in most areas. Few areas sustain long-term monitoring programs to evaluate short-term trends in pollution levels. Although restricted to a few sites, coastal erosion and/or sedimentation is an increasing concern and already accounts for significant changes in some coastlines. Lack of extensive surveys on biological components hampers decision making in some areas.	Long-term monitoring of water, sediment and contaminant fluxes through river catchments are needed in almost all sites. Detailed surveys of biological communities and experiments on their sensitivity to habitat changes are also necessary. Multilateral programs are important instruments at least in the MERCOSUR region and along the Colombian-Ecuadorian border.

Table 2.9 continued

River catchment	“Hot spot” catchment scale		“Hot spot” sub regional/ country scale: Brazil	
	Key issue, trend and gaps	Scientific approach	Key issue, Trend and gaps	Scientific approach
Cocó and Ceará rivers of metropolitan Fortaleza (NE Brazil)	Eutrophication due to urbanization will probably increase soon.	Trace metal indicators of land use change (urbanization and industrialization) along river catchments. Due to increasing industrialization and urbanization of watersheds, flux studies of C, N and P to the ocean are necessary, as are monitoring of coastal biological communities.	See above	See above
River Paraiba do Sul / Sepetiba Bay/ Guanabara Basin and Ribeira de Iguaçu watershed (SE, Brazil)	Eutrophication due to urbanization and industrialization. Pollution due to urbanization and industrialization. Although nearly stable, involves huge amount of pollutants in general. Most biological communities already affected with significant loss of biodiversity.	Existing biogeochemical fluxes suggest the use of indicators linking natural capital depreciation and biogeochemical variables. Trace metal indicators of land use change (urbanization and industrialization) along river catchments. Due to increasing industrialization and urbanization of watersheds, flux studies of C, N and P to the ocean are necessary, as well as monitoring the effects on coastal biological communities to quantify their distance from background situations.	See above	See above
Patos Lagoon estuary, South Brazil	Changes in biodiversity and occurrence of harmful algae. Habitat degradation of shallow waters and marshes.	Remote sensing monitoring of salt marsh areas. Animal and plant communities monitoring. Experimental evaluation of sensitivity of organisms to causal agents.	See above	See above

Table 2.9 cont.

River catchment	“hot spot” catchment scale			sub regional/ country scale: La Plata Region, Buenos Aires Province and Patagonia
	Key issue, trend and gaps	Scientific approach	Key issue, trend and gaps	
La Plata River	Water circulation. Water and sediment pollution by hazardous substances. Introduction of exotic species and toxic algal blooms. Socio-economic situation and legal framework.	Model applications and remote sensing. <i>In situ</i> measurements of pollutants. Binational strategy for aquatic species, biodiversity and commercial species. Food chain transfer of pollutants. Studies on social and economics diagnosis and legal instruments.	Water and sediment pollution. Introduction of exotic species and toxic algal blooms. Socio-economic situation and legal framework.	Scientific approach Binational strategy for aquatic species, biodiversity and commercial species. Aquatic pollution monitoring.
Small rivers of the Buenos Aires Province coast	Eutrophication and pollution due to urbanization and industrialization. Although nearly stable, involves huge amount of pollutants in general. Most biological communities already affected with significant loss of biodiversity.	Monitoring of trace metal indicators of land use change (urbanization and industrialization) along river catchments. Also, due to increasing industrialization and urbanization of watersheds, flux studies of C, N and P to the coast are necessary, as well as monitoring the effects on coastal biological communities to quantify their distance from background situations.	Eutrophication and pollution due to urbanization and industrialization is increasing. Few studies on nutrient and pollutant fluxes to the coastal zone.	Trace metal indicators of land use change (urbanization and industrialization) along river catchments. Due to increasing industrialization and urbanization of watersheds, flux studies of C, N and P to the ocean are necessary.
Patagonian rivers	Eutrophication and pollution due to urbanization and industrialization are increasing. Few studies on nutrient and pollutant fluxes to the coastal zone.	Trace metal indicators of land use change (urbanization and industrialization) along river catchments. Due to increasing industrialization and urbanization of watersheds, flux studies of C, N and P to the ocean are needed.		

Table 2.9 continued

River catchment	“Hot spot” catchment scale		“Hot spot” Sub regional/ country scale: Ecuador	
	Key issue, trend and gaps	Scientific approach	Key issue, Trend and gaps	Scientific approach
Esmeraldas – Chone rivers coast	Temporal and spatial variability of physico-chemical parameters, linked to eutrophication and pollution. Monitoring erosion rates.	Water circulation and coastal-oceanic water interaction studies. Monitoring of pollutants and pollutant transfer through food chains. Sediment load monitoring (quality and quantity).		
Guayaquil Gulf	Loss of biodiversity, requires surveys and monitoring.	Creation of a taxonomic center for the Gulf of Guayaquil species. Monitoring and assessment of the contamination.		
			“Hot spot” Sub regional/ country scale: Chile	
Chilean coastal catchments	Two major sub-regions are validated by environmental criteria regarding marine ecosystems. Humboldt Current influenced and Sub-antarctic region.	Social-economic information adequately validated and geo-referenced for indicators to assess the state of coastal populations.	Historical biogeochemical and physical data in identified “hot spot”.	

3. Outlook and future projects

by H.H. Kremer and Wim Salomons

The group of experts who convened during the two SAmBas workshops generated an overall but preliminary picture of land-based activities and their impacts on the coastal zone of South America. This chapter provides a synopsis of the findings of the two **SAmBas** workshops. In particular it provides a rationale for the list of key areas or “hot spots” of current or expected land-based coastal change or perturbation that were identified and scored to be most appropriate for future research.

Table 3.1 summarises 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. Eutrophication 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 which needs improvement for a continued up-scaling effort. An overview on the biogeochemical characteristics of South American estuaries and lagoons has been produced, based on available information (Smith *et al.* 2000).

Table 3.1 Major activities and present status and trends affecting South American coastal zones

Anthropogenic drivers	Major state changes and impact	Present status	Trend expectations
Urbanisation	Eutrophication	Major	Increasing ↑
Damming/Diversion	Erosion/sedimentation	Major	Increasing ↑
Industrialization	Pollution	Medium	Increasing ↑
Agriculture	Eutrophication/ pollution	Medium	Increasing ↑
Deforestation	Erosion/sedimentation	Medium	Increasing ↑
Aquaculture	Eutrophication	Low	Increasing ↑
Tourism	Erosion/eutrophication	Low	Increasing ↑
Fisheries	Loss of biodiversity	Low	Stable ⇒
Navigation	Erosion/sedimentation	Low	Stable ⇒
Mining	Erosion/pollution	Low	Decreasing ↓

A significant information gap exists for small rivers, in particular for those on the Pacific coast. There was 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.

There was a broad consensus that there is an urgent need for a coherent set of case studies using a common framework and a common tool set which allows not only a better understanding of the dynamic interaction of catchments and “their” coastal zone but to upscale the findings to the various catchment-coast system classes at sub-regional scales. This would not only be of benefit to the overall **LOICZ Basins** effort but also to advance the state of the coastal zone and related river catchment management in the South American region.

Consequently, a South American research initiative will focus on two out of the three different classes of basins *viz.*:

1. Coastal zones affected by small river catchments, (<10,000 km² area), including those located along the geologically active continental margin of the Pacific coast (e.g., Bio Bio River, Chile; Guayas River, Ecuador), and those located on the geologically passive Atlantic coast (e.g., Pacoti River, NE Brazil and Sepetiba Bay basin, SE Brazil).

2. Coastal zones affected by medium-sized basins(10,000 - 200,000 km²), draining into the two different continental margin types of the Caribbean and the Atlantic (e.g., Magdalena River, Colombia; Jaguaribe River, NE Brazil; Patos Lagoon estuary, South Brazil; Negro River, Patagonia, Argentina).

The pilot studies will aim to synthesize the physical, biogeochemical and human interaction processes relevant to land-sea interactions and human dimension of change. A systemic understanding of the natural and anthropogenic forcing of coastal processes will be included along with the development tools for regional and global comparison and upscaling and to assist with decision support. For each site, a relatively unimpacted catchment should be included as a reference site. Also, whenever funds allow, other catchments under similar situations should also be studied. The scientific templates on which to build these pilot projects will be adapted from the “EuroCat” (European Catchments - Catchments changes and their impact on the coast – EU/ELOISE project under the 5th Framework Programme adopted autumn 2000, <http://www.iiia-cnr.unical.it/EUROCATCH/project.htm>) and SARCS/WOTRO/LOICZ projects (McManus *et al.* 2001).

Within the LOICZ framework, assessment and synthesis is also expected to continue integrating the results and further developing typology tools and processing software (LOICZView). Currently focussed on biogeochemical assessment, LOICZView will provide useful tools for the catchment-based **LOICZ Basins** upscaling. Available at the following internet pages <http://www.kgs.ukans.edu/Hexacoral> or www.nioz.nl/loicz/.

The “SAmCat” project proposal outline

It was possible, based on the information summarised in tables 2.9 and 3.1, to derive a refined list of “hot spots”/sites where the **LOICZ Basins** assessment and modelling approach can be tested. These sites can become the focus of either a 1-2 year pre-investment phase project, to allow long-term proposals to be developed, or a full proposal after finishing each draft project outline. Table 3.2 summarises the “hot spots”/sites with their major driver-pressure-state change characteristics.

Although a preliminary assessment of critical loads could be developed, it is clear that these are still preliminary and need testing and elaboration. Notwithstanding, a set of indicators of environmental changes has been selected for each case study site. Eventually these indicators should be linked to human dimension change in a manner similar to that described for the SE Brazil coast by Bidone and Lacerda (this report).

Most of the pressures and corresponding coastal state changes and impacts significantly alter the receiving ecosystems - their functioning and biodiversity. This has been included in the matrix table. A recent worldwide conservation effort has proposed a number of so-called “biodiversity hotspots” for conservation priorities (Myers *et al.* 2000). Among the 25 suggested areas, which may represent up to 44% of all species of vascular plants and 35% of all species in four vertebrate groups, at least four are in the operational area of **SAmBas**: Brazil’s Atlantic Forest, the Caribbean (which includes the Caribbean coast of Colombia and Venezuela); the coastline of Central Chile and the Chocó Darién region of western Ecuador. Thus, biodiversity loss should be encompassed in future **SAmBas** activities, aiming to contribute to the UN biodiversity convention.

Not adequately taken into consideration in this first assessment are hydrological watershed alterations combined with opportunistic preconditions. Global forcing functions such as climatic change are apparently overlapping here with anthropogenic drivers. Examples are natural disasters such as hurricanes, when immediate effects of flooding may become quite significant, leading to outbreaks of diseases such as cholera, malaria and dengue, or causing significant, but reversible, changes in coastal geomorphology.

Table 3.2. Proposed “hot spots”/sites, key drivers and impacts on the coastal zone. Selected sites for integrated modelling and indicator development.

“hot spots”/sites	Major drivers	Major Impact	Present status and trend expectations	Examples of indicators of environmental change
South-eastern Brazil (Sepetiba and Guanabara Bays)	Urbanisation	Eutrophication	Major - Increasing	Nutrient ration and flux from rivers (Bidone and Lacerda, this report).
	Damming/ Diversion	Sedimentation	Major - Increasing	Natural sedimentation rates of 30 mg·cm ⁻² ·yr ⁻¹ (Forte 1996). Present sedimentation rates 320 mg·cm ⁻² ·yr ⁻¹ (Lacerda <i>et al.</i> 2001).
	Industrialization	Pollution	Major - Increasing	Maximum allowed concentrations of heavy metals (CONAMA 1996).
North-eastern Brazil (Jaguaripe and Pacoti rivers)	Damming/ Diversion	Erosion	Major - Increasing	Terrigenous sediment flux. Presently around 10-50% of the minimum to keep beach morphology (Morais <i>et al.</i> 1999). Present water withdrawal for agriculture (9.8 km ³ ·ha) (SRH 1998).
		Sedimentation	Major - Increasing	Mangrove siltation: natural rate 1 mm·m ⁻² ·yr ⁻¹ (Smoak and Patchineelam 1999).
	Urbanization and agriculture	Eutrophication	Minor - Increasing	C:N:P ratios equal to Redfield relation (Medeiros <i>et al.</i> 1999).
South Brazil/Uruguay/ Argentina Patos Lagoon estuary (La Plata Estuary and Buenos Aires Province small catchments),	Agriculture and urbanization	Water withdrawal	Major - Increasing	Historical annual water use: domestic and industrial: 0.46 km ³ ·yr ⁻¹ Agriculture: 3.89 km ³ ·yr ⁻¹ (Seeliger and Costa 1997).
	Urbanization	Eutrophication	Major - Increasing	Cumulative increase of P- total and PO ₄ in the water column. Data available for the last 7 years (Baich 1997; Baumgarten <i>et al.</i> 1995).
		Wetland area loss	Medium - Increasing	10% of marsh loss over the last 40 years. Annual loss rate of 0.25% of marsh area at the Patos Lagoon estuary (Seeliger and Costa 1997).
Ecuador Guayas River/Gulf of Guayaquil	Deforestation/ navigation	Erosion/ sedimentation	Medium - Increasing	Mangrove area change (7% average annual deforestation rate from 1984 to 1999 (CLIRSEN 1999).
	Urbanization	Eutrophication	Low - Stable	Total suspended solids. Historical data available for the last decade (INOCAR 1998a).
		Sedimentation	High - Stable	Fisheries yield at the delta responds to eutrophication level. Annual catches decrease rates available for historical period (INVEMAR 2000).
Patagonia, Argentina Negro and other rivers	Damming/ diversion			Total sediment yield, decennial historical data available (Restrepo and Kjerfve 2000a)
		Erosion/ eutrophication	Medium - Stable Low - Increasing	Coral reef bleaching rate. Available at Corales del Rosario for historical period (Vernette 1985).
		Urbanization	Low - Increasing	Bedload transport (Gaiero <i>et al.</i> 2001). Redfield ratios.
Colombia Calle River, Bio Bio River, Chile	Eutrophication	Urbanization	Low - Increasing	Redfield ratios.
	Erosion/ sedimentation	Agriculture	Low Increasing	Total suspended solids concentrations.

The selection of sites aims to provide a good coverage of key issues and representation of sub regional river-coast classes. A **SAmCat** proposal should be based mainly on existing data which is expected to be feasible in the cases of the catchments listed. The SAmBas network has identified key persons for each of the case study sites (Table 3.3) agreed to carry further the process of proposal development and to investigate the options for capacities to involve and potential funding on national and international levels.

Table 3.3. the SAmBas scientific networks and potential site coordinators.

Demonstration sites	Site coordinators
San Juan and Patia rivers , Colombia and Esmeraldas River, Ecuador	J.D. Restrepo, Colombia
Guayas and Chaira rivers, Ecuador; Tumbes River, Peru; Loa, Aconcagua and Bio Bio rivers, Chile	R. Martinez G., Ecuador; G. Daneri, Chile
Calle River , Chile	G. Daneri, Chile
Magdalena River , Colombia	J.D. Restrepo, Colombia
Ceará , Pacoti, Jaguaribe and São Francisco rivers, Brazil	R.V. Marins and G.S.S. Freire, Brazil
Doce, Paraíba do Sul and Iguape rivers, Guanabara and Sepetiba bays, Brazil	E.D. Bidone and R. Sales, Brazil
Patos lagoon estuary , Brazil; La Plata River estuary , Uruguay; Buenos Aires coast rivers, Argentina	U. Seeliger, Brazil; J. Cantera, Uruguay; ; P. DePetrís, Argentina
Negro , Gaillegos and Colorado rivers, Patagonia, Argentina	P. DePetrís, Argentina

Proposed contents for case studies and project structure of “SAmCat”

Aspects to be addressed by the case studies:

1. A scientific review and trend analysis of the changes in freshwater flows, diversions, dams, dimensions of change in the hydrological regimes and consequences on the water discharge, sediment transport, sedimentation rates and biogeochemical cycling at the coastal end of the “water continuum”.
2. An advanced metadata base on available information for South American catchments indicating the issues and data sources and quality backgrounds.
3. Identification and development of modelling tools and their adaptation as necessary for description of surface material transport, groundwater pathways and retention processes.
4. Derivation of the systemic link between pressures on the river catchments resulting in changing discharge and material flux and observed or projected impacts on the coastal zone. This includes the development of ecological “critical loads” to the coastal zone based on investigating the carrying capacity for waste and soil erosion in various parts of the catchments and considering the major drivers for environmental pressures and change in South America now and in the future. Land use and cover change information and potential effects on the water continuum are key inputs for these **SAmCat** pilot studies. As the critical loads are derived, indicating current and future ecological systems functioning e.g., biodiversity, health and sustained provision of goods and services, they can be fed into the monitoring efforts of C-GOOS and the management initiatives for ICAM in UNESCO’s Intergovernmental Oceanographic Commission.
5. The move from the ecological “critical loads” linked to changing C, N, P, sediment and water transport to sectoral activities. Methods used will aim to model that part of ambient material concentrations that can be attributed to economic activity (residual production). In a second step the related socio-economic i.e., employment and monetary figures will be developed and used in scenario analysis of coastal change and resource provision based on expected trend analysis of sectoral activities in the frame of national, regional and global economies. This step aims to translate coastal systems, their goods and services and change into monetary figures (Costanza *et al.* 1997) thus giving an indication of performance of policy and management response and related options – the IR of the DPSIR framework (Turner *et al.* 1998, Kremer and Köhn 2000).
6. Up-scaling of information to the other sites identified for comparison on a regional scale.

Structure and Organisation

To make the **SAmCat** project and its sub-elements manageable, it is intended to divide the effort into workpackages. It is realised that not all case studies will have all the necessary expertise. Hence each workpackage will have a scientific coordinator who has responsibility for contents and deliverables and will initiate (if deemed necessary) capacity building across the sites. At case study level, the site manager will take responsibility for the regional workpackages as a whole. The workpackage coordinators and the site managers constitute the management team (Figure 3.1.)

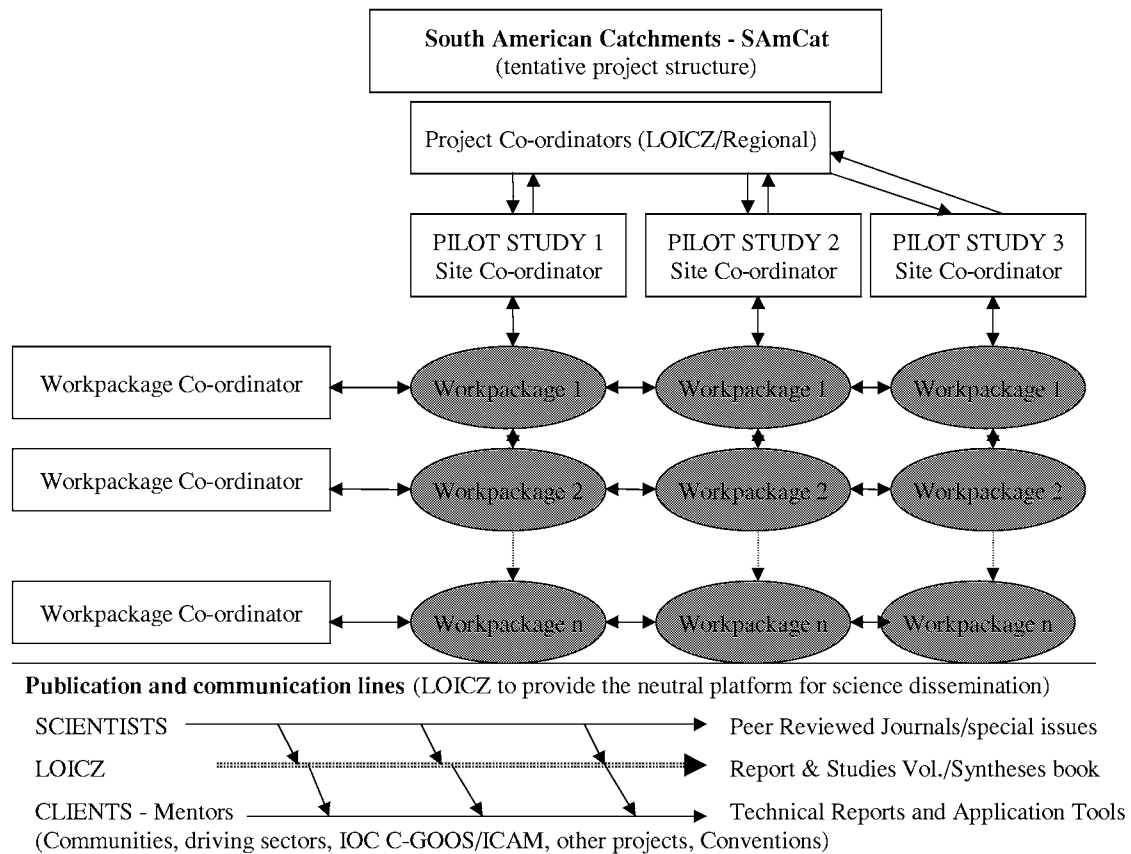


Figure 3.1. Tentative project and task structure for SAmCat and its potential pilot studies.

For effective integrated modelling including forecasting capacities to be developed, a close integration of the tasks and interaction between the work packages is needed. Figure 3.2 shows an example for this interaction as applied in the **EuroCat** project (see: <http://www.iiu-cnr.unical.it/EUROCAT/project.htm> for further detail).

The project database, as well as including the cause-effect relationships of catchment processes to coastal impact and state of coastal resources, will assist in the development of site-based macro-economic analysis of the impacts of the catchment economy on the coastal zone economy. Scenarios representing various forcing conditions will provide information on biogeochemical changes and key questions in the realm of coastal management, addressing issues such as:

- scaling of coastal change issues resulting from land-based fluxes and efforts for mitigation, i.e. specified land-use practices;
- technical and economic feasibility of modified land-use practices;
- economic instruments applicable for enforcement of improved changes in land-use;
- types of public education and community participation needed to bring about appropriate changes (management response);
- institutional dimensions (national or river basin authorities) needed to formulate and achieve the desired changes.

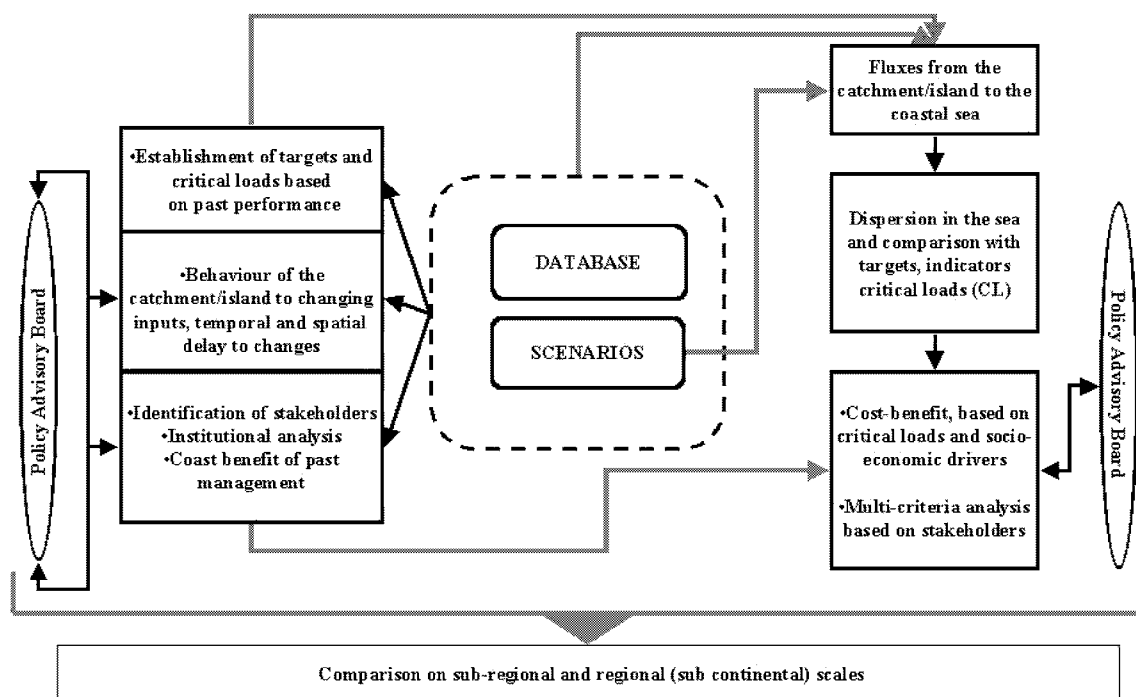


Figure 3.2. A tentative SAMCat workplan.

In the first phase of the project, most of the effort will go into establishing databases (WP 1) for the catchment and coastal seas (monitoring data, geographical and socio-economic database). A geographical information system is the basis for the presentation of all of the spatial data and the results. This will draw on data and information provided through existing regional networks and regional projects.

WP 2 will describe impacts in the coastal zone and derive (based on existing data and readily available models) indicators and critical thresholds for South America. Existing natural and social science models & tools will be combined to make an instrument suitable for carrying out the regional scenarios.

WP 3 deals explicitly with the development of plausible scenario's of future change. These scenarios will be based on readily available global scenarios but downscaled to the South America and then to the site studies and the sub-regions they represent. The socio-economic analysis of the scenarios and present functioning of the coastal zone can draw on experiences (as appropriate) from related global activities carried out in the LOICZ framework and elsewhere. Methodologies as applied in the current **EuroCat** project, such as the decision support software package DEFINITE, could prove valuable for the implementation of **SAMCat** and experiences be exchanged. The package can assist decision-making with the help of cost-benefit and multi-criteria analyses, the latter allowing the inclusion of costs and benefits which cannot be expressed in monetary terms (see <http://www.vu.nl/ivm/> for more detail).

Table 3.4. Outline of workpackages.

No	Description
1	Databases and tools
2	Impacts, indicators and critical loads
3	Scenarios and response/management options
4	Past, present and future changes in catchment fluxes
5	Integration at the continental level

To model catchment fluxes we aim to rely on models including point and diffuse sources, groundwater transports and land cover. Existing models such as the German MONERIS or Elbe-model (Behrendt *et al.* 2000; Kunkel and Wendland 1999) and the Mississippi River Model (Rabalais, this report) can be evaluated and adapted to South American application needs.

In the second phase the databases and the modelling tools will be used to analyse the past and present behaviour of the system. Trend data will be used to assess the past influence on fluxes within the drainage basin of, for example, land-use change, water regulation management, industrial development and population. The temporal and spatial delay of the response of the coastal sea to these changes at the catchment level (regulations and socio-economic) will be evaluated and incorporated in the modelling tools. WP 5 will deal with integrating the results of the individual studies to the South American level.

It is intended to set up a Policy Advisory Board which will be involved in stakeholder identification, institutional analysis and cost-benefit analysis of past measures. Dissemination of scientific findings to various target groups will be a key objective of the board.

Products

The project will not only provide a better understanding of the functioning and change of South American coastal systems under natural and human forcing based on an integrative coupling of biogeochemistry and socio economic sciences but also address scenarios and future developments. It sets up a framework of analysis for coastal zone managers and will continue to contribute on regional scales to the overall global LOICZ assessment and synthesis effort. Products will include:

- Catchment case studies in peer-reviewed articles;
- Regional synthesis for evaluation in the global LOICZ network now and under a future IGBP II integrated earth system science framework (with potential for close links to IHDP, WCRP and Diversitas);
- Protocols for integrated assessment, modelling and forecasting for dissemination in training workshops and through
- A continuous platform for participation and client involvement to be established in form of Policy Advisory Boards (PAB's - see EuroCat web page for detail). They will assist extracting information from the project that is suitable for managing purposes. They will be actively involved in workpackages 2, 4 and 6. Members of the PAB that will be set up in the countries where the studies are carried out will use their own channels to disseminate relevant findings of the project. PAB's will consist of local users and stakeholders.

Contribution from LOICZ

The global LOICZ project which is expected to continue beyond 2002 into a second phase of "Earth System Science" under IGBP and likely IHDP continues to develop and apply tools for assessment, analysis and modeling on various levels. As outlined above some of these instruments as well as experiences from other projects may suite the needs of SAmCat and are open for adjustment and application. Of significant importance are:

- Budget-models of C, N, P cycling and budgeting tools in the coastal sea (the LOICZ approach, where appropriate) – with strong encouragement from LOICZ to also employ further sophisticated investigations to evaluate the water-salt flux model and allow for adjustment where needed (see <http://data.ecology.su.se/MNODE/> for further information)
- Tools for integrated modeling to be drawn from the SARCS/WOTRO/LOICZ project in South East Asia (Input/Output and Rapid Assessment modelling (McManus *et al.* 1998, McManus *et al.* 2001) – aimed to determine the residual production of material-fluxes by human activities in biogeochemical, economic and social terms;
- Typology database and upscaling tools enabling similarity/dissimilarity analysis, clustering and upscaling of catchment – coastal sea systems using the driver, pressure and state settings and to deliver comparable answers to scientists and users;

- Links and synergies with the UN conventions (Biodiversity, Climate Change) and other projects dealing with assessment of environmental change and water such as Coastal-GOOS, the Millennium Ecosystem Assessment, WWAP, GIWA (UNEP/GEF) and regional efforts as appropriate.
- LOICZ furthermore provides the platform for global exchange and comparison of results, publication and science dissemination for the scientific networks involved in Basins and other activities. In addition a neutral basis for dialogue is provided, enabling a continuous engagement with users as integral part of the studies undertaken (this includes intergovernmental bodies such as IOC/UNESCO, the private sectors and the local communities). The goal is to facilitate a joint ownership of issues and actions taken.

4. Human dimensions of land-based fluxes to the coastal zone: the LOICZ-Basins approach

by H.H. Kremer, Wim Salomons and C.J. Crossland

Through the standardised workshops, the **LOICZ Basins** approach offers a common, globally applied framework for analysis, assessment and synthesis of coastal zone and management issues. It aims to assist in the acquisition of funding on regional scales and to consolidate exchange between the regional networks using the common methodology, common assessment protocols and project designs for future work.

This chapter provides the background and methodology for regional assessment and synthesis of human dimensions of land-based fluxes to the coastal zone.

Background

Coasts worldwide are subject to many pressures which are expected to continue or increase in the future. Despite decreasing inputs of “classical” contaminants such as heavy metals, nutrients and PCB’s, these compounds are still of concern in a number of areas globally and will remain important (GESAMP 2001). Past and planned physical changes in rivers (e.g., damming) influence the natural flow of water, nutrients and sediments to the coast. New classes of chemicals have entered the priority lists of international organizations and will require coastal zone impact and monitoring studies. In addition, the increase in economic activities from tourism, fisheries, urbanization and the traffic will offer challenges for the coastal zone managers and regulators. The management issues and their solutions require an integrated approach of both natural and socio-economic sciences (Turner *et al.* 1998; Salomons *et al.* 1999). Numerous studies (usually mono-disciplinary) have been conducted to deal with these issues but they could benefit greatly from more integrated assessment.

Improved knowledge from integration of the results of past studies requires a simple and harmonized framework for assessment and analysis. **LOICZ Basins** uses the DPSIR framework to combine results from the natural and social sciences as well to allow feedback from and to policy/management options (see Chapter 3 for further details on the DPSIR framework).

Coastal zone pressures are manifold, so we have to narrow them down within the LOICZ context, which deals with changes in biogeochemical cycles as major indicators. **LOICZ Basins** deals with the impact of human society on transport of materials such as water, sediments, nutrients, heavy metals and man-made chemicals to the coast. It assesses their coastal impact and tries to provide feasible management options from analysis of success and failure of past regulatory measures. Since the changes in fluxes are mostly land or river catchment based the catchment-coastal sea system is treated as one unit – a water continuum.

In particular the following are being assessed:

- material flow of water, sediments, nutrients and contaminant substances (past, current and future trends);
- socio-economic drivers which have changed or will change the material flows;
- indicators for the impact on coastal zone functioning; and to derive from them
- a "critical load" for the coastal zone and “critical thresholds” for system functioning;

Linking coastal response to socio-economic drivers

This critical load and threshold concept will develop this link. This approach is being developed by the United Nations Economic Commission for Europe’s convention on Long-Range Transboundary Air Pollution. Several workshops have produced handbooks on the critical load concept for terrestrial and freshwater systems. **LOICZ Basins** will extend these concepts to the marine environment. In a systems approach, it can be used for a cost-benefit analysis of management options. Scenario building is an integral

part of this analysis. Critical loads provide key information for the development and application of indicators for monitoring purposes as required for example for the implementation of the Coastal Global Ocean Observation System (C-GOOS) of UNESCO's Intergovernmental Oceanographic Commission.

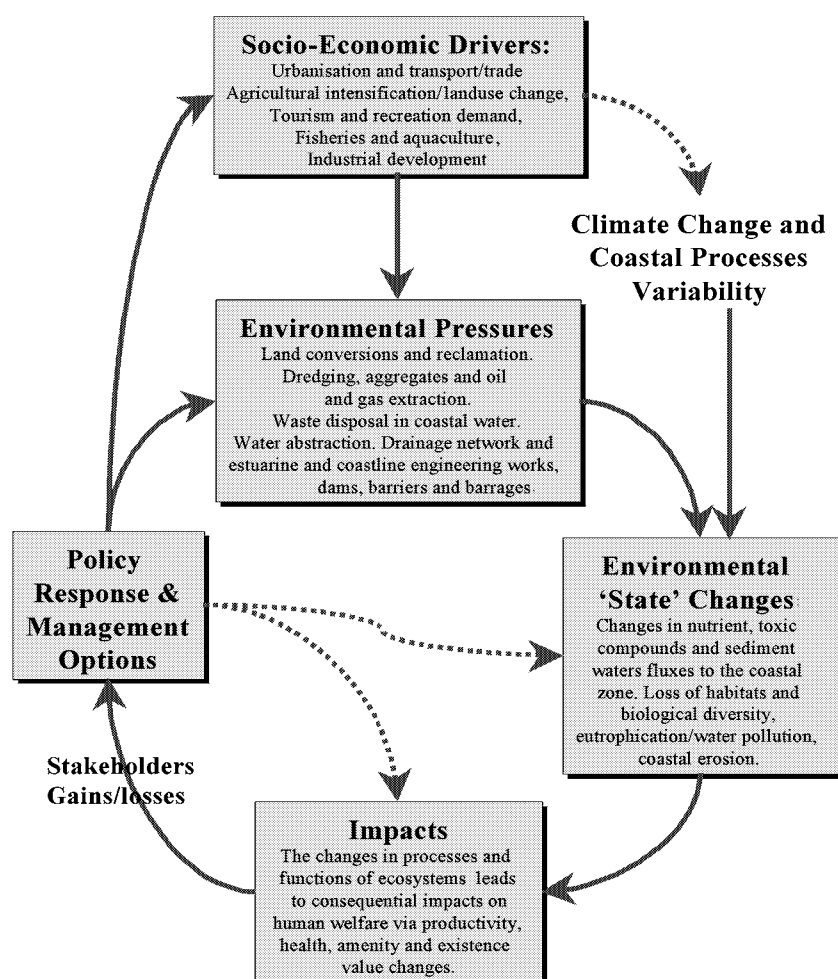


Figure 4.1. The Driver-Pressure-State-Impact-Response (DPSIR) Framework.

LOICZ Basins employs different approaches to identify **targets and indicators** for coastal response:

- The most simple, the “policy-oriented” approach, uses the critical loads which have been agreed upon in international treaties (e.g., the 50% reduction scenario within the Rhine Action Plan, later also adopted for the North Sea).
- The second, “ecosystem”, approach uses historical data describing the response of the coastal system to changing loads and identifies indicators. This approach incorporates an attempt to discriminate between a natural state and an anthropogenically altered state.
- A third, “regional management”, approach is based on consultation with local, national and other authorities and identifies their criteria for indicators or critical loads. This encompasses a broader range of indicators than those based on scientific arguments alone.

The indicators and targets for sustained system functions versus state changes will be used to derive critical concentrations. Subsequently, a critical load to the coastal zone can be calculated. This critical load, the **critical outflow** of the catchment, is a combination of inputs by socio-economic activities and transformations in the catchment and its delta/estuary. Once these links and the transformations of the loads have been established it will be possible to build scenarios for cost-benefit analysis and trade-offs. This will require the integration of existing modeling tools from the natural and social sciences.

LOICZ Basins uses the DPSIR framework to determine the critical load of selected substances discharging into the coastal seas, under different development scenarios, with various biophysical and socio-economic settings. It aims to provide the interdisciplinary platform for participatory approaches between scientists and community representatives or stakeholders.

The **LOICZ-Basins** approach relies on meeting three major challenges:

- 1) to determine the time delay between changes in land-based material flows (due to socio-economic activities, morphological changes or regulatory measures) and their impact on the coastal zone system.
- 2) to generate an improved understanding of the complexities of the coastal sea environments and to derive from this complex environment the “critical loads”.
- 3) to consider the multiplicity of interests and stakeholders affected by transboundary issues, in particular dealing with conflicting interests across various scales e.g., local, regional, national, international.

Large catchments are obvious examples to be addressed within a global LOICZ synthesizing effort (e.g., Orinoco, Amazon). However, in the context of coastal change, the major influence from land-based flows is generated in small to medium-sized catchments with high socio-economic activities. Changes in land cover and sectoral use need much shorter time-frames to translate into coastal change and usually exhibit more visible impact than do large catchments where the “buffer capacity” against land-based change is higher simply as a function of catchment size. Thus, small and medium-sized catchment areas are of priority to the **LOICZ Basins** assessment. Furthermore these catchments dominate the global coastal zone. In island-dominated regions such as the South Pacific or the Caribbean, frequently a whole island is a catchment affecting the coastal zone and influences are generated by anthropogenic drivers as well as global forcing.

Regional networks, assessment workshops/desk studies

Through two-stage regional workshops, **LOICZ Basins** is building up regional multidisciplinary networks of scientists who bring their experience and existing information into the synthesis process. The first workshop identifies the pertinent regional issues and provides a ranking order of current and predicted impacts with trend analysis, based on expert judgement and published scientific information. A second workshop finalizes the first regional synthesis, improves the geographical and thematic coverage and assists in preparing research proposals for local and regional funding. Emphasis is given to close coupling of biogeochemical and physical sciences with human dimensions. Workshops have been held and networks established in Europe, Latin America, East Asia and Africa. In February 2001 the European Catchments (EuroCat) project, funded by the European Union, started (<http://www.iaa-cnr.unical.it/EUROCAT/project.htm>). This is a direct offspring of a LOICZ assessment. The EuroCat design, objectives and modelling approaches serve as templates for the development of other regional catchment-coastal zone projects currently being developed for Africa, Latin America and East Asia. Individual projects and proposals that develop out of the **LOICZ Basins** efforts usually contribute further to the global LOICZ work as relevant or regional projects.

A preliminary **LOICZ Basins** WWW page is currently available at the GKSS research center, Geesthacht, Germany, (http://w3g.gkss.de/projects/loicz_basins/) and a definitive version will be accessible soon through the LOICZ web-site (www.nioz.nl/loicz/).

The approach

The **LOICZ Basins** assessment was developed through the various regional workshops and approved by the **LOICZ Basins** task group. This methodology was applied to the South American Basins assessment contained in this report.

The framework for LOICZ Basins synthesis and project development

Since **LOICZ Basins** workshops have a regional focus, assessment and ranking follow a hierarchy of scales finally generating a composite regional picture – the scales range from:

- local catchments, to
- sub-regional or provincial levels, to
- regional, national e.g., Brazil or international if a subcontinent is considered.

To facilitate common thinking and to guide the evaluation of existing information, the Driver/Pressure/State/Impact/Response scheme (DPSIR) has proven to be an appropriate descriptive framework. The steps taken are:

- to set up a **list of coastal change issues** of and **related drivers** in the catchment.
- to characterize and rank the various issues of change based on either **qualitative information** (i.e., expert judgement) or **quantitative data**; this step includes identification of **critical load** and **threshold** information for system functioning
- to derive a list of current or potential “**hot spots**” representative of a certain type or class of catchment-coastal systems from which to develop a **proposal** for future interdisciplinary work

Thus, **LOICZ Basins** aims to provide an **expert 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 which cover the various aspects and scales of the DPSIR analysis (Figure 5.2) and follow a sequence of **assessment tables**. Participants are asked to complete these tables prior to the workshops. A generic scheme is shown below. All major assessment tables closely follow this scheme, and provide for intra- and inter-regional comparison within the global **LOICZ Basins** effort.

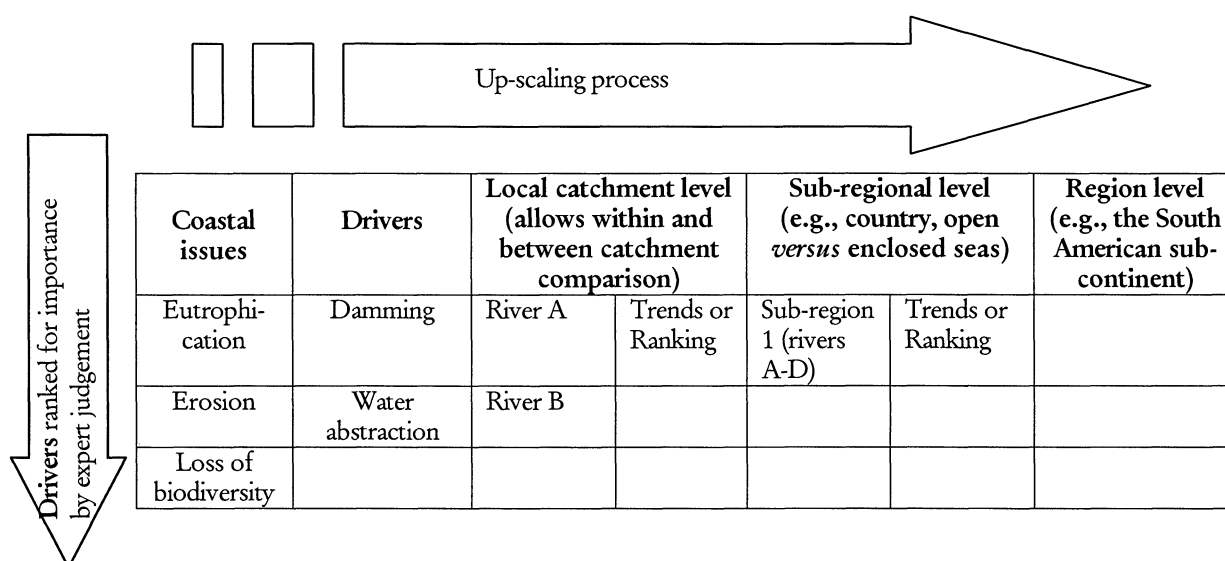


Figure 4.2. Schema of assessment tables.

Ranking and classification

The currently published OSPAR 2000 quality status report (<http://www.ospar.com>) lists human pressures on coastal seas in a ranking order with four classes according to their relative impact on the regional ecosystem - including sustainable use. Pressures are attributed to various drivers or pressure classes.

Table 4.1 contains a few examples compiled within OSPAR guidelines (OSPAR 2000) but adapted to fit the **LOICZ Basins** approach. It focuses on issues which link to land-based activities.

Table 4.1. Examples of human pressures on the coastal sea (OSPAR 2000).

Impact priority	Priority Classes of Human Pressures	Driver – sectoral; land- or catchment- or sea-based
A (highest impact)	Input of organic contaminants – land-based	Various economic sectors
	Inputs of nutrients – land based	Various sectors, urbanization, (waste water, agriculture)
B (upper intermediate impact)	Input of oil and PAH – land-/sea-based	Oil industry/shipping
	Input of other hazardous substances – land-/sea-based	Industry/shipping/various sectors
C (lower intermediate impact)	Input of nutrients and organic material, antibiotics etc.	Mariculture
	Mineral extraction – land/ sea based	Engineering, mining
	Inputs of radio nuclides from land	Energy and other sectors
D (lowest impact)	Input of waste/litter	Recreation, tourism

LOICZ-Basins Regional Assessment Tables and key questions for workshops, synthesis and project development

The tabulated Driver/Pressure/State/Impact/Response analysis has proven to be an appropriate descriptive framework for this purpose. The questions leading through the following tables are normally addressed in the first **LOICZ Basins** regional workshop. The tables ensure a standardized approach within the global Basins effort. They allow integration of the regional assessments and expert typologies into the global scales help fill gaps and harmonise the regional synthesis. Data included in the first workshop are confirmed and reviewed in light of new information delivered to the second regional workshop. Detailed source references for data or critical load information are included wherever possible.

The analysis involves a series of steps, which are outlined and explained in the following **REGIONAL ASSESSMENT (RA)** tables.

Table input

Major data needed for the assessment are material flows (historic data and those of relatively unimpacted systems if possible. Fluxes to be considered are:

- Water
- Sediments
- N, P, C, (Si)
- Contaminants

The trend information on expected changes in the DPSIR scenarios across the various scales (how will drivers change and will this affect the loads to the coastal sea?) provides a preliminary assessment that sets the stage for dynamic scenario analysis.

The critical thresholds information can be derived from: ecological (State/Impact relationship) as well as political and managerial information (Response) which refers to environmental quality standards, regulations, water directives and other similar instruments.

Table RA1. Major coastal Impacts/issues and critical thresholds in coastal zones – Overview and qualitative ranking

based on change in the region following the key questions

- What are major impacts (coastal issues) along the coastal zone?
- How close are they to a critical threshold of system functioning?

Coastal impact/issue e.g.	Local site/region (contributing river basins) e.g.	Critical Threshold (for system functioning) e.g.:	Distance to Critical Threshold (qualitative or quantitative) e.g.:	Impact category (Impact code and rank of importance e.g. 1- 10)	References/ data source
Erosion (coastal geomorphology)	River ABC - Delta	<ul style="list-style-type: none"> • For coastal stability; Sustained delivery of xy t per year • 	Qualitative or quantitative information. about the amount needed for coastal security. (e.g.: no distance since the sediment delivery due to damming has been reduced to such a level that coastal erosion becomes a continuous process)	Erosion - 10	Database xyz, Reference abcd, 19.....
Eutrophication (habitat loss)	Bay ACEF – (rivers draining into the Bay a,b,c,...)	<ul style="list-style-type: none"> • Seagrasses show signs of destruction; • Occurrence of anoxia or low oxygen in estuaries; • Nutrient load is at the threshold. 	Further increased nutrient load by 20-30% will change the system	Eutrophication - 8	
Pollution	Rivers XYZ				

Notes for use

This table is a first priority list of issues for the regional coast based on riverine (i.e. catchment-based) forcing. It serves to compile as much information as possible on critical fluxes, loads and thresholds for systems functions. It provides a first overview of a remaining capacity for material input or withdrawal that a target ecosystem might be able to handle without observable change. This can refer to a single function such as the stability of a coastal area against erosion. It can also refer to a multicausal impact affecting for example fisheries or water quality. These critical load and threshold estimates return in tables 6 and 7 as part of the “hot spot” and response assessment. The ranking involves 4 main categories: values 1-3 no or minor importance, values 4-6 = medium importance, values 7-9 = major importance and value 10 = critical.

Table RA2. DPSI matrix characterizing major catchment-based Drivers/Pressures and a qualitative ranking of related coastal State changes Impacting the coastal zone *versus* catchments size class.

State change dimension: major; medium ; minor ; no impact; ? = insufficient information; Time scale: p = progressive (continuous); d = discrete (spontaneous)
n.a. = not applicable

Key questions and examples:

- What are the major (max. 10) driver/pressure settings on river catchment level causing coastal change?
- Can we identify spatial scales on which certain driver/pressure settings dominate coastal issues?

Driver	Pressures	State change			index	Impact on the coastal system	Time scale
		Large basins	Medium basins	Small basins: active coast			
Agriculture	▪ Waste/nutrient (excess fertilizer)	minor	medium	major	major	<ul style="list-style-type: none"> ▪ Eutrophication; ▪ Contamination; ▪ Siltation, etc.... 	p
	▪ Increasing sediment transport						
	▪ Water extraction						
Damming	▪ Nutrient and sediment sequestration	?	major	n.a.	medium	<ul style="list-style-type: none"> ▪ Coastal erosion; ▪ Nutrient depletion; ▪ Salinization 	d
	▪ Changing hydrological cycles						
Deforestation	▪ Sediment budget alteration	minor	major	major	major	<ul style="list-style-type: none"> ▪ Siltation; ▪ Sediment accretion/Erosion 	p
	▪						
etc	etc					etc	

Notes for use

Please refer to the basins in your sub-region or for which you have information and make a judgement on how intense the effects of the various drivers on these catchments are and to what extent this may impact on the coastal zone. Ranking is in three categories (also used in tables 1 and 3-5); those are: minor importance equals 1-3, medium importance equals 4-6, major importance equals 7-10. The example here is from Latin America:

Deforestation even on large scale if conducted in a huge catchment such as the Amazon will have less if any coastal effect compared to effects in small catchments where even minor deforestation can dramatically influence the sediment budget in the coastal zone. So, deforestation in the Amazon would score a “minor” while in a small catchment it could go score a “major” ranking.

Where your information is referring to only one catchment type or class (e.g., large >200,000 km², medium 10,000 – 200,000 and small <10,000 km²), delete or ignore the other columns.

Active/passive coast refers to geomorphology, tectonics and climate. Small rivers along the South American west coast for example are in a tectonically rather active area with high slopes and high seasonality in runoff while small rivers in other areas may be rather passive exhibiting more moderate runoff characteristics on a yearly time-scale.

Table RA3. Linking coastal issues/Impacts and land based Drivers in coastal zones – Overview, qualitative ranking and trend expectations on local or catchment scale.

Key questions:

- What are the major pressure/driver settings at catchment level causing coastal impacts?
- What are the future trends (based on hard data or expert judgement)?

Coastal Impact/issues	Drivers	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ Data sources
	River A	Category (1 low – 10 high)			
Erosion	Damming	<ul style="list-style-type: none"> • Area... • Volume... • Run off reduction... • 	10	Increasing	XYZ, 2000
	Deforestation	<ul style="list-style-type: none"> • Area... • Residual TSS production... • 	8	stable	
	Diversion	<ul style="list-style-type: none"> • Little, area...; effect on water flow... • 	4	decreasing	
Erosion total	All drivers	In River A	Ranking weighted from information above	Overall trend	
		River A	Category		
Eutrophication	Agriculture	Residual nutrient production...	9		
	Mariculture	Local residual nutrient production...	5		
	Municipal waste	Local urbanisation areas...; xy t/tear residual production	10		
Eutrophication total	All drivers	In River A	Ranking weighted from information above	Overall trend	
Further issues					
etc					

Notes for use:

After finishing River A, continue with River B,C etc. Where possible please treat pollution separately from eutrophication.

The ranking involves four main categories with values 1-3 = no or minor importance; values 4-6 = medium importance; values 7-9 = major importance and value 10 = critical;

Table RA4. Linking coastal issues/Impacts and land-based Drivers in coastal zones – Overview, qualitative ranking and trend expectations on country or sub-regional scale;

Key questions and example:

- What are the major pressure/driver settings on country or sub-regional level causing coastal impact observed?
- What are the future trends (based on hard data or expert judgement)?

Coastal impact/issues	Drivers	Sub-regional (i.e. by country or comparing open versus enclosed seas)		Trend- expectation	References/ data sources
		Sub Region A	Category (1 low – 10 high)		
Erosion	Damming	<ul style="list-style-type: none"> • Catchments involved • Area... • Volume... • Run off reduction... 	5	stable	
	Deforestation	<ul style="list-style-type: none"> • Area... • Residual TSS production... 	8	increasing	
	Diversion	<ul style="list-style-type: none"> • Little, area...; effect on water flow... 	4	increasing	
Erosion (total in sub region A)	All dDrivers and rivers weighted	Sub Region A	Ranking weighted from information above		
Eutrophication	Agriculture	Residual Nutrient production...	9		
	Mariculture	Local residual nutrient production...	5		
	Municipal waste	Local urbanisation areas... ; xy t/year residual production	10		
Eutrophication (total in sub region A)					
etc.	etc.	etc.			

Notes for use:

If you have information about more than one sub-region e.g. north-west Africa or north-east Brazil, please treat them separately. Information involved here should summarize the coastal issues for the whole region and consider all the rivers reaching the coast.

The ranking involves 4 main categories: values 1-3 = no or minor importance, values 4-6 = medium importance, values 7-9 = major importance and value 10 = critical.

Table RA5. Linking coastal issues/Impacts and land-based Drivers in coastal zones – Overview, qualitative ranking and trend expectations on whole regional or continental/sub-continental scale;

Key questions:

- What are the major pressure/driver settings at whole regional, continental/sub-continental level causing coastal impact observed?
- What are the future trends (based on hard data or expert judgement)?

Coastal impact/issues	Drivers	Full regional (continent or sub-continent)	Trend-expectation	Reference/ data source
Erosion	Damming	e.g. Africa or South America <ul style="list-style-type: none"> • Sub-regions involved • Area... • Volume... • Runoff reduction... • Area... • Residual TSS production... • Little, area...; effect on water flow... 	increasing	
	Deforestation		stable	
	Diversions		increasing	
Erosion (total in the region)	All Drivers and Rivers weighted	Ranking weighted from info above		
Eutrophication	Agriculture	Full region scale		
	Mariculture			
	Municipal waste			
Eutrophication (total in the region)				
etc.	etc.	etc.		

Notes for use:

This table should be filled in during the workshop since it will help synthesising the working group discussions on up-scaling individual catchment and sub-region based information. The ranking involves 4 main categories: values 1-3 = no or minor importance, 4-6 = medium importance, 7-9 = major importance and 10 = critical.

TABLE RA6. Scientific and/or management Response to coastal impact/issues in (continental region) coastal zones on catchment, sub-regional and regional scale.

Assessment of scientific and/or management Response on the various scales: overview of monitoring programmes and scientific investigations as well as (if applicable) management interventions, environmental quality standards, legislation, river and other commissions).

Key questions:

- What is the current status of response taken at scientific policy and/or management levels against the major coastal issues in the region?

River catchment	RESPONSE catchment scale		RESPONSE Sub regional/ country scale		RESPONSE Regional scale	
	Scientific	Management	Scientific	Management	Scientific	Management
River A	e.g. monitoring programme 19-2001, Data: ...; Source:	e.g. commission established; thresholds set; legislation in place... Source:	e.g. (combining catchments A-B-... Programs? Data? Source:	e.g....	e.g. UNEP Regional Seas programme Source:	e.g. quality criteria for the regional waters? Source
River B						
River C						
River D						
River E						

Notes for users:

This table describes the current activities dealing with the issues on either a scientific or a policy level. This can include databases and monitoring efforts, local GOOS networks or simply investigations. On policy and management levels, this focus can be on guidelines, threshold values and environmental standards (political critical loads). The scale to which these measures are being applied or should apply should be mentioned.

The information and ranking of DPSIR scenarios (tables 1-5) together with this "Response" information should lead to the identification of "hot spots" to be listed in Table 7.

Table RA7. “Hot spots” of land-based coastal Impact and gaps in understanding; a first overview of issues to be addressed in future research (identifying the appropriate scale for the design of a new scientific effort).

Key questions:

- What are the major gaps in our current understanding of river catchment - coastal sea interactions?
- Which “hot spots” should be addressed in a future integrated scientific effort (natural and socio economic disciplines)

River catchment	“Hot spot” catchment scale		“Hot spot” sub regional/ country scale (e.g. Maputo Bay or SADC region)		“Hot spot” regional scale	
	Key issue, trend and gaps	Scientific approach	Key issue, Trend and gaps	Scientific approach e.g....	Key issue, Trend and gaps	Scientific approach
River A	...	<ul style="list-style-type: none"> • Biogeochemical studies • Residual calculation by economic sectors • Critical flux investigation • Stakeholder and scale analysis • ACTION •
River B						
River C						
River D						

Notes for use:

This table extracts from the regional assessment the potential demonstration sites which can be included in a proposal for a future Regional Catchment/Coast Assessment Project – “...Cat”. Ideally the sites should represent different settings which are typical for a special sub-region. This would allow up-scaling of the findings to comparable “classes” of catchment/coastal systems at a later stage. An accompanying note may be given informing about ongoing activities, link suggestions and key contact persons. Emphasis should be on the human dimensions of catchment–coastal sea interaction considering the co-evolution of natural and societal systems (i.e. involving natural and socio-economic sciences).

5. Contributed Papers

5.1 Restoration trajectory of structural and functional processes in a tropical mangrove-estuarine ecosystem (Ciénaga Grande de Santa Marta) in Caribbean Colombia.

Leonor Botero

Jefe Programa Nacional de Ciencia y Tecnología del Mar - COLCIENCIAS

The estuarine lagoon system known as Ciénaga Grande de Santa Marta (CGSM) is part of the exterior delta of the Magdalena River, the largest river in Colombia and the largest of its kind in the Caribbean area, with an annual average water discharge of $7,106 \text{ m}^3 \text{ s}^{-1}$ and a sediment transport of $139 \times 10^6 \text{ t yr}^{-1}$ (Restrepo and Kjerfve 2000). It is located on the Caribbean coast of Colombia, South America ($10^{\circ}40' - 10^{\circ}59' \text{ N}$, $74^{\circ}15' - 74^{\circ}38' \text{ W}$) and historically was the main fish and shellfish source for the north coast of Colombia. Its extensive oyster beds, prop root habitats and small creeks and lagoons were important habitats and nursing and feeding grounds for a number of species which are commercially important or are food for other valuable commercial species higher in the food web (Alvarez and Blanco 1985; Santos-Martínez and Acero P. 1991; Cataño and Garzón 1994).

The estuarine system (coastal lagoons, creeks and mangrove swamps) covers about 1280 km^2 , with two main water bodies (Ciénaga Grande 450 km^2 and Ciénaga de Pajarales 120 km^2), several smaller lagoons (Ciénagas Redonda, Luna, Ahuyama, Tigre, Conchal, Juncal, Aguja, Piedra, Cuatro Bocas, Atascosa, Torno, Poza Verde), connecting creeks and canals. Until around 1960 this entire system was surrounded by about 520 km^2 of mangrove forests. Four fishing towns on the northern coast of the system and three stilt-villages in the two larger water bodies have a total population of about 20,000, of which 3,200 are fishermen.



Figure 5.1 The Magdalena River estuary system, Colombia.

To the east and south-east, the lagoon-delta complex is limited by the foothills of the Sierra Nevada de Santa Marta (SNSM), the highest coastal mountain in the world ($5,800 \text{ m}$) and from where 4 main rivers drain into the CGSM (average yearly flow of $19.25 \text{ m}^3 \text{ sec}^{-1}$). To the north it is separated from the Caribbean Sea by a barrier island, Isla de Salamanca, which has an inlet about 100 m wide and 10 m deep on its eastern end that connects the largest lagoon (Ciénaga Grande) directly to the sea. To the west and

south-west, the lagoon/delta complex adjoins the flood plain of the Magdalena River through which five main distributaries brought fresh water from the river to the system until the 1970's.

The lagoon-delta complex of the CGSM resulted from a sea level rise of about 2 m during the last 2300 years (Wiedemann 1973). During the last great marine transgression, the zone was covered by seawater as far south as El Banco, Magdalena (Raasveldt and Tomic 1958). At the start of the Holocene period, sea level regression and sediment input from the Magdalena River started the formation of the delta between the Magdalena River and the Caño Schiller, a process continuing today (Hernández *et al.* 1978; Wiedemann 1973). According to Thom's (1982) classification of tropical coastal landforms in relation to their geomorphological, geophysical and biological characteristics, the CGSM region can be classified as a Type I setting (river-dominated, arid, low tidal), containing fringe, basin and riverine mangroves.

Climatically the zone is dry (arid), with 6-7 dry months a year (HIMAT 1988) and a net annual water deficit of 1031 mm yr⁻¹: evapotranspiration (1431 mm yr⁻¹) greatly exceeds precipitation (400 mm yr⁻¹) (IGAC 1975; CETIH 1978). Dry and wet seasons are well-defined, with a long dry season from December to April, a short rainy season from May to June, a short dry season from July to August and a long rainy season from September to November. The temperature regime is isomegathemic with annual means between 27-28°C and daily amplitudes of 8-9°C (Wiedeman 1973). This type of climate is characteristic of a tropical dry forest life zone (Holdridge 1967). Tidal ranges are relatively small (\pm 30 cm) (UniAndes 1990). Changes in the water level in lagoons and creeks as well as in the mangrove forests are due mainly to seasonal inputs from the terrestrial sources (the Magdalena River and the rivers flowing from the SNSM) and from precipitation.

Since 1956 this estuarine ecosystem has been impacted by anthropogenic alterations to its hydrological regime, mainly through the construction of a highway along the Isla de Salamanca and of a road, dikes and berms along the eastern bank of the Magdalena River and its distributaries. The highway (built from 1956 to 1960) along Isla de Salamanca interrupted all but one of the natural surface connections between the sea and the system, as well as most of the groundwater flow (due to soil compaction). During the late 1960's and early 1970's, freshwater flow from the Magdalena River to the system was also interrupted by dikes and berms built along the river and distributaries to prevent flooding of farmlands and to divert fresh water for irrigation purposes. Sedimentation along the distributaries due to the high sediment load of the Magdalena River also contributed to the obstruction of freshwater flow. During the late 1970's a road was built parallel to the Magdalena River without culverts or bridges to allow for laminar flow during flood periods and this further contributed to the interruption of freshwater flow from the river to the mangrove system. Although major hydrological alterations have not occurred yet on the eastern boundary of the system, water flow has also decreased in the rivers draining the SNSM through extraction elsewhere to meet irrigation needs in the agricultural foothills of the mountain, and as a result of increasing sediment loads (from deforestation and erosion in the watersheds) and sedimentation rates in the river mouths.

Water diversion from the lagoon-delta complex associated with a water deficit of 1031 mm yr⁻¹ has resulted in hypersalinization of mangrove soils, (higher than 100 mm or 7 months a year) (Botero 1990; Cardona and Botero 1998) and consequent die-off of almost 270 km² of mangrove forests over a 39-year period. Mortality rates have increased (González 1991) and then decreased (Gonima *et al.* 1996). Between 1956 and 1995, 66% of the original mangrove forest died (Tables 5.1 and 5.2). Heights of dead *Avicennia germinans* trees as well as the size of dead *Rhizophora mangle* prop roots suggest that pre-disturbance environmental conditions sustained well-developed forests in the area such as could only develop in a dry life zone with substantial fresh water input from rivers.

Table 5.1. Live mangrove coverage changes between 1956 and 1995 determined through analysis of aerial photographs and satellite images.

Year	1956	1968	1987	1993	1995
Mangrove cover (km ²)	511.5	490.6	303.4	210.2	177.5

The alteration of the hydrological regime has also caused water quality changes in the lagoons and associated creeks. These are mainly reflected in temperature, salinity and inorganic nutrient increments

(Botero and Mancera-Pineda 1996), frequent drops in dissolved oxygen concentrations (Mancera-Pineda and Vidal 1994) and quantitative and qualitative changes of the phytoplankton community (Botero and Mancera-Pineda 1996).

Table 5.2. Extinction rates of mangrove vegetation in CGSM during different time periods between 1956 and 1995.

Period	1956-1968	1968-1987	1987-1993	1993-1995
Cover extinct (km ²)	20.9	187.1	81.7	32.6
Extinction rate (km ² /yr)	1.75	9.8	18.43	16.32

Several fish kills caused by low oxygen concentrations and eutrophication have occurred during the past 2-4 years (Mancera-Pineda and Vidal 1994). Fish, invertebrate and avian biodiversity have been reported to be consistently lower in the western side of the system affected by the mangrove mortality (Botero and Marshall 1994). A general decrease in fish abundance and biomass throughout the lagoon complex as well as in artisanal fisheries yields have also been documented and are directly related to the general degradation of the ecosystem (Botero and Mancera-Pineda, 1996).

These problems are aggravated by urban, agricultural, mining and industrial activities in the watersheds drained by the Magdalena River and rivers from the SNSM. Toxic contaminants in the CGSM are present mainly in the form of chlorinated and phosphorylated organic compounds and heavy metals such as cadmium, zinc, lead, copper and mercury (Campos 1990, 1991, 1992; Plata *et al.* 1993; Gallo 1994; Espinosa *et al.* 1995). Higher levels of organic and inorganic nutrients are mainly a consequence of sewage and fertilizer inputs from the urban and agricultural areas present in the watersheds of the CGSM, SNSM rivers and the Magdalena River. Input of untreated sewage has resulted in a high concentration of fecal bacteria in both lagoon waters and tissues of filter-feeding organisms such as oysters and clams (Escobar-Nieves 1988; Botero and Mancera-Pineda 1996).

The social and economic conditions of the human population inhabiting the area have been traditionally characterized by extreme poverty and governmental insufficiency in the fulfilment of basic needs and services such as drinking water, adequate sewage systems, medical and educational services. The environmental degradation of the ecosystem, with its consequent decrease in fish yields and water quality, has contributed further to the impoverishment of the population which responds by exerting more pressure on the ecosystem. Both the government and the inhabitants acted for several decades without thought of environmental preservation or sustainable development for future generations. Human activities for the past 3-4 decades have seriously endangered the survival of fauna and flora of the area, the quantity and quality of the hydrological resources of the estuarine ecosystem, thus jeopardizing future social and economic development in the area.

Management of disturbed ecosystems to hasten their regeneration is, in its simplest interpretation, the management of ecological processes for a specific purpose. Recognising the severe negative impacts that the death of almost 70% of the forest has had on the natural resources of the mangrove and estuarine ecosystems, the Colombian government (supported by technical cooperation from the German Agency for Technical Cooperation (GTZ), and funded by a loan of the Interamerican Development Bank (IDB)) has been implementing since 1993 a major rehabilitation program for the area (PROCIÉNAGA 1995). The program is aimed mainly at the restoration of mangrove forests through re-diversion of freshwater into the area, for the recovery of fish and shellfish populations and the general biodiversity of the ecosystem. By December 1998, five of the natural pre-existing distributaries to the system had been re-dredged, bringing into the estuarine system approximately 163 m³/s of freshwater from the Magdalena River. Several box-culverts were built under the highway along Isla de Salamanca, partially recovering the communication between the sea and the estuary. The rehabilitation program has also involved activities and projects that include organization by and participation of CGSM stakeholders in social relief, communication and environmental education programs for the social development of the area.

As a result of these measures, mangrove regeneration in the areas so far reached by freshwater, and adjacent to the newly dredged canals and box-culverts, is clearly visible. Soil salinities have decreased to values

ranging between 20-50 psu. It is expected that once the system is well-washed through several flooding-flushing seasons, more areas of now-dead mangroves will start to recover.

Knowledge of the ecological theory pertaining to community regeneration may permit the development of a more effective management program, that is, one that is less expensive, can be more quickly implemented and gives more desirable final results. Presently, a joint monitoring and research program in the area is looking at the changes occurring along the restoration trajectory as related mainly to the following:

- Hydrological properties in the mangrove wetland
- Responses in mangrove structure and productivity
- Nutrient and organic matter exchange between mangrove wetlands and adjacent lagoon waters to evaluate the role of mangroves as sources, sinks and transformers of these materials
- Role of mangroves as a source of energy and habitat for primary and secondary producers in an arid lagoon-delta complex
- Fish and shellfish populations and fishing activities in the area
- Mangrove associated biodiversity.

The mangroves of the CGSM offer a unique experimental setup to test hypotheses on mangrove structure and function in the context of restoration ecology. The hydrological restoration of the system will be used as a landscape-scale field manipulation to answer questions of ecological processes in mangroves. Quantification of the changes of inorganic and organic materials through changing biogeochemical processes such as decomposition, remineralization, immobilization, denitrification and nitrogen fixation are aimed at evaluating the role of these mangroves as sources, sinks and transformers and how these processes are affected by disturbance. The study of the utilization of mangrove-derived particulate and dissolved organic matter in the estuarine food web will assess the degree of coupling between mangrove and estuarine productivity.

The Instituto de Investigaciones Marinas (INVEMAR) has a 10-year (1988-1997) database on lagoon physical-chemical conditions, primary productivity and plankton, fish and invertebrate fauna biodiversity assessments together with a 6-year (1992-1996) database on mangrove soil conditions, forest structure, seedling recruitment, litterfall and reproductive phenology. These are providing baseline information on lagoon and forest conditions prior to the freshwater re-diversion into the system.

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5.2 Geoenvironmental characterization of the Orinoco Delta: a processes approach

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Introduction

The Orinoco River is the third largest river in the world, in terms of water discharge. It drains 1×10^6 km² of Venezuela and Eastern Colombia, (see Figure 5.2) with a mean flow rate of about 37,000 m³ s⁻¹, and discharges through the delta of the Orinoco River which forms an intricate network of channels before discharging into the ocean. The Orinoco River is responsible for most of the supply of water and sediment to eastern Venezuela. The Orinoco Delta also receives an large amount of sediment from the Amazon River, transported by the Guyana Current along the coastline of the continent. Thus, it has a particular and unique sediment composition throughout the year, independent of the season.

The Orinoco Delta is the seventh largest delta complex in the world and is one of the most important because of its mega-diversity, but it has not been well-documented and there are gaps in information, such as the quantity and variety of avifauna, some of which include the delta in their migration route. There may also exist unidentified species of animals and plants, and others that need to be better described and related to the different habitats and ecoregions. On the other hand, the Orinoco Delta is one of the least-intervened by humans in the world, so that most of its environment is in a fairly pristine state. This is a consequence of the low economic and demographic pressure that has existed in that area. However, the exploitation of local species and the potential for oil production in the region pose important threats that must be anticipated to prevent extinction and/or non-recoverable impacts on the environment.

The delta forms a broad triangle that covers 22,000 km² of lowland swamps and waterways, bordered to the south by the Guayana Shield, west by the quaternary uplands of the Llanos Orientales and north and east by the Atlantic Ocean. A significant portion of the delta is subaqueous and the prograding delta platform extends offshore to water depths of about 50 m. Much of the dry areas of the delta are seasonally flooded by a combination of bank overflow, tidal fluctuation and direct rainfall. The tropical climate, high heterogeneous spatial variability and moderately nutrient-rich water of the delta have contributed to its high biological diversity and productivity and lead to rapid and widespread organic sediment accumulation. Also, crevasse splay formations appear along some of the main discharge channels, pouring nutrient-rich waters into predominantly black water sectors and creating suitable conditions for biodiversity to proceed.

The information available suggests that the Orinoco Delta system has certain factors that significantly influence its development and several potentially unique characteristics compared with other major deltas. These include the importance of littoral currents, tides and long-term allocthonous sediment transport from the Amazon basin. These play a much more important role in the aggradation process of the Orinoco Delta than in other deltas in the world.

In order to create an adequate pressure-state-response model for the Orinoco Delta, which can be used as a managerial tool and for policy-making for either regional or national governments, we need to generate the geoenvironmental characterization of the region. This geoenvironmental characterization aims to understand the range of processes that take place in the delta, i.e., how the changes in some variables of the physical medium affect other physical variables, biodiversity and anthropological development. Thus, the project includes a variety of themes involving social, economical and natural sciences. Those aspects related to biodiversity conservation will be carried out with the aid of other international agencies such as the Global Environment Facility of the United Nations. However, the details associated with the physical and biological data, and with the pressure-state-response model, still need funding and support.

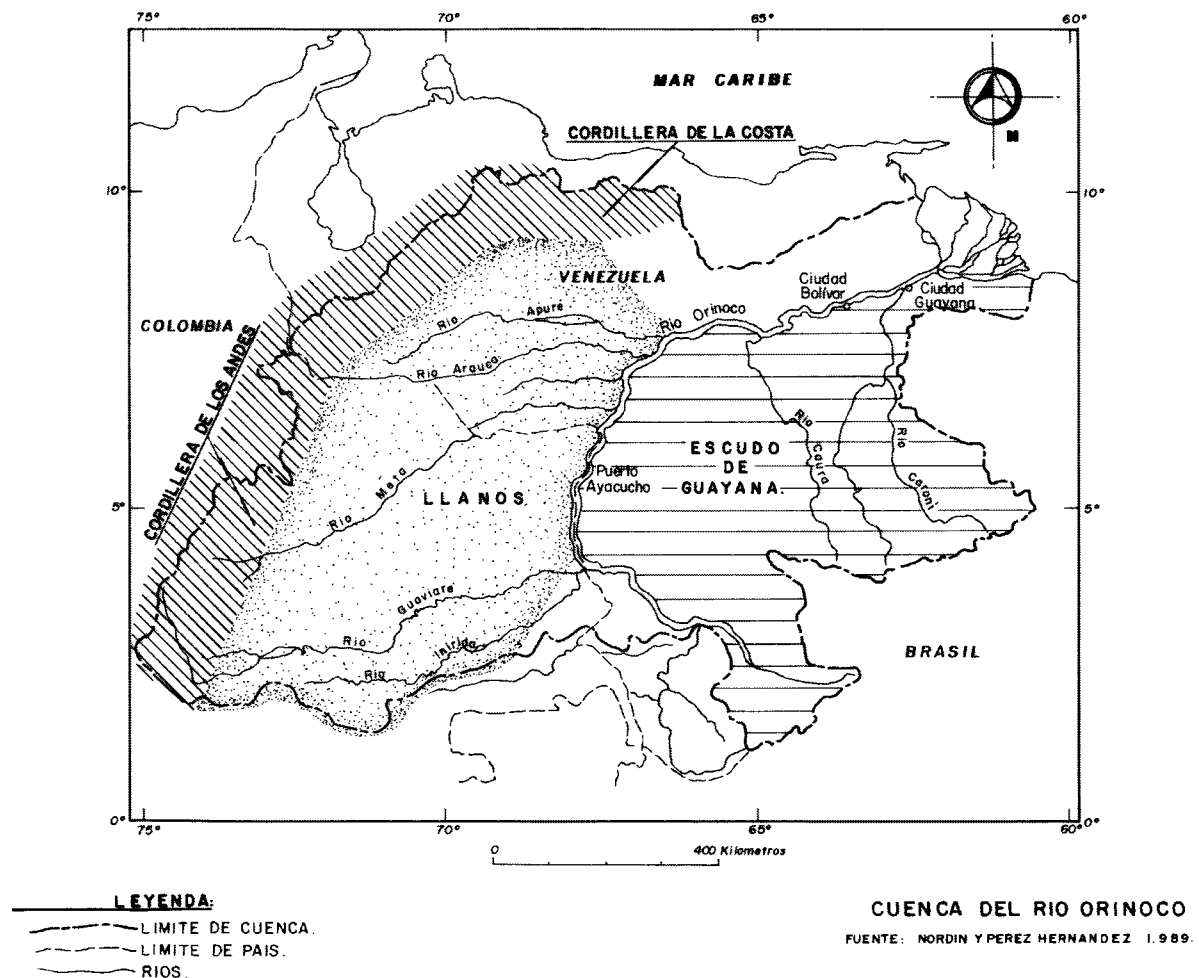


Figure 5.2. The Orinoco River watershed

The following paragraphs contain a summary of the most important aspects of several physical variables that have been studied in sectors of the Orinoco Delta. A major effort is still needed to link them with the different processes and establish the appropriate data and baseline information to anticipate, prevent or remediate particular situations arising from human intervention.

Preliminary Geo-Environmental Characterization of Orinoco Delta

Climate

The Orinoco Delta is located in northeastern region of Tropical Atlantic Ocean inside the equatorial belt. In this region the temporal location of Intertropical Convergence Zone (ITC) and the direct effect of north-east trade winds control climate, which determines the beginning and end of the rainy season. Temperature temporal variation in the delta region is negligible, so that precipitation is used as the most important variable to characterize the climate, which can be classified as oceanic or humid marine. Spatial variability of annual precipitation is shown in Figure 5.3, which shows two high precipitation areas located on either side of delta region, following the coastline direction. Monthly rainfall regime is bimodal; Figure 5.4 illustrates this variability.

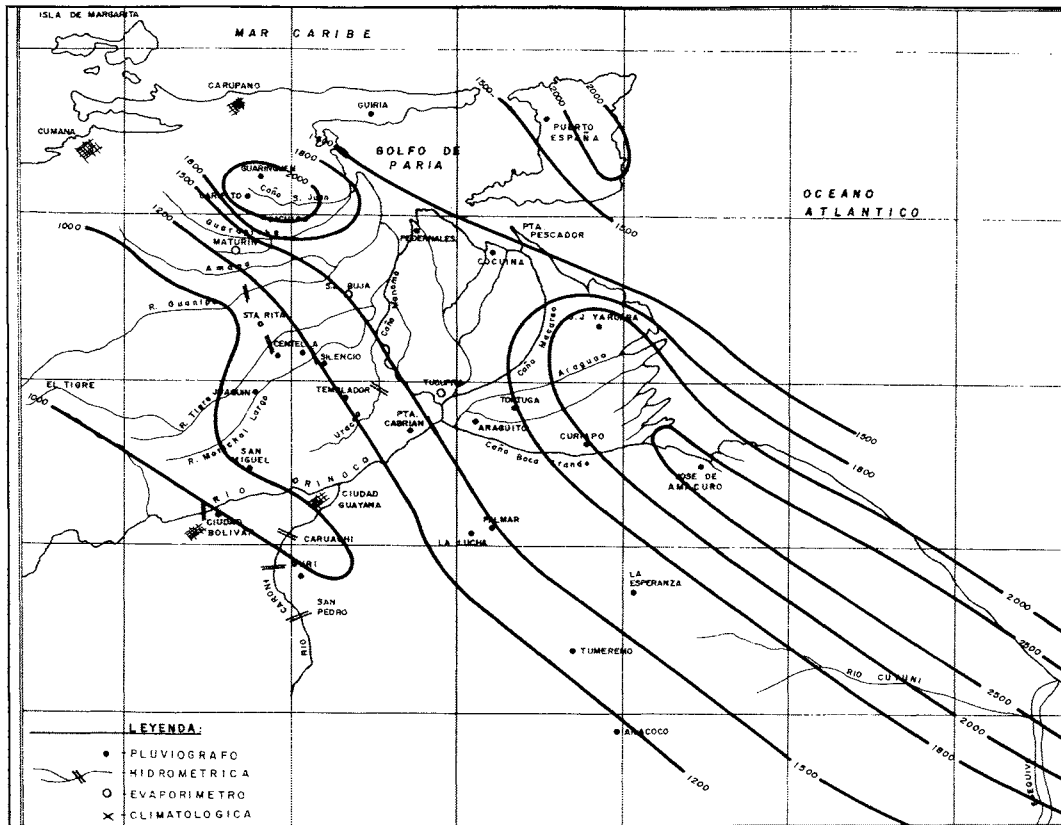


Figure 5.3. Annual isohyetal (mm) map of the Orinoco River delta.

In general, the mean temperature in the region is about 26°C, the mean annual precipitation is 1,900 mm, mean annual pan evaporation is 1,700 mm, which are characteristics of humid and warm tropical climates. Other climatic variables show a mean solar radiation of 363 cal cm⁻²; an annual mean relative humidity of 80%, with maximum value of 96% and minimal of 43%; maximum wind velocities of 77 km h⁻¹, occurs between February and April, and minimal values occur in October.

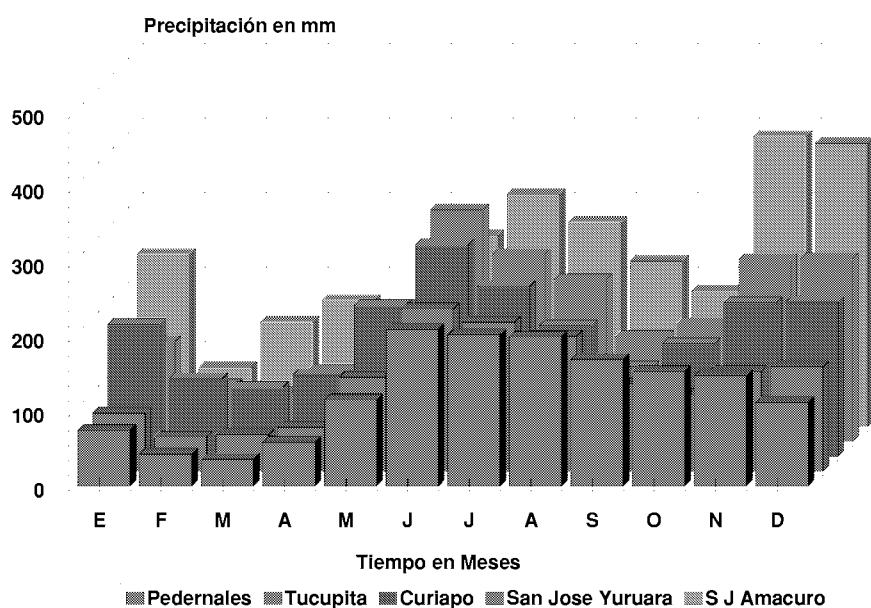


Figure 5.4. Monthly precipitation (mm) in the Orinoco Delta region.

Hydrology

The network of watercourses within the delta region are formed by five main “caños” or streams: Manamo, Macareo, Mariusa, Araguao and the main course called Caño Grande (Figure 5.5). The Manamo watercourse is controlled by a dam built in 1966, so that a third of its delta area is no longer influenced by the Orinoco River discharges, but is now controlled by tidal flow.

The discharge flow of the Orinoco River into these main channels is characterized by a unimodal monthly hydrography as shown in Figure 5.6. Mean annual maximal runoff into the delta is about $79,000 \text{ m}^3 \text{ s}^{-1}$, twice its mean discharge. The 100 years peak discharge is about $94,000 \text{ m}^3 \text{ s}^{-1}$. Major hydroelectric reservoirs have been constructed in the Caroni River (see Figure 5.5), an important tributary that discharges its water close to the delta. This river has a $90,000 \text{ km}^2$ watershed and an annual mean flow of $4,800 \text{ m}^3 \text{ s}^{-1}$. The reservoirs have positively impacted the minimum-flow regime in the Orinoco River, since they have a constant discharge close to $4,000 \text{ m}^3 \text{ s}^{-1}$ through the whole year; the mean minimum flow at the delta entrance is close to $6,000 \text{ m}^3 \text{ s}^{-1}$.

The total water inflow at the delta entrance is divided in three main water courses (see Figure 5.5): Caño Mánamo, Caño Macareo and Río Grande. Before the Caño Mánamo closure, the water distribution into these water courses was 10% to Caño Mánamo, 6 % to Caño Macareo and 84 % to Río Grande. After the closure, gates located at this structure allows a discharge of only 250 m³ s⁻¹ toward Caño Mánamo, therefore the distribution was changed to less than 1 % to Caño Mánamo, 11 % to Caño Macareo and 88 % to Río Grande.

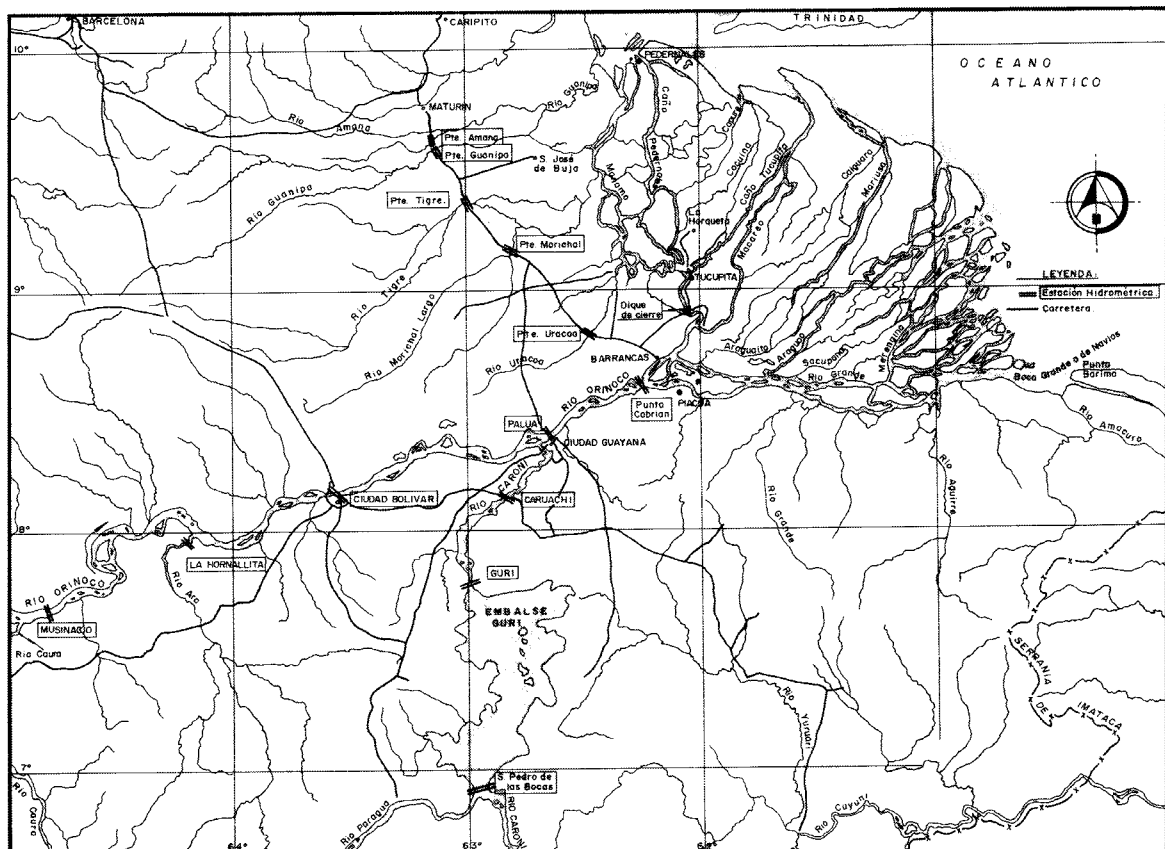


Figure 5.5. Network of water courses in the Orinoco River delta.

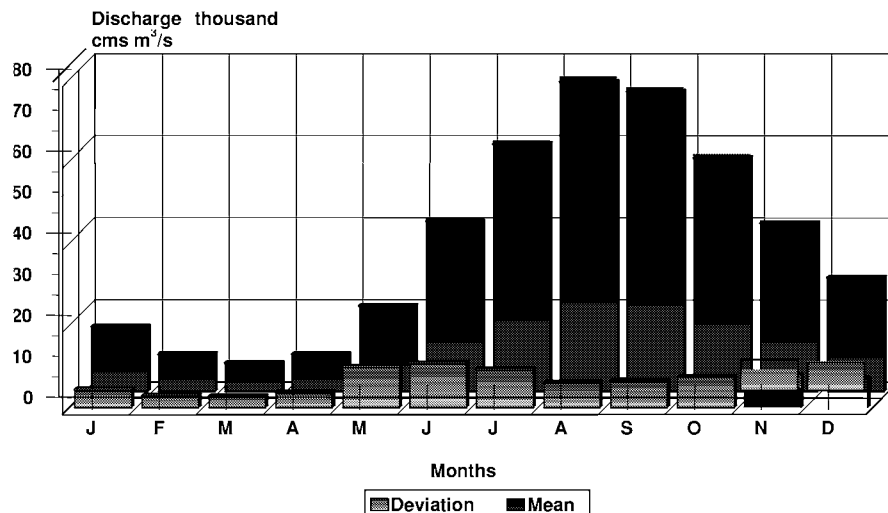


Figure 5.6. Mean and standard deviation of monthly discharges of the Orinoco River at the delta entrance.

Sediment yield in the Orinoco River up to the delta entrance has been estimated in the order of 210 million tonnes per year. Approximately 95% of this figure is transported as suspended load and only 5% as bed load.

Tidal effects are very important in the delta region. In the first year of this study the tide-monitoring effort was concentrated in Caño Mánamo. Figure 5.7 shows the location of tide, currents and salinity gauging stations. Preliminary results shows tidal amplitudes of 1.2 m and maximum current velocities close to 1.00 m s^{-1} at Caño Mánamo mouth, while at the closure structure the tide amplitude is of 1.00 m and maximum current velocities are close to 0.30 m s^{-1} . Salinity near the Caño Mánamo mouth is estimated at 0.81 ‰ and near to closure structure it is about 0.01‰.

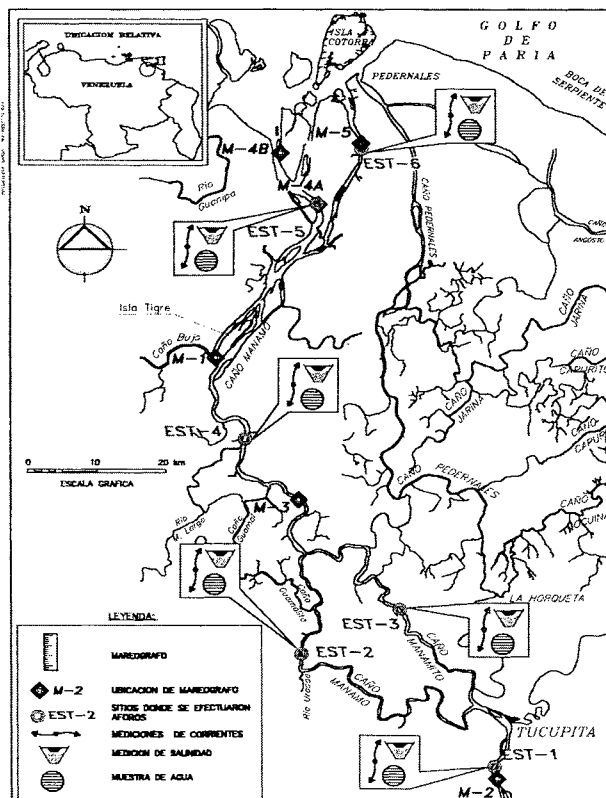


Figure 5.7. Location of tidal gauging stations in the Orinoco River delta.

Vegetation

The Orinoco River delta shows the typical fan shape of most of the world's deltas. The delta has been divided into three natural subregions: Upper, Middle and Lower Delta. This classification is based upon the influence of the original source of sediments, either marine or fluvial or a combination of both, and the tidal action as a vehicle to redistribute them and to create lateral and longitudinal salinity gradients along the main distributaries. The flora and the plant communities which form its vegetation are still little-known.

The results of the first year of studies in a subsection of 7,000 km² between the Manamo and Macareo channels have allowed us to recognize 47 different plant communities, of which seven are reported for the first time. At the same time, there were three new plant species found for Venezuela and many others reported for the first time for the Orinoco Delta. The Upper Delta is controlled by fluvial processes, the Middle Delta and Lower Delta by fluvio-marine and marine environments, which create and condition lateral and longitudinal gradients along the main distributaries regulated by gradual changes in salinity and oxygen levels. This, associated with increasingly poor drainage towards the backswamp (internal depressed areas) gradually increases the thickness of the peat layer on the original mineral soil associated with the tidal channel margins covered by distinct mangrove communities.

The coastline and the lower sections of the main distributaries are richer in species and exhibit the highest rate of primary productivity of the Venezuelan mangrove communities. The different species of mangrove play a very important role on the initial stabilisation of the prograding sediments along the delta coast.

Mangrove communities are also important as nurseries and refuges for many fish and crustacean species. The high rate of primary productivity in mangrove communities reflects a high input of particulate and dissolved organic matter which support a diversified trophic chain and is the basis of very important fisheries and shrimp commercial resources along the Atlantic coast and in the Paria Gulf.

Despite the presence of mangrove communities all along the delta coast, we have detected several places where mangroves are retreating due to the combined effects of wave and marine currents. This points to future lines of research on the relationship between the possible roles of the different mangrove species in the process of aggradation and erosion of the coastal margins of the Lower Delta.

The possibility of oil extraction provides an urgent reason to support the base-line studies to evaluate the possible impacts of oil exploitation upon the biota of the Orinoco Delta. The choice of directions for future research in the Orinoco Delta will rely upon knowledge of the structure and floristic composition of the different plant communities and their relationships with the edaphic and the geomorphological settings as a very important step to consolidate the initial baseline data.

Geology and geochemistry

The deltaic coast to the north of the mouth of Caño Macareo is undergoing changes in sedimentation pattern, leading to erosive processes which are diminishing the deltaic aggradation in those areas (see Figure 5.5). The sedimentation change is manifested in a larger fraction of sands, which are forming banks along the whole coast and a system of *denier facies*. These *denier facies* are depositing on top of the existing silts and clays, which had maintained an active process of aggradation, complemented by the establishment of mangrove communities. The reduction of silt and clay deposits inhibits the growth of the mangrove, while the sedimentation of sands reduces the aggradation process, as the aggradation speed with silt and clays is much faster than with sands. It is believed that the change in the sedimentation process results from the partial closing of the Caño Manamo which has increased both the water flow and the volume of suspended and bottom sediments along Caño Macareo. These two variables have increased considerably in the last thirty years, changing the sedimentation patterns and the development of facies in the coast line. Similarly, the transport and discharge of nutrients in the flooded basin areas, mainly in the sectors of the middle and lower delta and along the coast line, have also changed considerably, as the hydrographic basin controlled by the Caño Manamo (around 25% of the total area of the delta) no longer contributes as much sediments and nutrients to the flooded basin and the coastal zone.

Geochemical analyses of the water of Caño Manamo in the dry season have indicated changes in the hydrogeochemical characteristic of this aquatic system. They indicate that the regulation of the Caño Manamo in the decade of the sixties by the construction of the El Volcán dam in Tucupita has caused a series of hydrochemical modifications in the drainage basin and its influence area in the north part of the Orinoco Delta. The flow of the Manamo has been reduced to fifteen times less than its previous value (3,000–4,000 m³ s⁻¹ before the closure with El Volcán dam), thus increasing the estuarine character of a large portion of the northern region of the delta, between the Caño Manamo and Macareo, due to the increased mixing between the tidal prisms and the freshwater. Concentrations of chloride, sodium, sulfate and magnesium in the waters of the Manamo have been increased considerably from the outlet towards Tucupita. This is reflected in the higher values of conductivity and concentration of total dissolved salts whose effects can be appreciated in front of the island of Manamito and near the city of Tucupita, and are observed to several kilometers upstream. The best indicator in this process of influence of the marine waters is the chloride ion, and the molar Na/Cl ratio. At the same time, the concentration of sulfate in some sectors of the Caño Manamo is higher than expected, perhaps due to oxidation of the pyrite in the soils affected by the changes in the regime of flooding in the region. This contrasts with the soils of the Caño Macareo whose water is similar to that of the Orinoco River at the apex of the delta.

The distribution of suspended sediments along the Caño Manamo is not uniform, although it is smaller than that observed in Caño Macareo. The highest values are found near the mouth and diminish upstream. The presence and abundance of montmorillonite in the suspended sediments along the lower part of the Caño Manamo implies that a large concentrations of suspended sediments are brought by the the marine currents from the Amazon, as this mineral is characteristic of the Amazon basin but not of the Orinoco's watershed. A larger portion of those sediments now enter into Caño Manamo with the tide. It is reasonable to assume that a similar process might also take place, although at a different scale, in other caños and the Río Grande (main discharge channel) of the river. The quantity of clay minerals varies upstream, with a reduction in the concentration of montmorillonite and an increase of caolinite and the illite which are typical of the Orinoco River basin.

The changes in the sedimentation pattern along the Caño Manamo due to the significant reduction in the flow has also accelerated the buildup of banks and estuarine islands at its mouth and the generation of sand deposits upstream in front of El Volcán dam. This confirms the low transport of suspended silts to the coast line by Caño Manamo inferred from satellite images (Landsat TM).

The chemical composition of the fine sediment fraction (<63 µm), susceptible to leaching and acid attack, and present in the sediments of the Caños Manamo, Macareo and other important caños as well as along the coastline is quite homogeneous. In addition, there is a statistically significant relationship between the concentrations of iron and manganese with those of aluminum and some heavy elements (e.g. Zn, Cu) that suggests a possible coating of hydroxide iron and manganese on clay surfaces. On the other hand there was no significant relationship between the TOC and the concentration of the heavy elements. Thus, removal of these heavy elements is probably a result of adsorption processes on the fine particles coated with iron and manganese hydroxides. Formation of those particles would be favored where pyrite oxidation occurs. The degree of anthropogenic intervention could favor the accumulation of heavy metals in the fine fraction of sediments, with a possible accumulation in those areas where the estuarine effects are stronger.

Main general objectives of the proposed geo-environmental study of Orinoco River delta

The purpose of the study on the geo-environmental characterization of the Orinoco River delta is to provide a reliable source of information to authorities, policy-makers and managers about the region. The study area will be limited to the delta region but some reference sites will be established upstream in the basin, and appropriate parameters will be selected as indicators and monitored in time and space.

The main objectives of the proposed study are as follows:

Oceanographic studies

- To establish the effect and extension of sea current and tides in the most important distributaries (caños) of the Orinoco River in the delta, including the penetration of the saline water.
- To determine the characteristics of the different oceanographic parameters in the marine areas of the delta which affect the distribution and transport of the sediments, as well as the dynamics of the sedimentation and erosion processes along the coast.
- To establish the chemical conditions and the quality of the water spatially in the delta and at reference sites, as well as variability in time.
- To determine the characteristics and distribution of planctonic and benthic organisms in the area of influence along the coast and the delta itself.
- To analyze the fish population, distribution and associated fisheries.

Geological study

- To identify the current active processes which condition the sedimentation and erosion of this system.
- To identify in detail the different geologic and sedimentological parameters that interact in the formation of the delta.
- To define characteristic facies and geological evolution during the Holocene.

Geochemical studies

- To determine environmental indicators and baseline values of total organic carbon (TOC) and a spectrum of major and trace elements (P, S and total N; heavy metals including Hg, Pb, Cr, Cd, Cu, Fe, Zn, Ni, Ba, Sb, Be, Se, As, Ti and Ag; organic compounds such as total hydrocarbons).
- To determine textural and geochemical relationships between sediment size and trace metal concentrations in the surface sediments of the main channels the Orinoco River delta.
- To generate distribution map of each element by surface sediments of the delta region.

Vegetation studies

- To characterize from the floristic and physiognomic approach the different plant communities, which as a whole forms the vegetation of the Orinoco Delta.
- To establish the variations, limits, and ecotones, of different kinds of plant communities (mangroves, scrub, palm and swamp forests, and herbaceous swamp communities). These communities occur in a sequence, from the riverine mangroves associated with tidal channels up to the interior peat basins, along lateral gradients controlled by tides, salinity, nutrients, oxygen, and organic matter levels.
- To establish, using appropriate multivariate techniques, the main environmental factors which control the spatial patterns of zonation of the different plant communities along the gradients.
- To express in a vegetation map scaled 1:100,000, the area and the geographical location of the main plant communities using a four-entry legend, defining the community by the dominant growth form, the two most abundant species, and the geomorphological and edaphic setting.

Faunal studies

- To make an inventory through sampling efforts of the main faunistic groups, mainly the vertebrate fauna, birds (native and migratory), reptiles and mammals.

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5.3 River discharge and sediment load variability in South America

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Introduction

The South American continent includes three of the largest river basins of the world, with some of the highest river discharges and sediment loads: the Amazon, the Orinoco, and the Paraná. All three rivers discharge into the Atlantic Ocean (Figure 5.8). In general, the drainage basins on the eastern side of the continent are very large, whereas the numerous basins with discharge into the Pacific are comparatively small because of the crowding of the drainage basins west of the Andes imposed by regional geology and tectonics. However, the sediment yield (expressed in $\text{t km}^{-2} \text{ yr}^{-1}$) from the smaller Pacific river basins is significantly higher than for larger river basins draining into the Atlantic Ocean (Restrepo and Kjerfve 2000) because of basin relief and geology (Figure 5.9). This is consistent with the global trend of sediment yield decreasing for larger basins (Milliman and Meade 1983; Milliman and Syvitski 1992). A summary table of some river statistics are shown in Table 5.3.

All South American rivers, independent of size, display a strong seasonal signal of discharge and sediment load variability, typically a factor 5-10 comparing low monthly to high monthly discharge (Figure 5.10). The interannual variability of discharge and sediment load associated with the ENSO or El Niño-La Niña cycle can be almost equally great, typically a factor of 2-4, comparing low annual to high annual discharges (Richey *et al.* 1986, 1989; Depetris *et al.* 1996; Vörösmarty *et al.* 1996). This cycle can be quantified by the Southern Oscillation Index (SOI), which is defined as the difference in atmospheric sea level pressure between Tahiti and Darwin (Glantz 1997). The cold La Niña phase of the SOI is characterized by a positive peak SOI index of approximately +5 hPa, whereas the warm El Niño phase is characterized by a negative peak SOI index of approximately -5 hPa (Figure 5.10B). The El Niño-La Niña cycle gives rise to a significant variability in regional rainfall, river discharge, and sediment load. However, the northern and southern portions of the South American continent have a response which is completely opposite in phase.

El Niño brings about heavy rainfall south of a line which stretches approximately from Quito, Ecuador to São Paulo, Brazil. The rivers respond with large increases in both sediment discharge and sediment load during the southern hemisphere late summer, when extensive river flooding impacts Paraná and Santa Catarina, Brazil, the delta of the Paraná River in Argentina, and many other river basins in the south of the continent (Mechozo and Perez-Iribarren 1992; Probst and Tardy 1989). This causes destructive and costly flooding of cities, roads, agricultural fields and brings about much hardship. At the same time, river basins in South America, north of the front, suffer from drought conditions and low river discharges, which have negative impacts on the regional agriculture and water resources.

In contrast, during the La Niña phase, the southeast trade winds are well developed, and the Inter Tropical Convergent Zone (ITCZ) remains north of its typical position in the Eastern Pacific. This results in drier than normal conditions in the southern portion of the South American continent, but brings about intense rainfall in the northern parts of the continent (Ropelewski and Halpert 1987). Rivers in Colombia (Figure 5.10A and 5.10C) and Venezuela, in particular, experience catastrophic flood conditions, which often have drastic social and economic impacts.



Figure 5.8. Map showing the eleven major rivers in South America draining into the Atlantic Ocean and the smaller Pacific rivers of Colombia (San Juan and Patia) and Peru (Chira) listed in Table 5.3.

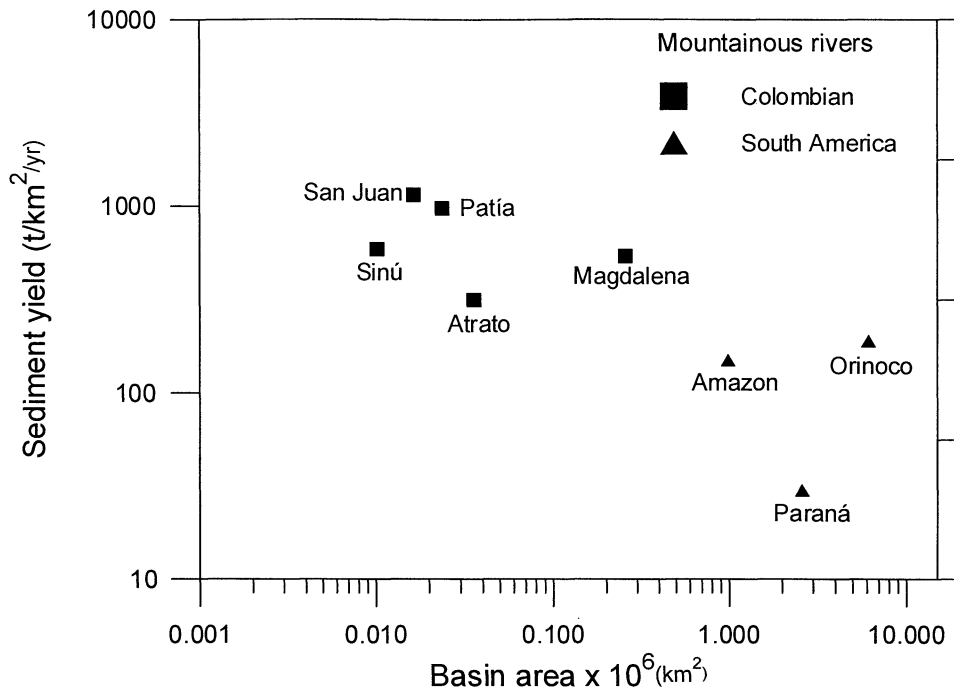


Figure 5.9. Variation of sediment yield with basin area for several mountainous rivers of South America (Amazon, Orinoco, and Paraná) and Colombian rivers draining into the Caribbean Sea (Magdalena, Sinú, and Atrato) and into the Pacific Ocean, San Juan and Patía (modified from Restrepo and Kjerfve 2000a).

Table 5.3. Drainage basin, water discharge, sediment load, calculated yields, and receiving basin for some rivers of South America (Figure 5.9) (from Milliman and Meade 1983; Milliman and Syvitski 1992; Goniadzki 1999; Restrepo and Kjerfve 2000).

<i>River</i>	<i>Basin Area</i> ($\times 10^6 \text{ km}^2$)	<i>Water Discharge</i> ($\text{km}^3 \text{ yr}^{-1}$)	<i>Sediment Load</i> ($\times 10^6 \text{ t yr}^{-1}$)	<i>Sediment Yield</i> (t $\text{km}^2 \text{ yr}^{-1}$)	<i>Receiving Basin</i>
R. Amazon (Brazil)	6.15	6300	1200	190	N. Atlantic
R. Orinoco (Venezuela)	0.99	1100	150	150	N. Atlantic
R. Paraná (Argentina)	2.60	470	79	30	S. Atlantic
R. Magdalena (Colombia)	0.25	228	144	560	Caribbean
R. Atrato (Colombia)	.035	81	11	315	Caribbean
R. Uruguay (Uruguay)	0.24	253	11	45	S. Atlantic
R. Negro (Argentina)	0.10	30	13	140	S. Atlantic
R. S. Fran (Brazil)	0.64	97	6	10	S. Atlantic
R. San Juan (Colombia)	0.014	82	16	1150	N. Pacific
R. Patía (Colombia)	0.014	10	14	972	N. Pacific
R. Chira (Peru)	0.020	5	20	1000	S. Pacific

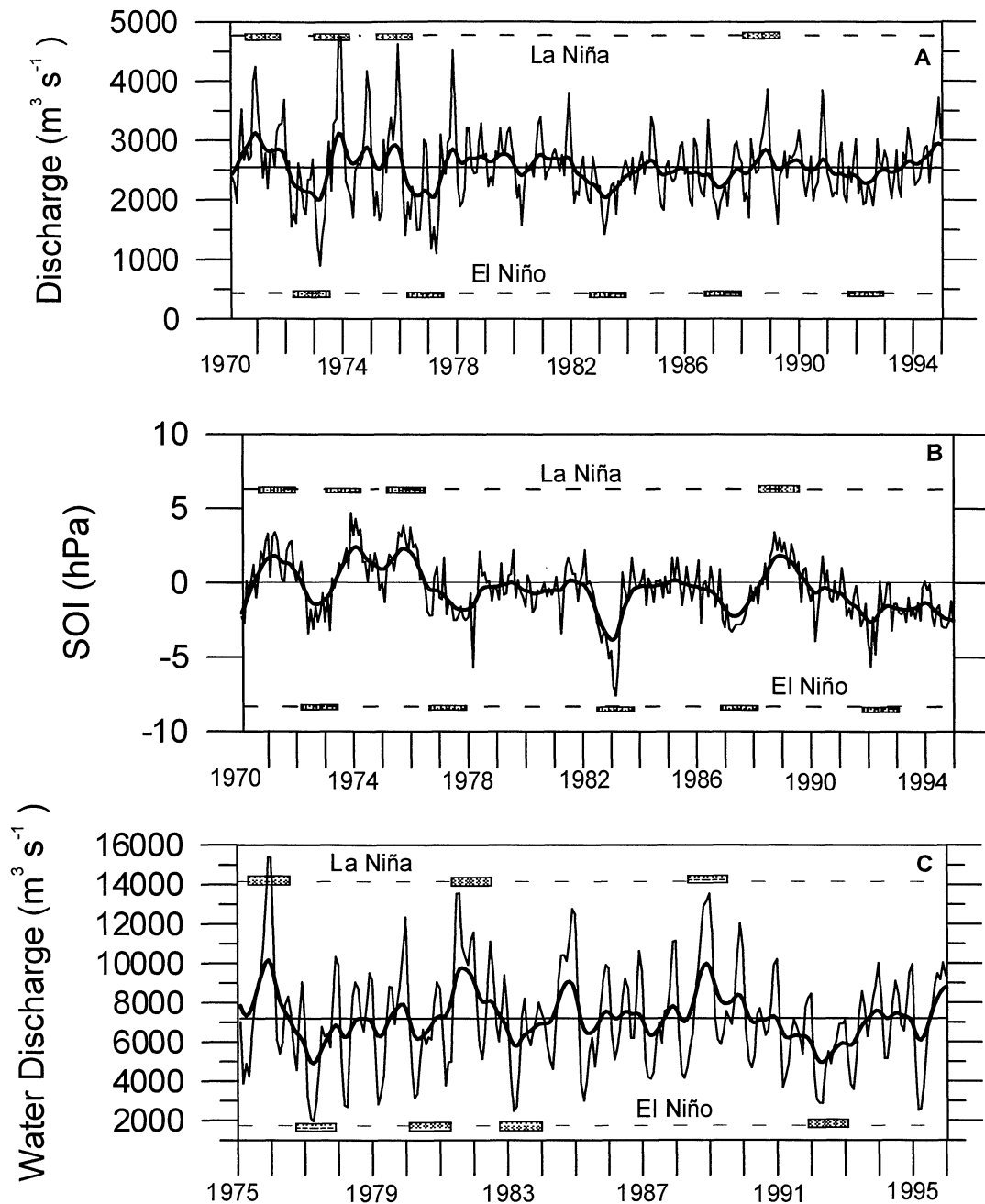


Figure 5.10. Time series plots of mean monthly (thin lines) and low-frequency pass filter with zero phase (bold lines) (A) water discharge for San Juan River 1970-1994; (B) the Southern Oscillation Index (SOI) (National Oceanic and Atmospheric Administration-NOAA, 1999, data-base on the Internet at <http://ftp.ncep.noaa.gov/pub/cpc/wd52dg/data/indices>); and (C) water discharge for Magdalena River 1975-1995 (modified from Restrepo and Kjerfve 2000a and 2000b).

To understand the relationships between natural climatic variability and the anthropogenic changes that have taken place in the drainage basins of South America during the past century, on one hand, and how these factors influence the delivery of water and sediments to coastal areas, on the other hand, has economic and social importance. Sediment delivery is often associated with the input of nutrients, heavy metals, and chemicals, which frequently are adsorbed to sediment surfaces. However, to be able to manage rivers and water resources rationally requires the collection of reliable data from fixed river gauging stations. Such data should include daily stage measurements, daily sediment concentration measurements, and daily measurements of appropriate water quality parameters, along with the determination of a stage rating curve

for the gauge site. Although some of the rivers in South America have been monitored since the beginning of the century, as in the case of the Paraná River, many rivers are not being monitored routinely. This is unfortunate, and it seems that it would be in the best interest of all countries of the continent to expand or initiate national river monitoring programs. The collected data are usually entered into databases by government agencies but are not necessarily shared or easily obtained by research scientists. This is also unfortunate, as continental-scale analysis of river hydrology would probably result in better understanding of physical processes and also allow for better predictions, and thus aid in the management and planning process.

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5.4 Impacts of land-based activities on the Ceará coast, north-eastern Brazil

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Introduction

The north-eastern coast of Brazil, and in particular the coast of Ceará State, has witnessed a rapid economic growth during the last two decades, mostly associated with activities in the coastal zone. The establishment of large harbor facilities associated with industrial complexes, plus the exponential growth of tourism and aquaculture, have resulted in fast urbanization and population growth, mostly without the infra-structure necessary to keep the exploitation of the natural resources sustainable. For example, the population of Fortaleza, the State's capital, increased from 140,000 in the 1950's to over 2.3 million in 1995 (Valentini 1996). Population density along the coast is 108 inhab.km² - over 60% of the state's population. Notwithstanding this development in the coastal region, many traditional artisanal activities still support a large portion of the local population, in particular artisanal fisheries, exploitation of mangrove products and subsistence agriculture.

The region's countryside is semi-arid, with annual rainfall of 500-700 mm. Water is of crucial importance to support the development of the state's economy, mostly for irrigated agriculture and for human consumption. Since the late 1800's over 170 dams have been built in most river basins, mostly medium-sized and at least two large ones, with clear impacts on the coastline. Land-based activities are significant sources of environmental impact on the coastal zone but are still not well understood or taken into consideration in regional integrated coastal zone management plans.

The region

The coast of Ceará State, north-eastern Brazil, extends for roughly 570 km between latitudes 3°7' S and 4°50' S and longitudes 42°15' W and 39°45' W (Figure 5.11). The region's population is about 3.1 million with an average density of 110 inh.km² (MMA 1996a,b). The climate is semi-arid, with rains concentrated in 3-4 months of the year (February-May), when about 400-1,200 mm falls.

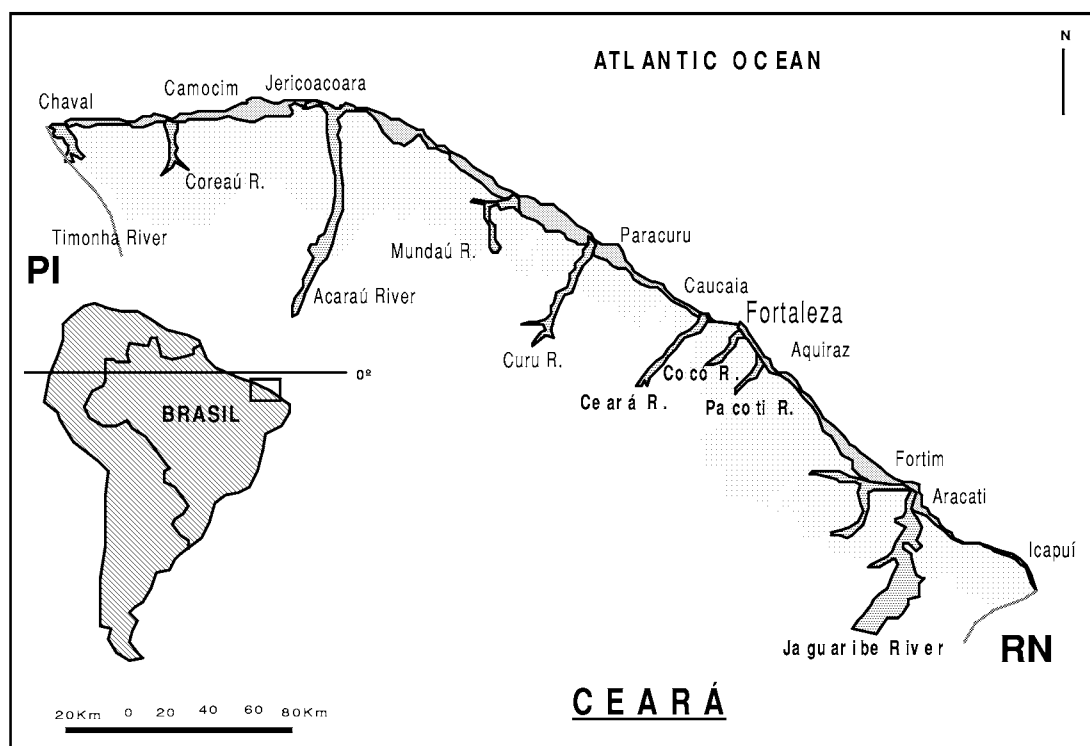


Figure 5.11. Map showing the coastline of Ceará State and major catchments.

Monthly rainfall of the remaining 8 months is always less than 80 mm (ANEEL 2000). Rainfall patterns in Ceará State show large site-specific spatial and temporal variation. Thus, annual rainfall can be consistently below 400 mm at Inhamuns in the central lowlands and more than 2,000 mm in the Ibiapaba Mountains. There is a similar increase from 500-700 to 800-1000 mm in annual rainfall from east to west. During the rainy season strong rains followed by floods are common.

Coastal sandy plains with large aeolian dune fields, driven by the year-round almost constant south-easterly winds with average speed 6.3-7.9 m.sec⁻¹, characterize the coastline (Jimenez *et al.* 1999). The total drainage basin is about 200,000 km² and total river discharge to the sea is about 200 m³.sec⁻¹, being strongly seasonal (ANEEL 2000). Maximum tidal amplitude reaches 2.8 m (DHN 2001) and the generally small freshwater supply results in salt intrusion for a few kilometers inland (Freire *et al.* 1991). The brackish water tidal flood plains are covered by about 11,000-23,000 ha of mangroves (estimates by Herz, 1991; Freire and Oliveira 1993). Coastal lagoons created by the blocking of small river mouths by sand ridges due to marine and aeolian sand transport are also a typical feature of the coastline. Major river basins are the Jaguaribe River at the eastern end of the coast, the Fortaleza metropolitan basin, including the Pacoti, Cocó and Ceará rivers and the Acaraú River to the west.

Major coastal impacts from land-based activities

Major impacts/issues and critical thresholds on the north-eastern Brazilian coast are summarized in Table 5.5. Sediment trapping through damming, and water withdrawal for irrigated agriculture, are the major drivers causing impacts on the coastal zone. Most significant impacts are erosion, increasing saline intrusion, nutrient depletion and, for some areas, sedimentation due to increasing marine sand deposition in estuaries. In some rivers sand-mining also results in similar impacts at the coastal zone.

Most rivers that drain to the Ceará coast are affected by erosion, due to decreasing continental sediment fluxes because of damming. Within the metropolitan area of Fortaleza, erosion has destroyed about 6 x10⁶ m² of seafront (Valentini 1996), but this is mostly due to jetty and harbor construction rather than decreasing continental sediment load through rivers, since rivers are seasonal and total less than 40 m³.s⁻¹ along that section of coastline (ANEEL 2000).

Rebouças (1999) estimated the availability of freshwater in Ceará State as 2,279 m³.inhab⁻¹.yr⁻¹, close to the lower end of what is considered a regular water supply (2,000 to 10,000 m³.inhab⁻¹.yr⁻¹: UNDP 1997). This water scarcity triggered a process of river damming and reservoir construction in the 20th century. Today most of freshwater flux from all river basins of Ceará State is artificially controlled. Damming levels of the major catchments of Ceará State are summarized in Table 5.4. The Jaguaribe River Basin (Figure 5.11) has over 87% of its freshwater flow controlled by artificial dams and reservoirs, while the Aracaré and the Metropolitan basins both have over 70% of their freshwater flow artificially controlled.

Table 5.4. Damming density of major river basins in Ceará State, NE Brazil.

Basin	Basin area (km ²)	Damming density (10 ³ m ³ .km ⁻²)
Jaguaribe River	72,043	92.7
Acaraú River	14,423	13.3 – 34.7
Metropolitan	15,085	13.2 – 46.36

The river most affected by erosion due to damming is the Jaguaribe River, at the eastern end of the region. The Jaguaribe basin is mostly semi-arid with average annual temperature higher than 18°C and annual rainfall less than 500 mm inland, reaching 800-1,000 mm at the coast. Along its basin hundreds of dams and reservoirs have been built since 1906. Small reservoirs accumulate about 20% of the total dammed freshwater, whereas the few large reservoirs, less than 1% of the all reservoirs in the basin, concentrate over 70% of the accumulated freshwater. The largest of them, the Orós, with a nominal capacity of 1.94x10⁹ m³, was built in 1962, followed by the Banabuiú (1.0x10⁹ m³) and the Pedras Brancas (0.43x10⁹ m³); these drastically affected the genetic systems, mostly by transforming the river into a perennial flow, but avoiding the seasonal high inputs of sediments during the rainy period.

The Jaguaribe River basin covers about 72,000 km², representing almost half of the Ceará State's territory (Campos *et al.* 1997). This river is responsible for about 70% of the total freshwater input to the adjacent Atlantic Ocean and has been used as major freshwater supply for irrigation and urban uses along its entire length. Average freshwater discharge to the Atlantic Ocean ranges from 60-130 m³.s⁻¹ (ANEEL 2000), but can vary widely over long periods from nearly zero to about 7,000 m³.s⁻¹ (Campos *et al.* 1997). Freshwater discharges during the 20th century modeled by Campos *et al.* (1997) reflected the building of dams along the Jaguaribe River. Prior to the building of the Orós Reservoir, discharges to the Atlantic Ocean reached 200 m³.s⁻¹. During the 1960's and 1980's, discharge to the ocean decreased to 80 m³.s⁻¹. After 1996 freshwater discharge reached its present level of about 60 m³.s⁻¹. With the building of the Castanhão reservoir (4.5x10⁹ m³ storage capacity) programmed to start operations in 2002, the freshwater input to the ocean is expected to decrease further to about 40 m³.s⁻¹ (Bezerra 1996).

Present estimated sediment load to the Atlantic Ocean from the Jaguaribe River is about 60,000 t.yr⁻¹ (Cavalcante 2000). This extremely low sediment supply results in a coastal morphology dominated by marine and aeolian process. Marine sand transport is estimated as 600,000 m³.yr⁻¹, whereas aeolian transport reaches about 200,000 m³.yr⁻¹ (Valentini 1996). Although significant erosion is occurring at the river estuary (Morais and Pinheiro 1999) due to marine and aeolian sand transport, sedimentation of mangroves and coastal lagoons by marine sands also occurs (Freire 1989).

The decrease in sediment transport to the sea due to damming and water withdrawal also affects important coastal ecosystems, particularly mangroves. These forests require sedimentation rates of about 1 mm.yr⁻¹ to keep pace with the general sea level increase (Smoak and Patchineelam 1999) to avoid erosion. Along many estuaries the supply of sediments to the coast is much less than that, resulting in severe erosion and death of mangrove trees. The immediate impact is on crab fisheries, a significant income for the local population. Sequestering of sediments in dams may also decrease nutrient inputs to the coastal area. The Ceara coast of Brazil is fairly oligotrophic, with chlorophyll *a* concentrations ranging from 0.05 to 0.5 mg.m⁻³ and primary production ranging from 0.02 to 0.2 gC.m⁻².d⁻¹. Most of the primary production of coastal waters depends on outwelling of river-derived nutrients (Ekkau and Knoppers 1999a,b; Medeiros *et al.* 1999).

The Acaráu River basin and the Metropolitan basin also show high rates of impoundment. The Acaráu River (Figure 5.11) runs for 315 km from the 800 m high Ibiapaba Mountains to the west coast of the state. Impoundment density is also high and 650 to 680 reservoirs exist in the basin; 170-190x10⁶ m³ of water are accumulated in reservoirs with nominal capacity larger than 50x10⁶ m³. The Metropolitan basin includes 16 sub-basins with headwaters in the Baturité Mountain range. One third of the state's population lives in this basin. Most important sub-basins are the Ceará River with nearly 780 km² and the Pacoti River (1,260 km²). Impoundment density is also high (294 m³.km⁻²) with major dams on the Pacoti River (370x10⁶ m³).

Another key impact generator at the coastal zone is the rapid urbanization, in particular in the metropolitan area of Fortaleza. The major rivers of the area, the Cocó and Ceará rivers, are showing strong signs of eutrophication. In the Cocó River dissolved oxygen, a good index of eutrophication, is less than 4.0 mg.l⁻¹ 25 km from the mouth. Ammonium concentrations are also higher than the maximum allowed concentration (1.0 mg.l⁻¹, CONAMA 1986). Other nutrients and pathogens are also present in this river at elevated concentrations (Almeida *et al.* 2000, Mavignier 1992). Algal blooms are frequent in the shallow waters of the Cocó River estuary, particularly during the rainy season.

Urbanization, and to a lesser extent industrialization, has also caused the increase in the concentration of trace metals in rivers and estuaries. The relatively extensive mangrove forest acts as a barrier to the transport of trace metals to the sea (Marins *et al.* 2001). However this natural sink of pollutants is presently threatened by development of estuarine areas for tourism and aquaculture. Aquaculture has rocketed from a few thousand dollars in the 1980's to over 10 million in 2000 (Junior 2000) and new farms are planned to start operation in the next few years. Although the local environmental authorities and the Ministry of the Environment tightly control mangrove and water quality, most of these farms constitute a permanent threat to the local biological communities since they largely utilize exotic species.

The damming of the rivers has allowed the development of irrigated agriculture, contributing to the water withdrawals and increasing soil erosion. Agriculture residues may contribute to pollutant discharge to rivers

and salinization. Water withdrawal for agriculture also contributes to the increasing salinity in groundwater in many coastal sites. At the Pacoti River, annual salt balance showed a residual accumulation of salt of about 135,000 t in the local mangroves, nearly 680 t.ha⁻¹ (Freire *et al.* 1991). Some of it may be flushed out to the ocean in exceptionally rainy years, but a residual buildup in soil salinity and landward intrusion through groundwater occur.

Management and scientific response to coastal impacts

Surveys and monitoring of water and sediment fluxes of the Ceará rivers are maintained by both State and Federal agencies (SRH and ANEEL, respectively). The coastal zone is managed by the National Integrated Coastal Zone Program of the Ministry of the Environment, enforced by the State's Secretary of the Environment. Federal organisms also monitor mineral resources and fisheries. The legal framework is, in general, able to cope with most problems related to the coastal zone. However, there are not sufficient initiatives to control and/or minimize impacts along river catchments. The example of the Jaguaribe River damming is outstanding. While water management plans along the basin take care of bank erosion, water quality and other problems related to the river itself, they completely fail to foresee erosion or nutrient depletion problems in the coastal seas. Scientifically, two large universities and research institutes from the Navy, the Ministry of Agriculture and the Ministry of Energy and Mines develop programs along the Ceará coastline. However, most projects also lack interdisciplinary efforts to cope with catchment-coastal zone interactions, although recent programs under the National Research Council include this factor.

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Table 5.5. Major coastal impacts/issues and critical thresholds in the north-eastern Brazilian coastal zone – Overview and qualitative ranking. Refer to Figure 3.1 for location. Impact category: Class of importance: 0 = none, 1 = minimum, 10 = maximum. Time scale: progressive, d = discrete. Trend expectation: \uparrow = increasing, \downarrow = decreasing, \leftrightarrow = stable

Driver	Coastal impacts	River basins	Pressures	Critical threshold	Distance to critical threshold	Impact category	Scientific and management response
Damming	Erosion (coastal geomorphology)	Jaguaribe River estuary at Fortins (1) Icaraí coastline (2)	Sediment trapping and decreasing river transport capacity.	For coastal stability a sustained delivery of $0.6 \times 10^6 \text{ t yr}^{-1}$ of sediments is necessary at the Jaguaribe river (1)	Present sediment delivery is from 10-50% of the critical load. Strong seasonal variation however, occurs (3)	9, p, \uparrow	Region description CPRM monitoring of natural resources (4), hydrological monitoring (5,6)
	Sediment and sorting depletion	Jaguaribe River Delta flood-plains, mangroves and mud flats Pacoti River estuary	Sediment trapping and decreasing river transport capacity.	Supply of about 1 mm yr^{-1} of fine sediments to keep mangrove and mud flat communities (7,8)	Not known, needs measurements of sedimentation rates of local mangroves. However, erosion and siltation can be seen in many mangrove areas of both rivers (9)	5, p, \uparrow	Sediment and nutrient monitoring (11), PRODETUR (12), PROURB (13)
	Increasing marine sand supply	Jaguaribe and Pacoti river estuaries		Benthic and mangrove community siltation. Critical threshold about less than 100 t yr^{-1} (10)	Unknown, indication of occurrence due to dying mangroves	4, p, \uparrow	Sedimentological balance (9)
	Nutrient depletion	Estuary and adjacent coastal zone of the Jaguaribe River mouth	Sediment trapping	Chlorophyll <i>a</i> concentrations 0.05 to 0.5 mg m^{-3} . Primary production 0.02 to $0.2 \text{ gC m}^{-2} \text{ d}^{-1}$, - a typical oligotrophic water mass. Surface NO_3 and PO_4 concentrations about 0.2 and $0.25 \text{ }\mu\text{M}$ (14)	Regional oligotrophy may increase, but no site-specific historical trend study is available. Majority of the coastal primary production depends on river-transported nutrients (14,15).	4, p, \uparrow	Nutrient flux monitoring (11), JOP's I and II (15),

Urbanization	Eutrophication Pollution	Cocó and Ceará Rivers and adjacent beaches	Increase of nutrient-rich and BOD-rich wastes. O ₂ depletion. Algal blooms. Increasing trace metal levels in estuarine sediments	Pristine rivers in the region have dissolved oxygen levels of about 5.0 mg.l ⁻¹ , NO ₃ is in general <1 µg.l ⁻¹ , whereas dissolved organic nitrogen (DON) is <0.6 µg.l ⁻¹ (11, 16, 17)	Estuaries of affected rivers present dissolved O ₂ ranging from 2.5 to 4.9 mg.l ⁻¹ . NO ₃ and DON concentrations may reach 60-80 µg.l ⁻¹ and 6 to 15 µg.l ⁻¹ (11, 16, 17)	8, p, ↑	Nutrient flux monitoring (11), PRODETUR (12) and PROURB (13)
Agriculture	Altering food webs and trophic status	Estuaries of metropolitan rivers of Fortaleza, Cocó and Ceará rivers	Increase of nutrient-rich and BOD-rich wastes. O ₂ depletion. Algal blooms	Existing ecological communities, presently very poorly known	Totally unknown but algal blooms occurs typically during the rainy season	4, p, ↑	(18)
Agriculture	Erosion	Jaguaribe River	Decrease of water volume and flow transport capacity due to water withdrawal for irrigation	For coastal stability a sustained delivery of 0.6x10 ⁶ t per year of sediments is necessary at the Jaguaribe River	Unknown	1, p, ↑	(1)
Agriculture	Sedimentation	Acarau and Pacoti rivers	Facilitating soil erosion	Background concentrations equal to zero (pesticides) or very low (< 0.5 µg.l ⁻¹ for Cu) (19)	Unknown	1, p, ↑	(9)
Aquaculture	Pollution	Jaguaribe River	Increasing inputs of pesticides and some trace metals (e.g. Cu)	Background concentrations equal to zero (pesticides) or very low (< 0.5 µg.l ⁻¹ for Cu) (19)	Unknown	1, p, ↑	No response to now
Aquaculture	Eutrophication	Prangi and Jaguaribe rivers	Increasing inputs of nutrients	Unknown	Unknown	1, p, ↑	Monitoring by the local environmental authority

* During the filling phase of reservoirs, flooding of marginal areas results in discrete (short-term, months to a few years) increase in nutrients (Tundisi, 1999).

1 – Morais and Pinheiro (1999), 2 – Valentini (1996), 3 – Lacerda (pers. comm.) 4 – CPRM (1996), 5 – ANEEL (2000), 6 – SRH (1998), 7 – Patchineelam and Smoak (1999), 8 – Ellison (1993), 9 – Freire (1989), 10 – Lacerda (1993), 11 – Marins et al (2001), 12 – PRODETUR – Programa de Ação Para o Desenvolvimento do Turismo no Nordeste, Banco do Nordeste, 13 – PROURB – Projeto de Desenvolvimento Urbano e Gestão de Recursos Hídricos do Ceará, 14 – Medeiros *et al.* (1999), 15 – Ekau and Knoppers (1999a,b), 16 – Mavignier (1992), 17 – Almeida *et al.* (2000), 18 – Soares Filho and Alves (1996), 19 – CONAMA (1986).

5.5 Anthropogenic fluxes of sediments and trace metals of environmental significance to Sepetiba Bay, SE Brazil

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Introduction

Coastal areas are integrators of the activities taking place within their basins. Notwithstanding their increasing socio-economic value, which results in the enforcement of regulations on the use of coastal areas and other *in situ* activities, they are permanently threatened by basin activities. Among the major stressors on coastal ecosystems generated within their basins are trace elements. These substances are the ubiquitous by-products of most anthropogenic activities and reach coastal waters through rivers and the atmosphere, even when sources are located far from the coastline. One example, mercury contamination of ecologically and economically important coastal areas of SE Brazil, is due to diffuse inputs from the atmosphere, which receives mercury from a variety of sources located along river basins far from the coastal area (Marins *et al.* 1996; 1999). Copper contamination of Empress Augusta Bay, Papua New Guinea, is due to the fluvial transport of tailings material from mining operations located 700 m above sea level in the central mountain range of the island, as far as 50 km inland (Jeffery *et al.* 1988). Despite controls applied to metal-emitting activities located in the coastal area, basin activities can still contribute to a significant input of trace metals to coastal ecosystems and time-delayed effects can occur even many years after the banning of the trace metal source.

Sepetiba Bay and basin, SE Brazil (Figure 5.11) is an example of the environmental significance of basin-generated impacts on the coastal zone. The concentration of industries, urban centers and agriculture along the north-eastern shore of Sepetiba Bay make this area of SE Brazil the most critical in terms of environmental contamination by trace metals. The bay itself is relatively free of direct inputs of most industrial contaminants, which are delivered by rivers and atmospheric deposition (Lacerda *et al.* 1987). Table 1 summarizes major economic activities of Sepetiba Bay basin. Despite the anthropogenic activities, the bay still harbors important ecological areas for fish reproduction (Barcellos 1995; Marins 1998). Engineering works carried out during the 20th century to improve water supply, energy generation and land reclamation have also resulted in significant changes in sediment load to the bay.

Physical setting

Sepetiba Bay (Figure 5.12) is a semi-enclosed water body, connected to the sea in the east by a small, shallow inlet, with little water flow which crosses extensive mangrove forests. In the west a large natural channel, running between the large islands of Jaguanaum and Itacurussa, with depths of 30 m, keeps a regular water exchange with the sea. The bay's area at high tide is 447 km² while minimum area at low tide is 419 km². Mean water volume is 2.56x10⁹ m³, ranging from a maximum of 3.06x10⁹ m³ and a minimum of 2.38x10⁹ m³. The depth averages about 6 m. The tidal prism volume is 3.4x10⁸ m³, and the ratio between tidal prism and fluvial inputs is ~0.03, characterizing the bay as a typical well-mixed estuary. The turnover time of the water mass was estimated at around 6 days, with maximum current velocity at peak of tides ranging from 50-75 cm.s⁻¹ (Barcellos *et al.* 1997).

Sepetiba Bay is in a region with hot-humid tropical weather, with mean annual precipitation of 1,400 mm, and mean evaporation of 960 mm. Nine rivers draining the quaternary plain at the north-eastern coast of the bay, are responsible for almost all freshwater inputs to the bay, with an annual flow of 7.6x10⁶ m³. Among them, the São Francisco Canal, with an annual flow of 6.5x10⁶ m³, accounts for 86% of the total fluvial inputs. This canal is artificial, keeping an almost constant flow throughout the year. Circulation in the bay is driven by the winds and tides. The dominant wind is from the south-west (250°), bringing seawater from the Atlantic through the western channel. This water gets hotter in the inner portion of the

bay close to river mouths, creating a clockwise current pattern, driving freshwater and fluvial sediments southwards, and keeping water salinity around 30 psu. However during strong north-east (70°) winds, this clockwise pattern is disrupted and most of fluvial inputs goes directly through the main channel to the Atlantic, dropping surface salinity to about 25 psu (Barcellos 1995; Marins 1998).

Apart from the marine ecosystem, and the islands and the rocky northern shore covered by tropical rain forests, the bay supports 40 km² of mangrove forests, which are most developed at the inner eastern end and provide nursery and feeding areas for the bay's fisheries (Lacerda 1998).

Socio-economical setting

The lowlands of the eastern coast of Sepetiba Bay, with good transport facilities, cheap and ample land, good fresh water supply and low population density, became a focus for industrial and urban development within the state from the late 1970's, after the construction of large harbor facilities. In the last two decades 400 industries, basically metallurgical, have been established in the region, including a large petrochemical plant and two other large (>10,000 t per year production) pyrometallurgical factories currently under construction.

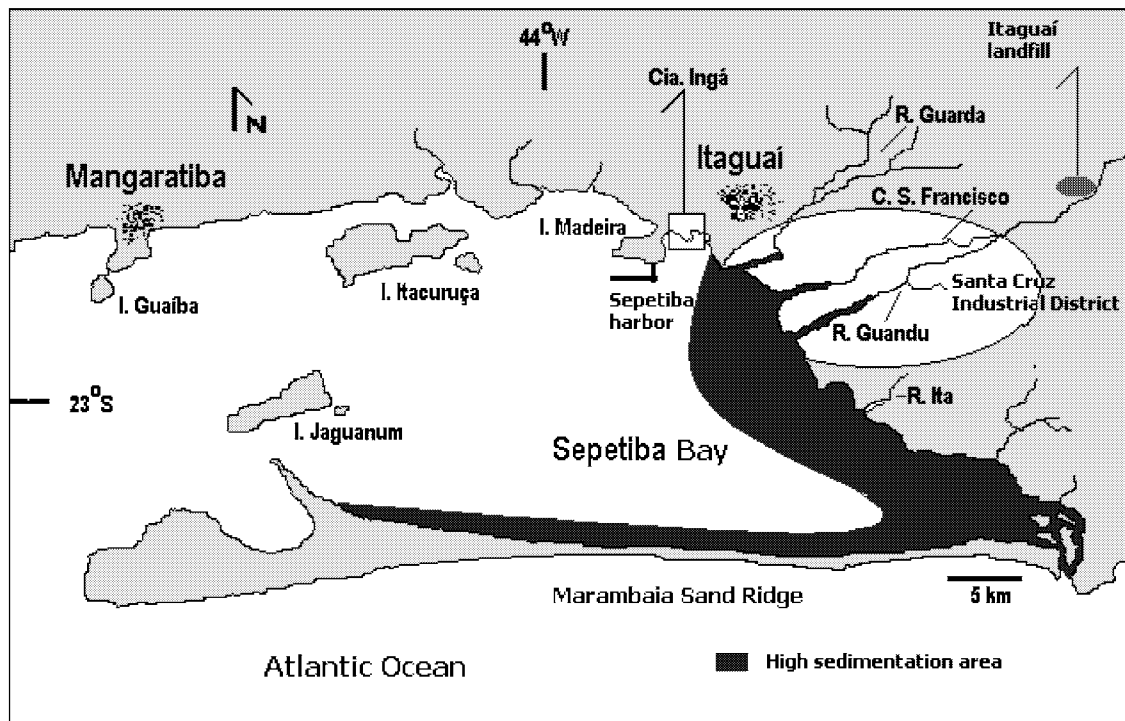


Figure 5.12. Major geographical features of Sepetiba Bay, SE Brazil

Apart from industry, agriculture and urban developments, fishing and tourism are two other main activities in Sepetiba Bay. Fishing employs about 3,000 people directly, catching shrimp, flatfish and mullet. Total commercial catches were about 800 tons in 1987 (270 tons shrimp), after a peak in the early 1980's of about 1,000 tons (550 tons shrimp). The reduction in fish catches, in particular of shrimp, is probably due to over-fishing; a fish reserve has been established in the area. During the last decade, commercial annual fish catches remained around 1,000 tons, with 30 to 50 % being shrimps.

Artisanal fisheries, mostly of mangrove-dwelling species, were typically of the same order of magnitude of commercial fisheries (~1,000 tons) during the 1980's. However, over-fishing by commercial trawlers damaged the nursery grounds, resulting in an 80% reduction of artisanal fish catch. Unemployment was avoided by transferring the work force from artisanal fishing to tourism-related activities.

Tourism is growing fast in the region. More than 30 hotels and dozens of restaurants are operating along the bay's shores, and sightseeing boats attract 5,000–10,000 tourists in summer weekends. As a result of the unplanned development, environmental contamination of the bay is now in direct conflict with the many economic options for the region's development (Lacerda *et al.* 1988).

Sediment loads and sedimentation rates during the twentieth century

One of the most striking aspects of coastal zone change due to anthropogenic activities in Sepetiba Bay basin is related to sediment transport and sedimentation rates in the bay. Figure 5.13 shows the evolution of sedimentation rates during the past 100 years, based on ^{210}Pb dated sediment cores collected in the north-eastern shore of the bay (Forte 1996). Prior to 1900, sedimentation rates were about $30 \text{ mg cm}^{-2} \text{ yr}^{-1}$. At the beginning of the 20th century, civil engineering works were initiated in the bay's basin, mostly to control malaria, by digging and straightening river channels and building artificial canals. Although of relatively small scale, these engineering works have more than doubled the sediment accumulation rates in the bay.

The engineering works continued until the 1950's, when a large hydro-electric dam was built to collect waters from the Paraíba do Sul River, an adjacent basin that until then discharged into the Atlantic Ocean 400 km north of Sepetiba Bay. Up to 80% of the flow of the Paraíba do Sul River was diverted to the Sepetiba Bay basin, and a large artificial canal (the São Francisco Canal), with flow volume of about $180 \text{ m}^3 \text{ s}^{-1}$, was built to carry the waters to Sepetiba Bay. This not only increased the amount of fresh waters reaching the bay by a factor of 10, but also increased sedimentation rates to over $250 \text{ mg cm}^{-2} \text{ yr}^{-1}$. After the 1970's, the creation of an industrial district and the increasing population resulted in extensive deforestation of the basin, leading to a further increase in sedimentation rates to the present level of about $320 \text{ mg cm}^{-2} \text{ yr}^{-1}$.

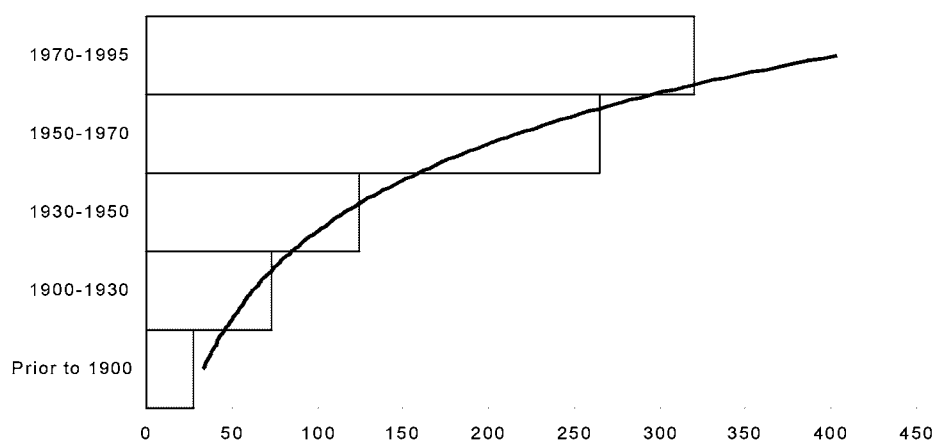


Figure 5.13. Sediment accumulation rates in Sepetiba Bay, SE Brazil ($\text{mg cm}^{-2} \text{ yr}^{-1}$; from Forte 1996).

Trace metals emission to Sepetiba Bay and basin

Several studies have characterized the emissions of trace metals to Sepetiba Bay and quantified their loads (Table 5.6) (Barcellos 1995; Barcellos and Lacerda 1994). These studies identified Cd, Zn and Pb as the major contaminants of the bay. Recently, estimates of mercury inputs from diffuse sources to the Sepetiba Bay basin highlighted the importance of this element to the overall contamination of the bay. Table 5.7 shows emission estimates for the four metals to Sepetiba Bay and basin (Barcellos and Lacerda 1994; Marins *et al.* 1998).

Table 5.6. Major economic activities which contribute with trace metals load to Sepetiba Bay (Barcellos and Lacerda 1994).

	Number of plants	Production (t.year ⁻¹)	Number of employees
<i>Metal smelting</i>			
Fe	03	1.102,000	4,053
Al	02	98,500	925
Zn	01	36,000	438
<i>Manufacturing</i>			
Paper	05	534,000	4,041
Chemicals	16	176,900	3,887
Metallurgy	19	33,370	4,372
Plastics and Rubber	03	30,900	1,722
Food processing	08	16,700	1,645
Other	13	7,200	1,996
Thermoelectric plant	01	160 MW	250
Fishery and agriculture	-	10,500	14,000
Harbor and navigation	01	19,000,000	300
Total	72	-	37,879

The principal sources of Cd and Zn are smelting works, particularly Zn smelters - these are typically point-source types of trace metals. Estimated emissions for Cd and Zn reach 29 and 4,153 t y⁻¹, respectively. Major emissions of Pb are from iron and steel production, about 346 t y⁻¹. Manufacturing, particularly of paper and plastics, are also significant sources of Zn and Pb. In the case of Hg, however, diffuse sources such as solid waste disposal and a thermoelectric power plant are the major contributors, with a total annual emission of about 0.41 tons (Barcellos and Lacerda 1994; Marins *et al.* 1999).

Emission of all metals is mostly to soils, associated with tailings and contained in solid wastes from metal smelting and landfill. Contributions to soils from all emission is estimated as 82%, 78%, 59% and 56% for Zn, Pb, Cd and Hg respectively. Direct contribution to the basin water bodies are less important for all metals, in particular for Zn and Pb. Emissions to waters are only 10%, 8%, 5%, 3% for Hg, Cd, Pb and Zn, respectively. Atmospheric emissions contribute significant amounts of trace metals, particularly Hg and Cd, reaching up to 36%, 34%, 17%, and 15%, for Hg, Cd, Pb and Zn, respectively. The greater emission to Sepetiba Bay basin soils highlights the significance of soil use changes as a key factor controlling the further mobilization of trace metals to the bay.

Trace metals input to Sepetiba Bay proper

Measurements of river and atmospheric inputs of trace metals to Sepetiba Bay are shown in Table 5.8. Major inputs are from rivers, particularly the three major rivers draining the most industrialized and urbanized sectors of Sepetiba Bay basin (Guandú River, Guarda River and São Francisco Canal).

Table 5.7. Estimated Cd, Zn, Pb and Hg loads to Sepetiba Bay and Basin from major economic activities in t.year⁻¹ (source: Barcellos and Lacerda (1994); Marins *et al.* 1999).

Activity	To soil				To air				To water				Total			
	Cd	Zn	Pb	Hg	Cd	Zn	Pb	Hg	Cd	Zn	Pb	Hg	Cd	Zn	Pb	Hg
Metal Smelters																
Fe	1.0	168	165	?	0.33	30	55	0.1	0.1	17	8.3	?	1.43	198	228	0.1
Al	0.03	1.6	0.4	?	0.01	1.1	0.1	?	0.01	0.03	0.01	?	0.05	2.73	0.55	?
Zn	14	3,000	29	?	9	600	3.6	?	1	60	0.58	?	24	3,660	33	?
Power plant																
	0.05	3.0	4.4	-	0.02	0.5	1.1	0.05	0.01	0.6	0.88	-	0.08	4.10	6.4	0.05
Sewage	-	-	-	-	-	-	-	-	0.05	12	3.07	0.01	0.05	12.0	3.1	0.01
Solid waste disposal	0.4	42	14	0.2	-	-	-	?	0.02	2.1	0.28	?	0.42	44.1	14.3	0.2
Agriculture	0.01	0.15	-	0.01	0.01	0.1	-	-	0.01	0.01	-	-	0.03	0.26	-	0.01
Urban runoff	0.3	6	2	-	-	-	-	-	0.03	0.6	0.1	-	0.33	6.60	2.1	-
Harbor and navigation	0.5	95	19	-	-	-	-	-	0.05	10	0.95	-	0.55	105	20	-
Manufing																
Paper	0.3	58	29	-	0.01	0.03	0.03	-	0.01	2.4	0.25	?	0.32	60.5	29.3	?
Chemicals	0.4	35	0.02	-	0.01	0.2	0.12	-	0.04	0.02	0.20	0.01	0.42	36.4	0.34	0.01
Plastic and rubber	0.04	3.9	7.7	-	0.9	8.3	1.24	-	0.01	0.26	0.01	0.01	0.95	12.5	9	0.01
Metallurgy	-	10	?	0.02	-	1.0	-	-	-	1.1	-	0.04	-	12.1	-	0.02
Total	17	3,423	271	0.23	10.3	641	61	0.15	1.3	106	15	0.07	29	4,153	346	0.41

Significant inputs of Zn and Cd (about 38% and 11% of the total, respectively) reach the bay through the atmosphere. Direct atmospheric Hg and Pb input to the bay corresponds to only 5% and 2% of the total inputs (Marins *et al.* 1999).

Table 5.8. Heavy metals inputs to Sepetiba Bay (t y⁻¹; from Lacerda 1983; Pedlowiski *et al.* 1991; Barcellos and Lacerda 1994; Marins *et al.* 1999).

Input/metal	Zn	Cd	Pb	Hg
Atmospheric	56	0.2	3	0.03
Fluvial	144	1.8	43	0.65
Total	200	2	46	0.68

Comparison of measured inputs with estimated emissions for the four metals presents contrasting results. Inputs of Cd, Zn and Pb are lower than the estimated emissions by a factor of 21 for Zn, 15 for Cd, and 8 for Pb, suggesting that a significant portion of the emissions are retained in the basin. Basin retention therefore, is as high as 95%, 93% and 88% for Zn, Cd, and Pb, respectively. This also reflects the greater emissions to soils compared with that to the atmosphere and waters. In the case of Hg however, measured inputs to Sepetiba Bay are higher than the estimated emissions by a factor of 1.7, although emissions to soils are still greater, as for Zn and Cd. Marins *et al.* (1999) suggested that fluvial inputs from the Paraíba do Sul river basin, which are diverted to Sepetiba Bay basin for the water supply for Rio de Janeiro city, may bring Hg to Sepetiba Bay basin. The Paraíba do Sul River has been found to contain larger Hg concentrations than the rivers of Sepetiba Bay basin (Marins *et al.* 1999).

Within the bay, trace metals are transported mostly associated with suspended particles and, following surface currents. This creates an area of high trace metals concentrations in sediments close to river mouths, moving clockwise to the south-west coast of the bay, where, unfortunately, a fishery reserve is located. Previous studies on the trace metal contamination of Sepetiba Bay biota have shown moderate to

high contamination, in particular for Cd and Zn, and to a lesser level of Hg (Pfeiffer *et al.* 1985; Carvalho *et al.* 1991; Kherig 1995).

Mass balance studies suggest that most of the trace metal loads to Sepetiba Bay are not buried immediately into bottom sediments. Rather, due to easy resuspension and high biological production in the water column, large fractions of the trace metals are exchanged between bottom sediments and the water column, which explains the contamination level found in the local biota. Modeling of trace metals cycling in Sepetiba Bay however, is not possible, due to the lack of a historical record for the region.

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