SOUTH AMERICAN BASINS

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

by

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

** Universidade Federal do Ceará, Brazil*
*** LOICZ International Project Office, Texel, The Netherlands*
**** University of South Carolina, Columbia, South Carolina, USA;*
***** Free University, Amsterdam, The Netherlands*

LOICZ REPORTS & STUDIES NO. 21

Published in the Netherlands, 2002 by:
LOICZ International Project Office
Netherlands Institute for Sea Research
P.O. Box 59
1790 AB Den Burg - Texel
The Netherlands
Email: loicz@nioz.nl

The Land-Ocean Interactions in the Coastal Zone Project is a Core Project of the "International Geosphere-Biosphere Programme: A Study Of Global Change" (IGBP), of the International Council of Scientific Unions.

The LOICZ IPO is financially supported through the Netherlands Organisation for Scientific Research by: the Ministry of Education, Culture and Science (OCenW); the Ministry of Transport, Public Works and Water Management (V&W RIKZ); and by The Royal Netherlands Academy of Sciences (KNAW), and The Netherlands Institute for Sea Research (NIOZ).

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.

Citation: L.D. de Lacerda, H.H. Kremer, B. Kjerfve, W. Salomons, J.I. Marshall Crossland and C.J. Crossland 2002. South American Basins: LOICZ Global Change Assessment and Synthesis of River Catchment – Coastal Sea Interaction and Human Dimensions. LOICZ Reports & Studies No. 21: ii+212 pages, LOICZ, Texel, The Netherlands.

ISSN: 1383-4304

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).

The LOICZ Reports and Studies series is published and distributed free of charge to scientists involved in global change research in coastal areas.

TABLE OF CONTENTS

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.

Acknowledgements

LOICZ is grateful for the generous sponsorship and support for the meeting by the Intergovernmental Oceanographic Commission IOC/UNESCO and the National Research Council of Brazil, CNPq.
LOICZ is indebted to Profs L. Drude de Lacerda and Gerardo Perillo and their teams from the University of Fortaleza and the Instituto Argentino de Oceanografia, Bahia Blanca, in dealing with the local organizational requirements needed for the successful meetings and the substantial scientific contribution they made to the progress of the SAmBas workshops.
These meetings set the scientific stage for the current second phase of the LOICZ Basins core project in Latin America and, with support from the regional networks that have been set up, will lead the way to continued work. We thank all participants who ensured the vitality of the highly interactive meetings, and contributed to this report.

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).

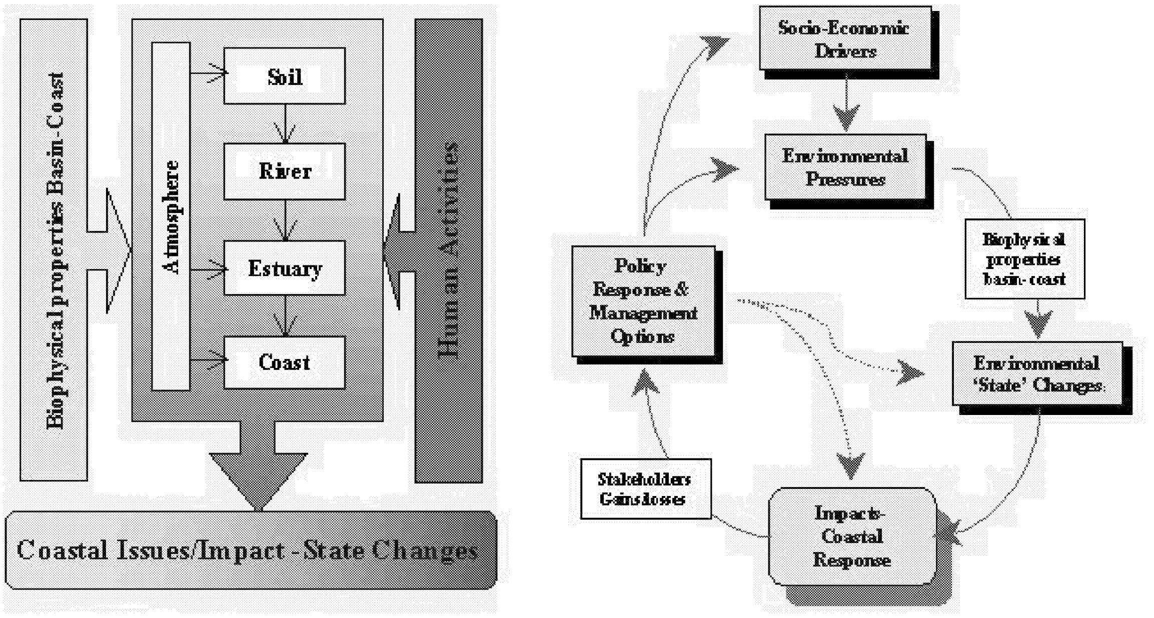


Figure 1.1 The catchment (island)-coastal zone system and the DPSIR framework.

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 dricvers-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 km^2, has a sediment yield of only 30 t.km^{-2}.yr^{-1}; the Negro River in Patagonia with similar basin area (100,000 km^2) also has relatively low water and sediment yields (860 m^3.s^{-1} and 140 t.km^2.yr^{-1}), compared with the much greater sediment yields of Pacific and Caribbean coastal catchments in Colombia, with basin areas 10 times smaller.

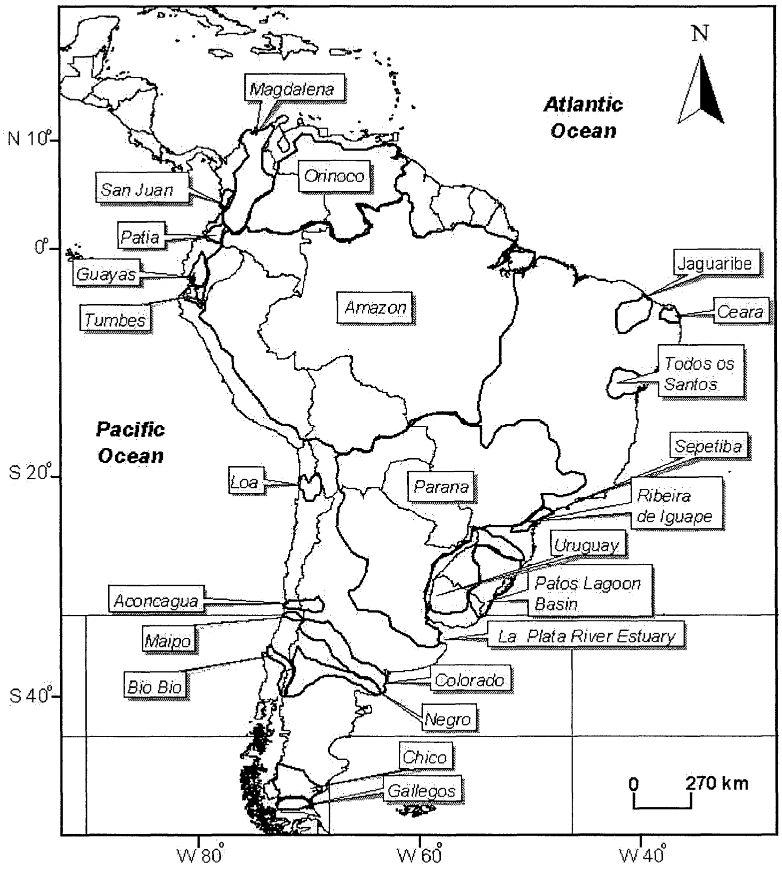


Figure 1.3. Rivers evaluated for issues, pressures, drivers and land-based activities in SAmBas Workshop 2.

Demonstration sites

After analysis and discussion of the various drivers, pressures, issues and impacts affecting changes in the catchment-coastal systems of South America, demonstrations 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	Diversion/ 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	Eutrophicatio/ 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	Eutrophicatio/ 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)	• Percentage of urban houses attended by treated sewage • Urban *vs* rural area • Dissolved oxygen concentrations. • Primary productivity rates
Emission of heavy metals	Concentrations of heavy metals in coastal waters, sediments and biota	MAC	• Frequency of occurrence of surpassing the MAC
Mangrove and salt marsh loss	Mangrove and salt marsh area	Replanting Conservation	• 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	• 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	• Beach loss rates • Dune loss rates • Mangrove and salt marsh erosion
Freshwater withdrawal	Ground water salinity	MAC	• Groundwater conductivity variation along gradients • Soil salinity
Fisheries losses	Fish stocks	Fisheries management legislation. Maximum capture Temporary bans	• 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.

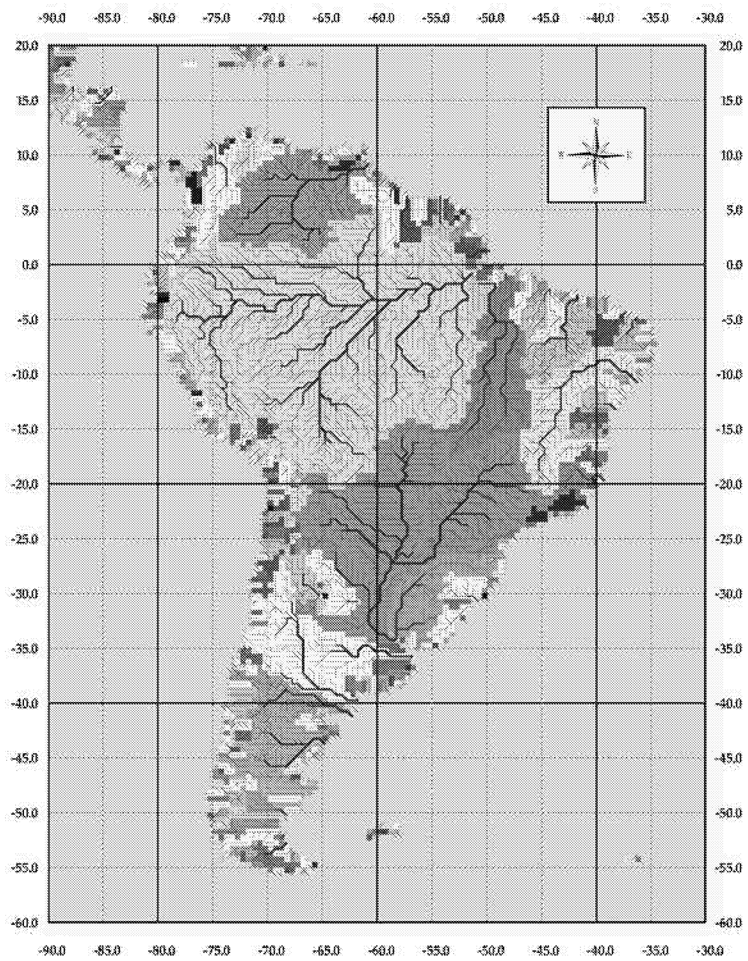


Figure 2.1. Major and minor river catchments in South America. Note the predominance of small river basins along the tectonically active Pacific coast, the Caribbean and a large stretch of the Brazilian coast (from: South American Drainage Basins: http://r-hydronet.sr.unh.edu).

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 km^2 in area

- medium basins, 10,000-200,000 km^2 in area
- large basins, >200,000 km^2 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.

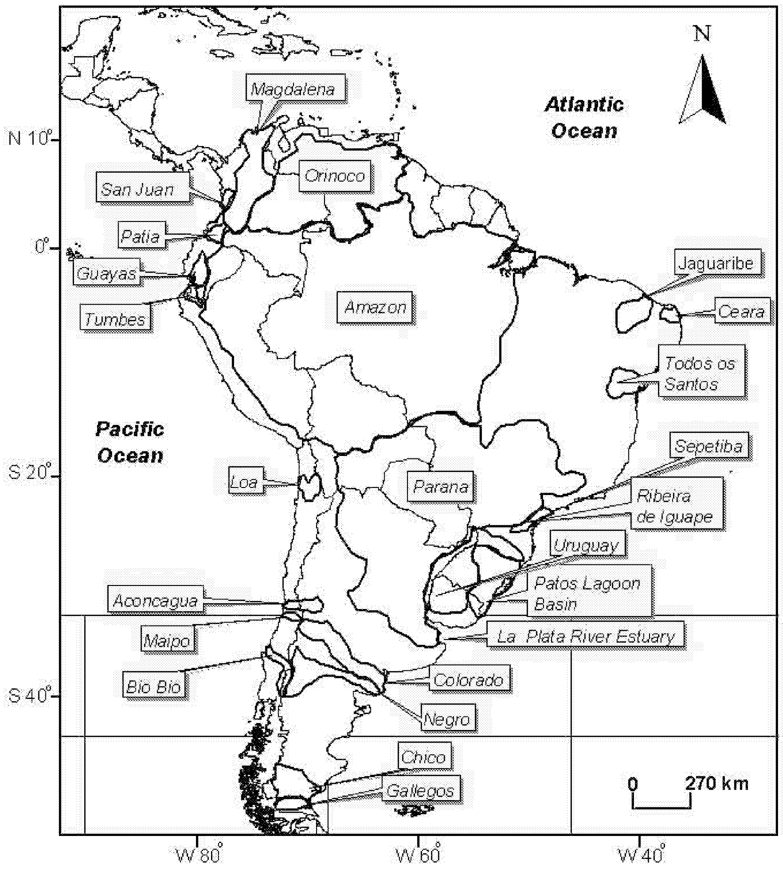


Figure 2.2. **Major catchments in South America addressed in the regional SAmBas assessment.**

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 km^2, 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 km^2, 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. Paríba 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.

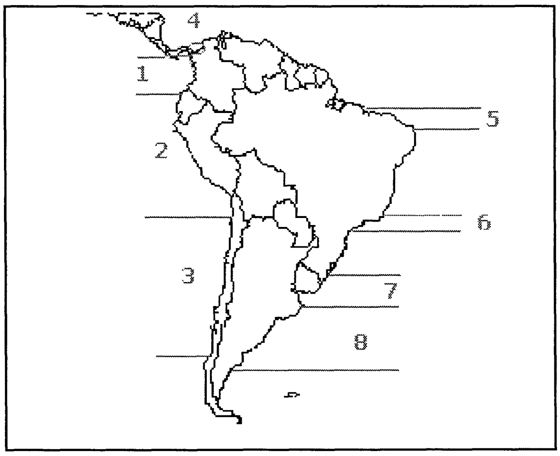


Figure 2.3. Sub- regional typology of South American river catchment–coastal sea interaction.

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 km^2 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 km^3 of freshwater is discharged annually into the Pacific Ocean, with a sediment load of nearly 31x10^6 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 km^2 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 km^3 of water and 144x10^6 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 22x10^3 km^2, respectively. However, water discharge is relatively small, less than 2,000 m^3 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	• Pollution (generated by urbanization, industry, mining • Deforestation (generated by agriculture) • Diversion of river discharges	• Rio Magdalena • Cartagena Lagoon (to be opened to the Caribbean)	• Nutrient and sediment discharges and concentrations available for the Magdalena River back to the 1970's, but refers only to the delta and the river.
Venezuela	• Industrial liquid discharges • Oil exploration and extraction • Livestock land use • Sewage (prevention still possible) • Agriculture	• Orinoco Delta • Neveri River • Catatumbo River • Maracaibo Lake • Tuy River • Limon and Aroa rivers • Unare/ Chama rivers	• Available information in comprehensive reviews, including nutrient and sediment discharges, have been published by MARNR and other government agencies.
Argentina	• Pollution (generated by urbanization and industry) • Erosion, siltation due to land use change • Oil spills (upstream)	• Rosario and Buenos Aires Province (due to transboundary transport from Brazil through the Paraná River) • Patagonia	• Overview reports on the Parana-La Plata rivers* • Bibliography from various case studies in small Patagonian rivers
Brazil	• Damming • Diversion • Irrigation • Agriculture (nutrient loads) • Deforestation • Navigation	• Jaguaribe River, NE coast, Ceará State • SE coast from the São Francisco River to Bay of Paranaguá • The Paraíba do Sul River-Sepetiba Bay, Rio de Janeiro	• Major bibliography sources reviewed and published, addressing major issues on Integrated Coastal Zone Management. The national Water Agency (ANEEL), monitors water fluxes in major rivers. Historical data available on the internet.
Uruguay	• Navigation (timber transport) • Agriculture (more irrigated rice paddies) • Irrigation	• Parana River* • Uruguay River • La Plata River	• 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 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 environmental 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 µm) 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 mg $cm^{-2}.yr^{1}$ in the early 1970's to >320 mg cm^{-2} 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 $2x10^{6}$ t yr^{1}, with a sediment yield of about 28 t $km^{-2}.yr^{-1}$. 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 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 rhreshold (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 *et al.* (2001); Isla (1997); Lopez and Marcomini (1998); Cionchi *et al.* (1993); Pasquine *et al.* (1997)
	b. Paraiba 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 x 10^3 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 *et al.* (2001); Bidone *et al.* (1999)
	c. Northeastern coast of Brazil: Jaguaribe River, Pacoti River, São Francisco River	c. 0.02-0.1 10^6 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 *et al.* (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^3yr^{-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, Bio Bio and Aconcagua rivers, Chile	i. Areas of low sediment dynamics	i. Sedimentation occurring in estuaries.	i. 3-5	i. Hajek *et al.* (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 *et al.* (1998); Manassero *et al.* (1998, 2000); Ronco *et al.* (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 *et al.* (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 rations 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 *et al.* (1999); Knoppers *et al.* (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 *et al.* (2001); Almeida *et al.* (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 *et al.* (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 µMN-NH_4 in the water column.	f. 6	f. Baisch (1997); Almeida *et al.* (1993) Baumgarten *et al.* (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 *et al.* (1990); Espinoza *et al.* (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*	a. Northern Patagonia rivers (Chubut; Negro, Colorado) and Gallegos River.	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. Organic micro-pollutants should be absent.	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.	a. 4-5	a. Gaiero *et al.* (2001); Gil *et al.* (1999); Harvey and Gil (1988); Amin *et al.* (1996)
	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		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}.	b. 10	b. Moyano *et al.* (1992, 1993); AGOSBA-OSN-SIHN, (1994); Moyano (1991); CARU (1993); ECOPLATA (1999); Marcovecchio and Moreno (1992, 1993); Segneur *et al.* (1991); Lacerda *et al.* (1998); Seeliger *et al.* (1988)
	c. Patos Lagoon basin.		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}.	c. 5	c. Niencheski and Baumgarten (1997)
	d. Iguape River to Sepetiba/ Guanabara basin		d. Cd, Cu and Zn concentrations in bivalves are extremely high in Sepetiba Bay, more than 20 times the maximum allowed for human consumption.	d. 10	d. Barcellos and Lacerda (1994), Lacerda *et al.* (1993); Seeliger *et al.* (1988);
	e. Todos os Santos Bay, Cocó/Ceara rivers, CE		e. Present Hg concentrations reach about 2-5 times baseline levels in "hot spots" along the SE Brazilian coast.	e. 4	e. Marins *et al.* (2001); Muller *et al.* (1999).

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		f. Cd, Cu and Zn concentrations in bivalves are extremely high in Cienaga Grande de Santa Marta, Colombia.	f. 3	f. INVEMAR (1997, 2000)
	g. Esmeraldas and Chone Rivers, Ecuador		g. Esmeraldas River shows high levels of Cu in waters (0.1-7.2 $\mu g\ l^{-1}$)and some organic micro-pollutants: Heptacloro = 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}.	g.7-8	g. PMRC (1993b)
	h. Acocagua and Loa Rivers		h. High flushing to open ocean due to coastal upwelling results in large dilution and low pollutants concentrations.	h. 1	h. Hajek *et al.* (1990); Espinoza *et al.* (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 *et al.* (2000).
	b. Magdalena River		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.glomis.com" }).
	c. La Plata River Estuary	Increasing introduction of exotic species such as *Vibrio chloreae*, bivalves and other groups.	c. Various reports of loss of fisheries. Mortality of mammals and fish, quantitatively unknown.	c. 8	c. Graña and Pineiro (1997); Acuña *et al.* (1997); INAPE reports; INIDEP reports
	d. Patos Lagoon estuary		d. Changes in zooplankton community structure; anatomic anomalies. Overexploited *Netuma* spp. stocks. Decline of up to 90% in abundance of viviparous sharks (*Rhinobathos horkelii; Galeorhinus galeus*).	d. 5	d. Montu and Gloeden, (1982); Haimovici *et al.* (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 *et al.* (2001); Barcelos *et al.* (1999); Lacerda *et al.* (2001); Forte (1996); Knoppers *et al.* (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. Vernette (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	a. Oligotrophic coastal area: Chl-*a* (0.05-0.5 mg.m^{-3}).	a. Not known	a. 3	a. Ekau and Knoppers (1999); Medeiros *et al.* (1999)
	b. Northern Patagonian rivers (Colorado, Negro and Neuquén)	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}.	b. Historical evolution of nutrient fluxes is unknown. However, there is evidence of nutrients being trapped in reservoirs.	b. 5	b. Depetris *et al.* (1999); Gaiero *et al.* (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**	• 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**	• 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**	• 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**	• 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**	• 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**	• Pollution • Sedimentation	**p**
Aquaculture	Increase of nutrient-rich and DBO-rich waste effluents. Deforestation. Water extraction.	**no impact**	**minor**	**major**	**major**	• 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 *et al.* (in prep.); Gaiero *et al.* (2001)
					b. Maia (1992)
		b. Jaguaribe River, NE Brazil	b. 3	⇑	c. COLCIÊNCIAS-FEN (1989)
		c. Magdalena River, Colombia	c. 8	⇑	d. Baish (1997), Baumgarten *et al.* (1995)
		d. Patos Lagoon estuary, Brazil	d. 7	⇑	e. Daneri *pers. comm.*
		e. Aconcagua River, Chile	e. 4	⇑	f. Daneri *pers. Comm.*
		f. Maipo River, Chile	f. 4	⇑	g. Kurucz *et al.* (1997)
		g. Rio de La Plata, Uruguay	g. 9	⇑	
	Urbanisation	a. Chubut River, Patagonia	a. 7	⇑	a. Gaiero *et al.* (2001)
		b. Rivers of the SE coast of Brazil	b. 10	⇑	b. Bidone *et al.* (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 *et al.* (2001)
		f. La Plata River, Uruguay	f. 10	⇑	f. ECOPLATA (1999)
		g. Patos Lagoon estuary	g. 3	⇑	g. Baish (1997); Baumgarten *et al.* (1995); Almeida *et al.* (1993)
		h. Esmeralds 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 *pers. comm.*
		k. Bio Bio River, Chile	k. 7	⇑	k. Daneri *pers. comm.*
	Industrialisation	a. Rivers of the SE coast of Brazil	a. 5	⇑	a. Bidone *et al.* (1999); Lacerda *et al.* (2001)
		b. Rivers of the Buenos Aires coast	b. 2	⇑	b. ECOPLATA (1999)
		c. Patos Lagoon estuary	c. 3	⇑	c. Baish (1997); Baumgarten *et al.* (1995); Almeida *et al.* (1993)
		d. Chubut River, Patagonia	d. 2	⇑	d. Depetris *et al.* (in prep.); Gaiero *et al.* (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	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ Data sources
		RIVER	CATEGORY		
Erosion	Damming	a. Negro, Colorado and Chubut rivers, Patagonia, southern Argentina	a. 5	=	a. Isla and Bujalevsky (1995); Pasquini *et al.* (1997)
		b. Jaguaribe River, NE Brazil	b. 3	⇑	b. Cavalcante (2000)
		c. Paraíba do Sul River, SE Brazil	c. 8	⇑	c. Dias and Silva (1984); Salomão (2001)
		d. Guayaquil Gulf, Ecuador	d. 8	⇑	d. CAAM (1996)
		e. La Plata River estuary, Uruguay	e. 9	=	e. ECOPLATA (1999)
		f. Patia River, Colombia	f. 10	=	f. Restrepo and Kjerfve (2000b)
		g. Buenos Aires Province rivers	g. 8	⇑	g. Cionchi *et al.* (1993); Isla (1997); Lopez and Marcomini (1998); Violante *et al.* (2001)
	Deforestation	a. Patagonia Rivers	a. 8	⇑	a. Passovani *et al.* (1992)
		b. Rivers of the SE coast of Brazil	b. 6	=	b. Lacerda *et al.* (2001)
		c. Magdalena River, Colombia	c. 10	⇑	c. COLCIÊNCIAS-FEN (1989)
		d. La Plata River Estuary, Uruguay	d. 9	⇑	d. ECOPLATA (1999)
		e. Esmeralds and Chone rivers, Ecuador	e. 7-10	⇑	e. PMRC (1993a,b)
		f. Guayas River/Guayaquil Gulf, Ecuador	f. 8	⇑	f. INOCAR (1998a,b)
	Navigation	a. Magdalena River, Colombia	a. 8	⇑	a. Correa (1991); Martínez (1993)
		b. Guayaquil Gulf, Ecuador	b. 8	⇑	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. 10	⇑	a. Esteves and Lacerda (2000); Bidone *et al.* (1999); Barcellos and Lacerda (1994)
		b. Rivers of the Buenos Aires coast	b. 8	⇑	b. Seeliger *et al.* (1988); Moyano (1991)
		c. Patos Lagoon Estuary	c. 5	=	c. Niencheski and Baumgarten (1997)
		d. Esmeralds and Chone rRivers, Ecuador	d. 2-4	⇑	d. PMRC (1993a)
		e. Guayaquil Gulf, Ecuador	e. 8	⇑	e. PMRC (1993a)
		f. Tumbes and Chira rivers, Peru	f. 6	?	f. Daneri *pers. comm.*
		g. Loa and Bio Bio rivers, Chile	g. 8	?	g. Daneri *pers. comm.*
		h. Aconcagua and Maipo rivers, Chile	h. 7		h. Daneri *pers. comm.*
	Navigation	a. Rivers of SE Brazil	a. 7	⇑	a. Barcellos and Lacerda (1994)
		b. Rivers of the Buenos Aires coast	b. 5	⇑	b. Wells and Daborn (1997); ECOPLATA (1999)
		c. Patos Lagoon estuary, Brazil	c. 3	=	c. SUPRG (1996)
	Agriculture	a. Patagonia rivers	a. 7	⇑	a. Gaiero *et al.* (2001)
		b. Rivers of the Buenos Aires coast	b. 6	⇑	b. ECOPLATA (1999)
		c. Jaguaribe River, NE Brazil	c. 2	⇑	c. Bezerra (1996)
		d. Patos Lagoon estuary, Brazil	d. 2	⇑	d. Niencheski and Baumgarten (1997)
		e. Guayaquil Gulf, Ecuador	e. 7	⇑	e. CAAM (1996)
		f. Aconcagua River, Chile	f. 4	⇑	f. Hajek *et al.* (1990)
		g. Maipo River, Chile	g. 4	⇑	g. Parra and Habit (1998)
	Urbanization	a. Patagonia rivers	a. 8	⇑	a. Gaiero *et al.* (2001)
		b. Rivers of the SE coast of Brazil	b. 7	⇑	b. Bidone *et al.* (1999); Knoppers *et al.* (1999), Esteves and Lacerda (2000)
		c. Cocó and Ceará rivers, Fortaleza metropolitan area, NE Brazil	c. 3	⇑	c. Marins *et al.* (2001)
		d. Patos Lagoon estuary	d. 5	=	d. Almeida *et al.* (1993); Baisch (1997)
		e. Maipo River, Chile	e. 7	⇑	e. Hajek *et al.* (1990)
		f. Biobio River, Chile	f. 7	⇑	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 *et al.* (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 *et al.* (2001), Knoppers *et al.* (1999)
		d. Patos Lagoon estuary	d. 3	⇑	d. Caliari (1980)
		e. Esmeralds 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 *pers. comm.*
	Damming/ Diversion	a. Jaguaribe River, NE Brazil	a. 8	⇑	a. Bezerra (1996); ANEEL (1999)
		b. Magdalena River, Colombia	b. 10	=	b. Vernette (1985); Restrepo and Kjerfve (2000)
		c. Sepetiba Bay, SE Brazil	c. 10	⇑	c. Lacerda *et al.* (2001)
	Deforestation	a. Patagonia Rivers, Argentina	a. 8	⇑	a. Gaiero *et al.* (2001)
		b. Rivers of SE Brazil	b. 10	⇑	b. Salomão *et al.* (2001); Knoppers *et al.* (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 *pers. comm.*
		g. Itata and Bio Bio rivers, Chile	g. 8	=	g. Daneri *pers. comm.*
	Urbanization	a. Maipo River, Chile	a. 3	⇑	h. Daneri *pers. comm.*
	Sand Mining	a. Negro River, Patagonia	a. 4	=	a. Cionchi *et al.* (1993); Pasquini *et al.* (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 *et al.* (2001); Depetris *et al.* (in prep.)
		b. Rivers of SE Brazil	b. 6	=	b. Salomão *et al.* (2001); Knoppers *et al.* (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 *et al.* (1988); Fernandes and Niencheski (1998)
Loss of biodiversity	Fisheries	a. Patagonia rivers, Argentina	a. ?	?	a. Gaiero *et al.* (2001)
		b. Rivers of SE Brazil	b. 6	⇑	b. MMA (1996); Knoppers *et al.* (1999)
		c. Cocó and Ceará rivers, Fortaleza metropolitan area, NE Brazil	c. 4	⇑	c. Marins *et al.* (2001)
		d. Rivers of the Buenos Aires coast	d. ?	?	d. ECOPLATA (1999)
		e. Patos Lagoon estuary	e. 5	⇑	e. Montu and Gloeden (1982); Haimovici *et al.* (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: ⇒ = stable; ⇑ = increasing; n.o. = not observed

Coastal impact/ issues	Driver	Full regional		Trend- expectation	Reference/ data source
		Coast	Category		
Erosion	Damming	Atlantic coast Pacific coast	6-7 1	⇒/⇑ ⇒	Annex tables 1, 2 , 3 , 4 and 5 Annex table 6
	Deforestation	Atlantic coast Pacific coast	7 6	⇒/⇑ ⇒	Annex tables 1, 2 and 3 Annex table 6
	Navigation	Atlantic coast Pacific coast	1 7	⇒ ⇑	Annex table 4 Annex table 6
Eutrophication	Agriculture	Atlantic coast Pacific coast	4-5 2	⇑ ⇑	Annex tables 3, 4 and 5 Annex table 6
	Urbanisation	Atlantic coast Pacific coast	8 5	⇑ ⇑	Annex tables 1, 2, 4 and 5 Annex tables 6
	Industrialisation	Atlantic coast Pacific coast	3 2	⇑ ⇑	Annex tables 2, 4 and 5 Annex tables 6
Pollution	Industrialisation	Atlantic coast Pacific coast	9 2	⇑ ⇑	Annex tables 1, 2 and 5 Annex tables 6
	Navigation	Atlantic coast Pacific coast	7 5	⇑ ⇑	Annex tables 1, 2 and 5
	Agriculture	Atlantic coast Pacific coast	5-6	⇑ ⇑	Annex tables 1, 4 and 5 Annex tables 6
	Urbanization	Atlantic coast Pacific coast	6 5	⇑ ⇑	Annex tables 2, 4 and 5 Annex tables 6
Sedimentation	Agriculture	Atlantic coast Pacific coast	4 2	⇒/⇑ ⇒	Annex tables 2, 4 and 5 Annex tables 6
	Navigation	Atlantic coast Pacific coast	6 n.o.	⇑ n.o	Annex tables 2, 3 and 4 n.o
	Damming	Atlantic coast Pacific coast	8 n.o	⇑ n.o.	Annex tables 3 and 5 n.o.
	Deforestation	Atlantic coast Pacific coast	7-8 6-7	⇑ ⇒	Annex tables 2 and 5 Annex tables 6
Nutrient depletion	Damming	Atlantic coast Pacific coast	8 n.o.	⇑ n.o.	Annex tables 2 and 5 n.o.
Salinization	Damming	Atlantic coast Pacific coast	4 n.o	⇑ n.o.	Annex tables 3, 4 and 5 n.o.
Loss of biodiversity	Fisheries	Atlantic coast Pacific coast	4-6 2	?-6 ⇑	Annex tables 1, 2, 4 and 5 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 Geologia y Mineria) 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 Paraíaba 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 3.1x10^6 km^2. The three major rivers that flow into the Rio de la Plata are the Paraná, the Uruguay and the Santa Lucia rivers. The Río de la Plata estuary covers 35,500 km^2 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 km^2 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 m^3 s^{-1}, with a range from 800 to 14,300 m^3 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 Rio de la Plata were recently budgeted (Nagy 2000).

Since 1953, the Uruguay River discharge has increased: from 5,200 m^3 s^{-1} for a 30-year running mean, 5,450 m^3 s^{-1} for a 20-year running mean, and up to 6,000 m^3 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 Rio 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 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 km^2

(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 47.2x10^6 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 13x10^6 km^2 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 Rio 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 Managment of Matanza and Riachuelo Basins. It is mostly carried out by IADO (Instituto Argentino de Oceanografia), 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 Bahia 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	
BRAZIL	**Scientific**	**Management**	**Scientific**	**Management**	**Scientific**	**Management**
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 *et al.* 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 *et al.* 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 *Cont.*	**Scientific**	**Management**	**Scientific**	**Management**	**Scientific**	**Management**
Pacoti River	Monitoring of water quality including trace metals and Hg (Lacerda *et al.* 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.				
Paraíaba 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 De-pollution 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. Monitoring of water fluxes of the Parana and Uruguay rivers. National Environmental Systems (Argentina).	Fisheries Research Plan. ECOPLATA Project. Coastal Sensitivity Atlas of Argentina.	GEF Program: Environmental Protection of the La Plata River. Transboundary Diagnostic Analysis. Monitoring GOOS Monitoring of *Vibrio colera.*. Meso-scale Atmospheric Modeling.	Strategic Action Plan of the Administrative Commission on the Rio de La Plata. Technical commission of the Maritime Front 2000-2004.
Parana River	Environmental Stress of the Paraná River Project. River-Flood Plain Interactions in The Parana River Project.	-				
La Plata River	ECOPLATA (GEF)	Integrated Coastal Zone Management of the Uruguayan coast of the La Plata River (DINAMA, INAPE, Universidad de la Republica.				
Small coastal streams	ECOPLATA (GEF)	IMM, MVOTMA				
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-INGEOM (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 Rio 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 cacthments. 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 Iguape 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 cacthments. 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		"Hot spot" sub regional/ country scale: La Plata Region, Buenos Aires Province and Patagonia	
	Key issue, trend and gaps	Scientific approach	Key issue, trend and gaps	Scientific approach
La Plata River	Water circulation. Water and sediment pollution by harzardous substances. Introduction of exotic species and toxic algal blooms. Socio-economic situation and legal framework.	Model applications and remote sensing. *In situ* 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.	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 cacthments. 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 km^2 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 km^2), 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.iia-cnr.unical.it/EUROCAT/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 *et al.* 2001).
	Industrialization	Pollution	Major - Increasing	Maximum allowed concentrations of heavy metals (CONAMA 1996).
North-eastern Brazil (**Jaguaribe and Pacoti rivers**)	Damming/ Diversion	Erosion	Major - Increasing	Terrigenous sediment flux. Presently around 10-50% of the minimum to keep beach morphology (Morais *et al.* 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 rations equal to Redfield relation (Medeiros *et al.* 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 (Baisch 1997; Baumgarten *et al.* 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). Total suspended solids. Historical data available for the last decade (INOCAR 1998a).
Colombia **Magdalena River** delta-lagoon complex	Urbanization	Eutrophication	Low - Stable	Fisheries yield at the delta responds to eutrophication level. Annual catches decrease rates available for historical period (INVEMAR 2000).
	Damming/ diversion	Sedimentation	High - Stable	Total sediment yield, decennial historical data available (Restrepo and Kjerfve 2000a) Coral reef bleaching rate. Available at Coralles del Rosario for historical period (Vernette 1985).
Patagonia, Argentina **Negro and other rivers**	Damming/ urbanisation	Erosion/ eutrophication	Medium – Stable Low - Increasing	Bedload transport (Gaiero *et al.* 2001). Redfield ratios.
Calle River, **Bio Bio River**, Chile	Eutrophication	Urbanization	Low - Increasing	Redfield ratios.
Colombia **San Juan and Patia rivers**	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. DePetris, Argentina
Negro, Gaillegos and Colorado rivers, Patagonia, Argentina	P. DePetris, 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.)

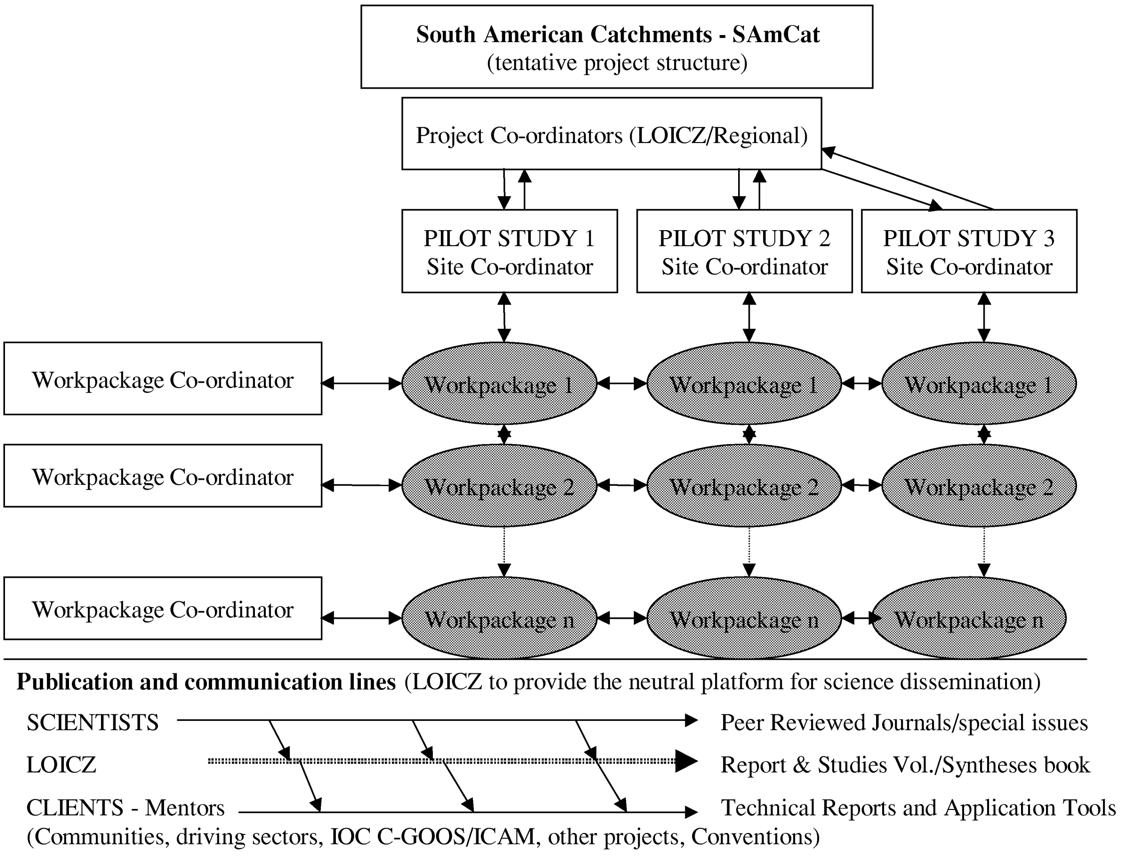


Figure 3.1. Tentative project and task structure for SAmCat and its potential pilot studies.

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.iia-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.

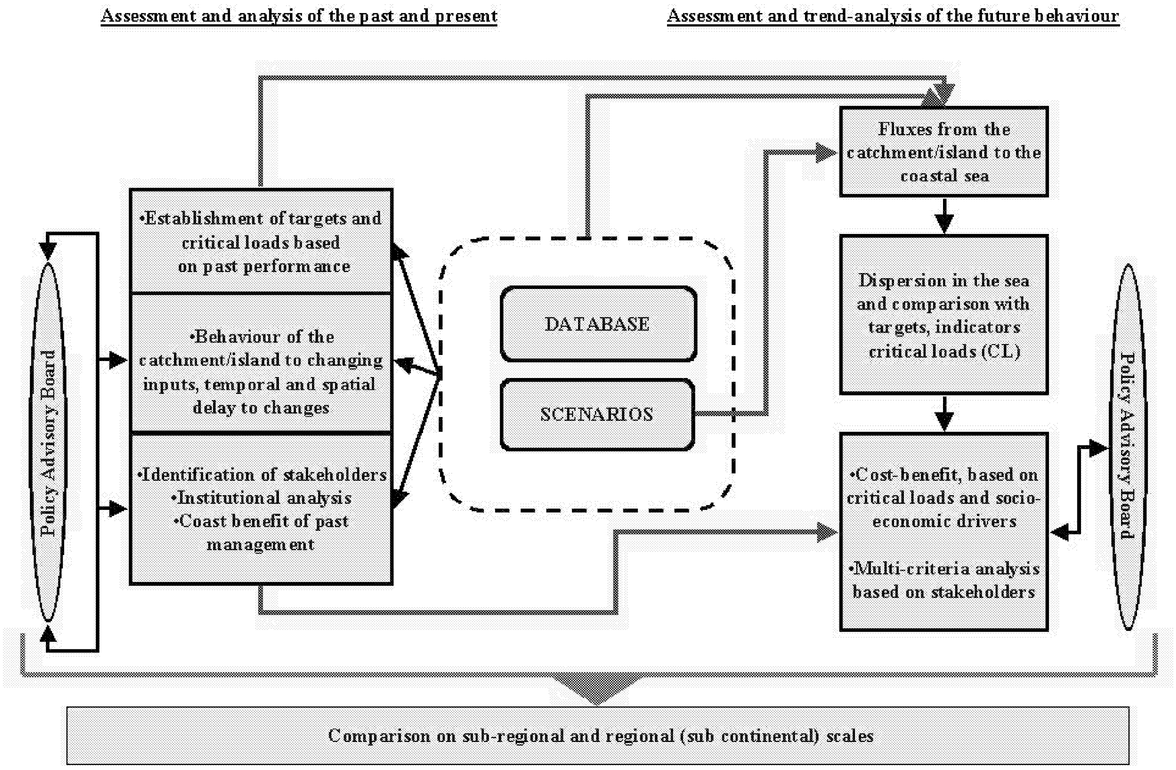


Figure 3.2. A tentative SAmCat workplan.

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.

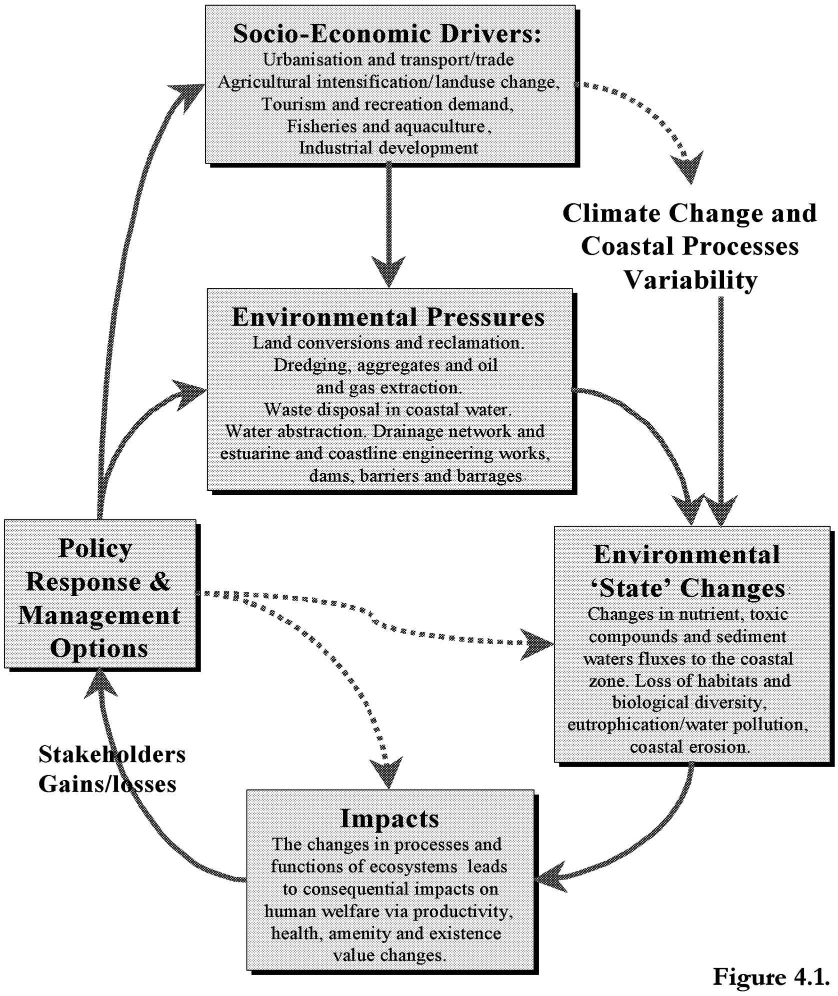


Figure 4.1. The Driver-Pressure-State-Impact-Response (DPSIR) Framework.

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 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.iia-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

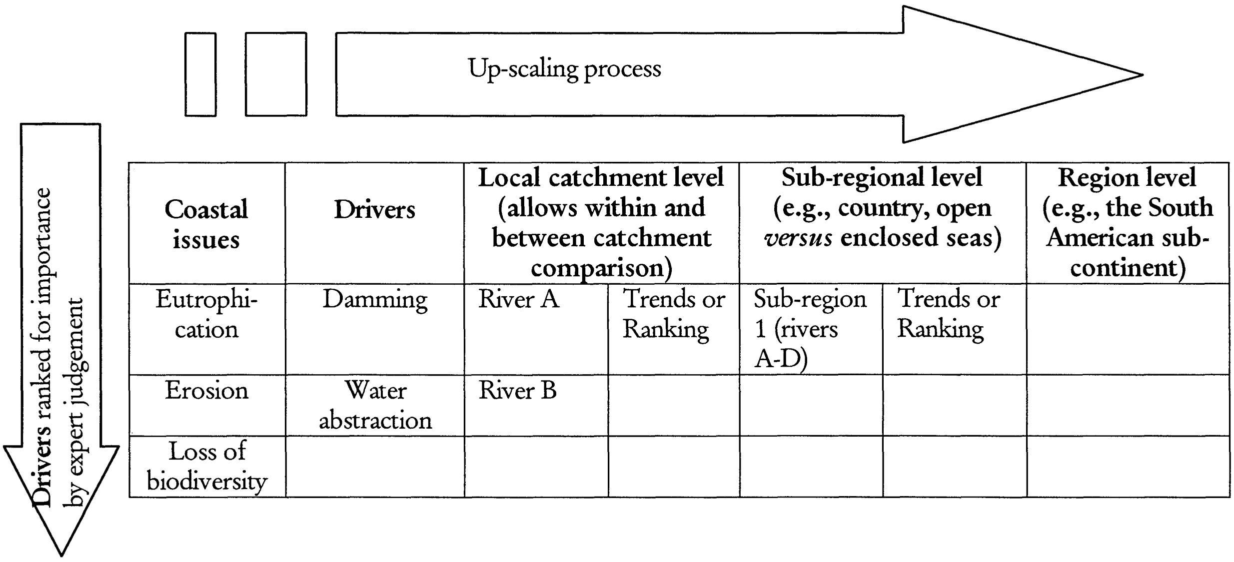
Since **LOICZ Basins** workshops have a regional focus, assessment and ranking follow a heirarchy of scales finally generating a composite regional picture – the scales range from:

a) local catchments, to
b) sub-regional or provincial levels, to
c) 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:

1) to set up a **list of coastal change issues** of and **related drivers** in the catchment.
2) 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
3) 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.



Coastal issues	**Drivers**	**Local catchment level (allows within and between catchment comparison)**		**Sub-regional level (e.g., country, open *versus* enclosed seas)**		**Region level (e.g., the South American sub-continent)**
Eutrophication	Damming	River A	Trends or Ranking	Sub-region 1 (rivers A-D)	Trends or Ranking	
Erosion	Water abstraction	River B				
Loss of biodiversity						

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	• 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 continuos process)	Erosion - 10	Database xyz, Reference abcd, 19...…
Eutrophication (habitat loss)	Bay ACEF – (rivers draining into the Bay a,b,c,…)	• 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				

<u>*Notes for use*</u>
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 (qualitative index)				Impact on the coastal system	Time scale
		Large basins	**Medium basins**	**Small basins: active coast**	**Small basins: passive coast**		
Agriculture	▪ Waste/nutrient (excess fertilizer) ▪ Increasing sediment transport ▪ Water extraction	**minor**	**medium**	**major**	**major**	▪ Eutrophication; ▪ Contamination; ▪ Siltation, etc….	**p**
Damming	▪ Nutrient and sediment sequestration ▪ Changing hydrological cycles	**?**	**major**	**n.a.**	**medium**	▪ Coastal erosion; ▪ Nutrient depletion; ▪ Salinization	**d**
Deforestation	▪ Sediment budget alteration ▪ …..	**minor**	**major**	**major**	**major**	▪ 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 km^2, medium 10.000 – 200.000 and small <10.000 km^2), 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	• Area… • Volume… • Run off reduction… • …..	10	Increasing	XYZ, 2000
	Deforestation	• Area… • Rseidual TSS production… • …..	8	stable	
	Diversion	• 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	• Catchments involved • Area… • Volume… • Run off reduction…	5	stable	
	Deforestation	• Area… • Rseidual TSS production…	8	increasing	
	Diversion	• 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 value10 = 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**
		e.g. Africa or South America	Category (1 low – 10 high)		
Erosion	Damming	• Sub-regions involved • Area… • Volume… • Runoff reduction…	2	increasing	
	Deforestation	• Area… • Residual TSS production…	8	stable	
	Diversion	• Little, area…; effect on water flow…	4	increasing	
Erosion (total in the region)	All Drivers and Rivers weighted	Full region scale	Ranking weighted from info above		
Eutrophication	Agriculture	• Residual nutrient production…	4		
	Mariculture	• Local residual nutrient production…	5		
	Municipal waste	• Local urbanisation areas… ; xy t/tear residual production	10		
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. commision 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	Key issue, Trend and gaps	Scientific approach
River A	…	• Biogeochemical studies • Residual calculation by ecponomic sectors • Critical flux investigation • Stakeholder and scale analysis • ACTION • ….		e.g.…	…	…
River B						
River C						
River D						

<u>Notes for use:</u>

This table extracts from the regional assessment the potential demonstration sites which can be included in a proposal for a future <u>Regional Catchment/Coast Assessment Project - “…Cat”</u>. 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 m^3 s^{-1} and a sediment transport of 139x10^6 t yr^{-1} (Restrepo and Kjerfve 2000). It is located on the Caribbean coast of Colombia, South America (10°40 – 10°59N, 74°15 – 74°38W) 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.

© 1999 Microsoft Corp. All rights reserved.

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 m) and from where 4 main rivers drain into the CGSM (average yearly flow of 19.25 m^3 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 isomegathermic 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 (± 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 km^2 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 *etal.* 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 m^3/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.

References

Alvarez León, R. and Blanco Racedo, J. 1985 Composición de las comunidades ictiofaunísticas de los complejos lagunares estuarinos de la Bahía de Cartagena, Ciénaga de Tesca y Ciénaga Grande de Santa Marta, Caribe colombiano. Pages 535-555 in A. Yañez-Arancibia (ed.): *Ecología de comunidades de peces en estuarios y lagunas costeras: hacia una integración de ecosistemas*, Universidad Nacional Autónoma de Mexico, Mexico.

Botero, L. 1990 Massive mangrove mortality on the Caribbean Coast of Colombia. *Vida Silvestre Neotropical* **2**:77-78.

Botero, L. and Mancera-Pineda, J.E. 1996 Síntesis de los cambios de origen antrópico ocurridos en los últimos 40 años en la Ciénaga Grande de Santa Marta (Colombia*). Revista de la Academia Colombiana de Ciencia Exacta Fisica y Natural* **20**:465-474.

Botero, L. and Marshall, M. 1994 Biodiversity within the living, dying and dead mangrove forests of the Ciénaga Grande de Santa Marta, Colombia. *Mote Marine Laboratory Technical Report Number* 366. Submitted to World Wildlife Fund Biodiversity Support Program. INVEMAR (Santa Marta)-Mote Marine Laboratory (Sarrassotta), 34 pages.

Campos, N.H. 1990 La contaminación por metales en la Ciénaga Grande de Santa Marta, Caribe colombiano. *Caldasia* **16**:623-631.

Campos, N.H. 1991 La ostra comercial de la Ciénaga Grande de Santa Marta Crassostrea rhizophorae y la problemática de la contaminación por metales. *Trianea* **4**:623-631.

Campos, N.H. 1992 Descarga de metales pesados en la Ciénaga Grande de Santa Marta, Caribe colombiano, con el material suspendido. *Revista Contaminación Ambiental* **23**:11-31.

Cardona, P. and Botero, L. 1998 Soil characteristics and vegetation structure in a heavily deteriorated mangrove forest in the Caribbean coast of Colombia. *Biotropica* 30:24-34.

Cataño, S. and Garzón, J. 1994 Ecología trófica del sábalo Megalops atlanticus (Pisces: Megalopidae) en el área de Ciénaga Grande de Santa Marta, Caribe colombiano. *Revista de Biologia Tropical* **42**:673-684.

CETIH 1978 *Diagnóstico sobre el comportamiento hídrico de la Ciénaga Grande de Santa Marta.* Informe final. Universidad de los Andes-Inderena, Bogotá.

Escobar-Nieves, A. 1988 Condición bacteriológica de las ostras del manglar (Crassostrea rhizophorae Guilding) en la Ciénaga Grande de Santa Marta, Caribe colombiano. *Anales del Instituto de Investigaciones Marinas de Punta Betín* **18**:137-152.

Espinosa, L.F., Ramírez, G. and Campos, N.H. 1995 Análisis de residuos organoclorados en los sedimentos de zonas de manglar en la Ciénaga Grande de Santa Marta y la Bahía de Chengue, Caribe colombiano. *Anales del Instituto de Investigaciones Marinas de Punta Betín* **24**:79-94.

Gallo, M.C. 1994 *Contaminación por metales pesados en áreas de manglar de la Ciénaga Grande de Santa Marta y la Bahía de Chengue, Caribe colombiano.* Tesis de grado. Universidad Nacional de Colombia, Bogotá. 71 pp. + anexos.

Gonima, L., Mancera, J.E. and Botero, L. 1996 *Análisis e interpretación de imágenes de satélite para estudios de vegetación, suelos y aguas en la Ciénaga Grande de Santa Marta.* Informe final, Universidad Nacional de Colombia e INVEMAR.

González, E. 1991 El manglar de la Ciénaga Grande de Santa Marta: Ecosistema en peligro de extinción. *Colombia, sus gentes y regiones*, IGAC, **21**:2-21.

Hernández, J., Hildebrand, P.von, and Alvarez, R. 1978 Problemática del manejo de manglares con especial referencia al sector occidental de la Ciénaga Grande de Santa Marta, Magdalena, Colombia. En: *Estudio científico e impacto humano en el ecosistema de manglar*, UNESCO, p. 364-386.

HIMAT 1988 Calendario meteorológico. Instituto Colombiano de Hidrología, Meteorología y Adecuación de Tierras.

Holdridge, L.R., Grenke, W.C., Hatheway, W.H., Liong T. and Tosi, J.A. 1967 *Forest Environments in the Tropical Life Zones*, Pergamon Press, 747 pages.

IGAC 1975 *Estudio Hidroclimático de la Región Caribe.* Instituto Geográfico Agustín Codazzi, Bogotá, 77 pages.

Mancera-Pineda, J.E. and Vidal, L.A. 1994. Florecimiento de microalgas relacionado con mortandad masiva de peces en el Complejo Lagunar Ciénaga Grande de Santa Marta. *Anales del Instituto de Investigaciones Marinas de Punta de Betín* **23**:103-117.

Plata, J. Campos, N.H. and Ramírez, G. 1993 Flujo de compuestos organoclorados en las cadenas tróficas de la Ciénaga Grande de Santa Marta. *Caldasia* **17**:199-204.

PRO-CIENAGA 1995 *Plan de manejo ambiental de la subregión Ciénaga Grande de Santa Marta 1995-1998.* Cooperación República de Colombia-República Federal de Alemania, CORPAMAG, INVEMAR, CORPES C.A., GTZ.

Raasveldt, H.C. and Tomic, A. 1958 Lagunas colombianas. *Revista de la Academia Colombiana de Ciencia Exacta Fisica y Natural* **10**:1-40.

Restrepo, J.D. and Kjerfve, B. 2000 Water and sediment discharges from the western slopes of the Colombian Andes with focus on Río San Juan. *Journal of Geology* **108**(1):17-33.

Santos-Martínez, A. and Acero, P.A. 1991 Fish community of the Ciénaga Grande de Santa Marta (Colombia): composition and zoogeography. *Ichthyological Exploration Freshwaters* **2**:247-263.

Thom, B.G. 1982 *Mangrove Ecology-A Geomorphological Perspective.* Pages 3-17 in Clough, B.F. (ed.): *Mangrove Ecosystems in Australia.* Australian National University Press, Canberra.

Universidad de los Andes 1993 Modelación hidrodinámica de la Ciénaga Grande de Santa Marta. *Informe final.*

Wiedemann, H. 1973 Reconnaissance of the Ciénaga Grande de Santa Marta: physical parameters and geological history. *Mitt. Instituto Colombo-Alemán Investigaciones Cientificas de Santa Marta* **7**:85-119.

5.2 Geoenvironmental characterization of the Orinoco Delta: a processes approach

H. Echezuría[1], J. Córdova[2], M. González[2], V. González[3], J. Méndez[3] and C. Yanes[3]
[1] *PDVSA-Intevep, Petróleos de Venezuela S.A.*
[2] *Funindes, Universidad Simón Bolívar*
[3] *Fundación UCV, Universidad Central de Venezuela*

Introduction

The Orinoco River is the third largest river in the world, in terms of water discharge. It drains $1x10^6$ km^2 of Venezuela and Eastern Colombia, (see Figure 5.2) with a mean flow rate of about 37,000 $m^3 s^{-1}$, 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 km^2 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 agradation 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.

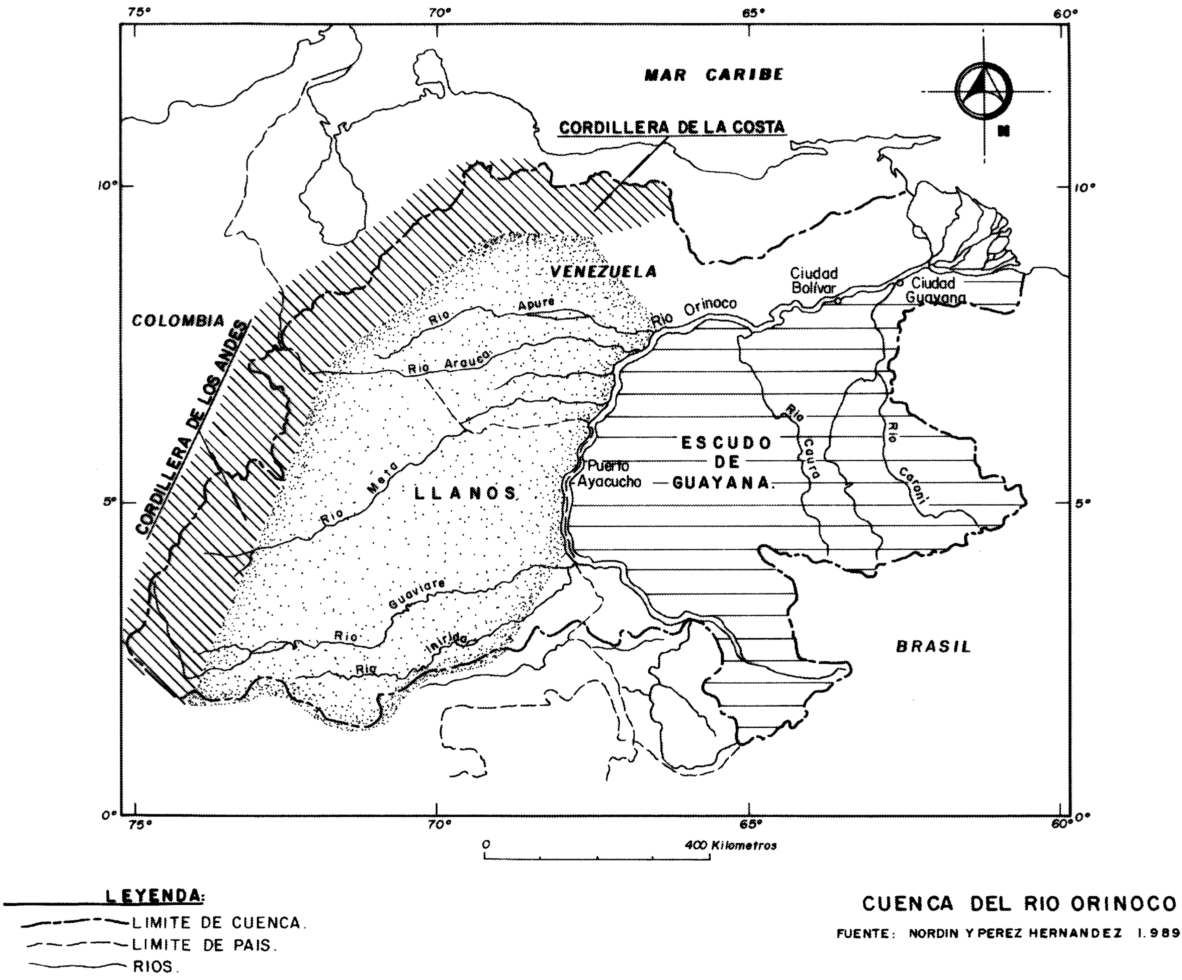


Figure 5.2. The Orinoco River watershed

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.

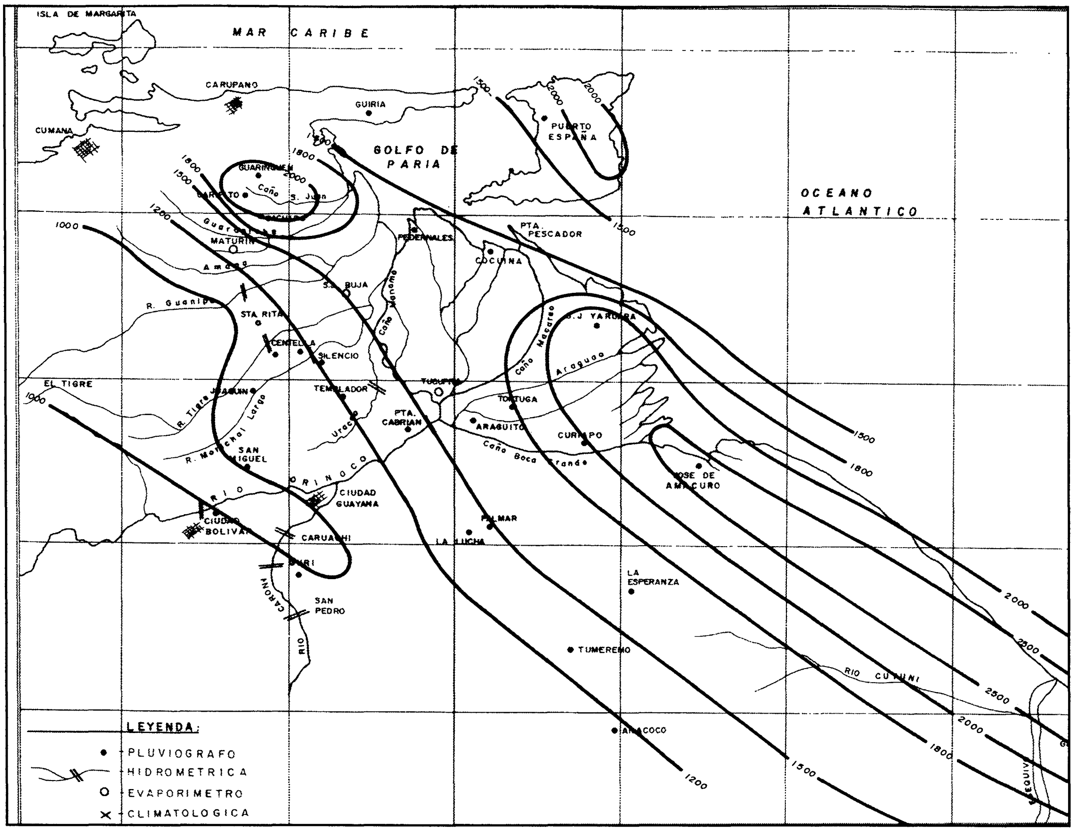


Figure 5.3. Annual isohyetal (mm) map of the Orinoco River delta.

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.

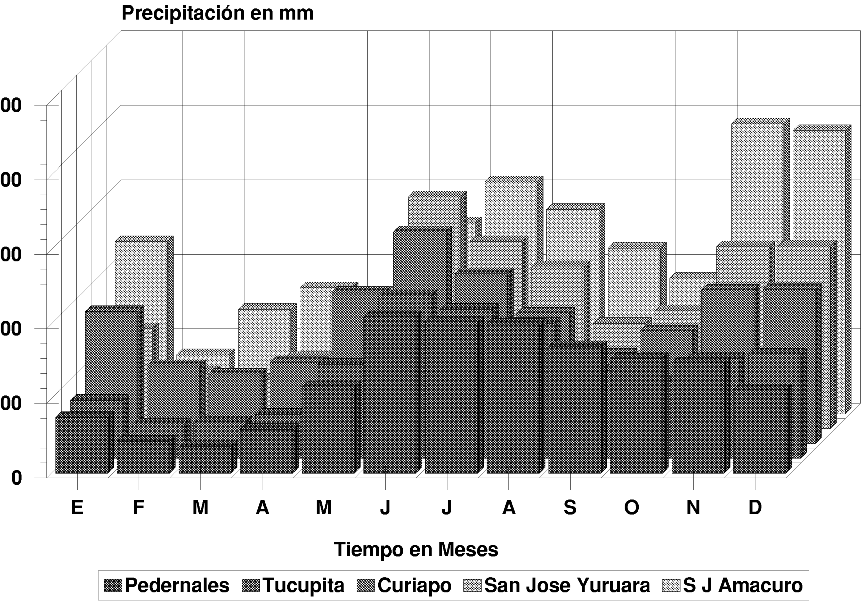


Figure 5.4. Monthly precipitation (mm) in the Orinoco Delta region.

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 m^3 s^{-1}, twice its mean discharge. The 100 years peak discharge is about 94,000 m^3 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 km^2 watershed and an annual mean flow of 4,800 m^3 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 m^3 s^{-1} through the whole year; the mean minimum flow at the delta entrance is close to 6,000 m^3 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 m^3 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.

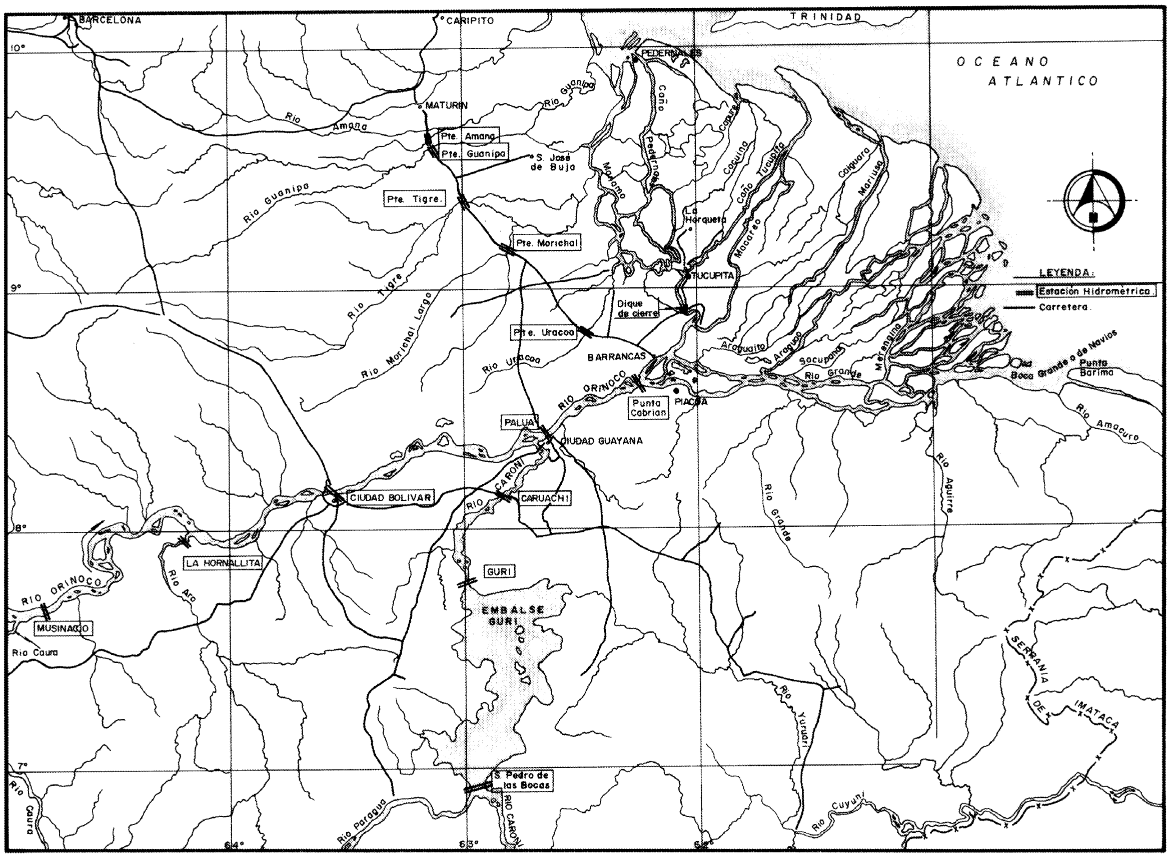


Figure 5.5. Network of water courses in the Orinoco River delta.

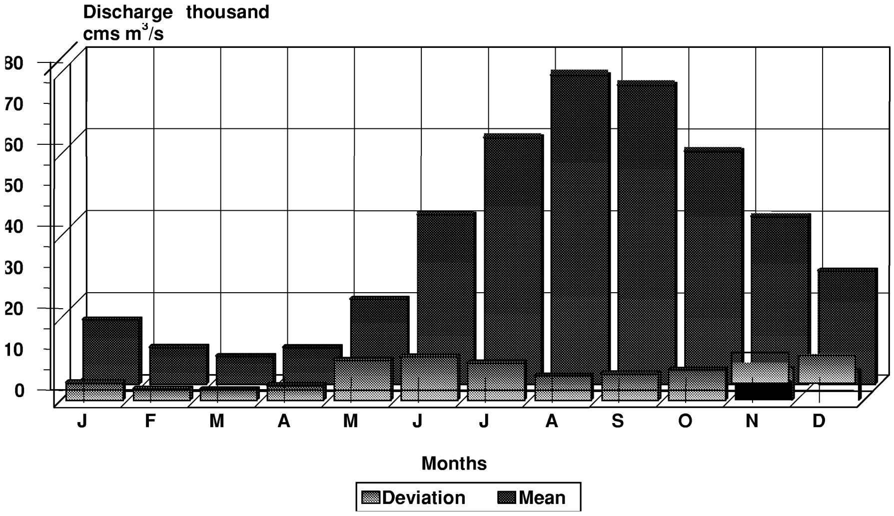


Figure 5.6. Mean and standard deviation of monthly discharges of the Orinoco River at the delta entrance.

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%.

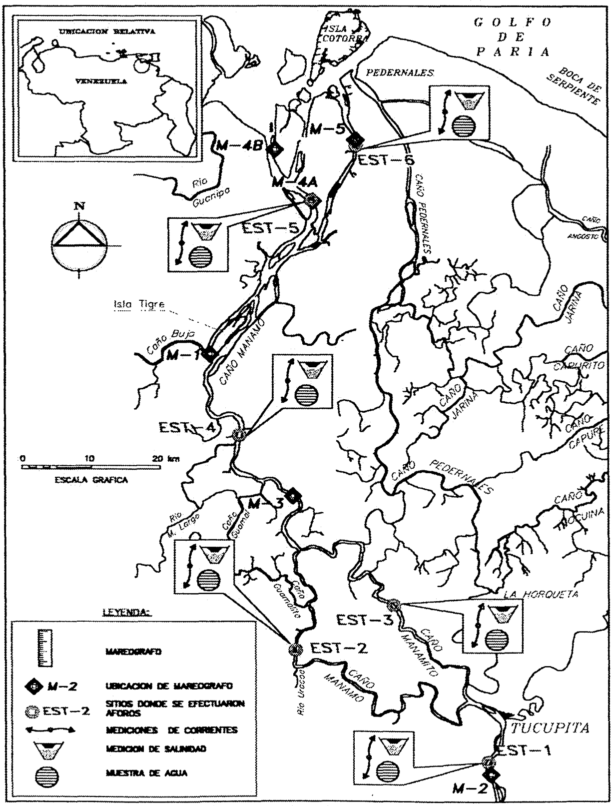


Figure 5.7. Location of tidal gauging stations in the Orinoco River delta.

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 km^2 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 agradation 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 agradation 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 *chenier facies*. These *chenier facies* are depositing on top of the existing silts and clays, which had maintained an active process of agradation, 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 agradation process, as the agradation 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 incresed 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 $m^3 s^{-1}$ 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.

References

Note: the following references were provided by the authors but not cited in the paper.

Bureau of Economic Geology 1998 Annual Report. Year One: Geo-Environmental Characterization of the Delta del Orinoco, Venezuela. The University of Texas at Austin. *Report* submitted to PDVSA, 190 pages.

Funindes-Universidad Simón Bolívar 1999 Caracterización Climática y del Funcionamiento Hidráulico-Fluvial del Delta del Río Orinoco. Resumen de las Actividades Desarrolladas Durante el Primer Año del Estudio. *Technical Report* Submitted to PDVSA, 80 pages.

Weibezahn, F.H, Alvarez, H. and Lewis, J.R. 1990 *El Río Orinoco como Ecosistema*. Simón Bolivar University, 430 pages.

López, J.L., Saavedra, I. and Dobois, M. (eds) 1998 *El Río Orinoco. Aprovechamiento Sustentable*. Instituto de Mecánica de Fluidos, Facultad de Ingeniería, Universidad Central de Venezuela, 414 pages. ISBN: 980-00-1384-9.

Fundación Universidad Central de Venezuela - Instituto de Ciencias de la Tierra 1999 Estudio Geoambiental del Delta del Orinoco. Informe de los Aspectos geológicos y geoquímicos estudiados durante el primer año. *Technical Report* submitted to PDVSA, 250 pages.

Fundación Universidad Central de Venezuela – Instituto de Zoología Tropical 1999 Estudio de la vegetación del Delta del Orinoco entre los caños Manamo y Macareo. *Technical Report* submitted to PDVSA, 200 pages.

5.3 River discharge and sediment load variability in South America

Björn Kjerfve [1,2] and Juan Dario Restrepo [1,3]

1 - Marine Science Program and Department of Geological Sciences, University of South Carolina, Columbia, SC 29208, USA
2 - Departamento de Geoquímica, Universidade Federal Fluminense, CEP-24.020-007 Niterói, Brazil
3 - Departamento de Geología, Area de Ciencias del Mar, Universidad EAFIT, A. A. 3300, Medellín, Colombia.

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 t km^{-2} 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 (Mechoso 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.

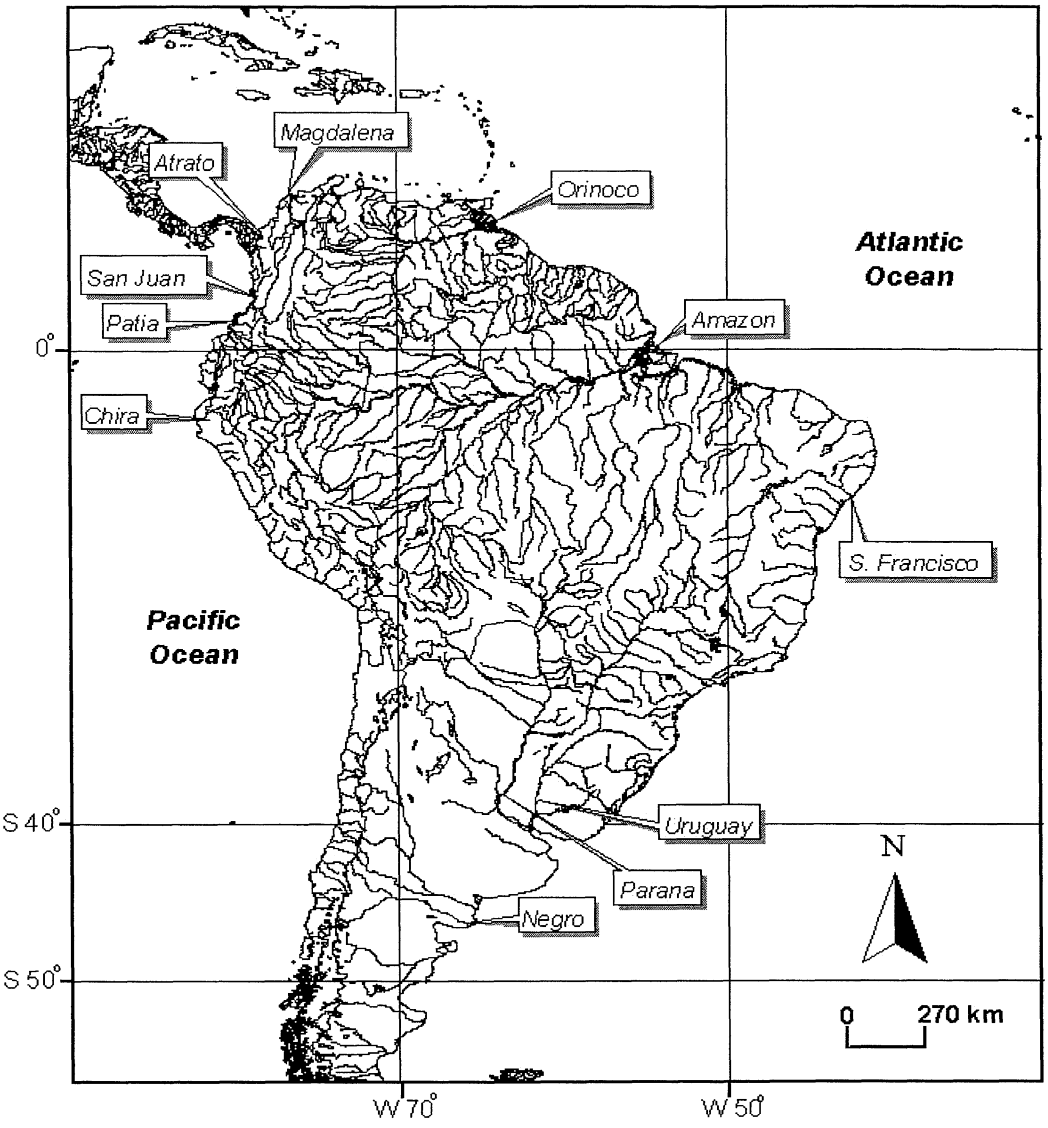


Figure 5.8. Map showing the eleven major rivers in South America draining into the Atlantic Ocean and the smaller Pacific rivers of Colombia (San Juan and Patia) and Peru (Chira) listed in Table 5.3.

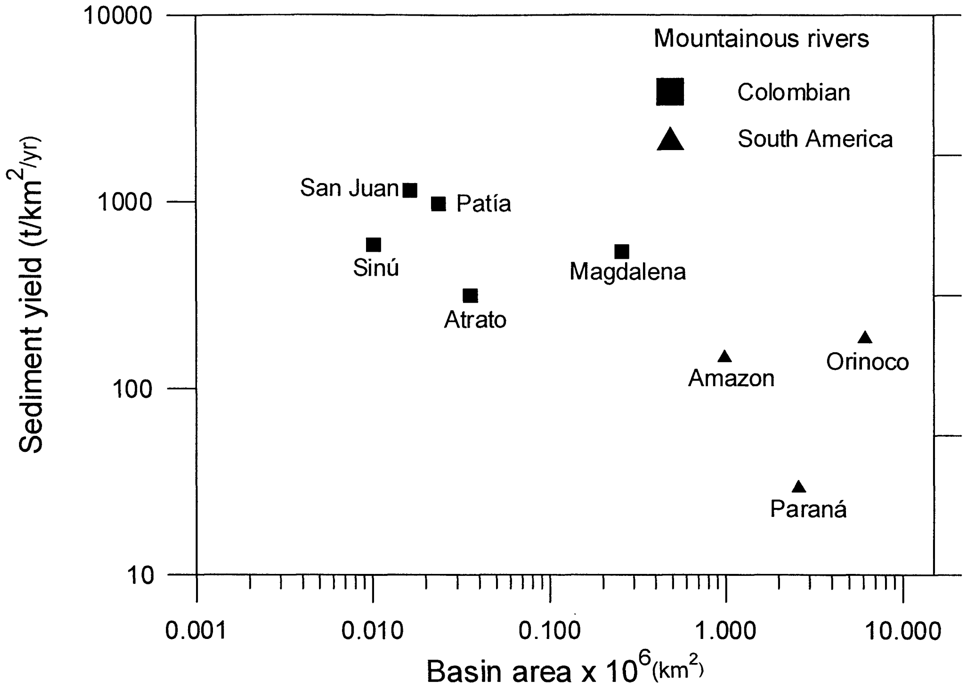


Figure 5.9. Variation of sediment yield with basin area for several mountainous rivers of South America (Amazon, Orinoco, and Paraná) and Colombian rivers draining into the Caribbean Sea (Magdalena, Sinú, and Atrato) and into the Pacific Ocean, San Juan and Patía (modified from Restrepo and Kjerfve 2000a).

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).

River	*Basin Area ($x10^6$ km²)*	*Water Discharge (km³ yr⁻¹)*	*Sediment Load ($x10^6$ t yr⁻¹)*	*Sediment Yield (t km⁻² yr⁻¹)*	*Receiving Basin*
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

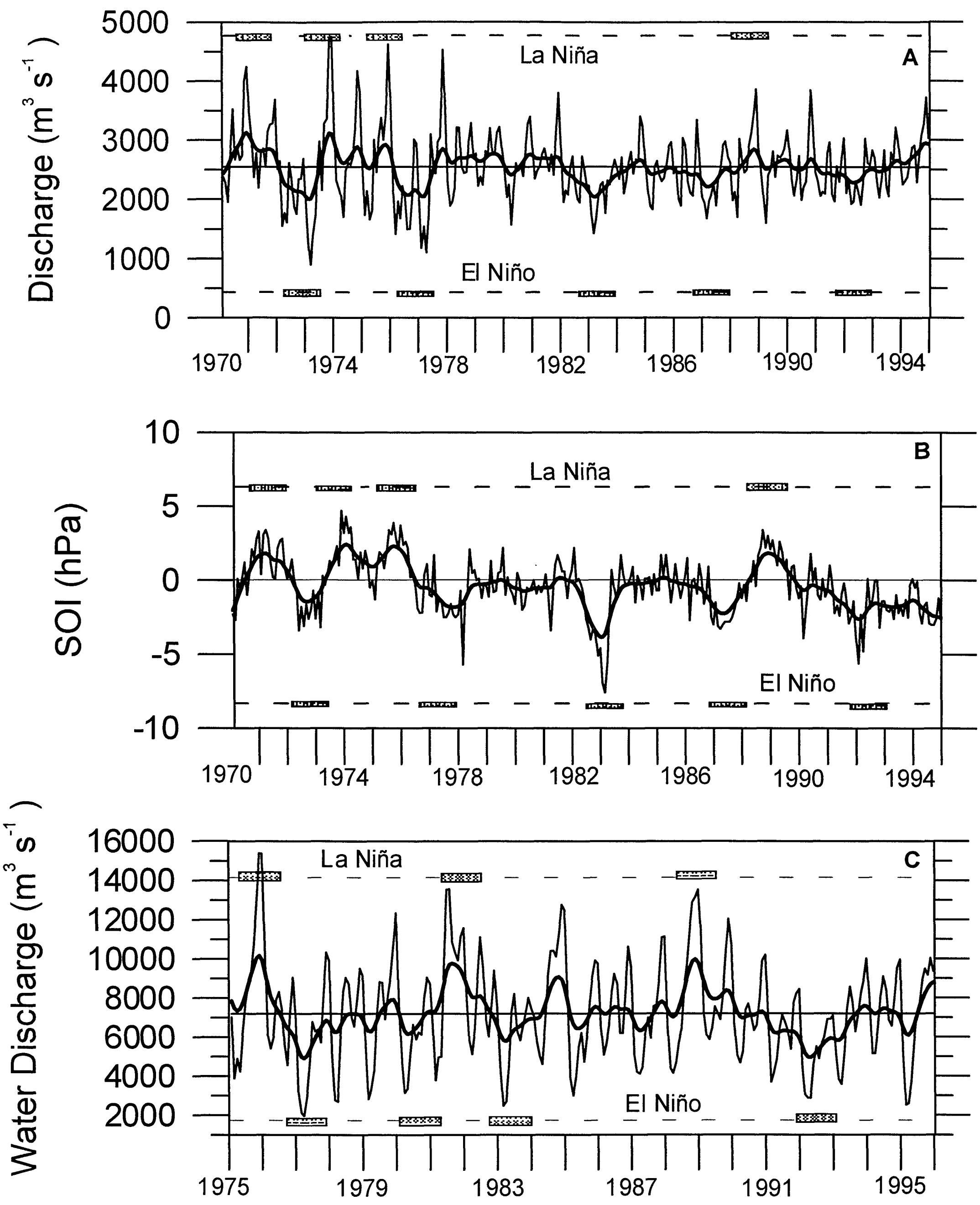


Figure 5.10. Time series plots of mean monthly (thin lines) and low-frequency pass filter with zero phase (bold lines) (A) water discharge for San Juan River 1970-1994; (B) the Southern Oscillation Index (SOI) (National Oceanic and Atmospheric Administration-NOAA, 1999, data-base on the Internet at http://ftp.ncep.noaa.gov/pub/cpc/wd52dg/data/indices);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

References

Depetris, P.J.; Kempe, S.; Latif, M. and Mook, W.G. 1996 ENSO-Controlled flooding in the Paraná river (1904-1991). *Naturwissenschaften* **83**:127-129.

Glantz, M.H. 1997 *Currents of Change, El Niño's Impact on Climate and Society*. Cambridge University Press, Cambridge, 194 pages.

Goniadzki, D. 1999 *Hydrological warning and information system for the Plata basin*. Instituto Nacional del Agua y del Ambiente, Buenos Aires, 70 pages.

Mechoso, C.R. and Perez-Iribarren, G. 1992 Streamflow in the South-eastern South America and the Southern Oscillation. *Journal of Climate* **5**:1535-1539.

Milliman, J.D., and Meade, R.H. 1983 World-wide delivery of river sediment to the oceans. *J. Geology* **91**:1-21.

Milliman, J.D. and Syvitski, J.P.M. 1992 Geomorphic/tectonic control of sediment transport to the ocean: the importance of small mountainous rivers. *Journal of Geology* **100**:525-544.

Probst, J.L. and Tardy, Y. 1989 Global runoff fluctuations during the last 80 years in relation to world temperature change. *American Journal of Science* **289**:267-285.

Restrepo, J.D. and Kjerfve, B. 2000a Water discharge and sediment load from the western slopes of the Colombian Andes with focus on Rio San Juan. *Journal of Geology* **108**: 17-33.

Restrepo, J.D. and Kjerfve, B. 2000b Magdalena River: interannual variability (1975-1995) and revised water discharge and sediment load estimates. *Journal of Hydrology* **235**: 135-149.

Ropelewski, C.F. and Halpert, M.S. 1987 Global and regional scales precipitation associated with El Niño-Southern Oscillation. *Monthly Weather Review* **115**:1606-1626.

Richey, J.E., Meade, R.H., Salati, E., Devol, A.H., Nordin, C.F. and dos Santos, U. 1986 Water discharge and suspended sediment concentrations in the Amazon River: 1982-1984. *Water Resources Research* **22**:756-764.

Richey, J.E., Nobre, C. and Deser, C. 1989 Amazon river discharge and climate variability: 1903 to 1985. *Science* **246**:101-103.

Vörösmarty, C.J., Willmott, C.J., Choudhury, B.J., Schloss, A.L., Stearns, T.K., Robeson, S.M. and Dorman, T.J. 1996 Analyzing the discharge regime of a large tropical river through remote sensing, ground-based climatic data and modeling. *Water Resources Research* **32**:3137-3150.

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

*R.V. Marins, G.S.S. Freire, L.P. Maia, J.P.R. Lima, and L.D. Lacerda**
Centro de Ciências, Universidade Federal do Ceará, Campus do Pici, 60455-970, Fortaleza, CE, Brazil
**Also: On leave from the Dept. Geoquímica, Universidade Federal Fluminense, Niteroi, RJ, Brazil*

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.km^{-2} - 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.km^{-2} (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.

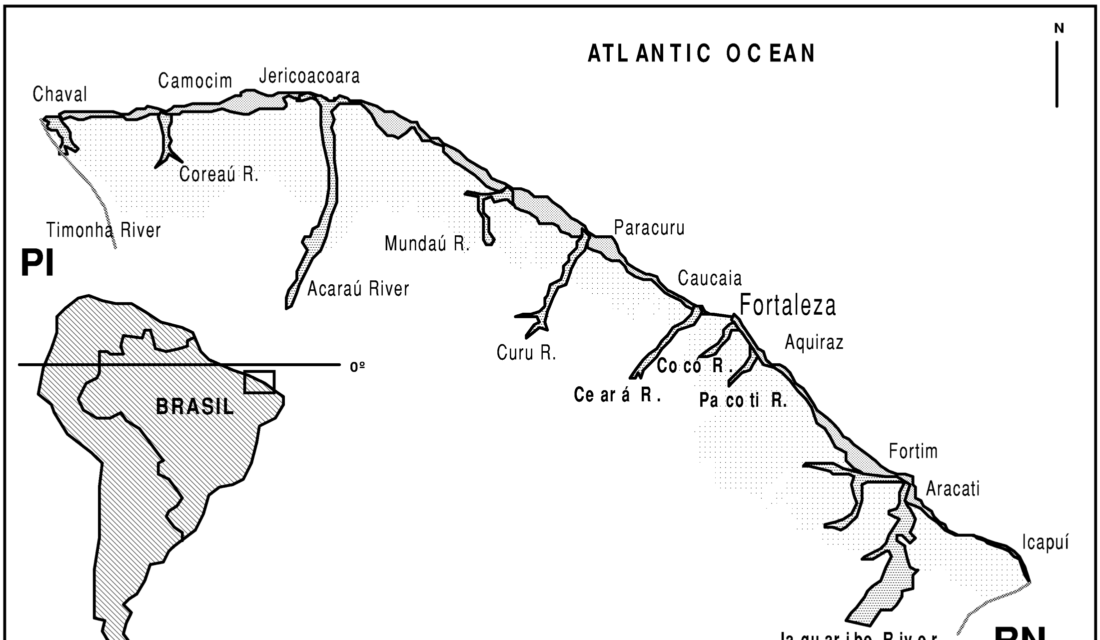


Figure 5.11. Map showing the coastline of Ceará State and major catchments.

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 aeolean 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 km^2 and total river discharge to the sea is about 200 $m^3.sec^{-1}$, 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 Jaquaribe River at the eastern end of the coast, the Fortaleza metropolitan basin, including the Pacoti, Cocó and Ceará rivers and the Acarú 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 withdrawalal 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 $x10^6$ m^2 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 $m^3.s^{-1}$ along that section of coastline (ANEEL 2000).

Rebouças (1999) estimated the availability of freshwater in Ceará State as 2,279 $m^3.inhab^{-1}.yr^{-1}$, dose to the lower end of what is considered a regular water supply (2,000 to 10,000 $m^3.inhab^{-1}.yr^{-1}$: 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 artifitially controlled. Damming levels of the major catchements 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 Aracarú 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 then 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 $1.94x10^9$ m^3, was built in 1962, followed by the Banabiú ($1.0x10^9$ m^3) and the Pedras Brancas ($0.43x10^9$ m^3); these drastically affected the çentic 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 km^2, 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 m^3.s^{-1} (ANEEL 2000), but can vary widely over long periods from nearly zero to about 7,000 m^3.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 m^3.s^{-1}. During the 1960's and 1980's, discharge to the ocean decreased to 80 m^3.s^{-1}. After 1996 freshwater discharge reached its present level of about 60 m^3.s^{-1}. With the building of the Castanhão reservoir (4.5x10^9 m^3 storage capacity) programmed to start operations in 2002, the freshwater input to the ocean is expected to decrease further to about 40 m^3.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 m^3.yr^{-1}, whereas aeolian transport reaches about 200,000 m^3.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; 170-190x10^6 m^3 of water are accumulated in reservoirs with nominal capacity larger than 50x10^6 m^3. 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 km^2 and the Pacoti River (1,260 km^2). Impoundment density is also high (294 m^3.km^{-2}) with major dams on the Pacoti River (370x10^6 m^3).

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.

Acknowledgements

This paper was partially supported by a grant from the National Research Council of Brazil (CNPq) to R.V. Marins. LDL, RVM, JPRL and LPM also received research grants from CNPq.

References

Almeida, M.M.M., Silva, F.J.A. and Araújo, L.F.P. 1999 Avaliação qualitativa da águas do principal rio da região metropolitana de Fortaleza. Pages 2154-2158 in: *Anais do 20º Congresso Brasileiro de Engenharia Sanitária e Ambiental*, Rio de Janeiro.

ANEEL 2000 Agencia Nacional de Energia Eletrica. Descargas medias de Longo Período, Bacia Atlântico NO/NE. http://www.anel.gov.br

Bezerra, E. 1996 *A Barragem do Castanhão e a Transposição do Rio São Francisco.* Universidade Federal do Ceará, Fortaleza, 53 pages.

Campos, J.N.B., Souza Filho, F. and Araújo, J.C. 1997 Errors and variability of reservoir yield estimation as a function of variation of annual inflows. Pages 1-7 in: *Proc. 27th IARH Congress*, San Francisco.

Cavalcante, A.A. 2000 Impactos ambientais na região do baixo curso do Rio Jaguaribe, CE. *MSc Dissertation. Universidade Estadual do Ceara, Fortaleza*, 317 pages.

CONAMA 1986 *Resoluções CONAMA 1984-86.* Conselho Nacional do Meio Ambiente, Ministério do Meio Ambiente, Brasília, DF, 92 pages.

CPRM 1996 *Avaliação das potencialidades hídrica e mineral do Médio-baixo Jaguaribe – CE.* Companhia de Pesquisas de Recursos Minerais. Fortaleza, 89 pages.

DHN 2001 *Tide Tables.* Diretoria de Hidrografia e Navegação of the Brazilian Navy, http://www.mar.mil.br

Ekau, W. and Knoppers, B. 1999a Sedimentation processes and productivity in the continental shelf waters off East and North-East Brazil. Brazilian-German Joint Oceanographic Projects II, 1994/95. *Archive of Fishery and Marine Research* 47 (2-3):109-340.

Ekau, W. and Knoppers, B. 1999b Sedimentation processes at the East and Northeast Brazil shelf . *Geo-Marine Letters* 19 (3): 171-218.

Ellison, J. 1993 Mangrove retreat with rising sea level in Bermuda. *Estuarine Coastal and Shelf Science* 37: 75-87.

Freire, G.S.S. 1989 Etude hydrologique e sedimentologique de l'estuaire du Rio Pacoti (Fortaleza – Ceará-Brésil). *These de Doctorat. Faculte dês Sciences et dês Techniques, Universite de Nantes*, Nantes, 229 pages.

Freire, G.S.S. and Hazin 2000 *Programa REVIZEE: Programade Avaliuação do Potencial Sustentável dos Recursos Vivos na Zona Econômica Exclusiva.* DEGEO/UFC, Fortaleza, 101pages.

Freire, G.S.S., Maia, L.P. and Castelo Branco, M.P.N. 1991 Frente salina e balanço do sal no estuário do Rio pacoti – Ceará. *Revista de Geologia* 4:33-41.

Freire, G.S.S. and Oliveira, A.M.E. 1993 Mangroves of northeastern Brazil. Pages 14-15 in Lacerda, L.D. and Field, C.D. (eds.). *Conservation and Sustainable Utilization of mangrove forests in Latin America.* International Society for Mangrove Ecosystems, Okinawa.

Herz, R. 1991 *Manguezais do Brazil.* Instituto Oceanográfico, USP, São Paulo, 227 pages.

Jimenez, J., Sarabia, J. and Maia, L.P. 1999 Aeolian dune migration, NE Brazil. *Sedimentology* **46**: 689-701.

Junior, J. 2000 Comércio Exterior, Ceará. *Gazeta Mercantil: Balanço Anual* **6**(6):26-27.

Lacerda, L.D. 1993 *Conservation and Sustainable Utilization of Mangrove Forests in Latin America and Africa Regions: Part I.* ISME Mangrove Ecosystems Reports, N°2, Inter. Soc. Mangrove Ecosystems, Okinawa, 272 pages.

Marins, R.V., Lacerda, L.D., Mounier, S. and Freire, G.S.S. 2001 Hidroquímica e concentração de mercúrio em rios metropolitanos de Fortaleza, Ceará. In: annais do VIII Congresso Brasileiro de Geoquímica, Curitiba, (in press).

Marins, R.V., Lacerda, L.D.,.Freire, G.S.S, Marques, V.S., Moura, L.A., Mounier, S. and Paraquetti, H.M.M.2001.Distribuição de mercúrio em águas dos rios da região metropolitana de Fortaleza, CE, NE – Brasil. In: 8th Congresso Brasileiro de Geoquímica. Curitiba (in press).

Mavignier, A.L. 1992 Estudo físico, químico e bacteriológico do Rio Cocó. *MSc Dissertation*, Universidade Federal do Ceará, Fortaleza, 107 pages.

Medeiros, C., Macêdo, S.J., Feitosa, F.A.N. and Koening, M.L. 1999 Hydrography and phytoplankton biomass and abundance on North-East and East Brazilian shelf. *Archive of Fishery and Marine Research* 47 (2-3):133-151.

MMA 1996a *Perfil dos estados litorâneos do Brasil: Subsídios para a Implantação do Programa Nacional de Gerenciamento Costeiro.* Ministério do Meio Ambiente Recursos Hídricos e da Amazônia Legal. Programa Nacional de Gerenciamento Costeiro, Brasília, DF, 301 pages.

MMA 1996b *Macrodiagnóstico da Zona Costeira do Brazil.* Ministerio do Meio Ambiente, Brasília, 277 pages.

Morais, J.O. and Pinheiro, L.S. 1999 The impacts of the Jaguaribe River flow on the erosion and sedimentation of Pontal de Maceió – State of Ceará, NE Brazil. *Abstract.* VII congresso da ABEQUA, Porto Seguro.

PRODETUR 2000 *Programa de Ação Para o Desenvolvimento do Turismo no Noerdeste*, Banco do Nordeste, Fortaleza.

PROURB – *Projeto de Desenvolvimento Urabno e Gestão de Recursos Hídricos do Ceará*, Governo do Estado, Fortaleza

Rebouças, A.C. 1999 Água doce no mundoe no Brasil. Pages 327-367 in: Rebouças, A.C., Braga, B. and Tundisi, J.G. (eds.): *Águas Doces no Brasil – Capital Ecológico, Uso e Conservação.* Escrituras Editora, São Paulo.

Smoak, J.M. and Patchineelam, S.R. 1999 Sediment mixing and accumulation in a mangrove ecosystem: evidence from ^{210}Pb, ^{234}Th and ^{7}Be . *Mangroves and Salt Marshes* **3**:17-27.

Soares Filho, A.A. and Alves, M.I.M. 1996 Peixes do estuario do Rio Jaguaribe (Ceará-Brasil): Aspectos fisioecológicos. *Ciência Agronômica* **27**:5-16.

SRH 1998 Secreataria de Reucrsos Hídricos, Estado do Ceará. Bacias Hidrográficas. Tabelas fluviometricas e pluviométricas. http://www.shr.gov

UNDP 1997 Commission on Sustainable Development. *Comprehensive Assessment on the Freshwater Resources of the World*, UNDP, Paris.

Valentini, E. 1996 Um modelo de balanço sedimentológico para o litoral do Ceará. Pages 251-259 in: *Anais do II Encontro Nacional de Engenharia de Sedimentos*, Rio de Janeiro.

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: ⇑ = increasing, ⇓ = decreasing, ⇔ = 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 0.6×10^6 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, ⇑**	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, ⇑**	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, ⇑**	Sedimentological balance (9)
	Nutrient depletion	Estuary and adjacent coastal zone of the Jaguaribe River mouth	Sediment trapping	Chlorophyll *a* concentrations 0.05 to 0.5 mg m^{-3}. Primary production 0.02 to 0.2 gC m^{-2} d^{-1}, - a typical oligotrophic water mass. Surface NO_3 and PO_4 concentrations about 0.2 and 0.25 µM (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, ⇑**	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. Inceasing 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 $\mu g.l^{-1}$, whereas dissolved organic nitrogen (DON) is < 0.6 $\mu g.l^{-1}$ (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 $\mu g.l^{-1}$ and 6 to 15 $\mu g.l^{-1}$ (11, 16, 17)	**8, p, ⇑**	Nutrient flux monitoring (11), PRODETUR (12) and PROURB (13)
	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 algae 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)
	Sedimentation	Acarau and Pacoti rivers	Facilitating soil erosion		Unknown	**1, p, ⇑**	(9)
	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 $\mu g.l^{-1}$ for Cu) (19)	Unknown	**1, p, ⇑**	No response to now
Aquaculture	Eutrophication	Pirangi 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 Noerdeste, Banco do Nordeste, 13 – PROURB – Projeto de Desenvolvimento Urabno 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

L.D. Lacerda[1]*, R.V. Marins*[2] *and C. Barcellos*[3]
1 Dept. Geoquímica, Universidade Federal Fluminense, Niteroi, RJ, Brasil, 242020-007
2 Laboratório de Geologia Marinha e Aplicada, Universidade Federal do Ceará, Campus do Pici, Fortaleza, Ceará;
3 Fundação Oswaldo Cruz, Rio de Janeiro, RJ, Brazil

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 km^2 while minimum area at low tide is 419 km^2. Mean water volume is 2.56x10^9 m^3, ranging from a maximum of 3.06x10^9 m^3 and a minimum of 2.38x10^9 m^3. The depth averages about 6 m. The tidal prism volume is 3.4x10^8 m^3, 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 7.6x10^6 m^3. Among them, the São Francisco Canal, with an annual flow of 6.5x10^6 m^3, 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 km^2 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.

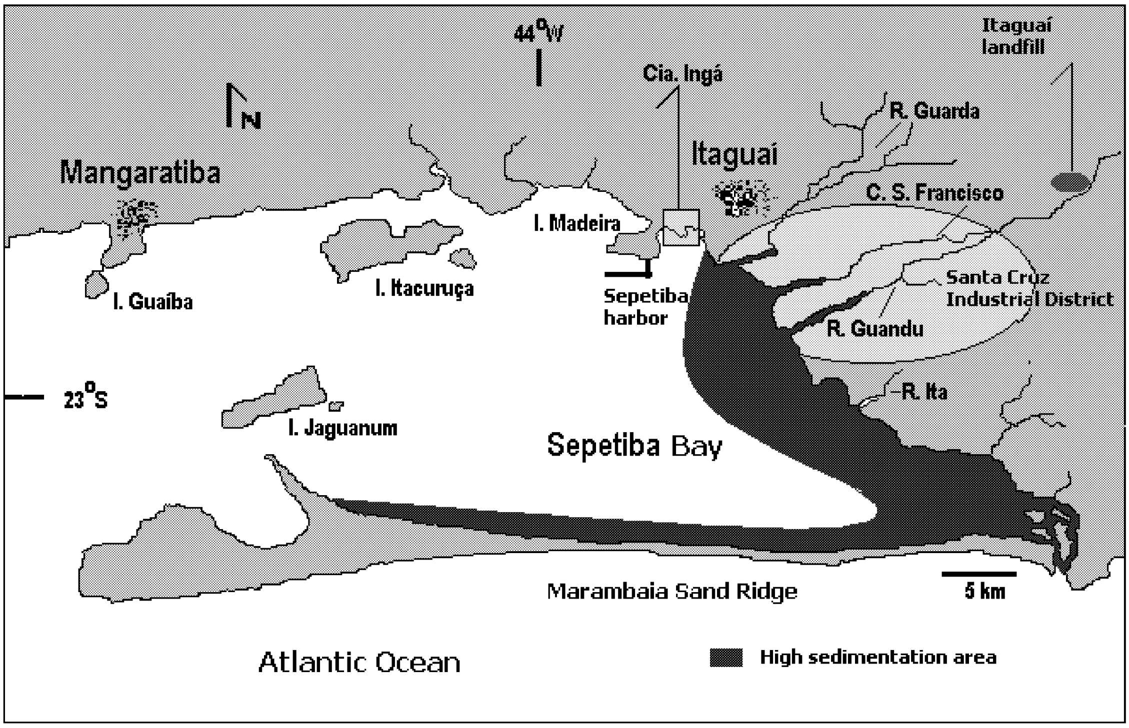


Figure 5.12. Major geographical features of Sepetiba Bay, SE Brazil

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 mg cm^{-2} 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 m^3 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 mg cm^{-2} 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 mg cm^{-2} yr^{-1}.

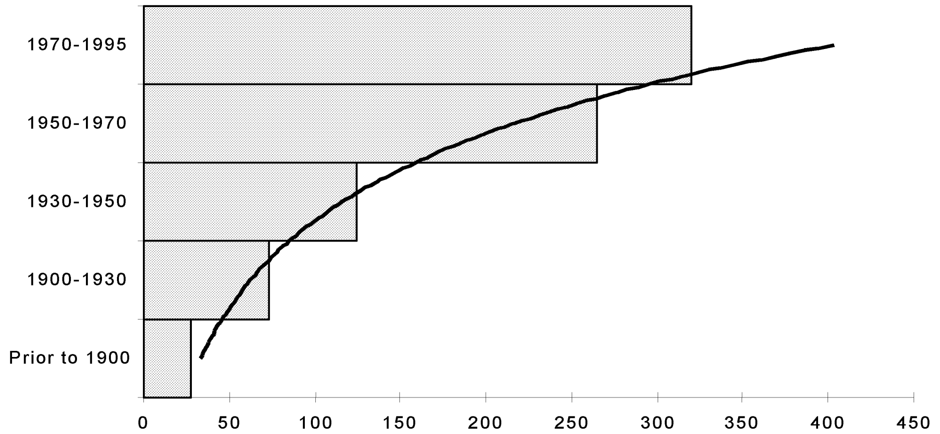


Figure 5.13. Sediment accumulation rates in Sepetiba Bay, SE Brazil (mg cm^2 yr^1; from Forte 1996).

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
Metal smelting			
Fe	03	1.102,000	4,053
Al	02	98,500	925
Zn	01	36,000	438
Manufacturing			
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			
Metal	Cd	Zn	Pb	Hg	Cd	Zn	Pb	Hg	Cd	Zn	Pb	Hg	Cd	Zn	Pb	Hg
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	-
Manuf'ing																
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	002	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 than 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.

References

Barcellos, C. 1995 Geodinâmica de Cádmio e Zinco na Baía de Sepetiba. *Doctor Thesis*, Instituto de Química. Universidade Federal Fluminense, Niterói, Brazil, 125 pages.

Barcellos, C. and Lacerda, L.D. 1994 Cadmium and zinc source assessment in the Sepetiba Bay and Basin. *Environmental Monitoring and Assessment* **29**:183-199.

Barcellos, C., Lacerda, L.D. and Ceradini, S. 1997 Sediment origin and budget in Sepetiba Bay (Brazil) - an approach based on multi-element analysis. *Environmental Geology* **32**:203-209.

Carvalho, C.E., Lacerda, L.D., Rezende, C.E. and Abrão, J.J. 1993 Titanium and calcium as tracers for continental and oceanic materials in the Brazilian continental shelf. Pages 122-127 in *Proceedings III Simpósio de Ecosistemas da Costa Brasileira*, Rio de Janeiro.

Forte, C.M.S. 1996 Determinação de taxas de sedimentação na porção nordeste da Baía de Sepetiba utilizando datação com radioisótopo ^{210}Pb. *Master Thesis*, Instituto de Química. Universidade Federal Fluminense, Niterói, Brazil.

Jeffery, J., Marshman, N., Salomons, W. 1988 Behavior of trace metals in a tropical river basin affected by mining. Pages 259-274 in Salomons W, Forstner U (eds) *Chemistry and biology of solid wastes*, Springer, Berlin.

Kherig, H.A. 1995 Estudo da contaminação por mercúrio em corvinas (*Micropogonias fumieri*) em quatro áreas costeiras do Brazil. *MSc Thesis*, Pontifícia Univesidade Católica, Rio de Janeiro.

Lacerda, L.D. 1983. Aplicação da metodologia de análise por parâmetros críticos no estudo da poluição por metais pesados na Baía de Sepetiba, Rio de Janeiro. *PhD thesis*, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil.

Lacerda, L.D. 1998 Biogeochemistry of trace metal and diffuse pollution in mangrove ecosystems. International Society for Mangrove Ecosystems, Okinawa.

Lacerda, L.D., Koudstaal, R., Blower, B.T. and Pfeiffer, W.C. 1988 *The Sepetiba Bay management study.* International Federation of Institutes of Advanced Studies, Rio de Janeiro, 65 pages.

Lacerda, L.D., Pfeiffer, W.C. and Fiszman, M. 1987 Heavy metal distribution, availability and fate in Sepetiba Bay, SE Brazil. *Science of the Total Environment* **65**:163-173.

Marins, R.V. 1998 Biogeoquimica de mercúrio na Baía de Sepetiba. *PhD thesis*, Universidade Federal Fluminense, Niteroi, Brazil.

Marins, R.V., Lacerda, L.D. and Villas Boas, R.C. 1999 Relative importance of non-point sources of mercury to an industrialized coastal system, Sepetiba Bay, SE Brazil. Pages 207-220 in Ebinghaus, R., Turner, R.R., Lacerda, L.D., Vasiliev, O. and Salomons, W. (eds). *Mercury Contaminated Sites*, Springer, Berlin.

Marins, R.V., Silva Filho, E.V. and Lacerda, L.D. 1996 Atmospheric mercury deposition over Sepetiba Bay, SE Brazil. *Journal of the Brazilian Chemical Society* **9**:177-181.

Pedlowiski, M.A., Lacerda, L.D., Ovalle, A.R.C., Watts, P.P.R. and Silva Filho, E.V. 1991 Atmospheric inputs of Fe, Zn and Mn to Sepetiba Bay, Rio de Janeiro. *Ciência and Cultura* **43**:380-382.

Pfeiffer, W.C., Lacerda, L.D., Fiszman, M. and Lima, N.R.W. 1985 Metais pesados no pescado da baía de Sepetiba. *Ciência and Cultura* **37**:297-302.

5.6 The Patos-Mirim basins, lagoons and estuary, South Brazil: natural and human forcing factors

Ulrich Seeliger and César S.B. Costa
Depto. de Oceanografia, Fundação Universidade Federal do Rio Grande, 96201-900 Rio Grande RS, Brazil

Introduction

The warm-temperate coastal region of Brazil's extreme south (Seeliger *et al.* 1997) comprises enormous ecological resources that, despite man's early interference (von Ihering 1885), have satisfied social and economic interests without management for many years. The dominant features of the coastal plain are the Patos and Mirim lagoons. The lagoons receive freshwater runoff from five sub-basins that extend over 201,626 km^2 (Herz 1977; Castello and Möller 1977; Hubold 1980; Ciotti *et al.* 1995). The Patos Lagoon has a surface area of 10,227 km^2 and is the world's largest choked lagoon (Kjerfve 1986). The lagoon has an average depth of 5 m, a maximum width of 60 km, and the main axis extends over 180 km in a NE-SW direction (Figure 5.14). Shallow marginal bays, freshwater marshes, and sandy beaches dominate the shorelines.

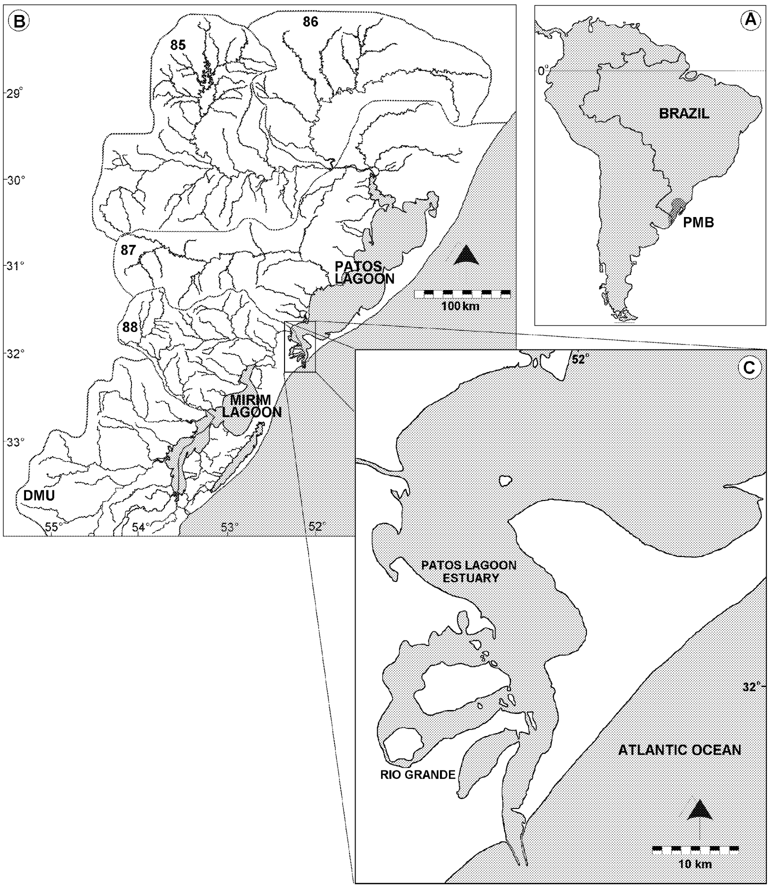


Figure 5.14. A - Geographic location of the Patos-Mirim Basin (PMB); B – Patos-Mirim Basin with sub-basins (85, 86, 87, 88, DMU); C – Patos Lagoon estuary.

About 85% of the runoff originates from the Guaíba River (basins 85, 86), the Camaquã River (basin 87), and from São Gonçalo Channel (basins 88, DMU) falling into the upper, central and lower Patos Lagoon, respectively (Figure 5.14). Freshwater runoff from the Guaíba basin may vary from 41 to 25,000 m^3 s^{-1} between summer/fall and winter/spring and runoff from the Camaquã basin from 6 to 5,300 m^3 s^{-1} (Herz 1977). Artificial locks in the São Gonçalo Channel, which impede saltwater penetration from the Patos

Lagoon estuary into the Mirim Lagoon, are only opened during periods of elevated freshwater accumulation, thus discharge into the upper estuary (700-3,000 $m^3\ s^{-1}$) is usually higher in winter/spring. Average runoff values are greatly exceeded during years under the influence of El Niño, with direct consequences on biogeochemical processes in the coastal marine ecosystem in the South-west Atlantic (Ciotti *et al.* 1995; Seeliger *et al.* 1997). Approximately 971 km^2 of the southern lagoon reaches are estuary through which waters exchange with the Atlantic Ocean. The estuary is dominated (70%) by extensive and shallow (<1.5 m) shoals, though the inlet and other channels may reach a depth of 18 m (Calliari 1980, Toldo 1991) (Figure 5.14).

Natural forcing

More than any other parameter, the nature of the narrow (700 m) and deep inlet channel characterize the system as a choked coastal lagoon (Kjerfve 1986). The inlet acts as a set-down filter and largely confines tidal influence (0.47 m) to the channel, strongly attenuating amplitudes as the tidal wave advances into the estuary and lagoon. After prolonged periods of heavy rainfall, flushing current velocities in the inlet may reach 1.7-1.9 $m\ s^{-1}$ (DNPVN 1941), whilst peak inflowing seawater current velocities approach 1.5 $m\ s^{-1}$ (Hartmann 1996).

Rather than being tidal-driven, the Patos Lagoon is forced by winds. Since the predominant NE (22% of the year; mean velocity 3.6-5.1 $m\ s^{-1}$) and SW (12% of the year; mean velocity 5.7-8.2 $m\ s^{-1}$) winds are parallel to the main axis of the lagoon, they were early identified as the principal forcing factor (Bicalho 1883; Malaval 1922). They decisively control circulation, salinity distribution and water levels, although fluvial discharge may also generate seasonal pressure gradients with elevated water levels after the onset of the rainy period.

Wind direction influences both local and large-scale circulation patterns. Under NE winds a pressure gradient rises along the main lagoon axis. A pressure gradient between the inlet channel and retreating adjacent coastal waters favors flushing of the lagoon water (Motta 1969). In contrast, SE and SW winds cause inversion of flow in the main lagoon body and raise the water level at its northern limits. In the inlet channel, outflowing currents are forced along the western margin under the influence of NE winds, whilst SE and SW winds direct inflowing currents towards the shallower eastern bank (Gafrée 1927, Moller *et al.* 1991, Hartmann 1996).

The time-space variability of physico-chemical estuarine parameters and their component concentrations lack tidal variability but relate to regional temperature cycles and wind and precipitation patterns (Vilas Boas 1990). The temperature and salinity profiles delineate different estuarine conditions. Homogeneous conditions, ranging from freshwater to full-strength seawater, are associated with high fluvial discharge and NE quarter winds or minimal freshwater discharge and southerly winds, respectively. NE quarter winds together with high fluvial discharge significantly decrease estuarine salinities (Calliari 1980; Costa *et al.* 1988). During periods of low fluvial discharge (i.e. summer/fall), southerly onshore winds force seawater through the inlet into the lower estuary and occasionally as far as 150 km into the lagoon (Hartmann 1996). In contrast, wind-induced seawater penetration and fluvial discharge in excess of 3,000 $m^3\ s^{-1}$ cause pronounced salinity stratification in the inlet because freshwater advances over the salt wedge. Even higher runoff values transfers the estuarine mixing zone into coastal waters (Möller *et al.* 1991).

The estuary receives sediments from a variety of sources. Suspended matter loads in the water column strongly depend on precipitation in the Patos-Mirim basins. However, owing to a gradual decrease (1 m/120 km) in elevation towards the estuary and slow currents, much of the sediment load is deposited in the main lagoon body during transport (Martins 1963; Hartmann *et al.* 1980). Apart from fluvial input, the erosion of estuarine margins contributes significant amounts of sediments. In general, suspension loads tend to increase in the inlet due to re-suspension of bottom sediments by inflowing seawater (Niencheski and Windom 1994, Hartmann 1996). Seasonal mean suspended matter loads in the inlet channel (50-350 $mg\ l^{-1}$) may sporadically exceed 1,200 $mg\ l^{-1}$ (Hartmann 1996). In years with average rainfall, hundreds of tons of silt and clay sediments (>95%) reach coastal waters every second. Based on the erosion of estuary margins, the annual sediment removal to coastal nearshore waters may approach $2.5x10^5\ m^3$ (about $4x10^5$ t; Calliari 1980). Even higher values of about $2.4x10^6\ m^3$ or $3.8x10^6$ t occurred during 143 days of flushing between May and October of 1984 (Hartmann 1996) (Figure

5.15). During the same period, 1.1x10^4 t of nitrogen and 1.2x10^5 t of carbon were exported, assuming mean total concentrations of 0.32% and 3.0%, respectively (Hartmann 1996).

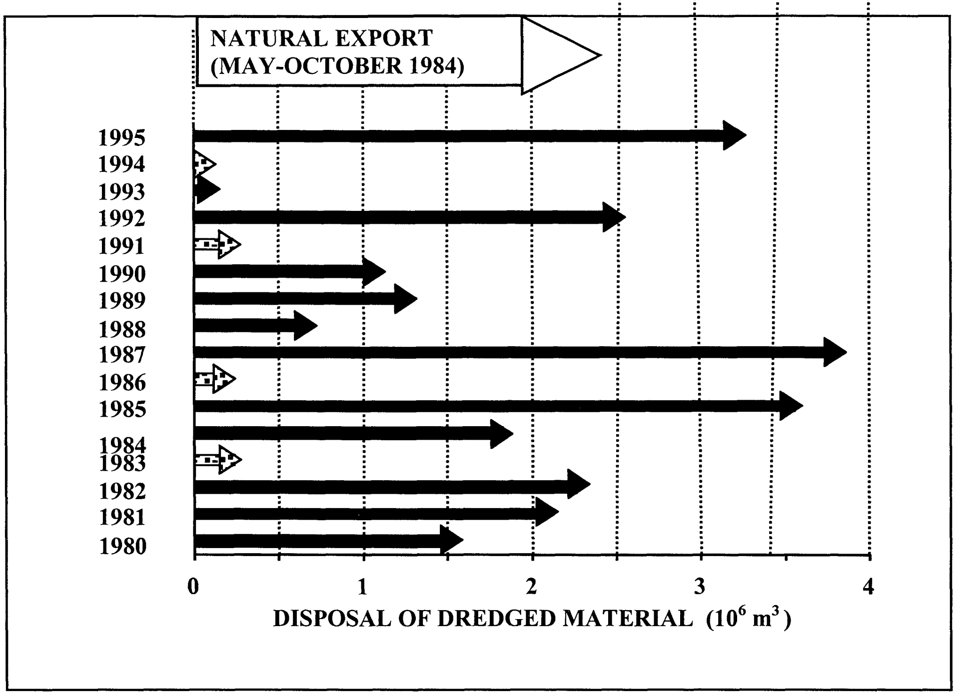


Figure 5.15. Estimate of natural sediment export from the Patos Lagoon estuary and disposal of dredged material in coastal waters (black arrows) and inside the estuary (dotted arrows) over a fifteen-year period (after Hartmann 1996, SUPRG 1996).

Despite high mean suspended matter loads in the channel and shallow shoals, dissolved oxygen in the water tends to be close to saturation or even at super-saturation levels (Niencheski and Windom 1994), especially in the inlet channel with pronounced hydrodynamic activity. The shallow depth (<1 m) of the larger part of the estuary favors water oxygen levels in equilibrium with the atmosphere.

Human forcing

Freshwater Flow

The water quality of the Patos Lagoon, estuary and coastal nearshore environments is ultimately related to natural freshwater runoff. Because of the assumption that runoff is available for expanding agricultural and industrial activities and domestic needs without any limitation, the importance of freshwater flow into the estuary has been overlooked. The annual estimated stream flow through the Patos Lagoon inlet averaged 109 km^3 between 1965 and 1975 (Castello and Möller 1978) but varied significantly within (CV=80%) and between (CV=29%) years. During the drought years 1968-1969 (IPAGRO 1977), the water demand for irrigated rice cultivation (EPAGRI 1992) and for the population of the watershed approximated 6% of the expected (75 km^3) annual runoff. Since then, the population and the area of irrigated rice cultivation have increased by more than 37% and 120%, respectively (IBGE 1993). Today, in drought periods as La Nina events (CPTEC/INPE 1998), more than 13% of the natural runoff may be diverted (Figure 5.16). Furthermore, retention of water for irrigation by the locks in the São Gonçalo Channel has considerably reduced freshwater flow into the estuary. The decreasing freshwater discharge into the estuary has modified seasonal variations in flow rates that are essential for flushing and maintaining the balance of salinity and nutrients in the estuary. Therefore, many of the commercially important fish and crustaceans in the south-western Atlantic, which visit the estuary periodically, may lose the benefit of low salinity waters, physical protection, and food sources for either growth or reproduction (Vieira and Castello 1997).

Nutrient Enrichment

Freshwater runoff not only influences estuarine salinity regimes but also affects the quality of surface waters through inputs of nutrients and toxic materials. Most urban centers around the Patos Lagoon (~3.5 million inhabitants) either lack or have inadequate sewage treatment facilities, which tend to overflow during heavy rains and discharge raw sewage directly into the lagoon or estuary. The major tributaries also add nutrients from large-scale agricultural activities; phosphate (2-3 μM) and nitrogen (> 40 μM) concentrations in particular tend to be seasonally elevated in the receiving waters of the Patos Lagoon (Vilas Boas 1990). Despite a substantial reduction during transport, estuarine nutrient levels are also occasionally elevated (Kantin 1983; Niencheski and Windom 1994), owing to remobilization of bottom sediments in the lower estuary (Abreu *et al.* 1992), local discharge of industrial and domestic effluents, and agricultural runoff through the São Gonçalo Channel. Excess nutrient loads in the estuary cause eutrophication, which favors blooms and changes in phytoplankton composition. Blooms of the potentially toxic blue-green alga *Microcystis aeruginos* form in limnic regions of the lagoon and, during years with high spring tributary discharge, are transported into the estuary (Odebrecht *et al.* 1987; Bergesch 1990). During the summer, estuarine embayments with prolonged water residence time favor blooms of other species (Persich 1993) that contribute to the decline of the submerged macrophyte biomass in the estuary, owing to attenuation of light penetration and epiphytic algae loading on *Ruppia* leaves (Cafruni 1983; Costa and Seeliger 1989). Recently, red tide blooms associated with the dinoflagelates *Gyrodinium aureolum*, *Dinophysis acuminata* (Odebrecht *et al.* 1995) and *Alexandrium tamarense* (Persich 2001) have been reported for waters adjacent to the estuarine mouth.

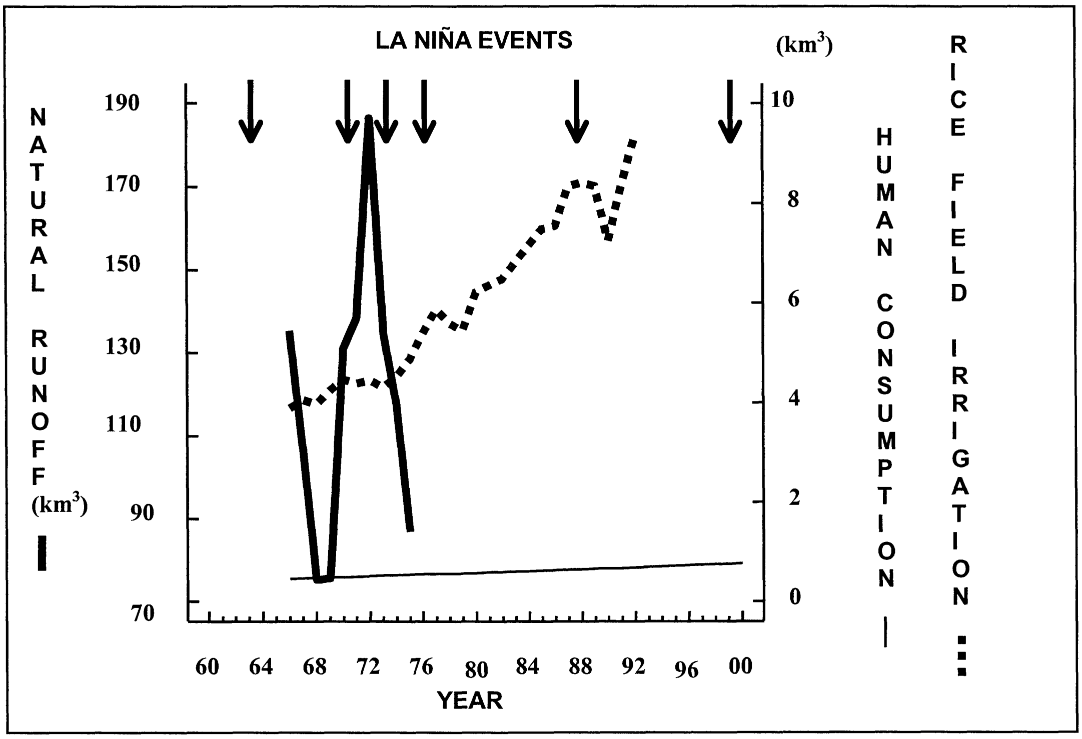


Figure 5.16. Estimated runoff from the Patos Lagoon estuary between 1965-1975 and projected water diversion for human use and rice field irrigation (after IPAGRO 1977, Castello and Moller 1978, EPAGRI 1992).

Hazardous Materials

Since large stretches of coastline north and south of the inlet are devoid of industrial discharge, trace metals are added to the estuary either through freshwater runoff from the Patos Lagoon or through local discharge of effluents (Seeliger *et al.* 1988). Average metal concentrations in estuarine waters with high suspension loads correspond to natural background levels (Seeliger and Knak 1982a; Niencheski *et al.* 1994) reported for estuarine systems elsewhere (Windom 1975), though dissolved copper concentrations are occasionally slightly higher (Seeliger and Knak 1982b). Sporadic increases of suspended copper and lead concentrations in the estuary may reflect metal input from industrial effluents and mining activities to the upper limnic part of the Patos Lagoon (Baumgarten 1987; Vilas Boas 1990). In general, metal concentrations correlate significantly with suspended matter loads, and estuarine metal gradients are not well defined (Seeliger and Cordazzo 1982) because physico-chemical processes add particulate metals through re-suspension of estuarine bottom sediments by inflowing seawater, wind and waves (Niencheski *et al.* 1994).

The biological effects of trace metal pollution have not yet been documented for the Patos Lagoon estuary, probably because estuarine organisms tend to display elevated metal tolerance and the concentrations are close to background levels. However, in shoals with reduced circulation and prolonged residence time of domestic and industrial effluents, even low pollution levels appear to induce changes in the zooplankton community structure and anatomical anomalies (Montú and Gloeden 1982). The excessive application of pesticides over vast extensions of agricultural lands around the Patos Lagoon (e.g., 890,000 ha of rice plantations: EPAGRI 1992) is likely to contribute through runoff elevated concentrations to the estuary. Some intertidal estuarine species (e.g. *Chasmagnathus granulata*), which decisively influence energy transfer in submersed and emersed habitats (D'Incao *et al.* 1992), appear to be highly susceptible to pesticide concentrations in warmer waters during the summer (Monserrat and Bianchini 1995). Surficial estuarine and coastal waters are especially prone to pollution by different fractions of hydrocarbons from urban discharge or washing of tanks of vessels and values of up to 30 mg l^{-1} of oil and 30 μm l^{-1} phenol have been measured in enclosed estuarine bays (Niencheski and Baumgarten 1997).

Sedimentation, Fill and Dredge
The introduction of large amounts of suspended sediments from the Patos Lagoon and the presence of extensive and shallow shoals occupied by *Ruppia* beds and fringing marshes provide an ideal setting for natural deposition processes in the estuary. Over the last two centuries the water area of the lower estuary has decreased by approximately 11%, which emphasizes the depositional character of this environment (Seeliger and Costa 1997). However, losses of lower estuarine water areas not only result from natural sedimentation but also from man-mediated processes. The expansion of Rio Grande port between 1909 and 1914 generated 8.8×10^6 m^3 of dredge material, which served for the establishment of islands and was deposited along lower estuary margins. The construction of jetties in 1917 has probably intensified natural sedimentation at the northern side of the inlet.

Furthermore, the natural sediment deposition in the lower estuary has interfered with navigation, thus dredging activities have concentrated in the navigation channel and inlet since 1833. Modern vessels with increasing draft require deeper waterways. Between 1980-1995, approximately 2.4×10^6 m^3 (3.8×10^6 tons) of channel and berth material was removed every year from the shipping channels and most (about 77%) was disposed of in nearshore waters four miles off the coast (SUPRG 1996; Figure 5.15). Although dredging activities may have solved immediate problems, they also resulted in unexpected and long-term changes by modifying depth, circulation, and sediment deposition patterns (Calliari 1980). Since the accumulative effects of frequent dredging are comparable to natural geological processes (Figure 5.15), the export of fine sediments to the adjacent coast is likely to have increased (Villwock and Martins 1972; Hartmann *et al.* 1980; Borzone and Griep 1991; Calliari and Fachin 1993).

The filling of intertidal and shallow water flats in the lower estuary for port, residential, and more recently industrial development has decreased or destroyed vital seagrass and tidal marsh habitats. Filling along lower estuarine margins and over and around small islands has destroyed as much as 10% of the total salt marsh area (Seeliger and Costa 1997). Seagrasses are especially susceptible to filling, and burial by dredged sediments results in their immediate eradication. Only if plants are lightly covered and the root-rhizome systems are not damaged may re-growth occur through the sediments. Since dredged sediments are readily re-suspended, they represent a source of excess suspended matter for long periods of time. The gradually increasing water turbidity reduces seagrass production and depth distribution. Therefore, the extension of natural beds and their valuable functions as habitat and shelter decrease. Although the disposal of dredged material is clearly affecting estuarine resources, the State government only recently established a monitoring program for dredging activities in the main shipping channel and disposals in nearshore waters.

Conclusions

Over the last few decades, demographic and industrial growth in the Patos-Mirim basins and around the lagoons have altered natural processes and magnified environmental conflicts. Elevated runoff from tributaries adds ever-increasing sediment loads, nutrients, hazardous heavy metals (Baisch *et al.* 1989), and agro-toxins to the Patos Lagoon, while port activities and fertilizers, fish processing and petroleum refining plants have led to deterioration of the waters in the estuary (Almeida *et al.* 1993). Escalating conflicts between human impact and resource exploration call for an increasing commitment to solve current management problems of the Patos-Mirim coastal ecosystem (Asmus *et al.* 1984). Contrary to the historic situation in other parts of the world that suffered consequences of uncontrolled human impacts decades ago, the information now available may still prevent further deterioration of the coastal ecosystem in Brazil's extreme south.

References

Abreu, P.C., Biddanda B. and Odebrecht, C. 1992 Bacterial dynamics of the Patos Lagoon estuary, Southern Brazil (32° S, 52° W): relationship with phytoplankton production and suspended material. *Estuar Coast Shelf Sci* **35**: 621-635

Almeida, M.T.A., Baumgarten, M.G.Z., Rodrigues, R.M.S. 1993 Identificação das possíveis fontes de contaminação das águas que margeiam a cidade do Rio Grande. *Documentos Técnicos, Oceanografia, Univ Rio Grande, Rio Grande* **6**: 1-63

Asmus, M.L. 1984 Estrutura da comunidade associada a *Ruppia maritima* no estuário da Lagoa dos Patos, RS, Brasil. *MSc Thesis*, Univ Rio Grande, Brazil

Baisch, P., Jouanneau, J.M., Asmus, H.E. 1989 Chemical composition of sediments from the Patos Lagoon. *XIII Int Geoch Expl Symp II Braz Geoch Cong* **1**: 11-20

Baumgarten, M.G.Z. 1987 Avaliação do *Balanus improvisus* como bioindicador dos níveis metálicos do estuário da Lagoa dos Patos. *MSc Thesis*, Univ Rio Grande, Brazil

Bergesch, M. 1990 Variações de biomassa e composição do fitoplâncton na área estuarina rasa da Lagoa dos Patos e suas relações com fatores de influência. *MSc Thesis*, Univ Rio Grande, Brazil

Bicalho, H. 1883 Descrição geral e observações preliminares. Estudos e projetos de melhoramentos. *Obras do Porto e Barra do Rio Grande, Oficinas Gráficas da Federação (Porto Alegre)* **3**: 1-455

Borzone, C.A., Griep, G.H. 1991 Características do sedimento superficial infralitoral da região costeira adjacente à desembocadura da Lagoa dos Patos, RS, Brasil. *Pesquisas* **18**(1): 71-78

Cafruni, A.M.S. 1983 Estudo autoecológico de *Ruppia maritima* no estuário da Lagoa dos Patos. *MSc Thesis*, Univ. Rio Grande, Brazil.

Calliari, L.J. 1980 Aspectos sedimentológicos e ambientais da região sul da Lagoa dos Patos. *MSc Thesis*, Univ. Fed Rio Grande Sul, Brazil.

Calliari, L.J. and Fachin, S. 1993 Laguna dos Patos. Influência nos depósitos lamíticos Costeiros. *Pesquisas* **20**(1): 57-69.

Castello, J.P. and Möller, O.O. Jr 1977 On the oceanographic conditions in the Rio Grande do Sul state. *Atlantica (Rio Grande)* **2(2)**:25 –110.

Castello, J.P. and Möller, O.O. Jr 1978 On the relationship between rainfall and shrimp production in the estuary of the Patos Lagoon (Rio Grande do Sul, Brazil). *Atlantica* **3**: 67-74.

Ciotti, A.M., Odebrecht, C., Fillmann, G. and Möller, O.O. Jr 1995 Freshwater outflow and Subtropical Convergence influence on phytoplankton biomass on the southern Brazilian continental shelf. *Cont Shelf Res* **15**(14): 1737-1756.

Costa, C.S.B. and Seeliger, U. 1989 Vertical distribution and biomass allocation of *Ruppia maritima* L. in a southern Brazilian estuary. *Aquat. Bot.* **33**: 123-129.

Costa, C.S.B., Seeliger, U. and Kinas, P.G. 1988 The effect of wind velocity and direction on the salinity regime in the Patos Lagoon estuary. *Ciencia Cult.* **40**(9): 909-912.

CPTEC/INPE 1998 *La Nina.* [http://www.cptec.inpe.br/products/laninha/laninha3p.html], INPE, Sao Jose dos Campos, Brazil.

D'Incao, F., Ruffino, M.L., Silva, K.G. and Braga, A.C. 1992 Responses of *Chasmagnathus granulata* Dana (Decapoda:Grapsidae) to salt marsh environmental variations. *J Exp. Mar. Biol. Ecol.* **161**: 179-188.

DNPVN 1941 Enchentes de maio de 1941. Diretoria Nacional de Portos e Vias de Navegação. *Relatório Técnico*, Porto Alegre.

EPAGRI 1992 *Arroz irrigado: recomendações técnicas de pesquisa para o sul do Brasil.* Empresa Pesq Agropec Difusão Tecnol Santa Catarina, Florianópolis.

Gafrée, C.L. 1927 *Relatório técnico da Barra de Rio Grande entre 6 de dezembro de 1926 e 16 de janeiro de 1927,* Porto Alegre.

Hartmann, C., Calliari, L., Charpy-Roubaud, C.J., Baumgarten, M.G.Z. and Kantin, R 1980 Estudo do material em suspensão e do material dissolvido das águas de superfície da plataforma do Rio Grande do Sul, entre Torres e Rio Grande (Operação GEOMAR XIII, 19 a 27 de novembro de 1979). *Anais XXXI Cong. Brasil Geol. Balneário Camburiú* **2**: 956-967

Hartmann. C., 1996 Dinâmica,distribuição e composição do material em suspensão na região sul da Laguna dos Patos, RS. *PhD Thesis*, Porto Alegre, Univ. Federal de Tio Grande do Sul, Porto Alegre, Brazil.

Herz, R. 1977 Circulação de águas de superfície na Lagoa dos Patos. *PhD thesis*, Univ. Sao Paulo, Brazil.

Hubold, G. 1980 Hydrography and plankton off southern Brazil and Rio de la Plata, August-November 1977. *Atlantica* **4**: 1-21

IBGE 1993 *Anuário Estatístico Brasileiro* Fund Inst Brasil Geogr Estat, vol **27** to **53**, Rio de Janeiro.

IPAGRO 1977 Observações meterológicas no Estado do Rio Grande do Sul. *Boln Tecn IPAGRO Porto Alegre* **3**:1-272.

Kantin, R. 1983 Hydrologie et qualité des eaux de la region sud de la Lagune dos Patos (Brasil) et de la plataforme continental adjacente. *PhD thesis*, Univ Bordeaux, France

Kjerfve, B. 1986 Comparative oceanography of coastal lagoons. Pages 63-81 in: Wolfe, D.A. (ed): *Estuarine Variability.* Academic Press, New York.

Malaval, M.B. 1922 *Travaux du port et la Barre de Rio Grande do Sul (Brésil).* Libraire de 1 Enseignement Technique. Ed Eyrolles, Paris.

Martins, I.L.R. 1963 Contribuição à sedimentologia da Lagoa dos Patos, 1. Saco do Rincão e Mendanha. *Boln Esc. Geol. Univ. Fed. Rio Grande Sul* **13**:1-43.

Möller, O.O. Jr, Paim, P.S.G., Soares, I.D. 1991 Facteurs et mechanismes de la circulation des eaux dans l'estuarie de la Lagune dos Patos (RS, Bresil). *Bull. Inst. Geol. Basin Aquitaine* **49**: 15-21.

Monserrat, J. and Bianchini, A. 1995 Effects of temperature and salinity on the toxicity of a commercial formulation of methyl parathion to *Chasmagnathus granulata* (Decapoda, Grapsidae). *Braz. J. Med. Biol. Res.* **28**: 74-78.

Montú, M. and Gloeden, I. 1982 Morphological alterations in *Acartia tonsa* (Saco da Mangueira, Lagoa dos Patos, Brasil). *Arq. Biol. Tecnol.* **25**(3/4): 361-369.

Motta, V.F. 1969 Relatório-diagnóstico sobre a melhoria e o aprofundamento do acesso pela Barra de Rio Grande. *Relat. Tec. Instituto Pesquisas Hidráulicas*, Univ Fed Rio Grande Sul, Porto Alegre.

Niencheski, L.F.H. and Windom, H.L. 1994 Nutrient flux and budget in Patos Lagoon Estuary. *Sci. Total Environ.* **149**(1-2): 53-60.

Niencheski, L.F.H., Windom, H.L. and Smith, R 1994 Distribution of particulate trace metal in Patos Lagoon estuary (Brazil). *Mar. Pollut. Bull.* **28**(2): 96-102.

Niencheski, L.F.H. and Baumgarten, M.G.Z. 1997 Nutrientes, óleos e fenóis. In: Tagliani, P.R.A. and Asmus, M.L. (coords): Estudo de Impacto Ambiental (EIA) do Porto de Rio Grande, RS - *Relatório Final.* Rio Grande, Fundação Universidade do Rio Grande.

Odebrecht, C., Seeliger, U., Coutinho, R. and Torgan, L. 1987 Florações de *Microcystis* (cianobactérias) na Lagoa dos Patos, RS. *Publ. Acad. Ciências Est. Sao Paulo* **54**(2): 280-287.

Odebrecht, C., Rörig, L., Garcia, V.T. and Abreu, P.C. 1995 Shellfish mortality and a redtide event in southern Brasil. Pages 213-215 in Lassus, P., Arzul, G., Erad, E., Gentlen, P. and Marcalliou, C., (eds.): *Harmful Marine Algal Blooms.* Lavoisier, Intercept Ltd.

Persich, G.R. 1993 Ciclo anual do fitoplâncton e alguns parâmetros abióticos no Saco da Mangueira, estuário da Lagoa dos Patos. *MSc thesis*, Univ. Rio Grande, Brazil.

Persich, G.R. 2001 Germinação, crescimento, identificação genética e perfil de toxinas do dinoflagelado tóxico *Alexandrium tamarense* Balech do sul do Brasil. *Tese de Doutorado.* Programa de Pós-Graduação em Oceanografia Biológica/FURG, Rio Grande.

Seeliger, U. and Cordazzo, C.V. 1982 Field and experimental evaluation of *Enteromorpha* as qualitative and quantitative monitoring organism for Cu and Hg in estuaries. *Environ. Pollut.* **29**(3): 197-206.

Seeliger, U. and Knak, R.B. 1982a Estuarine metal monitoring in southern Brazil. *Mar Pollut Bull* **13**(7): 253-254.

Seeliger, U. and Knak, R.B. 1982b Origin and concentration of copper and mercury in water and biota of the Patos Lagoon estuary, Brazil. *Atlantica* **5**(1): 35-42.

Seeliger, U., Lacerda, L.D. and Patchineelam, S.R. 1988 *Metals in Coastal Environments of Latin America.* Springer Verlag, Berlin-Heidelberg-New York, 287 pages.

Seeliger, U., Odebrecht, C. and Castello, J.P. 1997 *Subtropical Convergence Environments: The Coast and Sea in the Southwestern Atlantic.* Springer-Verlag, Heidelberg-New York, 308 pages.

Seeliger, U. and Costa, C.S.B. 1997 Natural and human impacts. Pages 197-203 in: Seeliger, U., Odebrecht, C. and Castello, J.P. (eds): *Subtropical Convergence Environments: The Coast and Sea in the Southwestern Atlantic.* Springer-Verlag, Heidelberg-New York, 308 pages.

SUPRG 1996 *Internal Records of the Rio Grande Harbor Administration.* Rio Grande, Superintendência do Porto de Rio Grande.

Toldo, E.E. Jr 1991 Morfodinâmica da Laguna dos Patos, Rio Grande do Sul. *Pesquisas* **18**(1): 58-63.

Vieira, J.P. and Castello, J.P. 1997 Fishfauna. Pages 56-61 in: Seeliger, U., Odebrecht, C., and Castello, J.P. (eds): *Subtropical Convergence Environments: The Coast and Sea in the Southwestern Atlantic.* Springer-Verlag, Heidelberg, New York, 308 pages.

Vilas Boas, D.F. 1990 Distribuição e comportamento dos sais nutrientes, elementos maiores e metais pesados na Lagoa dos Patos, RS. *MSc thesis*, Univ. Rio Grande, Brazil.

Villwock, J.A. and Martins, L.R.S. 1972 Depósitos lamíticos de pós-praia, Cassino, RS. *Pesquisas* **1**: 69-85.

von Ihering, H. 1885 Die Lagoa dos Patos. *Dtsch Geogr. Bl.* **8**: 182-204.

Windom, H.L. 1975 Heavy metal fluxes through salt marsh estuaries. Pages 137-152 in: Cronin, L.E. (ed): *Estuarine Research.* Academic Press, New York.

5.7 Some implications of inter-basin water transfers - Mercury emission to Sepetiba Bay from the Paraíba do Sul River basin, SE Brazil

M.M. Molisani, R.V. Marins, W. Machado, H.H.M. Paraquetti and L.D. Lacerda
Dept. Geoquímica, Universidade Federal Fluminense, Niteroi, RJ, Brasil, 242020-007

Introduction

Streams are considered an integral part of a watershed, mainly considering the water transport. But in some cases, principally for water supply, some forms of river basin manipulation can transfer water between different, adjacent basins, an event which under natural conditions does occur. Despite transformations of the landscape, the ecological implications of such schemes have been inadequately addressed.

The interaction between the two different basins may change the environmental conditions of the water body that receives water from them and will lead to alterations in hydrology and sedimentology, such as water additions, water quality changes, contaminants input, alterations in physical properties of channels, temperature regimes and transfer and mixing of organisms (Snaddon *et al.* 1998).

These effects may spread through rivers that receive the transferred water, through impoundments constructed along the river channel to control the tranfer fluxes between basins, and thence to coastal areas. In the case of trace metal contamination the impact that occurs in the continental location may be observed in areas away from the emission point. For example, mercury contamination in Sepetiba Bay, SE Brazil, originates from a variety of anthropogenic sources located along its basins. However, when emission *vs* fluvial output estimates are compared, the imbalance suggests that part of this emission may have originated from the adjacent Paraíba do Sul River basin, since over 80% of the water flux of this river is diverted to the Sepetiba Bay basin to supply the Rio de Janeiro metropolitan area (Marins *et al.* 1996; 1999). This is a typical case in which inter-basin water transfer may be contributing a pollutant load to a coastal environment that normally did not receive this load.

Study Area

The study area is located in Rio de Janeiro State, SE Brazil (Figure 5.17). The Paraíba do Sul River (PSR) discharges into the Atlantic Ocean about 400 km north of Sepetiba Bay, at Campos Municipality. It is a medium sized river, with a length of approximately 1,145 km and a watershed area of 55,400 km^{2-}. Maximum river flow is observed during November and March (4,380 m^3 s^{-1}) and the lowest discharges (180 m^3 s^{-1}) occur between June and September (DNAEE 1983). The river drains the most industrialized states of Brazil - São Paulo, Rio de Janeiro and Minas Gerais - and is the most important river for Rio de Janeiro State because its water is widely used for agriculture, industry and human consumption (>20 million inhabitants). However, the river also receives effluents from all these activities, generally without treatment, compromising its water quality.

Sepetiba Bay and basin, SE Brazil (Figure 5.17) is a semi-enclosed water body, connected to the sea by a small, shallow inlet, with minimal water flux that crosses extensive mangrove forests. Mean water volume is 2.56x10^9 m^3, ranging from a maximum of 3.0x10^9 m^3 and a minimum of 2.38x10^9 m^3 (Rodrigues 1990). The average depth is about 6 m. Nine rivers draining the quaternary plain at the northeastern coast of the Bay, are responsible for almost all the freshwater input to the bay, with an annual flow of 7.6x10^6 m^3. Among them, the São Francisco Canal, with an annual flow of 6.5x10^6 m^3, accounts for 86% of the total fluvial inputs. This canal is artificial, and has an almost uniform flow rate throughout the year.

The two basins are not naturally connected, but in the late 1950's, to supply water and electrical energy for adjacent regions, engineering works pumped up water (with a constant discharge of around 160 m^3/s) from the Paraíba do Sul River to form two successive reservoirs (Santana and Vigário) to supply water for generating electrical energy. The Paraíba do Sul waters flow to the Guandu River, to supply the Rio de Janeiro metropolitan area, and finally the excess volume is discharged into Sepetiba Bay through a large artificial channel, the São Francisco River, with a nearly constant flow volume of about 160-180 m^3.s^{-1}. In the Guandu River, there is the Guandu Water Treatment Plant that diverges waters from the Guandu River (originally Paraíba do Sul river waters) to supply the Rio de Janeiro City and other regions. The refuse of treatment processes is discharged into the Guandu Channel that also flows into Sepetiba Bay.

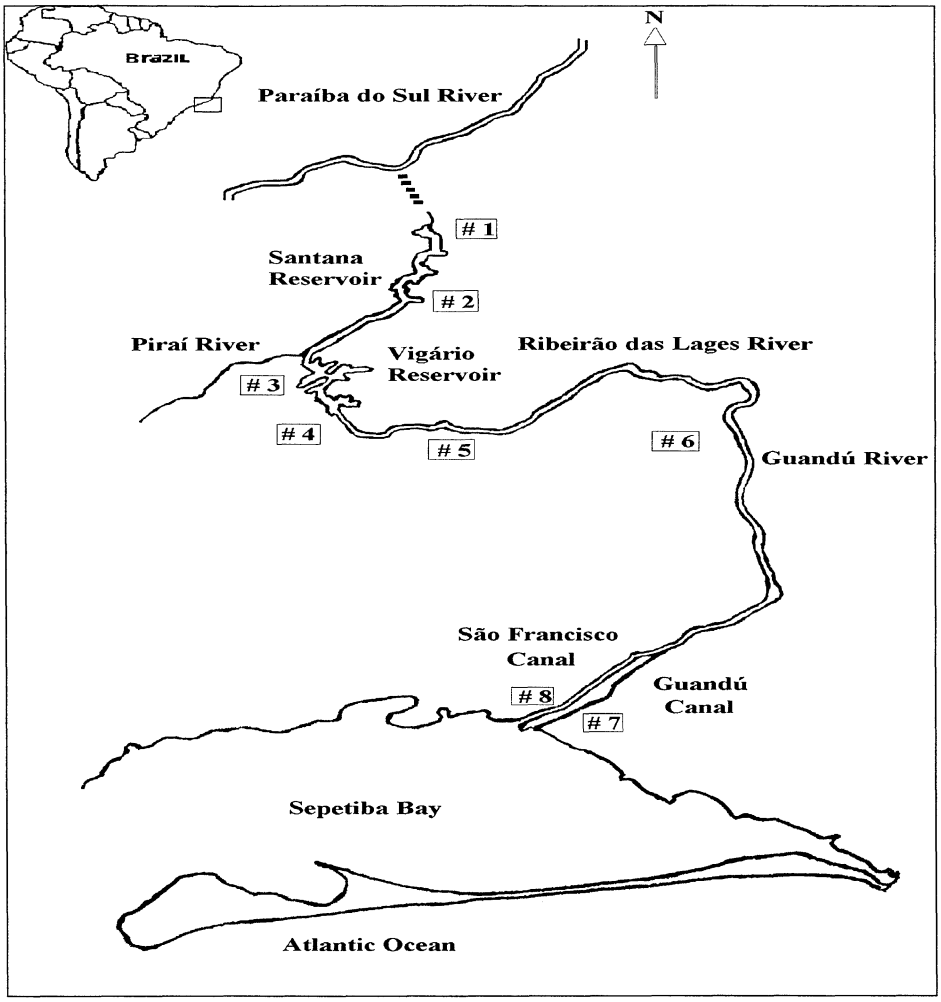


Figure 5.17. Sampling sites in Paraíba do Sul River - Sepetiba Bay system (scale 1:400,000).

Sepetiba Bay 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 portion of the Sepetiba Bay basin make this area of SE Brazil the most critical in terms of environmental contamination by trace metals. However, the bay itself is relatively free of direct inputs of most industrial contaminants, which reach the bay through rivers and atmospheric deposition (Lacerda *et al.* 1987).

Mercury emission from the Paraíba do Sul River

Method

Studies performed in the Paraíba do Sul River (PSR) indicated that trace metal contamination in the upper and middle basins originated mainly in industrial and domestic sewage (Pfeiffer *et al.* 1986; Malm 1988). The PSR portion before the water pump is considered the most mercury-impacted in the basin, due to the large industrial park in the river basin, which includes metallurgical, iron and steel production, paper, plastic, rubber and chemical factories, all of them producing mercury in their effluents. This is in addition to the inputs from a densely populated area, with wastes poorly treated before disposal into the river (Mello 1999). The mercury emitted by these activities may reach the river directly or after some time in the watershed, then transported by runoff to the river. Therefore, the Paraíba do Sul River water diversion can significantly contribute to mercury input into Sepetiba Bay. To verify this contribution the mercury concentrations along the fluvial system from the Paraíba do Sul River proper to Sepetiba Bay were monitored.

Results and discussion

Samples were collected during the wet season (February 2001), when most of the tranfer should occur, along the Paraíba do Sul River-São Francisco Canal waterway (Figure 5.17), showed similar concentrations of mercury in water and in suspended particulate matter from the Paraíba do Sul River end-member (site # 1) and the São Francisco Canal end-member (site #8), near its delta in Sepetiba Bay (Table 5.9). Mercury concentrations in the Paraíba do Sul River site reached 0.102 ng l^{-1} in water and 400 ng g^{-1} in suspended particulate matter, while in the São Fransisco Canal site the Hg contents in samples were 0.13 ng l^{-1} and 350 ng g^{-1}, respectively.

Mercury distribution among the sampling sites showed large variations, reaching 0.049 to 3.8 ng l^{-1} in water and 250 to 1,360 ng g^{-1} in suspended particulate matter. These differences may be explained by point sources from activities introduced along the waterway, mostly due to water withdrawal for industrial uses and human consumption. For example, in reservoirs such as the Santana reservoir (sites #1 and #2, Figure 5.17), hydrological conditions promote the settling of suspended particles, scavenging mercury to bottom sediments and thus decreasing mercury concentrations downstream (Table 1). This mechanism, however, may be reversed since average water depth of the Santana reservoir is only about 1.5 m, and bottom sediment resuspension due to strong winds may remobilize settled particles into the water, allowing downstream transport.

Table 5.9. Mercury concentrations in sampling sites between Paraíba do Sul River and Sepetiba Bay. Average concentrations of duplicate values

Station (Figure 5.17)	Total Dissolved Hg (ng l^{-1})	Particulate Hg (ng g^{-1})
# 1	0.102	400
# 2	0.049	260
# 3	0.051	750
# 4	0.157	1,360
# 5	0.128	620
# 6	0.122	250
# 7	3.851	960
# 8	0.130	350

Other activities like industrial plants, located mainly in the Sepetiba Bay basin and a large landfill (Marins *et al.* 1999), contribute with direct mercury emissions to streams. The mercury concentration in the São Fransisco Canal (site #8) also receives a significant contribution, through watershed runoff and atmospheric deposition, from the large industrial park located in the Sepetiba Bay basin, mainly metal manufacturing, iron and steel production, plastic and rubber production, and an oil-fired thermo-electric plant.

In the Guandu Canal (site #7), high mercury concentrations as dissolved and particulate forms may be explained by refuse discharge from a water treatment plant that collects water diverted from the Guandu River (Rodrigues 1990). The water cleaning processes use some techniques to settle particles and organic colloids in bottom sediments. But these contaminated sediments, rich in organic and inorganic substances, are eventually discharged into the Guandu Canal, at regular intervals.

Mercury concentration analyses are not sufficient to determine the actual contribution from the Paraíba do Sul River to Sepetiba Bay, so the use of mercury fluxes is an interesting tool to quantify this influence. Total mercury flux (particulate+dissolved) in the Paraíba do Sul River at site #1 reaches 107 kg yr^{-1}, while in the São Fransisco Canal site #8, the total mercury flux reaches 372 kg yr^{-1}. Also, although the Guandu Canal (site #7) has a smaller water flux compared with São Fransisco River, the mercury discharge, mainly as the dissolved forms, is very representative, being even larger than the dissolved flux from the Paraíba do Sul River or the São Francisco Canal (Table 5.10).

Table 5.10. Particulate and total dissolved mercury concentrations and fluxes (kg yr^{-1}).

River/Station (Figure 5.17)	Particulate Hg (ng g^{-1})	Total dissolved Hg (ng l^{-1})	Water flux (m^3/s)	Particulate Hg flux	Total Dissolved Hg flux
Paraíba do Sul River (site #1)	400	0.102	160 [a]	106	0.50
Guandu Channel (site #7)	3,850	0.96	6.1 [b]	42	0.83
São Francisco River (site #8)	350	0.13	180 [b]	371	0.75

[a] Light Electric Company (personal communication)

[b] Rodrigues (1990)

The mass balance shows that the Paraíba do Sul waters contributed 25% of the mercury load exported to Sepetiba Bay. The other 75% may come from sources along the river's course, such as industrial plants in the Sepetiba Bay basin or domestic sewage input. The results showed that 90–99% of the mercury is transported as particulate forms, at least during periods with high suspended matter concentrations (around 100 mg l^{-1}), such as the rainy season sampled in this study.

The present study is in agreement with previous balances performed in the Sepetiba Bay basin based on emission factors (Marins *et al.* 1998a) and mercury measurements through rivers (Marins *et al.* 1999; Paraquetti 2001). Marins *et al.* (1998a, 1999) estimated that mercury emissions from the Paraíba do Sul basin could contribute up to 30-45% (about 200-300 kg yr^{-1}) of the total fluvial mercury input to Sepetiba Bay, roughly the same order of the magnitude as the present estimate based on the rainy season flux. It is important to note that freshwater inputs, and therefore associated transported substances, do not vary significantly between the dry and rainy seasons, since over 85% of it is artificially controlled by the water management station of the two basins, for water supply to the Rio de Janeiro metropolitan area. Therefore our single-period data are probably valid for other periods of the year.

The inter-basin water transfer is significantly contributing mercury fluxes to Sepetiba Bay, emitted from diffuse and point sources along the waterway. About 25% of the mercury transport is determined by water pumped from the Paraíba do Sul River. This suggests that any control measures and guidelines being applied to Sepetiba Bay basin will not necessarily abate the entire mercury pollution problem of the bay.

The mercury discharged into Sepetiba Bay may cause environmental problems, since dispersion through biologically complex coastal ecosystems will favor contamination of aquatic organisms through food chain transfer. Whereas fish consumption along the Paraíba do Sul River is of very minor importance to the local population, embayments such as Sepetiba Bay are significant sources of marine protein to a large proportion of the population, increasing the chances of mercury reaching humans through seafood consumption. In addition, the artificial reservoirs existing along the waterway and the estuarine area of Sepetiba Bay are important locations for biotic production and reproduction of aquatic life. Marins *et al.* (1998b), for example, showed correlations between mercury concentrations and fish size in Sepetiba Bay suggesting that methyl-mercury availability and accumulation through food webs may compromise fish consumption, while artificial reservoirs are believed to act as reactors producing methyl-mercury at very high rates (Lacerda and Salomons 1998). Therefore, a nearly insignificant environmental toxicological problem along the Paraíba do Sul River may become a serious environmental threat to the local population using aquatic resources in the Sepetiba Bay basin.

Acknowledgements

This paper was supported in part by a PRONEX program from the Ministry of Science and Technology, Brazil. We thank the National Research Council of Brazil (CNPq) for supporting grants to the authors. Thanks are also due to the Light Electric Company personal for providing logistic help and information on the Paraíba do Sul River-Guandu Canal waterway.

References

DNAEE 1983 *Boletim Fluviométrico F-5.02, Bacia do Paraíba do Sul*. Departamento Nacional de Águas e Energia Elétrica. 786 pages.

Lacerda, L.D., Pfeiffer, W.C. and Fiszman, M. 1987 Heavy metal distribution, availability and fate in Sepetiba Bay, SE-Brazil. *Science of the Total Environment* **65**:163-173.

Lacerda, L.D. and Salomons, W. 1998 *Mercury from gold and silver mining: a chemical time-bomb?*. Springer Verlag, Berlin, 146 pages.

Malm, O., Pfeiffer, W.C., Fiszman, M. and Azcue, J.M. 1988 Transport and availability of heavy metals in the Paraíba do Sul – Guandu System, Rio de Janeiro, Brazil. *The Science of Total Environment* **75**: 201-209.

Marins, R.V., Silva Filho, E.V. and Lacerda, L.D. 1996 Atmospheric mercury deposition over Sepetiba Bay, SE Brazil. *Journal of the Brazilian Chemical Society* **9**:177-181

Marins, R.V., Lacerda, L.D. and Villas Boas, R.C. 1998a Mercury emission into Sepetiba Bay basin. *Ciência e Cultura Journal of the Brazilian Association for the Advancement of Science* **50**: 293-297.

Marins, R.V., Lacerda, L.D., Paraquetti, H.H.M., Paiva, E.C. and Villas Boas, R.C. 1998b Geochemistry of mercury in sediments of a sub-tropical coastal lagoon Sepetiba Bay, South-eastern Brazil. *Bulletin of Environmental Contamination and Toxicology* **61**: 57-64.

Marins, R.V., Lacerda, L.D. and Villas Boas, R.C. 1999 Relative importance of non-point sources of mercury to an industrialized coastal system, Sepetiba Bay, SE Brazil. Pages 207-220 in: Ebinghaus, R., Turner, R.R., Lacerda, L.D., Vasiliev, O. and Salomons, W. (eds): *Mercury Contaminated Sites*, Springer Verlag, Berlin.

Mello, C.S.B. 1999 Média dos teores de mercúrio e cádmio e suas distribuições ao longo da Bacia do Rio Paraíba do Sul no período de 1992 a 1997. Pages 32-34 in: *Anais do V Congresso de Geoquímica dos Países de Língua Portuguesa e VII Congresso Brasileiro de Geoquímica*, Porto Seguro, Bahia.

Paraquetti, H.H.M. 2001 Distribuição e reatividade de mercúrio em águas do complexo costeiro do Estado do Rio de Janeiro: Baía de Sepetiba. *MSc Thesys*, Universidade Federal Fluminense, Niteroi, 63 pages.

Pfeiffer, W.C., Fiszman, M., Malm, O. and Azcue, J.M. 1986 Heavy metal pollution in the Paraíba do Sul River, Brazil. *The Science of Total Environment* **58**:73-79.

Rodrigues, P.P.G.W. 1990 Aporte de metais pesados para a Baía de Sepetiba e seu comportamento na região estuarina. *MSc Thesys*, Universidade Federal Fluminense, Niteroi, 181 pages.

Snaddon, C.D.; Wishart, M.J.; Davies, B.R. 1998 Some implications of inter-basin water transfers for rivers ecossystem functioning and resources management in southern Africa. *Aquatic Ecossytem Health and Management* **1**: 159-182.

5.8 Heavy metal transfers from Patagonia to the South Atlantic Ocean

D.M.Gaiero[1,2], J.L. Probst[3], P.J. Depetris[1] and L. Leleyter[2]
1 - CONICET. F. C. E. F. y N., Univ. Nacional de Córdoba, Argentina
2 - Centre de Géochemie de la Surface (CNRS), Strasbourg, France
3 - Lab. des Méc. de Tranferts en Géologie (UMR CNRS), Toulouse, France

Introduction

Metals are introduced into the environment by different processes. Sources for trace metals are natural processes of weathering, erosion and volcanic activity. However, with the large-scale extraction of ore from the Earth's crust, pollution and other mechanisms have become increasingly important, almost obliterating natural rates in many regions of the world (Salomons and Förstner 1984; Nriagu 1990).

Important processes occur at the river/ocean interface and on the continental shelf, where accumulation of natural and anthropogenic trace metals take place. The arid/semiarid condition in the Atlantic seaboard of southern South America influences discharges to the South-West Atlantic Ocean through the supply of dissolved and particulate material transported from the continent via riverine and aeolian paths. Strong Patagonian westerly winds transfer sea-bound particles which may play a significant role in the input of trace elements to the ocean. Intense climatic anomalies may play a major role in transport of sediment load from continent to the ocean. The South Atlantic holds a wealth of biological resources, and the adjoining continental landmass may have a significant influence on the cycling of nutrients and heavy metals in the sea.

This paper reports the first results on the characteristics of heavy metals present in different Patagonian materials that are potential sources of such elements to the sea. Furthermore, the mass of heavy metals is estimated for the first time and the nature of these inputs to the Atlantic Ocean is discussed.

Study area

Continental Patagonia (38°- 52°S) has an area of about 700,000 km^2. The prevailing westerly winds supply all the moisture resulting in a strong west-to-east precipitation gradient. Only a small portion along the Andes (about 15 % of the total area) has a rainfall higher than 800 mm yr^{-1}.

The geology is dominated by volcanic rocks (basalts, rhyolites, andesites), and continental and, to a lesser extent, marine sediments. Also important are widespread Quaternary deposits dominated by alluvial, colluvial, lacustrine and glacial sediments. Metamorphic and plutonic rocks exist in relatively minor quantities.

Eight rivers drain this region and their drainage areas account for about 30% of the total Patagonian territories. The names, main features and localization of each basin can be seen in Table 5.11 and Figure 5.18. The set of river basins studied exhibits a spectrum of human impact. The main anthropogenic activity in the area is linked to oil production. Livestock breeding (mainly sheep) constitutes an important erosion agent that prevails from north to south within the area. Also environmentally important are the extensively farmed Negro, and to a lesser extent the Chubut and Colorado river valleys. Mining activities are of minor importance and are mostly restricted to coal mining in the headwaters of the Gallegos River.

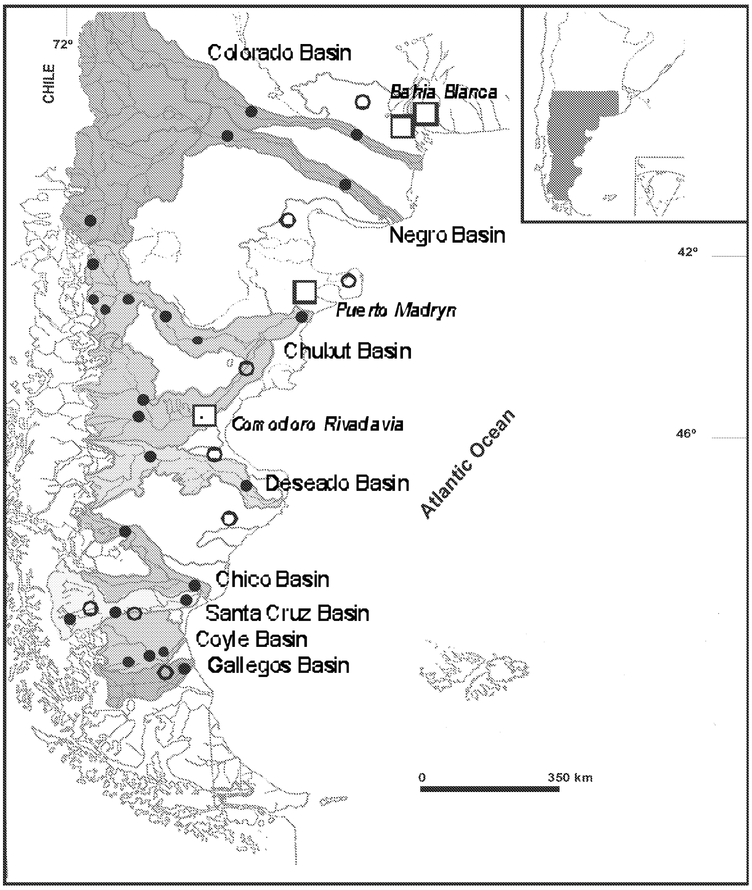


Figure 5.18. Patagonian river basins and sampling stations. The black dots represent water and bed sediment sampling points. The white dots indicate topsoil sampling stations. The white boxes indicate the location of the aeolian dust traps.

Table 5.11. Main features and average seasonal physico-chemical parameters measured along RN 3 in different Patagonian rivers.

River	Area (km^2)	Mean annual discharge ($m^3.s^{-1}$)	Population density (inhab.km^{-2})	Conductivity ($\mu S.cm^{-1}$)	pH	TSS ($mg.l^{-1}$)	DOC ($mg.l^{-1}$)	POC (% TSS)	$SI_{calcite}$
Colorado	22,300	134	1.0	942	8.1	62	1.2	2.6	0.3
Negro	95,000	930	7.1	157	7.7	16	1.2	4.4	-1.0
Chubut	29,400	49	7.5	295	7.7	62	2.1	2.5	-0.6
Deseado	14,450	5	0.4	3,730	8.8	355	7.6	1.7	0.7
Chico	16,800	30	1.5	141	7.7	356	2.1	1.1	-1.0
Santa Cruz	24,510	748	0.2	41	6.3	23	0.8	2.4	-3.2
Coyle	14,600	5	0.1	223	8.3	17	5.1	4.5	-0.2
Gallegos	5,100	17	1.3	112	7.1	32	6.7	7.8	-2.3

Materials and Methods

The sampling programs performed during the development of Project PARAT (EC-INCO/DC) involved trips at least 5,000 km long, stopping at the sampling stations to collect the samples and measure specific parameters in the field. Emphasis was placed on sampling the continent-sea interface along Patagonia's main road (RN 3). Some field trips included sampling along the Andean range (RN 40), to sample the headwaters of rivers crossing Patagonia from west to east (Figure 5.18).

Suspended matter was pre-concentrated by pressure filtration under 1.5 atm N_2 on 0.45μm Millipore filter (Ø 142 mm). Submerged sediments were collected in duplicate from opposite riverbanks with plastic scoops. With the purpose of correcting the grain-size effect (Förstner and Wittmann 1981), sediments were sieved with a 63 μm stainless steel mesh. The <63 μm material thus retained was then subjected to acid leaching with HCl 0.5 N. This kind of extraction is a rapid technique, suited for measuring the authigenically-formed metal fractions in sediments since it extracts metals from sediments without attacking the aluminosilicate minerals (Agemian and Chau 1976). Figure 5.18 also shows the sediment sampling points, generally coincident with water sampling stations. Atmospheric dust samples were and are being collected at Bahia Blanca (2 sites), Puerto Madryn, and Comodoro Rivadavia (Figure 5.18). A plastic inverted pyramid (50x50x40 cm depth) is employed in each site, following the methodology described by Orange *et al.* (1990) to collect fallout. For aeolian dust, a set of topsoil (upper 3 cm) samples were collected 300-400 km apart along the main route (RN 3). These samples were sieved with a 63 μm stainless steel mesh and then subjected to acid leaching with HCl 0.5 N.

Dissolved trace elements were analyzed by ICPMS (DL = 0.01 $\mu g\ l^{-1}$ and reproducibility<5%). Sediments, soils, and dust were chemically analyzed for major, minor and trace components with standard methodologies by inductively coupled plasma (ICPAES and ICPMS). Fine grain-size mineralogy (clays and silt) was determined by X-ray diffraction techniques. The relative abundance of carbonates and organic matter in the <63 μm size-fraction were respectively determined in riverbed sediment samples by means of a Scheibler-type calcimeter and the widely-used $K_2Cr_2O_7$ Walkley-Black method.

Total heavy metal in Patagonian sediments

In Table 5.11, the average heavy metal concentrations of different Patagonian sediment-types can be compared to those reported for other Argentinean rivers, as well as to basins in other world regions. The concentration of heavy metals in the Patagonian bed sediments (BS) are similar to those found in unpolluted Argentinian rivers (e.g. Manso River: Román Ross *et al.* 1995, Chicam-Toctina River: Gaiero unpublished data). In average topsoils (TS), heavy metal concentrations are very similar to both bed sediments located in remote areas and to those present in sampling stations close to the seaboard (Table 5.11). However, topsoil (TS) samples collected at Rio Colorado and San Antonio Oeste (Figure 5.18) exhibit the highest Cu concentrations (51.5±7.8 ppm) which explains the relatively high mean abundance of this element in TS as compared to other Patagonian sediments. Heavy metals present in the aeolian dust show high concentrations compared to those observed in topsoils (Table 5.11). Sample AD-1, (Ing. White) was collected in an area with a concentration of petrochemical industries. Hence, it shows a relatively high concentration of Pb, Ni, Cr, Zn and Cu.

In spite of the great affinity of trace elements with the finer sediment fractions, average concentrations of Mn, Pb, Ni, Co and Cr in the suspended matter (SM) are comparable to values found in riverbed sediment and topsoils of Patagonia (Table 5.11). In general, average heavy metal concentrations in Patagonian SM are lower than those found in non-polluted and polluted world rivers. Only Cu and Zn concentrations in SM show a clear enrichment compared to other Patagonian sediments and, in some cases, to world rivers suspended matter (Table 5.13). As a possible anthropogenic source, the Negro River had extremely high concentrations during December 1997 of both Cu and Zn (290 and 460 ppm, respectively). Also, the enrichment of Zn in the downstream sediments of this river are evident when compared to the concentration of this metal in the SM of the Manso River (Roman Ross *et al.* 1995) which can be considered as a natural background sample for this area. The Santa Cruz and Chico rivers also have high concentrations of Cu and Zn (248 and 179 ppm of Zn and 97 and 66 ppm of Cu), probably in response to a high natural lithological background of these metals in the area.

Non-residual heavy metals

Similar total average heavy metal concentrations are found in the finer grain-size fractions of Patagonian riverbed sediments from both the headwaters and the lower stretches (Table 5.12).

Table 5.12. Mean heavy metal concentration in different Patagonian sediment-types compared to other rivers. (BS) bed sediments, (TS) top soils, (AD) aeolian dust and (SM) suspended matter. All values are rounded to whole units.

Type	Site	Pb	Ni	Co	Cr	Zn	Cu	Reference
BS	Patagonia, headwaters (<63μ)	18±6	21±6	19±2	62±13	86±12	23±9	This study
BS	Patagonia, lower stretches (<63μ)	25±13	18±4	16±3	46±14	82±18	24±10	This study
BS	Manso River (<63μ)	-	-	17±7	36±22	89±38	-	Román Ross *et al.* (1995)
BS	Ch-Toctina, upper stretches (<63μ)	18±8	42±5	19±4	90±22	88±25	34±3	Gaiero (unpublished)
BS	Cordoba, Suquia downstream (<63μ)	95±16	26±1	16±0	77±2	205±8	132±69	Gaiero (unpublished)
BS	Patagonia, lower stretches (total)	-	21±3	13±4	39±10	58±11	14±6	This study
BS	De La Plata River (total)	-	-	-	99	117	26	Bilos *et al.* (1998)
BS	Rhine River	369	175	31	493	1,240	286	Forstner and Wittman (1981)
TS	Patagonia (<63 μ)	15±5	16±5	20±3	51±17	83±21	30±13	This study
TS	Around Córdoba (<63μ)	21±1	18±3	16±2	49±4	77±3	23±2	Gaiero (*unpublished*)
TS	Central Argentina (<63 μ)	17±1	20±11	21±9	54±27	97±36	34±3	Gaiero (*unpublished*)
AD-1	10 km north of Bahia Blanca	53	14	11	49	315	35	This study
AD-2	Inginero White	164	37	12	67	409	52	This study
SM	Patagonian rivers	32±18	26±8	16±5	52±22	176±120	61±72	This study
SM	Manso River	-	-	18±7	39±26	90±39	-	Román Ross *et al.* (1995)
SM	Upper Amazonas	-	65±57	18±15	-	189±167	34±25	Elbatz-Poulichet *et al.* (1999)
SM	Lower Paraiba do Sul River	-	-	-	81±42	297±178	75±41	Carvalho *et al* (1998)
SM	De La Plata River	-	-	-	203±139	-	51±37	Bilos *et al.* (1998)
SM	Huanghe River	17±9	40±6	14±2	77±8	70±8	27±8	Huang *et al.* (1992)
SM	Rhine River	131	69	-	207	908	138	Paalman and van der Weijden (1992)
SM	World average	223±190	102±75	55±124	127±72	303±221	123±109	Martin and Maybeck (1979)

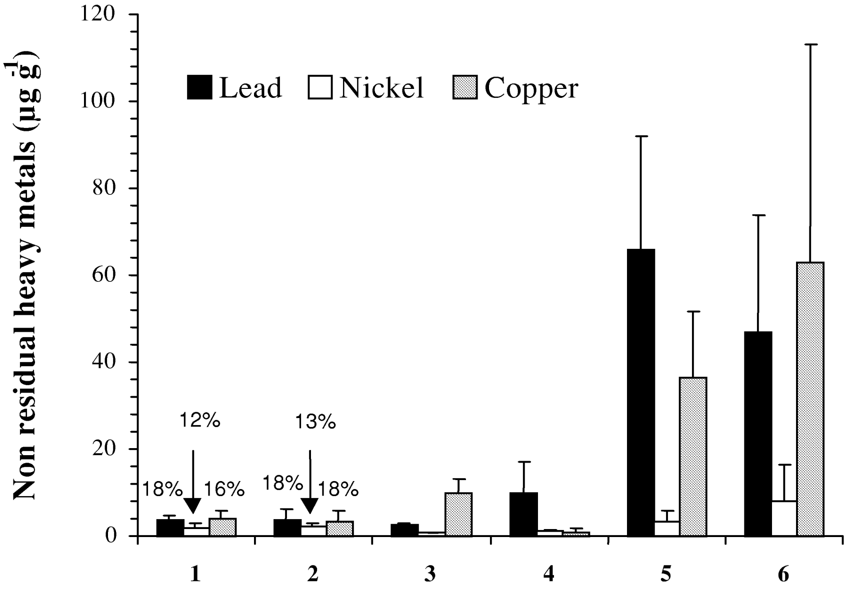


Figure 5.19. Mean concentrations of metals in the non-residual fraction of Patagonian bed sediments compared with other rivers. The horizontal axis corresponds to the average heavy metal concentration (< 63μm size-fraction and extracted with 0.5 N HCl) for the following rivers: 1-Patagonian rivers at the headwaters, 2- Patagonian rivers at the lower stretches, 3- and 5- Suquía River headwaters and downstream Córdoba City (Gaiero *et al.* 1997), 4- Chicam Toctina Stream basin (Gaiero, unpublished) and, 6 - Jacarepaguà Lagoon tributary rivers (Fernández *et al.* 1994). The numbers above the bars represent the percentage extracted with 0.5 N HCl from the total metal concentration in the Patagonian samples.

The comparatively high average concentration of Pb in the downstream sediments is similar to the increase in concentration of this element in the Chico, Santa Cruz and Gallegos riverbed sediments. Only in the last could the relatively high concentration of lead be related to anthropogenic activity (coal-mining) in its headwaters. The highest discharges occur in September during snow melt, with the possible transport of wind-spread coal-mining by-products. In September 1995 and 1996 the Gallegos River showed dissolved Pb concentrations of 1.71 ± 0.64 μg l^{-1}, contrasting with the base flow measurements (May and December 1996: 0.40 ± 0.02 μg l^{-1}).

Extraction with 0.5N HCl can give enough information about the potential amount of available (or non-residual) heavy metals (NRHM) in sediments that could be transported to the ocean. Patagonian river-bottom sediments are 30% more concentrated in exchangeable heavy metals than the TS. Patagonian topsoil mineralogy shows significant heterogeneity, due to extremely variable contents of calcite minerals. Carbonate minerals seem to exert important NRHM dilution in topsoil samples, as indicated by the negative relationship between the amount of calcite (determined by means of X-ray) and NR-Ni, Co, Cu, Fe and Mn (average $r = -0.78$; $p<0.01$). Figure 5.19 shows that Patagonian riverbed sediment samples from both the remote uninhabited areas and those close to the coastal ocean have NR-Pb, Ni and Cu concentration comparable with non polluted areas from central Argentina (e.g. Suquía River headwaters: Gaiero *et al.* 1997; Chicam-Toctina stream: Gaiero, in preparation). Leleyter (1998) and Leleyter and Probst (1999) found that Patagonian samples contain the lowest total and non-residual concentrations of Pb and Co.

The nearly pristine condition in the uppermost sectors of most of the Patagonian river headwaters enabled the use of the non-residual heavy metal concentrations as baseline values. Thus, the decreasing concentration trend of NRHM in the downstream direction shown by some Patagonian rivers (Figure 5.20) could indicate dilution by relative NR metal-free sediment from aeolian dust or bank erosion. However, increasing concentrations of Ni and Cu in the lower Negro River sediments could be associated to extended farm activity (use of fertilisers and pesticides) along its valley, while the scarcity of human activity within the boundary of the Santa Cruz River basin indicates that other natural processes could increase NRHM in the lower part of that river.

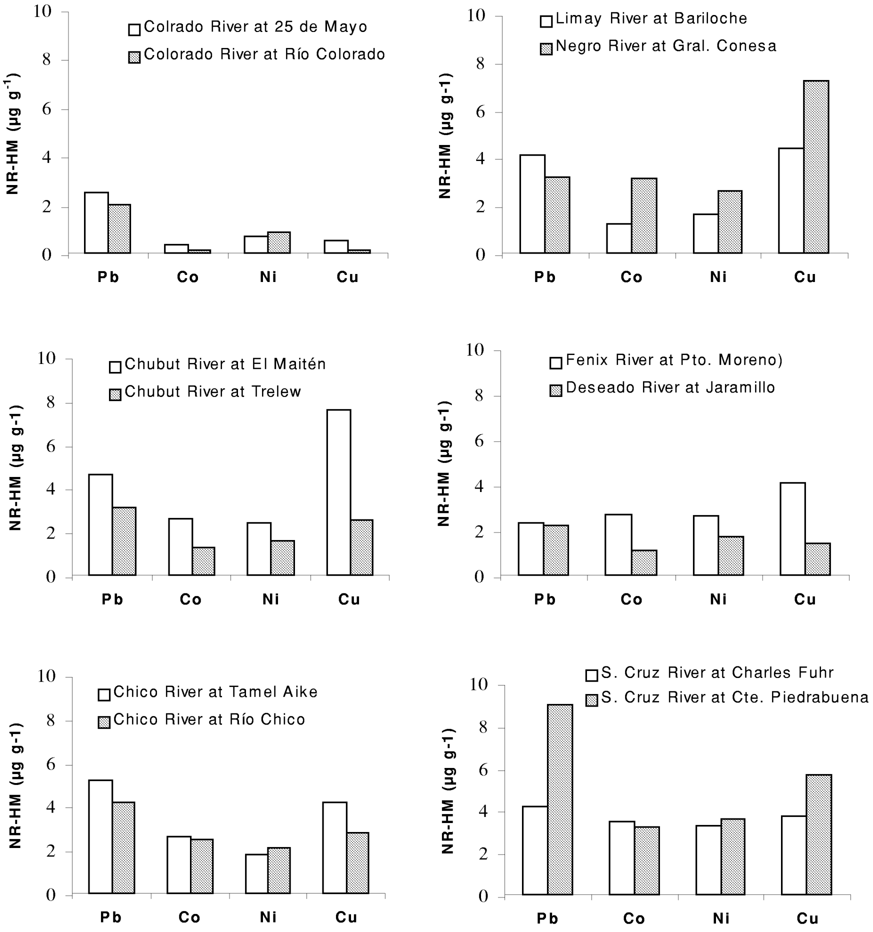


Figure 5.20. Comparison between non-residual heavy metals (NR-HM) concentration measured in bed sediments from headwaters and the lower stretches of some Patagonian rivers.

The non-residual heavy-metal fraction in the sediment is built up by means of different processes including adsorption onto clay, silt and organic matter, precipitation of secondary minerals, etc (e.g. Salomons and Förstner 1984). Patagonian bed sediments contain low concentrations of carbonate and organic matter, indicating that these phases could play a minor role in the control of heavy metal concentration. Apparently, iron oxides control non-residual heavy metals in Patagonian bed and suspended sediments. A significant correlation can be found between the concentration of NR-Fe and NR-Cu, Pb, Co and Ni (mean $r = 0.68\pm0.04$; $p< 0.05$) in the bed sediments. Leleyter (1998), using a sequential extraction procedure, found that the concentration of non-residual Fe, Mn, Pb and Co were mainly associated to iron oxide phases. To a lesser extent, Co and Pb were determined in the organic matter fraction. The Colorado and Deseado, which are the only Patagonian rivers with calcite supersaturation (Table 5.11), exhibit considerable amounts of NR-Mn and Pb in the carbonate fraction. Suspended sediment from the Chico and Colorado rivers studied by Leleyter (1998) indicate that in the Colorado River, significant proportions of Pb and Mn were linked to the carbonate fraction.

Table 5.13. Total heavy metals and corresponding percentages of non-residual fraction transported by the suspended matter of Patagonian rivers (t y^{-1}).

River/Metals	Pb	Cu	Zn	Ni	Cr
Patagonian rivers	67	104	335	47	85
Flux of NRHM	21 %	16 %	-	12 %	-
Rhine River[1]	278	358	2,466	256	458

1 -Paalman and Van der Weijden (1992).

Fluxes of heavy metals

Trace metals are transported from rivers to the marine environment mainly by suspended matter (Paalman and van der Weijden 1992). To estimate the particulate heavy metal fluxes, the amount of heavy metals present in the SM were considered as representative of the chemical composition of the suspended sediment concentration measured during the different PARAT sampling missions. Smaller particles (<63μm) seem sufficiently fine to be transported even in a very low flow conditions (e.g. Carvalho *et al.* 1998). Hence, we used the percentage of heavy metal extracted with 0.5 N HCl in the < 63μm size-fraction of bed sediment of each Patagonian rivers to estimate their concentration in the suspended sediments. Table 5.9 indicates that particulate (SM) Pb, Zn, Ni and Cr transported annually to the ocean represents on average 20% of that exported by the polluted Rhine River. As a likely response to anthropogenic contribution, the Negro River exports 60% of the total Cu transported by the Patagonian rivers. Their heavy metal productions are the highest in term of specific fluxes, indicative of a high natural background existing in the headwaters of the Chico and the Santa Cruz rivers.

The existence of dissolved Pb data allow us to make a more detailed budget of the characteristics of export of this metal to the ocean. An estimate of 10% of SM for the amount of transported sand is consistent with the literature (Milliman and Meade 1983; Pinet and Souriau 1988). Thus, Pb concentrations of total riverbed sediment samples and the percentage of heavy metal extracted with 0.5 N HCl in the < 63μm size-fraction of bed sediment were also considered in the budget. Figure 5.21 illustrates the total flux of Pb transported by Patagonian rivers. The Negro and Santa Cruz rivers produce about 70% of the total Pb transported to the ocean and the proportion of the available flux of this metal is very similar. Generally, Pb is transported in the particulate phase (65%) followed by the dissolved phase (30%) and to a lesser proportion by the bed load (5%) phase. Annually, the Coyle River transports almost 65% of Pb in the dissolved phase. The Colorado (with oil production in its headwaters) and Gallegos rivers transport more than 50% of total Pb as available form, mainly in the dissolved phase (more than 83%). The Chico River export 60% of the available Pb in the suspended sediment, while in the Negro, Chubut, and Santa Cruz rivers it is transported mainly in the dissolved phase (60 to 70%).

Conclusions

Most of the heavy metal concentrations found in the bed sediments and suspended matter from Patagonian rivers were comparable to those reported for non-polluted rivers. The presence of heavy metals in the non-residual fractions of the sediment represents an average of less than 20% of the total concentration and it is less significant in the topsoils. The studied Patagonian topsoils should be considered as a diluting agent in the riverine flux of sediments, as well as in its direct transfer by aeolian paths to the ocean. The heavy metals in the non-residual bed sediment fractions appear to be mainly bound to the iron oxides and they probably reach the ocean in this form. However, a more detailed study is needed, especially on the dissolved and suspended matter transported by Patagonian rivers.

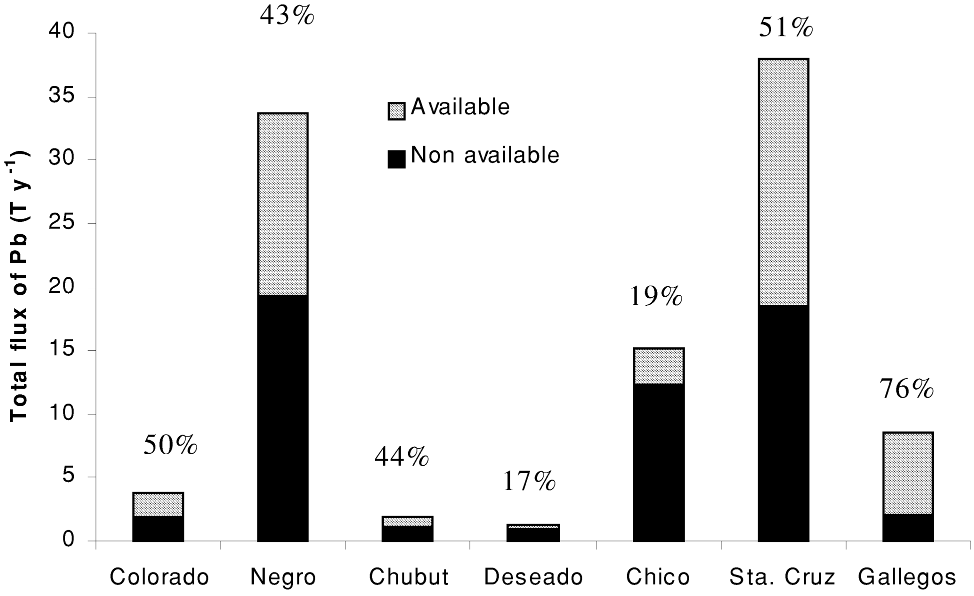


Figure 5.21. Total lead exported by Patagonian rivers. The numbers above the bars correspond to the percentage of Pb annually transported in the available form.

In agreement with the more intense human activity, higher Cu and Zn concentrations were found in the bed sediments and suspended matter of the Negro River as well as in the nearby topsoils. This river accounts for 60% of the total Cu transported by Patagonian rivers. The Colorado and Gallegos rivers have shown evidence of Pb contamination probably as a consequence of oil extraction and mining activity in their headwaters. In both rivers, more than 50% of Pb is transported in the available form, mostly in the dissolved phases (above 83%).

Acknowledgements –
This paper is a contribution to Argentina's CONICET project (PIP) 4829, and FONCYT project (PICT) 00966. We also acknowledge the contribution of the EC's project PARAT (Contract CI1*-CT94-0030) that provided valuable means to study the geochemistry of Patagonian rivers.

References

Agemian, H. and Chau, A.S.Y. 1976 Evaluation of extraction techniques for the determination of metals in aquatic sediments. *Analyst* 101:761-767.

Bilos, C., Colombo, J.C. and Rodriguez Presa, M.J. 1998 Trace metals in suspended particles, sediments and Asiatic clams (*Corbicula fluminea*) of the Río de la Plata estuary, Argentina. *Environmental Pollution* 99: 1-11.

Carvalho, C.E.V., Ovalle, A.R.C., Rezende, C.E., Molisani, M.M., Salomão, M.S.M.B. and Lacerda, L.D. 1998 Seasonal variation of particulate heavy metals in the lower Paraíba do Sul River, R.J., Brazil. *Environmental Geology* 37: 297-302.

Elbatz-Poulichet, F., Seyler, P., Mauroce-Bouroin, L., Guyot, J.L and Dupuy, C. 1999 Trace element geochemistry in upper Amazona drainage basin (Bolivia). *Chemical Geology* 157: 319-334.

Fernandez, H.M, Bidone, E.D., Veiga, L.H.S and Patchineelam, S.R. 1994 Heavy-metal pollution assessment in the coastal lagoons of Jacarepaguà, Rio de Janeiro, Brazil. *Environmental Pollution* 85:259-264.

Förstner, U. and Wittman, G.T.W. 1981 *Metal Pollution in Aquatic Environment*. Springer-Verlag, Berlin, 486 pages.

Gaiero, D.M., Roman Ross, G., Depetris J.P. and Kempe, S. 1997 Spatial and temporal variability of total non-residual heavy metals content in stream sediments from the Suquía River system, Córdoba, Argentina. *Water, Air and Soil Pollution.* **93**:303-319.

Huang W.W., Zhang, J. and Zhou, Z.H. 1992 Particulate element inventory of Huanghe (Yellow River): A large, high-turbidity river. *Geochimica et Cosmochimica Acta* **5**: 3669-3680.

Leleyter L. 1998 Spéciation chimique des éléments majeurs, traces et des terres rares dans les matières en suspension et dans les sédiments de fond des cours d'eau: Application aux fleuves de Patagonie (Argentine), à la Piracicaba (Brésil), à l'oued Sebou (Maroc) et à l'Ill (France). *PhD thesis, University Louis Pasteur, Strasbourg,* 297 pages.

Leleyter L. and Probst J.L. 1999 A new sequential extraction procedure for the speciation of particulate trace elements in river sediments. *International Journal of Environmental Analytical Chemistry* **73**:109-128.

Martin J.M. and Meybeck M. 1979 Elemental mass balance of material carried by major world rivers. *Marine Chemistry* **7**:201-223.

Milliman, J.D. and Meade R.H. 1983 World-wide delivery of river sediments to the ocean. *Journal of Geology* **1**:1-21.

Nriagu, J.O., 1990 Global metal pollution. Poisoning the Biosphere? *Environment* **32**: 7-33.

Orange, D., Gac, J.Y., Probst, J.L. and Tanre, D. 1990 Mesure du dépôt au sol des aérosol désertiques. Une methode simple de prélèvement: le capteur pyramidal. *Comptes Rendues de l'Academie des Sciences de Paris* **311**:167-172.

Paalman, M.A.A. and van der Weijden, C.H. 1992 Trace metals in suspended matter from the Rhine/Meuse estuary. *Netherlands Journal of Sea Research* **29**:311-321.

Pinet P. and Souriau, M. 1998 Continental erosion and large scale relief. *Tectonics* **7**:563-582.

Romàn Ross, G., Ribeiro Guevara, S. and Arribére, M.A. 1995 Rare earth geochemistry in sediments of upper Manso River Basin, Río Negro, Argentina. *Earth and Planetary Science Letters* **133**:47-57.

Salomons, W. and Förstner, U. 1984 *Metals in the Hydrocycle.* Springer-Verlag, New York, 349 pages.

5.9 A summary of land based activities and environmental impacts on the coastal zone of the Pacific coast of South America

Rodney Martínez Güingla[1]*, Giovani Danneri*[2] *and Hugo Salgado*[3]
1. Instituto Oceanográfico de la Armada del Ecuador, INOCAR, P.O. Box 5940, Guayaquil, Ecuador
2. Universidad del Mar (Chile)
3. Universidad de Concepción (Chile)

1. Ecuador

The coastline of Ecuador extends through 2,859 km including 31 cities and 260 smaller towns, with commercially important ports such as Esmeraldas, Manta, Puerto Bolivar and Guayaquil. A further 845 towns have been built within 15 km of the sea. The coastal fringe houses most of the population of Ecuador and supports important commercial activities related to fisheries, aquaculture, tourism, recreation and distribution and exploitation of gas. Most of the foreign currency earnings of Ecuador are generated along the coast. During "El Niño" events severe losses affect the coastal area and impact heavily on the Ecuadorian economy. The most important river systems of Ecuador include the Guayas, Chone and Esmeraldas rivers.

1.1. Guayaquil Gulf

Guayaquil Gulf is the largest estuary on the Pacific coast of South America. The entrance of the Gulf stretches 200 km from north to south along the meridian 81°W, from Santa Elena's Peninsula (2° 12′ S) in Ecuador to Máncora (4° 07′ S) in Peru (Figure 5.22); toward the interior, the Gulf penetrates in the Ecuadorian coast, approximately 120 km. The southern limit of Ecuadorian waters is demarcated by the parallel 3° 23′34′′ S (CAAM 1996). (Figure 5.23).

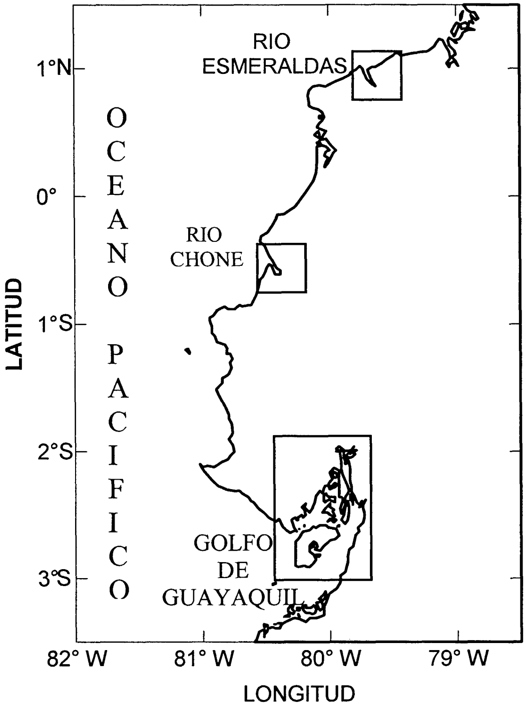


Figure 5.22 Profile of the Ecuadorian coast.

Guayaquil Gulf is naturally divided into two: an exterior estuary that originates on the western side of Puná Island (80°15′W) and extends to the meridian 81° 00′30′′ W, and an interior estuary that runs north-east from the western end of Puná Island, including the systems of the Guayas River. Puná Island also defines two channels: to the north-west, the El Morro Channel, 3 km wide, constitutes the main access to the Marine Port of Guayaquil and connects the external estuary with the Salado tideland. The extension of the system from the Marine Port of Guayaquil to Posorja is 60 km; while the system of the Guayas River from Guayaquil to parallel 3°S is 90 km. (CAAM 1996).

At the northern end of the gulf, the Guayas River and Salado tideland are connected artificially by a sluice built in the Cobina tideland for the traffic of small boats; while at the south end, just to the north of Puná Island, the Guayas River and Salado tideland are connected through the Channel of Cascajal, about 4 km wide and 8 m deep. Three channels, El Morro, Jambelí and Cascajal, have been formed by the presence of Puná Island, which is approximately 25 km wide. Almost 25 km south-west of Puná Island, aligned with the center of the entrance of Jambelí Channel (3°10′S) is Santa Clara Island, approximately 1.6 km long and 76 m high (INOCAR 1998).

Changes in the coastal ecosystem of the gulf due to different human activities impact on the same ecosystem and in consequence on the population. The most important economic activities along the coasts of Guayaquil Gulf and the impacts that each one can originate are summarized in Table 5.14 (PMRC 1993).

Table 5.14. Most important economic activities along the coast of Guayaquil Gulf and their major environmental impacts in the coastal zone (PMRC 1993). MB=Microbiology (fecal and total coliforms); PE=Pesticides (Cl, P); MP=Heavy metals (Cu, CR, Pb, Cd, Zn, Hg); A=Nutrients (NH_{4+}, NO_{2-}, NO_{3-}, PO_{4-}, SiO_2); HC=Hydrocarbons; BOD=Biochemical Oxygen Demand; SO=Solids (total, suspended, dissolved); PH=Potential of hydrogen, DO=Dissolved Oxygen.

	Indicators of Impacts								
ACTIVITIES	MB	PE	MP	NU	DO	HC	BOD	SO	PH
Urbanism	v	v	v	v	v	v	v	v	v
Tourism	v			v	v	v	v	v	v
Industry			v			v	v	v	v
Agriculture	v	v		v	v	v	v	v	v
Sailing						v			
Exploitation of petroleum					v	v	v	v	v
Aquaculture	v	v		v	v	v	v	v	v
Cattle raising	v	v		v	v		v	v	v
Mining			v					v	v
Fisheries	v			v	v		v		
Infrastructure works							v	v	v

One of the activities that increase the microbiological load in Guayaquil Gulf is tourism. During the wet season there is a big increment in the load of fecal coliforms in Posorja (from 23 to 14,000 NMP $100ml^{-1}$), Beaches (from 24,000 to 240,000 NMP $100ml^{-1}$), (NMP = Most Probable Number), due to the tourists (PMRC 1993).

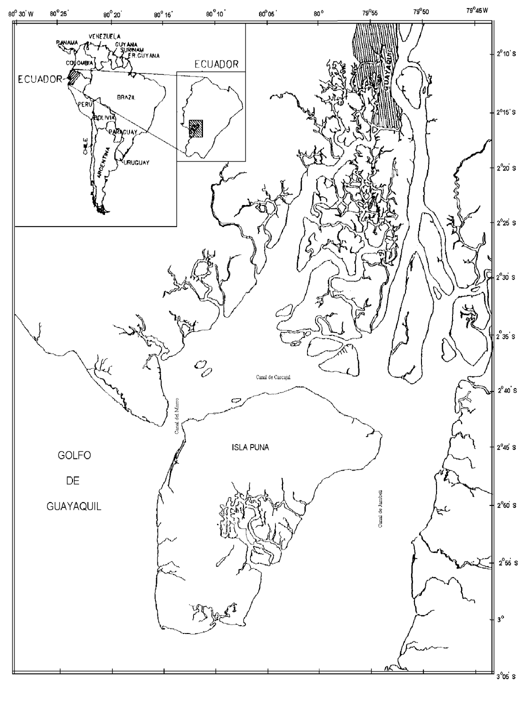


Figure 5.23. Location of Guayaquil Gulf.

In general, during the wet season the microbiological quality of the water along beaches of the gulf exceeds the limit of fecal coliforms allowed for swimming. In the dry season the water quality in these places is considered to be within acceptable limits.

One of the factors that have contributed to the generation of negative environmental impacts in the urban areas has been the rapid urbanization of Ecuador since the 1950's.

The urban increase in the cities around the gulf has led to an appreciable increase in contamination of the waterways. Some studies found high levels of total coliforms in tidelands near Guayaquil.

Water contamination by organic and industrial effluents is due to the lack of appropriate water treatment plants in the major cities. A preliminary calculation carried out in 1996 indicates that industrial discharges into the Guayas River and Salado tideland amount to an average 25480 m^3 day^{-1} (INOCAR 1998).

Additionally, the unplanned growths of cities along the coastal areas of Ecuador have resulted in important losses of mangrove. It is now estimated that the original mangrove area has been reduced by about 23% of its original area (from 125,528 ha in 1969 to 105,039 ha in 1995) due to the increase of shrimp farms in coastal areas.

Agricultural and cattle-raising activities require increasing levels of water usage and management (through damming for instance) which can have important consequences to the natural water tables of the rivers and waterways.

Damming of the Guayas River has resulted in an increased siltation process in the lower part of its basin. At the moment the average production of silts is about 15x10^6 m^3 yr^{-1} . This implies that the long and wide basin of the Guayas River is being eroded at an annual rate of 0.5 mm yr^{-1}

1.2. The Chone River estuary

The estuary of the Chone River (0°33'-0° 36.5'S, 80°26.8'-80°17.8'W), formed by the convergence of Chone and Carrizal rivers, has a length of 25 km., with an average discharge of 31 m^3 s^{-1}. The width of the estuary varies from about 3 km to about 15 m. The total area of the basin is about 2,696 km^2. This hydrographic system originates in the coastal cordillera with rivers of low flow, which increases during the wet season. The riverbanks of the exterior estuary are occupied by the cities of San Vicente and Bahía de Caráquez (PMRC 1998).

In the alluvial plain formed in the area of convergence of the Chone and Carrizal rivers there are important freshwater swamps covering a surface area of approximately 14,710 ha - this varies annually according to the intensity of the rains. The most important lagoon is Segua Lagoon.

Several silt banks exist inside and outside the estuary. In the outer estuary, a sandbank which has formed in the center of the channel due to longshore sediment transport from the south obstructs shipping and highlights the continuous action of erosion and sedimentation.

The main impact in this basin is the deforestation, as the estuarine area has suffered critical levels of pruning of mangrove, which decreased in area from 3,980 ha in 1969 to 392 ha in 1995. The conversion of 90% of the mangrove to shrimp farms happened in less than twenty years, changing drastically the natural ecological system of the estuary. The tropical forest has also decreased from 19.9% of the total surface area transformed into short cycle cultivation. (PMRC 1998).

There are indications that the water contribution of the Chone River to the estuary is diminishing. In the last few years water from the river is retained for the breeding of chame and tilapia fish. The daily water replacement between the estuary and shrimp ponds is very high (about 4x10^6 to 6x10^6 m^3 day^{-1}; PMRC 1998). Therefore the water quality in the estuary depends on its internal dynamics, which include the daily water replacement of pools. At the convergence of the Carrizal and Chone rivers, the water quality exceeds the standards for turbidity (0.5-44 NTU) and nitrate (0.12-12.1 μgrat l^{-1}) (PMRC 1993)

During the wet season (December-April) the discharge of fresh water from the rivers cleans the inner estuary and improves the water quality, so that the dissolved oxygen registered in all the tracts is above values the acceptable minimum. (PMRC 1993)

1.3. The Esmeraldas River Estuary

Esmeraldas is smaller in population density (16.3 inhabitants km^{-2}) than the other three counties. Important economic activity includes agriculture, cattle raising, hunting and fisheries. The Esmeraldas River is rich in resources like shrimps, lobsters shells, oysters, clams, crabs and other crustaceans, and also in small species of pelagic fish. The shark is an important marine species, while of the freshwater species the chame is dominant.

The Esmeraldas River system comprises 23 rivers which discharge about 1765 m^3 s^{-1}, or about 48% of the national freshwater contribution to the Pacific Ocean (INERHI-CONADE-OEA). The Esmeraldas system constitutes the second largest hydrographic system of the Ecuadorian coast, with the Guayllabamba, the largest tributary, picking up water from the Andean slopes and transporting the urban and industrial discharges from Quito through the Machángara. The Cojimíes River system in the south has a sand and mud riverbed. Many other smaller rivers flow directly to the sea across to the coastal front, the main one being the Muisne River, followed by the Verde, Tiaone, Atacames and Sua rivers (PMRC 1987).

CLIRSEN (1986) determined that until 1984 the Esmeraldas had 3,052 ha of mangrove, corresponding about 16.5% of the mangroves of the country. In 1969 the mangroves extended had covered 32,032 ha. As well as the tourist-attracting beaches, Esmeraldas also contains some areas of special landscape, ecological and scientific value, such as the San Lorenzo archipelago, Atacames, the forests of the cliffs between Galera and Quingue, and the Muisne and Cojimíes estuaries.

The main pressures on the coastal resources come from the extraction and traditional gathering practices. This is the case in the swamps, which have been depleted by decades of exploitation for house piles, to extract shell or to make coal, endangering species like crab and shell, causing muddy beaches from silt washed down by rains and rivers from deforested lands. The new sources of problems are related to the domestic and industrial discharges that the Esmeraldas River transports towards tourist areas.

Water quality has deteriorated due to discharges from the oil refinery and domestic and industrial wastes carried from Quito by the Machángara and Guayllabamba rivers. The great urban growth and the fact that 40% of the city doesn't have a sewerage system both degrade the quality of the city air. The operation of the petroleum refinery can cause significant discharge of hydrocarbons into the waters of Teaone River due to spills. To this is added discharges from shrimp farms in the tourist areas of Súa and Atacames, and release of ballast waters by oil tankers in front of the coasts of Esmeraldas. Industrial wastes have caused the accumulation of heavy metals in the water, sediment and organisms. Results from studies carried out by the CPPS-PNUMA (Montaño 1993) are summarised in Tables 5.14 and 5.15.

Table 5.15. Dissolved heavy metal concentrations in river waters of the Ecuadorian coast.

Place	Cu ($\mu g\ l^{-1}$)	Cd ($\mu g\ l^{-1}$)	Zn($\mu g\ l^{-1}$)
Esmeraldas River	0.1-7.2	0.14-5.42	1.6-3.7
Taone River	0.6-1.7		1.9-4.2

Table 5.16. Heavy metals concentrations in silts from the Esmeraldas River (based on dry weight samples).

Place	Cu ($\mu g\ l^{-1}$)	Cd ($\mu g\ l^{-1}$)	Zn($\mu g\ l^{-1}$)	Pb($\mu g\ l^{-1}$)
Esmeraldas River	10.0-35.0	1.0-5.3	48.8-70.0	12.5-42.5

1.4. Management plan

The Program of Coastal Resources Management (PMRC), has as its general objective the creation of an integral program for the management of the coastal resources of Ecuador, with the following specific objectives:

- To obtain and analyze the scientific information and techniques needed to sustain the decisions that will enable the appropriate integral development of the coastal area.
- To develop procedures to evaluate environmental impacts due to development of coastal cities.
- To identify and to analyze the factors that affect the condition and use of coastal ecosystems.
- To train personnel for the planning and management of coastal development.
- To develop the institutional capacity to resolve the conflicts of coastal resources use.

For appropriate management of coastal resources, the following problems need to be addressed:

- Overfishing of several species especially blackish shell, mangrove oyster, lobster, and blue crab.

- Low level of technological development in shrimp cultivation.
- Lack of access roads to areas of interest to tourists.
- Deficit in basic services such as drinkable water and sewerage treatment.
- Contamination from untreated urban discharges.
- Contamination from oil refinery.
- Shrimp farms discharges.

2. Chile

In Chile, the hydrological system is conformed mainly by the rivers Loa, Aconcagua, Maipo, Itata, Bío Bío and Calle Calle. The flows and surpluses of these rivers are given in Table 5.17.

Table 5.17. Flows and surpluses of main Chilean rivers (CoNaMa 1995).

Basin	Qa ($m^3 s^{-1}$)	Qs ($m^3 s^{-1}$)	Qms ($m^3 s^{-1}$)	Qs/Qa	Qms/Qa
Loa River	2.8	0.6	0.04	21.4	1.4
Aconcagua River	38	30	0	79	0
Maipo River	116	100	1.0	86	0.9
Maule River	257	569	58	221	22.6
Bio Bío River	639	1,000	120	156	18.8

Recent economic development has intensified the use of hydrological resources, where the biggest demands continue to be for drinkable water, irrigation and electricity generation (Table 5.18).

Table 5.18. General use of water in Chile. Source: CoNaMa (1995).

Water uses	Demand ($m^3 s^{-1}$)	Use percentage consumption	Use percentage of total
Agricultural	620	89	-
Domestic	38	6	-
Mining-Industrial	37	5	-
Total consuming	695	100	32
Hydroelectric	1.500	-	68
Total	2.195	-	100

Human interference has caused water contamination (Table 5.19), which can end up affecting the health of people and the environment. The longest river in Chile is the Loa River, which has at the moment serious problems of contamination, a product of the mining activities of the region; 440 km from the highland to the ocean are polluted with arsenic and xantato; the arsenic rate allowed in Chile is of 0.05 mg l^{-1} and the silt in Loa River registers a concentration of 4.64 mg l^{-1}.

Table 5.19. Pollutants (BOD, suspended solids and fecals coliforms) to the coastal zone of Chile (SISS 1993).

Zone	BOD (t $month^{-1}$)	Suspended solids (t $month^{-1}$)	Fecal coliforms ($x10^{17}$ col l^{-1})
North zone	2.617	1.562	9.3
Center zone	10.211	5.391	29.0
South Zone	9.182	6.419	14.3
Total	22.009	13.372	52.6

The Aconcagua River, which rises in the Los Andes Cordillera, extends from 32° 14'S and 70° 00' - 71° 31' W, a distance of 214 km westward from the convergence of the Juncal and Blanco rivers to its mouth in Concon Bay. The flow regime is mixed, increasing during the wet and thaw seasons (spring and summer). The Putaendo River, with a basin of 1192 km^2 and a length of 82 km, joins the Aconcagua half way along its course. The Aconcagua River has a catchment area of 7,640 km^2.

The main uses of water in the basin of the Aconcagua River are for agriculture and drinking. With respect to the total basin surface, 45% is dedicated to agricultural use. Irrigation is a very important factor in the agricultural practices of this area, supplying 18,500 ha (28% of the surface of the basin) for wheat, beet and other cereals (barley and oats). Cattle raising occupies a large area of the basin over artificial, improved and natural prairies (approximately 50%).

As a consequence of the intense human activity (i.e., agricultural, forest, industrial, urban) in this ecosystem, one of the main problems for the hydrographic basin is the alteration of floor, surface and underground water quality. The Aconcagua River valley contains the most important agricultural activity in Chile, with intensive use of pesticides and fertilizers to protect and to increase productivity as the discharge of industrial and urban wastes, added to the lack of an environmental administration system puts in risk the environmental status of this hydrographic basin for agricultural use.

The Region of Bio Bío is located in the continental center of Chile. It has a surface of 36,929 km^2 and comprises four counties: Concepción (regional capital), Ñuble, Bio Bío and Arauco with fifty-two communities. It is the second region in importance in the country in population terms and in contribution to the PGB. It contains 13% of the national population with 1,734,305 inhabitants and it contributes 10% approximately to the national PGB.

3. Colombia

In Colombia water supply divides the country into areas that indicate the supply and demand of each one:

a) Regions with large amounts of water because the rain exceeds 3000 mm yr^{-1} or because there are forest areas with high humidity retention; this region covers about 44% of the country, including the Pacific coast, the Caquetá, Vichada, Vaupes and Inírida river basins and the highlands of the Arauca River.
b) Regions with water almost all the year; this region covers 25% of the country, and includes the Nechi and Putumayo river basins, the plain and central part of Meta and Sierra Nevada de Santa Marta River;
c) Deficit and normal water supply regions, representing 26% of the national area, including the Magdalena, Cauca, Tomo, Tuparro y Vichada river basins.
d) Deficit water supply, 5% of the national total area suffers a strong water deficit during the whole year; this region includes the Baja Guajira, Córdoba and Sucre and Catatumbo river basins and the plain and central parts of the Chicamocha River.
e) High water supply deficit, very dry zones, 1% of the country area, including Guajira and Tatacoa desert in Huila.

4. Peru

The surface water resources of Perú come from the Amazon, flowing along the border with Ecuador, including the Napo, Tigre, Pastaza, Santiago, Morona, Cenepa and Chinchipe rivers, which all supply water to Amazon River and the Atlantic: its calculated annually to supply about 125 km^3 year^{-1}(Table 5.20).

In the highlands there are lagoons between 4,000 and 6,000 m altitude, which are filled by rain, thaw and filtration from high basins.

On the other hand, the low rain level in the coast and the occidental side of the cordillera needs of rules to take advantage of the irregular river water supply. Most dams are for agricultural purposes although there are multipurpose dams (agricultural, energy and human supply); one of the biggest dams has a capacity about 2680 millions m^3.

Table 5.20. **Main hydrographic features of Perú.**

Flowing	Drained surface (km²)	Flow (km³ yr⁻¹)	Main rivers (in flow supply)
Pacific	279,689	36	Santa, Chira, Ocoña, Majes-Camaná, Tumbes
Atlantic	956,751	1,577	Amazon, Yurua, Madre de Dios, Marañón,
Titicaca	48,775	7	Shared Titicaca Lake
Total	215	1,616	

Acknowledgements

The authors are grateful to the personnel of the Physical Oceanography department of the Institute for their contribution to this paper.

References

CAAM (Comisión Asesora Ambiental de la Presidencia de la República) 1996 Sistemas Biofísicos en el Golfo de Guayaquil, January 1996.

CLIRSEN 1986 *Estudio multitemporal de Manglares, Camaroneras y áreas salinas de la costa ecuatoriana mediante información de Sensores Remotos*, 1969-1984.

CONAMA 1996 (Conselho Nacional do Meio Ambiente). Legislação Básica. Ministerio do Meio Ambiente, Recursos Hidricos e Amazonia Legal. Brasilia, DF, 272 pages.

CPPS (Comisión Permanente del Pacífico Sur) 2000 *Informe Estado del medio ambiente marino y costero del Pacífico Sudeste.* Quito, Ecuador.

INERHI-CONADE-OEA.- Plan de desarrollo Región 1.

INOCAR (Informe Técnico del Instituto Oceanográfico de la Armada) 1998 *Proyecto Autoridad Portuaria de Guayaquil* (APG), Chapter 3.

INOCAR 1998 *Acta Oceanográfica del Pacífico* Vol. 9 No.1. ISSN No.1390 129X, Guayaquil.

Montaño, M. 1993 *Estudios de la Calidad de Agua Costera Ecuatoriana.* Guayaquil, March 1993.

PMRC (Programa de Manejo de Recursos Costeros) 1987 *Ecuador perfil de sus recursos costeros*, September 1987.

PMRC (Programa de Manejo de Recursos Costeros) 1993 *Plan de Manejo de la ZEM Bahía – San Vicente – Canoa*, May 1993, page.43.

SISS (Superintendencia de Servicios Sanitarios) 1993 *Catastro Nacional de Descargas de Residuos Industriales Líquidos*, Santiago, Chile.

SRH 1998 (Secretaria de Recursos Hidricos do Estado do Ceará). Levantamento do Recursos Hidricos do Estado do Ceará. 2 Vol. Fortaleza, 568 pages.

6. Case studies

6.1 Changes in Mississippi River nutrient fluxes and consequences for the northern Gulf of Mexico coastal ecosystem

Nancy N. Rabalais
Louisiana Universities Marine Consortium, 8124 Hwy. 56, Chauvin, LA 70344 USA

Nutrient over-enrichment from anthropogenic sources is one of the major stresses impacting coastal ecosystems. There is increasing concern in many areas around the world that an oversupply of nutrients from multiple sources is having pervasive ecological effects on shallow coastal and estuarine areas (e.g. Nixon 1995, Diaz and Rosenberg 1995). These effects include reduced light penetration, loss of aquatic habitat, harmful algal blooms, a decrease in dissolved oxygen (= hypoxia) and impacts on living resources. The largest zone of oxygen-depleted coastal waters in the United States, and the entire western Atlantic Ocean, is found in the northern Gulf of Mexico on the Louisiana/Texas continental shelf influenced by the freshwater discharge and nutrient flux of the Mississippi River system (Figure 6.1), which drains much of the North American continent (Rabalais *et al.* 1991, 1996, 1998, 1999).

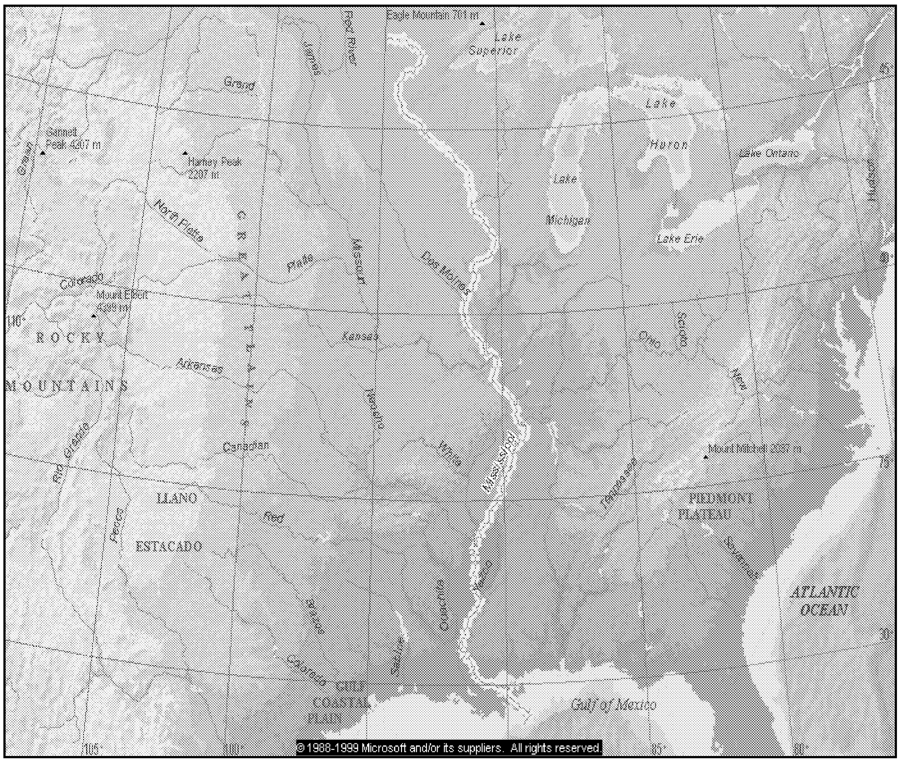


Figure 6.1. The Mississippi River.

General dimensions of hypoxia

The mid-summer bottom areal extent of hypoxic waters ($\leq$ 2mg l^{-1} O_2, or 2 ppm) in 1985-1992 averaged 8,000 to 9,000 km^2 but increased to 16,000 to 20,000 km^2 in 1993-1999. The estimated extent was 12,500 km^2 in mid-summer of 1998. Hypoxic conditions exist over broad regions of the shelf for extended periods in mid-summer. A compilation of thirteen mid-summer shelfwide surveys (1985-1997) demonstrates that the frequency of occurrence of hypoxia is higher to the west of the discharges of the Mississippi and Atchafalaya Rivers in a down-current direction from their influence (Rabalais *et al.* 1999) (Figure 6.2). Hypoxic waters are most prevalent from late spring through late summer and hypoxia is more widespread and persistent in some years than in others. Hypoxic waters are distributed from shallow depths near shore (4 to 5 m) to 60 m water depth but exist more typically between 5 and 30 m depth. Hypoxia occurs mostly in the lower water column but may encompass as much as the lower half to two-thirds of the water column.

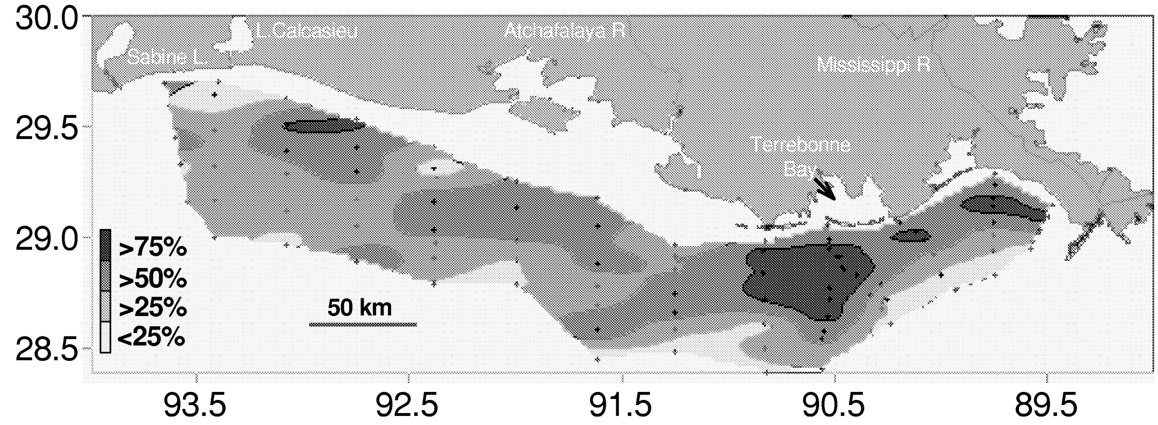


Figure 6.2. Distribution of frequency of occurrence of mid-summer hypoxia over the 60- to 80-station grid from 1985-1999 (modified from Rabalais *et al.* 1999).

River discharge and flux of materials

The Mississippi River catchment encompasses 41% of the conterminous United States and delivers an average of 580 km^3 of fresh water to the Gulf of Mexico yearly along with sediment yields of $210x10^6$ t yr^{-1}, $1.6x10^6$ t yr^{-1} nitrate, $0.1x10^6$ t yr^{-1} phosphorus and $2.1x10^6$ t yr^{-1} silica (Turner and Rabalais 1991). The best current knowledge is that the outflows of the Mississippi and Atchafalaya Rivers dominate the nutrient loads to the continental shelf where hypoxia is likely to develop. The 1820-1992 average discharge rate (decadal time scale) for the Mississippi River at Vicksburg is remarkably stable near 14,000 m^3 s^{-1} despite significant interannual variability and some decadal trends. Since the 1700s humans have altered the morphology and flow of the Mississippi River so that now 30% is diverted to the Atchafalaya that also captures the flow of the Red River. The discharge of the Atchafalaya increased during the period 1900-1992, primarily as a result of the tendency for the Atchafalaya to capture more of the flow of the Mississippi (until stabilized at 30% in 1977) (Bratkovich *et al.* 1994). A slight increase in Mississippi River discharge for 1900-1992 is accounted for by an increased discharge in September through December, a period that is much less important in the coastal ocean than spring and summer in the timing of important biological processes that lead to the development of hypoxia or the physical processes important in its maintenance.

Mississippi River nutrient concentrations and loading to the adjacent continental shelf have changed dramatically this century, with an acceleration of these changes in the last four decades depending on the constituent of concern. The mean annual concentration of nitrate was approximately the same in 1905-1906 and 1933-1934 as in the 1950s, but it has increased up to 3-fold from the 1950s to 1960s (Turner and Rabalais 1991). The increase in total nitrogen is almost entirely due to changes in nitrate concentration (Turner and Rabalais 1991, Goolsby *et al.* 1999).

There was no pronounced seasonal peak in nitrate concentration prior to 1960, whereas there was a spring peak from 1975 to 1985. Prior to the 1960s, nitrogen flux closely paralleled river discharge, a pattern that still holds but the load of nitrogen per volume discharge is greater now. There is no doubt that the concentration and unit flux of nitrogen (per unit volume discharge) has increased from the levels of the 1950s to 1960s, especially in the spring. The mean annual concentration of silicate was approximately the same in 1905-1906 as in the early 1950s, then it declined by 30 to 50%, depending on the type of statistical analysis used or the period of record. Concentrations of nitrate and silicate appear to have stabilized, but trends are masked by increased annual variability in the 1980s and 1990s data. There are no substantial records of total phosphorus concentrations in the lower Mississippi River before 1973 and subsequent values vary greatly among years. Application of a linear least-squares regression on the 1973-1987 data, however, indicates a two-fold increase in the total phosphorus concentration (Justic' *et al.* 1995a).

The proportions of dissolved Si, N and P in the lower Mississippi River have changed historically, and they now closely approximate the Redfield ratio (Si:N:P = 16:16:1) (Justic' *et al.* 1995a, b). Thus, any single nutrient is more likely to be limiting to phytoplankton production now than historically. Another reasonable hypothesis that follows a more balanced nutrient composition is that surface offshore primary productivity has increased. Fluctuations in the Si:N ratio within the riverine effluents and the offshore waters can affect diatom production and are believed to be major determinants in the coastal food web structure on a seasonal basis, with major implications to oxygen and carbon cycling (Turner *et al.* 1998).

Interaction of physics and biology

The physics of the system and the biological processes are linked and related to the freshwater discharge and nutrient flux of the Mississippi River system. The physics of the system defines where hypoxia can occur, and the biological processes of carbon production, flux and respiration lead to oxygen depletion. The high freshwater discharge, general circulation patterns on the Louisiana shelf and the presence of the Louisiana coastal current dictate a stratified system for much of the year, interrupted on occasion by wind-mixing events, notably tropical storms and winter cold fronts.

Nutrient-enhanced productivity

The evidence for nutrient enhanced primary production in the northern Gulf of Mexico and its linkage with oxygen depletion in the lower water column comes from information on a variety of scales - experiments for a parcel of water from a particular locale over a limited time to more integrative measures of ecosystem response (e.g., net production, carbon flux and respiration) and change over broader spatial and temporal scales. The concentrations, total loads and ratios of nutrients (nitrogen, phosphorus and silica) delivered to the coastal ocean influence the productivity of the phytoplankton community as well as the types of phytoplankton that are most likely to grow. The nutrient most relevant to overall phytoplankton production over the broad region fueling hypoxia is nitrogen, and nitrate-nitrogen makes up approximately two-thirds of the total nitrogen input from the Mississippi River. Silica and phosphorus may also be limiting at some times and places. There is clear evidence that primary production in shelf waters near the delta and to some distance from it is significantly correlated with nutrient inputs (nitrate+nitrite and orthophosphate) (Lohrenz *et al.* 1999). Similar relationships exist for net production (an indicator of the amount of carbon available for export to the lower water column and sediments) and nitrate flux (Justic' *et al.* 1997). There is also a strong relationship between the net production in surface waters, the amount of carbon exported, the accumulation rates of carbon, and the depletion of oxygen in bottom waters (Rabalais *et al.* 1999). Spatial and temporal variability in these components is closely related to the amplitude and phasing of Mississippi River discharge and nutrient fluxes. Thus, there are clear lines of evidence for nitrogen (particularly nitrate) driven phytoplankton production that leads to hypoxia. Although the Mississippi and Atchafalaya Rivers discharge organic matter to the shelf, the principal source of carbon reaching the bottom waters in the northern Gulf influenced by the river effluent and characterized by hypoxia is from in situ phytoplankton production (Turner and Rabalais 1994a, Eadie *et al.* 1994).

Long-term changes in the coastal ecosystem

It follows, and is supported with evidence from long-term data sets and the sedimentary record, that increases in riverine dissolved inorganic nitrogen concentration and loads are highly correlated with indicators of increased productivity in the overlying water column, i.e., eutrophication of the continental shelf waters, and subsequent worsening of oxygen stress in the bottom waters. Evidence from changes in diatom production, increased accumulation of diatom remains in the sediments, increased carbon accumulation in the sediments, decreased diversity of selected benthic fauna, and relative changes in selected benthic fauna indicate that oxygen concentrations are decreasing (Turner and Rabalais 1994a, b; Eadie *et al.* 1994; Nelsen *et al.* 1994; Rabalais *et al.* 1996; Sen Gupta *et al.* 1996). Human activities in the watershed undoubtedly changed the natural functioning of the Mississippi River system. Century-long patterns of freshwater discharge are not evident; thus, the long-term changes on the Louisiana shelf are linked to the quality of the discharge (nutrient loads and ratios of nutrients) and not the amount. While century-long changes are evident in some of the retrospective analyses, the most dramatic and accelerating changes have been since the 1950s, when nitrogen loads began to increase, primarily from nitrate inputs, and eventually tripled their earlier values. The fact that the most dramatic changes in the continental shelf ecosystem have occurred since the 1950s and are coincident with an increase in nitrate load, points to that aspect of human ecology for future management scenarios.

Evidence associates increased coastal ocean productivity and increasing severity of oxygen depletion with changes in landscape use and nutrient management that resulted in nutrient enrichment of receiving waters. Nutrient flux to coastal systems, while essential to overall productivity, has increased over time due to anthropogenic activities and has led to broad-scale degradation of the marine environment.

Modelling results

The northern Gulf of Mexico adjacent to the discharge of the Mississippi River system is an example of a coastal ocean that has undergone eutrophication (increased rate of primary production) as a result of increasing nutrients and that has worsened hypoxic conditions on century-long and accelerating recent decadal time scales. Models that link Mississippi River discharge with Gulf of Mexico hypoxia demonstrate increasing severity of hypoxia in bottom waters with increased freshwater discharge and even more extreme hypoxia with additional nitrogen accompanying the increased discharge. Conversely, the models show that a reduction in oxygen demand in the lower water column will result from a reduction in nitrogen (and to a lesser degree the phosphorus) load to the surface waters. In other words, hypoxia in the northern Gulf of Mexico can be alleviated to some degree by a reduction in the nutrient loading.

References

Bratkovich, A., Dinnel, S.P. and Goolsby, D.A. 1994 Variability and prediction of freshwater and nitrate fluxes for the Louisiana-Texas shelf: Mississippi and Atchafalaya River source functions. *Estuaries* 17:766-778.

Diaz, R.J. and Rosenberg, R. 1995 Marine benthic hypoxia: A review of its ecological effects and the behavioural responses of benthic macrofauna. *Oceanography and Marine Biology: an Annual Review* **33**:245-303.

Eadie, B.J., McKee, B.A., Lansing, M.B., Robbins, J.A., Metz, S. and Trefry, J.H. 1994 Records of nutrient-enhanced coastal productivity in sediments from the Louisiana continental shelf. *Estuaries* 17:754-765.

Goolsby, D.A., Battaglin, W.A., Lawrence, G.B., Artz, R.S., Aulenbach, B.T. and Hooper, R.P. 1999 Flux and Sources of Nutrients in the Mississippi-Atchafalaya River Basin: Topic 3. Report for the Integrated Assessment of Hypoxia in the Gulf of Mexico. *NOAA Coastal Ocean Program Decision Analysis Series* No. **17**. NOAA Coastal Ocean Program, Silver Spring, MD, in press.

Justic', D., Rabalais, N.N. and Turner, R.E. 1995a Stoichiometric nutrient balance and origin of coastal eutrophication. *Marine Pollution Bulletin* **30**:41-46.

Justic', D., Rabalais, N.N., Turner, R.E. and Dortch, Q. 1995b Changes in nutrient structure of river-dominated coastal waters: Stoichiometric nutrient balance and its consequences. *Estuarine, Coastal and Shelf Science* **40**:339-356.

Justic', D., Rabalais, N.N. and Turner, R.E. 1997 Impacts of climate change on net productivity of coastal waters: Implications for carbon budget and hypoxia. *Climate Research* **8**:225-237.

Lohrenz, S.E., Fahnenstiel, G.L., Redalje, D.G., Lang, G.A., Dagg, M.J., Whitledge, T.E. and Dortch, Q. 1999. The interplay of nutrients, irradiance and mixing as factors regulating primary production in coastal waters impacted by the Mississippi River plume. *Continental Shelf Research* **19**:1113-1141.

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

Nixon, S.W. 1995 Coastal marine eutrophication: A definition, social causes, and future concerns. *Ophelia* **41**:199-219.

Rabalais, N.N., Turner, R.E., Wiseman, W.J. Jr. and Boesch, D.F. 1991 A brief summary of hypoxia on the northern Gulf of Mexico continental shelf: 1985-1988. Pages 35-46 in Tyson, R.V. and Pearson, T.H. (eds.), Modern and Ancient Continental Shelf Anoxia. *Geological Society Special Publication* No. **58**, The Geological Society, London, 470 pages.

Rabalais, N.N., Turner, R.E., Justic', D., Dortch, Q., Wiseman, Jr., W.J. and Sen Gupta, B.K. 1996 Nutrient changes in the Mississippi River and system responses on the adjacent continental shelf. *Estuaries* **19**:386-407.

Rabalais, N.N., Turner, R.E., Wiseman, Jr., W.J. and Dortch, Q. 1998 Consequences of the 1993 Mississippi River flood in the Gulf of Mexico. *Regulated Rivers: Research and Management* **14**:161-177.

Rabalais, N.N., Turner, R.E., Justic', D., Dortch, Q. and Wiseman, Jr., W.J. 1999 Characterization of Hypoxia. Topic 1 Report for the Integrated Assessment of Hypoxia in the Gulf of Mexico. *NOAA Coastal Ocean Program Decision Analysis Series* No. **15**. NOAA Coastal Ocean Program, Silver Spring, MD, in press.[1]

Sen Gupta, B.K., Turner, R.E. and Rabalais, N.N. 1996 Seasonal oxygen depletion in continental-shelf waters of Louisiana: Historical record of benthic foraminifers. *Geology* **24**:227-230.

Turner, R.E. and Rabalais, N.N. 1991. Changes in Mississippi River water quality this century. Implications for coastal food webs. *BioScience* **41**:140-148.

Turner, R.E. and Rabalais, N.N. 1994a Coastal eutrophication near the Mississippi river delta. *Nature* **368**:619-621.

Turner, R.E. and Rabalais, N.N. 1994b Changes in the Mississippi River nutrient supply and offshore silicate-based phytoplankton community responses. Pages 147-150 in Dyer, K.R. and Orth, R.J. (eds.), *Changes in Fluxes in Estuaries: Implications from Science to Management.* Proceedings of ECSA22/ERF Symposium, International Symposium Series, Olsen and Olsen, Fredensborg, Denmark.

Turner, R.E., Qureshi, N., Rabalais, N.N, Dortch, Q., Justic', D., Shaw, R.F. and Cope, J. 1998 Fluctuating silicate:nitrate ratios and coastal plankton food webs. *Proceedings of the National Academy of Science, USA* **95**:13048-13051.

See also the full report available at http://state-of-coast.noaa.gov/bulletins/html/hyp_09/hyp.html

---

6.2 Estimation of the nutrient inputs into river basins – experiences from German rivers

Horst Behrendt
Institute of Freshwater Ecology and Inland Fisheries, Dept for Limnology of Shallow Lakes and Flatland Rivers, Seestrasse 82 12589 Berlin Germany

One of the main objectives of LOICZ is to determine the fluxes of nutrients to the coastal zone. Because most of the load to the coastal zone is caused by medium and large rivers, there is a need for tools to estimate the nutrient load from such river basins into the coastal zones depending on the uses of nutrients in the human sphere and on the inputs reach the river system by different point and diffuse pathways.

The model **MONERIS**[2] (**MO**delling **N**utrient **E**missions in **RI**ver **S**ystems) was developed to estimate the nutrient inputs into river basins of Germany by point sources and various diffuse pathways. The model is based on data of river flow and water quality as well as on a geographical information system (GIS), including digital maps and extensive statistical information (Behrendt et al., 2000). Whereas point inputs from waste-water treatment plants and industrial plants are directly discharged into the rivers, diffuse inputs into surface waters are caused by the sum of different pathways, which are realised by separate flow components and different nutrient concentrations. Consequently seven pathways are considered:

- point sources
- atmospheric deposition
- erosion
- surface runoff
- groundwater
- tile drainage
- paved urban areas

Along the path from the source into the river, substances are governed by manifold processes of transformation, retention and loss. Knowledge of these processes is necessary to quantify nutrient inputs into the rivers. Since this knowledge of the processes and the database are at present limited, the description of the processes could not be done by detailed dynamic models. Therefore, MONERIS estimates the pathways with existing and new conceptual approaches. One specific topic of the model development was to validate the different submodels by using independent data sets. For example, the groundwater model was developed on the basis of the observed nitrogen concentrations in the groundwater and not of the observed nutrient loads in the rivers.

The use of GIS allows a regionally differentiated quantification of nutrient inputs into river systems. Therefore, estimations were not only carried out for large river basins. Altogether the MONERIS model was applied to 300 different river basins for two time periods, 1983-1987 and 1993-1997. The temporal changes of nutrient inputs were calculated considering the difference in hydrological conditions for both periods.

Nitrogen

Total nitrogen input into the river system of the Rhine River basin (Figure 6.3a) in the period 1993-1997 was 400 ktN y^{-1}. This represents a reduction of 169 ktN y^{-1} or 28% since the mid-eighties. 46 % of the total nitrogen going into the Rhine basin are caused by groundwater. The second major source is discharges from municipal waste-water treatment plants. Whereas direct industrial discharges were the third dominant pathway in the mid-eighties, this source contributes now only 4.8 % to the total inputs.

For the Elbe River basin (Figure 6.3b), total nitrogen inputs into the river system of 233.8 ktN y^{-1} are estimated for the period 1993 to 1997. This is a decrease of 95 ktN y^{-1} or 29 % since the mid-eighties. In the Elbe River basin, the groundwater pathway is also the major source of N-inputs with 43.3 %. In contrast to the Rhine, the contribution of municipal waste-water treatment plants is lower, caused by a lower population density. Otherwise the proportion of tile drainage is much higher in the Elbe area,

---

[2] **MONERIS** was developed within a research project founded by the German Federal Environmental Agency

because more agricultural land was artificial drained by tiles. Direct industrial discharges show the largest reduction. The main reason for the decrease of the N-inputs into the river systems was the large reduction of N-discharges from point sources by 46 %. The estimated decrease of diffuse inputs was only about 10%.

In spite of the substantial decrease of the nitrogen surplus in agricultural areas, a slight reduction of the nitrogen inputs from the groundwater can only be estimated for the Rhine basin. In other river basins the nitrogen inputs along this pathway will still have increased during the nineties due to the long residence times of water in the unsaturated zone and in the aquifer. However, after the year 2000 the reduced nitrogen surplus will be followed by a slow reduction of the nitrogen inputs from groundwater. The consequence is that the nitrogen load from these rivers in the coastal zone will further decrease after the year 2000.

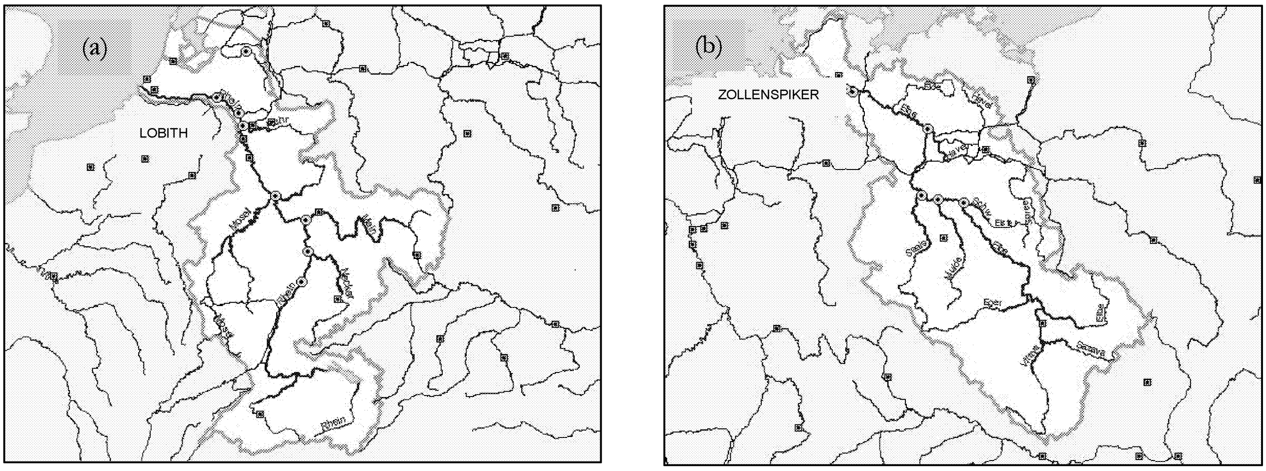


Figure 6.3. Catchment areas of the Rhine (a) and Elbe (b) rivers, Germany (from Behrendt *et al.* 2000).

Phosphorus

For the Rhine upstream of Lobith, a total P-input of 20,500 t P y^{-1} is calculated for the period 1993-1997. In comparison to the mid-eighties this is a reduction of 30.600 t P y^{-1} or 60 %. The enormous reduction in the discharges from municipal waste-water treatment plants could only partly change the dominance of this source. This pathway still accounts for 42.8 % of the P inputs. However, the sum of the diffuse inputs now represents more than half of the P-input to the Rhine basin. Among the diffuse pathways erosion is the major source followed by inputs of dissolved phosphorus via surface runoff and diffuse inputs from urban areas.

For the Elbe basin above Zollenspieker, a total P-input of 12,500 t P y^{-1} is estimated for the 1993-1997 period. The reduction amounts about 52 % (13,300 t P y^{-1}) since the 1983-1987 period. In the Elbe River basin the point sources also represent the major source of phosphorus inputs but the sum of the total diffuse pathways is now more than 60 %. The dominant diffuse pathway is also erosion, followed by diffuse inputs from urban areas.

The decrease of phosphorus inputs is again mainly caused by an 80 % reduction of point discharges. The decrease of diffuse phosphorus emissions was larger than for nitrogen, which is results from a 56 % reduction of the emissions from urban areas.

Among the basins of the large rivers, the changes of nutrient inputs into the river systems as well as the contribution of the individual pathways to the total inputs vary widely.

The observed N- and P-loads in the Rhine and Elbe rivers are lower than the inputs, due to retention and loss processes (e.g. denitrification, sedimentation, adsorption) within the surface waters of the basins. The level of the retention within the river system of Elbe is much higher than in the Rhine, which can be explained by the different hydrological and morphological conditions in both basins. If the conceptual model approaches of Behrendt and Opitz (1999) are applied the load can be calculated from the inputs.

References

Behrendt, H. and Opitz, D. 1999 Retention of nutrients in river systems: dependence on specific runoff and hydraulic load. *Hydrobiologia* **410**: 111-122.

Behrendt, H., Huber, P., Kornmilch, M., Opitz, D., Schmoll, O., Scholz, G. and Uebe, R. 2000 *Nutrient balances of German river basins.* UBA-Texte, 23/2000, 261 pages.

Behrendt, H., Huber, P., Kornmilch, M., Opitz, D., Schmoll, O., Scholz, G. and Uebe, R. 2000 Nutrient emissions into river basins of Germany. *Institute of Freshwater Ecology and Inland Fisheries, Research Report* **296 25 515**, 261 pages and CD-ROM.

6.3 A preliminary approach of the link between socio-economic and natural indicators into a driver-pressure-state-impact-response framework case study: Guanabara Bay basin, Rio de Janeiro, Brazil.

E.D. Bidone and L.D. Lacerda
Universidade Federal Fluminense, Niteroi, Rio de Janeiro 24020-007, Brazil

1. Introduction

The Land Ocean Interactions in the Coastal Zone (LOICZ) Core Project of the International Geosphere Biosphere Project focuses on the role of the world's coastal zones in the functioning of the Earth system: the way in which global changes will influence that role; the way in which such changes will affect the use of coastal space and resources by humanity; and the consequences of such changes for human welfare (Turner *et al.*. 1998).

Within Focus 1 of LOICZ, one of the main objectives is to determine the fluxes of nutrients to the coastal zone. Within Focus 4 the emphasis is on socio-economics issues. It is our goal to set up combined Focus 1 – Focus 4 project in Guanabara Bay, SE Brazil to:

1. Determine the fluxes of nutrients to the coastal zone (past, current and future);
2. identify the main socio-economic drivers, which have changed or will change the fluxes; and
3. identify indicators for the impact of land-based sources on the coastal zone and to derive from them a critical load (Salomons, 1999).

At a later stage these critical loads can be connected with the main socio-economic drivers on the continent and subsequently a cost-benefit analysis can be carried out those cases with negative impacts on the coastal zone and the need for remediation of land-based point and diffuses sources. To meet these objectives requires integration of natural, social and economic information into a broad analytical framework in which to set the more detailed analysis, and to provide the interdisciplinary working tool for a wide spectrum of users. The Driver-Pressure-State-Impact-Response (DPSIR) framework offers such a generalized context.

2. The Guanabara Bay basin: physical or primary environmental indicators

The study area, Guanabara Bay basin (Figure 6.4), located in Rio de Janeiro State (22°40' - 23°00' S and 43°00' - 43°20 W) is the most prominent coastal bay in Brazil. It was first occupied 4 centuries ago and but major industrial development only occurred in the early 1970's. Nowadays, there are 12 municipal districts, 7.8 million inhabitants and around 12,500 industries distributed unevenly over in the drainage basin area (4,000 km^2). As a result of this occupation there are heavy metals, phenols and cyanides but also 350 t of BOD and 18 t of oil thrown in the bay on a daily basis. This explains the poor quality of water and sediments observed mainly in the western part of the bay. The renewal time of 50% of the bay water volume is 11 days. The depth ranges from 1 m to 30 m (Kjerve *et al.* 1997).

The Guanabara Bay basin is backed by a high (1000 m to 1500 m) relief mountain range ("serras"). It has a large number of small catchments, usually <100 km^2. The river profiles have a very strong slope which change – over a few tens of kilometers - to a relief of hills before reaching the coastal plain. The ratio between slope:hill:coastal plain areas is variable and follows a general empirical rule: the magnitude of the hill and coastal plain areas increases with the size (i.e., total area) of the watersheds.

The predominant rock types are pre-Cambrian migmatites and gneisses with associated intrusive granites and diabase dykes. The material of the hills apparently originated from the weathering of the rocks at the base of the slopes. Alluvial Quaternary and Recent sediments compose the coastal plains. On the higher slopes, the predominant materials are essentially colluviums. Towards the lowlands the soils are thicker and generally of the latosol type. Hydromorphic soil types predominate in the lowlands.

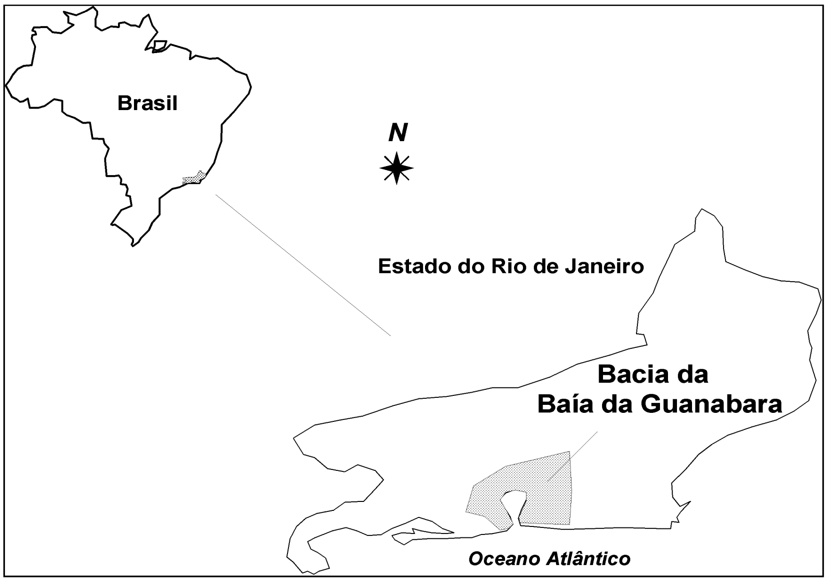


Figure 6.4. Study area: Guanabara Bay basin

The climate of the study area is tropical humid. Temperature and atmospheric precipitation are very variable, from >24°C and <1000 mm.year^{-1} in the lowlands, to <18 °C and >2500 mm.year^{-1} on the high slopes. The mean annual river discharges are small and vary from 10^{-2} to 10^{-1} m^3.s^{-1}. In densely populated areas, the river discharge increases due to wastewater inputs *in natura*, i.e., without previous treatment. Because of their small areas, the watersheds have low hydraulic retention times. Consequently, during large rainfalls or storms (~80 mm or more), the effects upon river discharge are almost instantaneous reaching several m^3 s^{-1}. In urban areas these storm surges may have catastrophic effects.

Bidone *et al.* (1999) classified the watersheds of the Guanabara Bay region into three types:

(i) the pristine type, without anthropogenic activities, which generally belong to legally protected areas, with Mata Atlântica (i.e., a tropical rain forest type) or/and similar abundant vegetation on the slopes and natural coastal vegetation in the lowlands (grasses, savannas, "restingas");

(ii) the weakly impacted type with well-preserved Mata Atlântica or/and other remnant vegetations on the slopes, and lowland sectors with human activities (small farming, tourist-urban activities); and

(iii) the highly impacted watersheds, densely populated and/or industrialized.

3. Integrated system model for the Guanabara Bay basin

The system model proposed for the Guanabara Bay basin is based on the generic Driver-Pressure-State-Impact-Response (DPSIR) framework (Figure 6.5). From top to bottom the diagram presents the specific system elements (socio-economic and natural) considered up to the present time in this case study.

(i) Socio-economic drivers: demographic growth and rise in land use/cover (principally residential land occupation) without sanitation improvement (above all domestic effluents treatment).

(ii) Physical drivers: seasonal change in climate conditions (essentially rain intensity and distribution).

(iii) River material fluxes: BOD, C, N, P, suspended solids and heavy metals.

(iv) Guanabara Bay: DOC, heavy metals and chlorophyll *a* concentrations in water; TOC, N, P and heavy metals in sediments, and heavy metals in fishes (particularly Hg).

(v) Socio-economic activities: fisheries and recreation in Guanabara Bay and small rivers draining into it.

(vi) Policy response and management options: approach based, firstly, on the evaluation (Cost-Benefit analysis) of those public policies and management actions included in the 'Guanabara Bay Recuperation Program', conducted by Rio de Janeiro State Government and supported by the World Bank, Interamerican Development Bank and Japan Bank financing; and, second, on the correcting account (Gross Product of Rio de Janeiro State) for environmental costs and physical natural capital depreciation.

(vii) Cost-Benefit analysis: this study proposes the use of extended Cost-Benefit analysis, in which standards of sustainability (reflecting estimated critical loads of selected substances/indicators) are fixed. The analysis attempts to highlight the cost of achieving them.

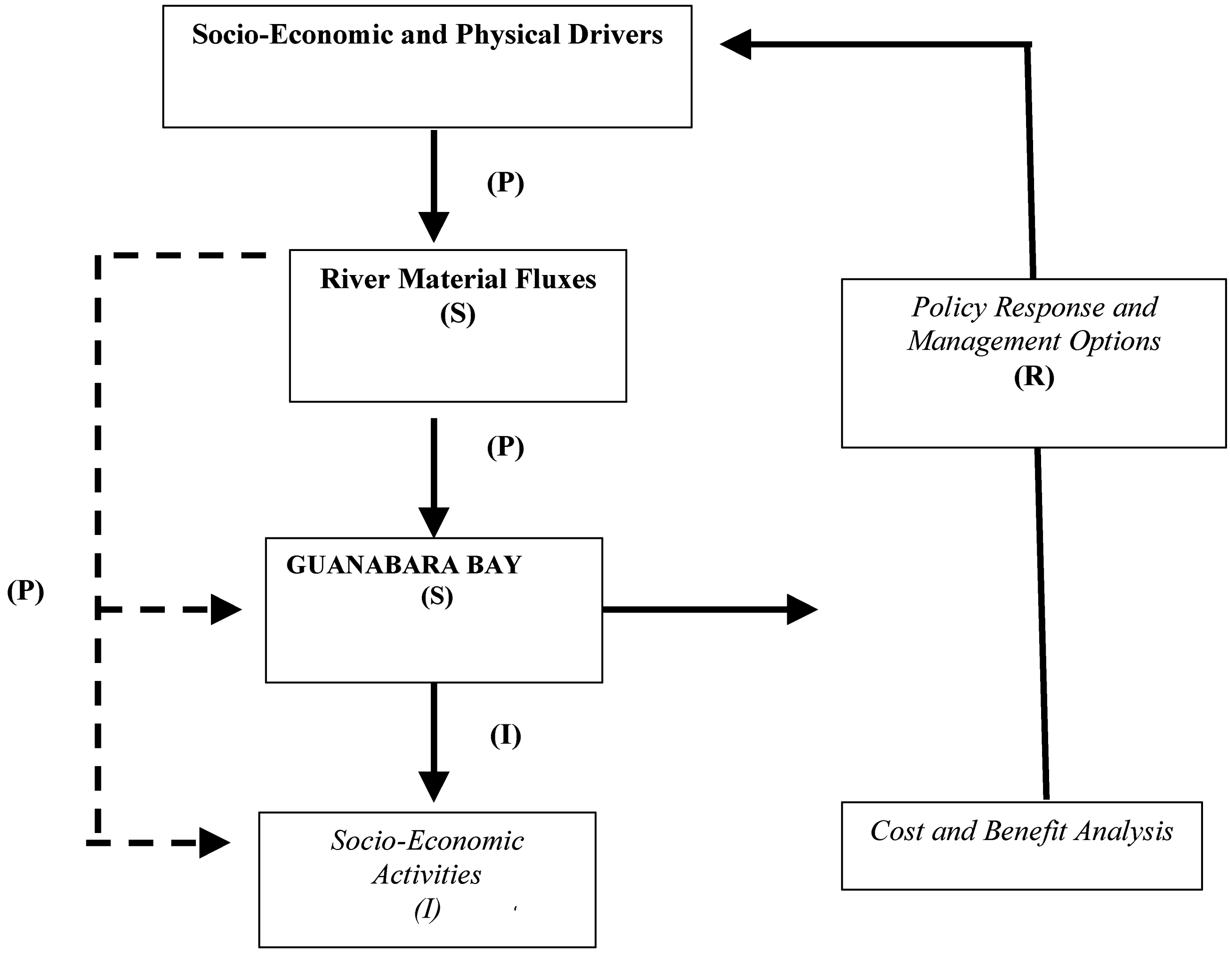


Figure 6.5. Integrated model used in Guanabara Bay case study, based on the Drivers-Pressure-State-Impact-Response framework. P = pressure indicators; S = state indicators; I = impact indicators; R = response indicators.

4. Integration of natural elements and indicators in the system model

The practical solution of each sub-system (specific system elements) of the proposed system model, and of the links between them (represented by arrows in Figure 6.5) shows different degrees of difficulty. Sub-systems involving natural elements and potential indicators of pressure, state change and environmental impact – i.e., rain distribution (physical driver), river material fluxes, Guanabara Bay water and sediment composition, and fish contamination - needs a standard, referenced scientific and technical approach. For example, to estimate river material fluxes and their links with rain distribution, several studies were carried out since the 1980's in the small coastal watersheds of Guanabara Bay basin, providing relevant data on the biogeochemistry of river waters. Essentially, the methodological approach used was to collect and rework the available data set in a compatible manner. It was demonstrated that the specific material fluxes of polluted and highly polluted rivers were one to two orders of magnitude higher than those estimated for unpolluted or weakly polluted rivers. It has been shown that the highly variable hydrology of the studied rivers directly controls the natural and anthropogenic river water concentration levels of biogeochemical materials, and their runoff loads. In pristine rivers during heavy rainfalls (80 mm or more), the increase in material fluxes was about one order of magnitude. In highly polluted watersheds measured on rainy days

(25 mm day^{-1} rainfall) the material fluxes were twice those measured on non-rainy days (when the preceding period of non-rainy days was five days or more). Detailed approach, results and discussion can be found in Bidone *et al.* (1999).

Transfer of materials through the aquatic continuum - including the river system, estuaries, wetlands and the bay - involves passage through ecosystems which can act as very effective and selective "filters" for materials. The effectiveness and selectivity of the processes of transformation, elimination or immobilization of materials during their transfer through the aquatic continuum depends on their biogeochemical behavior and are also strongly influenced by hydrology and land use (Billen 1993).

These are relevant aspects in all basic biogeochemical studies and for surveys of river water quality control and the establishment of watershed management policies. However, to evaluate the effectiveness and selectivity of controlling processes of the biogeochemical behavior of materials in river waters is often difficult. In this study, using a mass balance approach between continual river segments, it was possible to identify portions of the Guanabara Bay basin with active transformation processes, including the elimination or immobilization of materials during their transfer through the aquatic continuum.

For example, $P\text{-}PO_4$ and $N\text{-}NH_4$ concentrations increase exponentially with pollution level, by about three orders of magnitude from unpolluted rivers (or river stations placed on the uncontaminated slope portions) to highly polluted rivers by domestic wastewater. The $N\text{-}NO_3$ natural concentrations are apparently little affected by industrial pollution. On the contrary they increase by about one order of magnitude when the river waters are polluted by domestic wastewater. However, a decreasing trend appears when river waters are highly polluted. A similar fate can be observed in DO concentrations when pollution levels increase considerably.

It is possible to establish the rates of transport of the biogeochemical materials by the river along the watersheds and toward its destination, i.e., the estimation of the material loads carried by rivers into the Guanabara Bay. For example, the estimated loads of BOD, TN and TP into Guanabara Bay were, respectively, 350t, 122t and 20t, on a daily basis.

The principal impacts of biogeochemical loads into the bay are eutrophication, pollution, excess sedimentation and trophic state change from its original trophic characteristics to eutrophy to hypertrophy (Chlorophyll *a* concentrations >100 µg l^{-1}). This results in a reduction of fish production and loss of biodiversity (for which real numbers can be estimated), interdiction of beaches to recreation and high levels of heavy metal pollution in sediments.

To assess the ecological and human health risks resulting from heavy metal and other contaminants (particularly APH′s, toxins and DDT), we have adapted the Potential Ecological Risk Index (PERI) originally proposed by Håkanson (1980, 1988) as a contamination control for lakes and coastal systems of Scandinavia. The most important adaptation concerns the estimate of the trophic state system by using the bioproduction number (BPN). The N/organic matter ratio in sediments, originally used for the calculation of BPN, was substituted by the evaluation of chlorophyll *a* levels in the water column. Due to the high trophic state in Guanabara Bay, the PERI obtained was low (PERI = 36). Among heavy metals, Hg was identified as being the priority contamination to be detailed: PER: Hg = 25.4> Cd = 5.7> Cu = 2.8> Pb = 1.2> Cr = 0.3> Zn = 0.2. A detailed approach can be found in Campos and Bidone (2000). Risk assessment for the organic contaminants is still to be calculated.

To make the link (transfer) between contaminants and biota (fishes in this case study), we have used an approach developed by Castilhos *et al.* (2001) firstly to Hg contamination. This approach suggests:

- a parameter to normalize Hg concentration in fishes based on the time of exposure needed to reach some percentage of their maximum length, in this case 50%;
- a graphical method to estimate Hg daily uptake rate by these fishes;
- an estimate of the time of exposure necessary to achieve 0.5 µg g^{-1}, the United States Food and Drug Administration (FDA) advisory level for concentration of mercury in fish; and
- calculation of the dose-response relationship for Hg accumulation.

The results of the existing studies suggest that it is possible to integrate the results obtained in the different sub-systems involving the natural elements of the proposed model (river material fluxes, internal bay system etc.) to identify potential indicators of pressure, state change and impact. The current major requirement is to integrate the natural and the socio-economic elements included in the proposed system model for the Guanabara Bay basin.

5. Integration of socio-economic elements and indicators in the system model

5.1. The 'socio-economic drivers' and 'socio-economic activities' elements

The "pure" socio-economic elements included in the system model are the 'socio-economic drivers' and the 'socio-economic activities'. In the proposed approach, the 'cost-benefit analysis' and 'policy response' may be classed as merged natural-socioeconomic elements. For this case study, recognition and characterization of 'socio-economic activities' is not complicated since the Guanabara Bay basin is a relatively well-documented region because of its cultural and historic importance to Brazil. From the large numbers of urbanization and development programs and the many scientific studies from local universities and State agencies, it was possible to identify fisheries and tourism-recreation as the major activities affected by eutrophication and pollution of Guanabara Bay. Within the river catchment, major activities affected are the use of water by the population and industry, which need relatively unpolluted water. In general, surface water use is substituted by the use of groundwater, or water supplied by the State, generally from diversion of other basins such as the Paraíba do Sul River (Molisani *et al.*, this report).

The principal 'socio-economic drivers' identified are urbanization (demographic growth and increase in land occupation for residential purpose) and industrialization. Urbanization and industrialization processes generate, respectively, diffuse and point sources of wastewaters and toxic effluents to the rivers, and from them to Guanabara Bay.

This paper is restricted to the discussion of the socio-economic indicators linkable to the socio-economic driver "urbanization", responsible for the increased fluxes of materials and for the extensive contamination of Guanabara Bay (JICA 1994).

5.2. Demographic indicators *versus* biogeochemical indicators in river waters

Primarily, indicators of the socio-economic drivers must be directly linked to demography and land occupation (in this case, for residential purposes) indicators, to provide an understanding of the external forcing effects of socio-economic changes such as population growth on fluxes of biogeochemical materials. Population growth (i.e., human occupation) within watersheds draining into Guanabara Bay is linear and without treatment of domestic sewage. Consequently concentrations and fluxes of materials also change linearly with the population density (JICA 1994; Bidone 2000). For example, DIP and DIN increase by about three orders of magnitude from unpolluted rivers to highly polluted rivers. N:P ratios clearly define the different intensities of basin occupation and reflect the levels of fluvial water contamination. These ratios show a decreasing trend inversely proportional to the degree of contamination of fluvial waters. Thus, river waters in areas with remnant tropical rainforest (on the slope parts of the watersheds) and with a population density of about 10^{-2} inhab. km^{-2}, has a N:P ratio of about 100; in non-polluted river waters draining areas with population density of about 10^{-1} inhab. km^{-2}, the N:P ratio varies from 10 to 100; low contamination waters with similar population density show N:P ratios varying from 1 to 10; polluted waters in areas of moderately high population density (10^{2} inhab. km^{-2}) show N:P ratios from 0.1 to 1.0; and heavily polluted waters in high population density areas (10^{3} inhab. km^{-2}) show N:P ratios from 0.01 to 0.1. This pattern is in accordance with the *quasi*-exponential increase of P with water contamination levels and the occurrence of denitrification in heavily polluted waters (Bidone 2000).

From material fluvial fluxes it is possible to derive loads of substances from domestic sewage. Fluxes to Guanabara Bay of BOD, TN and TP were estimated as 0.03 kgBOD $inhab^{-1}$ day^{-1}, 0.01 kgTN $inhab^{-1}.day^{-1}$ and 0.002 kgTP $inhab^{-1}$ day^{-1} (Bidone 2000).

Other links between demographic and natural indicators must be established. However, the major objective of the present study is to highlight the importance of such an approach to question contained in the objectives of the **LOICZ Basins** project. These include:

- construction of future scenarios (forecasts) for pressures and state changes of fluvial waters and their inputs to coastal system;
- reconstruction of past scenarios of the historical occupation of watersheds;
- up-scaling of these indicators from the regional level towards a typology of the SE Brazilian coast and eventually to a sub-continental level;
- estimation of sustainability standards for fluvial waters and of defining critical loads (e.g. N:P ratios of about 16 for non-contaminated waters in this region); and eventually
- establishment of primary regulatory goals for river waters.

The sustainability standards should take into consideration a risk analysis at least for toxic substances (Bidone *et al.* 2000).

5.2 Other socio-economic driver indicators for basin 'typology' and 'up scaling'

An important aspect to be considered in the studied area is the linearity observed between the demographic growth and the increase of pollution levels as reflected by the increase in fluxes of biogeochemical materials. This is also important for the 'typology definition' for 'up-scaling' (Turner *et al.* 1998). In the Guanabara Bay basin this linearity is due to the high rates of population growth and to unplanned occupation of watersheds, without the proper infrastructure to cope with their effluents. In this case, the question is whether the fluxes of materials would still reflect the indicators of demographic change if all basins, independent of their population density, had their sewage effluents treated.

The more realistic answer to this question is probably, yes! Theoretically a reduction of the forcing of anthropogenic activities upon the study areas would be achieved by introducing environmental protection rules for these activities. However, technical measure frequently do not solve the problem but only decrease its velocity, since the growth of a give activity in general surpasses the effect of the measure or due to delayed effects of the contamination. Even considering the long term, the ideal environmental control of such typology as that of Guanabara Bay is probable an utopian concept.

Mitigation measures are being implemented under the 'Guanabara Bay Recuperation Programme' conducted by Rio de Janeiro State Government. There is no possibility of returning to original, natural state because of increasing occupation pressure, prohibitive costs, the impossibility of implementing ideal control measurements, e.g., lack of areas to construct tertiary treatment systems, the low level of development of the local society and the inadequacy of public policies. To better characterize and eventually develop a 'typology' and promote up-scaling, it is necessary to develop other 'socio-economic driver' indicators, which can better characterize the socio-economic profile of the population.

A commonly utilized socio-economic indicator for the characterization of the economic activity (wealth) of a population is its Gross Internal Product *per capita* (GIP/inhab). In the study area the GIP/inhab is about US$ 3,500. But in this case this indicator fails, since it doesn't take into consideration the concentration of income and the wealth distribution within the population. The higher the income concentration, the higher the number of poor and the worse the quality of life of the population, including sanitary conditions.

Other frequently-used income distribution indicators are the Gini Coefficient and the Theil Index. These indicators take into consideration the average family income *per capita* of a given region. An index of coefficient 1.0 represents the largest uneven distribution of income among the population. In Brazil, the average index is 0.74, one of the highest in the world. In Rio de Janeiro city, between 1981 and 1985, this value was 0.57 and between 1995 and 1999 it was 0.60, suggesting a deterioration of social conditions. Today, the 50% poorer of the population has only 13.1% of the city's income, whereas the 1% richest has 11.8%.

We have also been working on the application of the HDI (human Development Index) on the Guanabara Bay basin. This index allows the comparison of quality of life taking into consideration information on income, health and education level of the inhabitants. The HDI ranges from 0 to 1.0, where the higher the value the better development is achieved by a give population (HDI >0.8 = high, HDI between 0.5 and 0.8 = medium, and HDI <0.5 = low). Our results show that high (>0.8) development is associated with better sanitary conditions. Material fluxes through rivers are smaller, as are the impacts on the coastal zone. Sub-basins with high HDI also presented low population densities whereas low HDI occurs in areas of high population density. Thus considering two sub-basins of similar 'physical typology' (i.e., with similar primary environmental indicators) but with different values for the HDI, the sub-basin with the lower value will show the higher biogeochemical fluxes, and therefore pressure on fluvial waters and impacts on the coastal zone. We are presently ranking the sub-basins and relating HDI values to estimated biogeochemical fluxes. Independent of the result, these indexes showed fundamentally as a 'socio-economic driver' indicator essential to any desired 'typology definition' and/or 'up-scaling' procedure.

6. Supplementary socio-economic indicators based on sustainable development issues

In a wide sense, **LOICZ Basins** projects deal with sustainable coastal development, which can be described as 'the proper use and care of coastal environmental borrowed from future generations' (Turner *et al.* 1998). Sustainable development was defined by the Brundtlant Report, 'Our Common Future' (WCED 1987) as that which 'meets the needs of the present without compromising the ability of future generations to meet their own needs', and it was suggested that economic development and environmental well-being are not mutually exclusive goals. In order to achieve critical sustainable development objectives for coastal environments and coastal development policies, it is important to have strategies such as conserving and enhancing the coastal environment, managing risk and coastal vulnerability, and merging coastal environmental considerations with economics in decision making. However, to be socially sustainable, the total capital of a given economy requires the inclusion of those considerations related to the biophysical environment

Sustainability from an economic perspective requires a non-declining capital stock over time to be consistent with the criterion of intergenerational equity. Sustainability therefore requires a development process that allows for an increase in the well-being of the current generation, with particular emphasis on the welfare of the poorest members of society, while simultaneously avoiding uncompensated and significant costs on future generations. The process would be based on a long-term perspective, incorporating equity as well as an efficiency criterion, and would also emphasise the need to maintain a healthy global ecological system (Turner *et al.* 1998).

The total capital of an economy may be described as the sum of man-made capital, natural capital, human capital and social/moral capital. Thus, beyond the need of holding the natural capital constant or rising over time, social sustainable development requires an improvement in the human capital and social/moral capital.

Socioeconomic indicators of human capital and social/moral capital could be considered as 'supplementary socio-economic indicators'. The practical aim of their utilization into the DPSIR framework, would be to support additionally the social evaluations and considerations obtained from the use of the proposed 'socio-economic driver indicators', as well as, to reinforce: a) the basin typology characterization and the up scaling purposes; b) the characterization of the socio-economical profile of the population living in the basins (in terms of its 'quality of live' characterization); c) the evaluation of the results of public policies.

At Guanabara Bay basin, no study to date has included an evaluation of supplementary socio-economic indicators of human and social/moral capitals such as infantile mortality, poverty, education, health and public safety indicators in face of their links with biophysical indicators of environmental change.

For example, the 'infantile mortality' is an index measuring the number of children that die before the end of the first year of life (number of dead children/1000 births). That index for the Guanabara Bay region varies from about 5 in basin occupied by high HDI (>0.800) to about 45 in basins with population with low HDI (>0.500 - <0.800).

The 'poverty index' considers (as a percentage of inhabitants) the number of the poorest members of the population of a given area. A 'poor member' is defined as someone with monthly revenue of about US$40 or less. The preliminary Guanabara Bay results show that areas with a high HDI value have a 'poverty index' of about 4% or less; while areas with low HDI values have a 'poverty index' higher than 20%. The 'education index', average number of years spent in school of the adult population, varies from, 11 years in areas with higher HDI values to about 7 years in areas with lower HDI values. The 'public safety index' used in this case study is the number of violent crimes per year. This varies from about 200 in higher HDI areas to 4,000 in lower HDI areas.

6. Merged socio-economic and natural indicators: cost-benefit analysis (CBA) and response indicators

6.1 CBA: strengths and limitations

LOICZ objectives and the DPSIR framework include the assessment of the human welfare impacts of flux changes due to changes in processes and functions in coastal resource systems. Such assessments of the social costs and benefits involved will provide essential coastal management intelligence based on social science and possible resource and value trade-offs.

CBA are economic techniques that produce information intended to improve the quality of public policies. In this context, 'quality' refers to a measure of the social wellbeing that the policy conveys to society. Policies that reduce wellbeing are *a priori* inferior to those that improve wellbeing. Conceptually, then, CBA could be used:

a) to evaluate the results of a environmental public policy and/or a resource management action;
b) to rank policies and/or resource management options; and, even
c) to evaluate the results of the absence of a necessary environmental public policy and/or the absence of resource management action.

These evaluations and ranks are rated on the basis of their impacts on socio-economic wellbeing.

Because policy decisions are required for a range of spatial and temporal scales and different socio-economic and political levels, several broad assessment categories need to be distinguished (Barbier 1993). LOICZ proposes three assessment categories:

a) the impact analysis in which a specific environmental impact is assessed via the valuation of the environmental state changes in the coastal resource(s) connected to the impact;
b) the partial valuation analysis, which encompasses situations requiring the evaluation of alternative resource allocations or project options; and,
c) the total valuation analysis, to evaluate protected areas schemes involving restricted or controlled resource use (Turner *et al.* 1998).

All these assessment categories require estimates of the environmental benefits and costs. For example, in an impact analysis, the total cost of the environmental impact in social welfare terms is the foregone net of environmental benefits. This and other strategies of CBA are apparently simple, but to evaluate natural resources, environmental goods and services, environmental benefits and associated costs to the environmental degradation in monetary terms is a very difficult task. This is mostly due to the non-quantifiable nature of the environment in the existing economic framework.

There are various methods and approaches to the economic valuation of environmental state changes: hedonic property method, travel cost, cost of illness, contingent valuation (Turner *et al.* 1998). There are conceptual, theoretical and empirical problems encountered in quantifying economic value for the environment (e.g., Pearce and Turner 1990; Costanza 1991).

CBA is a technique intended to improve the quality of public-policy decisions, a quality defined according to the change in social wellbeing that they bring about. CBA forces one to use a measurement of social wellbeing, which we refer to as social welfare. The measurement of social welfare in CBA and how it is affected by a policy depend on how the welfare of individuals is affected by the policy and how individuals' welfare levels are aggregated. Individual welfare is assumed to depend on the satisfaction of preferences and on the theoretical construct of economic value derived from the axioms of preference satisfaction (Kopp *et al.* 1997).

Many of the critiques of CBA encountered in everyday policy debates are echoes of the more conceptual issues. They include the following:

(i) the environment is a public good that is not exchanged in markets and therefore defies economic valuation. Thus, the use of CBA to evaluate environmental policies is inappropriate;

(ii) environmental protection is often desirable for reasons that cannot be quantified (social, spiritual, and psychological values that defy valuation in simple economic terms);

(iii) CBA does not take the "rights" of future generation into account.

Beyond these and other conceptual issues, criticism of CBA focusses on several overlapping points: the notion that preference satisfaction gives rise to individual well-being, the elements of the social-welfare index, the notion that economic value is a measure of preference satisfaction, the empirical and philosophic problems encountered in quantifying economic value, the presumption that the well-being of society can be defined as some aggregation of the well-being of individual members of that society, and the methods by which the aggregation is performed, (Kopp *et al.* 1997).

6.2 CBA in the DPSIR framework for the Guanabara Bay case study

In this case study, the 'policy responses' and their practical 'management options' are those included into the 'Guanabara Bay Recuperation Programme', conducted by the Rio de Janeiro State Government supported by the World Bank, Interamerican Development Bank and Japan Bank. That programme is a water pollution control plan intended to reduce the inflow of wastewaters into Guanabara Bay. It includes the construction of several treatment plants, stabilization ponds, ocean outfalls with primary treatment, and other actions and facilities aiming for the recuperation of the bay.

Based on conceptual and theoretical issues, and the practical difficulties in valuation of environmental goods and services for a proper CBA of 'policy responses' and 'management options' of the "Guanabara Bay Recuperation Programme', we propose a strategy that does not require the valuation of the environment in monetary terms. Conceptually, this strategy is in agreement with the necessary environmental conservation paradigm implicit in sustainable development. Even with the best possible data and scientific understanding, the sense in which economists can value nature's services is limited. Valuing these services is much less important than providing incentives for their conservation, and valuation and providing incentives for conservation are quite different. Valuation is neither necessary nor sufficient for conservation, whereas providing the right incentives is (Heal 2000).

The theoretical and practical basis of the proposed strategy is partially based on Hueting (1991) with suggestions and modifications more suitable to the present situation. The first need is to assign a value which society attributes to the raw materials and products of a project or policy. This involves a theoretical concept directly related to the dichotomy between individual and collective (i.e. society's) preferences *vis-à-vis* the change in quality and quantity of natural resources. Thus: what standards (of environmental quality and quantity) are to be set? An answer to that question could be found in the notion of sustainable development: politicians, organizations and countries (more than 100 countries, including Brazil, which had already included the concept of sustainable development in its new constitution of 1988) declared in favor of sustainable development during and after the United Nations Environmental Summit in Rio de Janeiro in 1992. This can be conceived as a preference voiced by society, which opens up the possibility of basing a calculation on standards for a sustainable use of environmental functions, instead of (unknown) individual preferences.

The second need is the assignment of monetary values to the external benefits and costs to the environment which arise from the project or policy, so that these may be incorporated, together with market values of other project attributes, in the CBA. This is not a straightforward task, owing to the intangibility in monetary terms of most environmental goods and services. Hueting (1991) proposed the following procedure:

a) define physical standards for environmental functions, based on their sustainable use;

b) formulate the measures necessary to meet these standards;

c) estimate the amounts of money involved in putting the measures into practice.

In technical terms, this means that in the familiar diagram of the supply and demand curve for environmental functions we have to determine a point on the abscissa which represents the standard for sustainability. A perpendicular on this point intersects the supply curve; the perpendicular replaces the (unknown) demand curve. The point of intersection indicates the volume of activities, measured in terms of money, involved in attaining sustainable use of the environmental functions. Thus a technical demand function is created, rather than a 'true' demand curve (which, theoretically, should be constructed from the aggregation of all individual preferences by environmental quality).

We have focused on the economic-environmental evaluation of the results on fluvial water quality and the measurements adopted by the Guanabara Bay Recuperation Programme. The effects of these measurements on the water quality of the bay are also being evaluated. Table 1 shows a synthesis of the elements included in the proposed CBA. This procedure is being applied for each watershed draining into Guanabara Bay. Thus general considerations and total values to the elements listed in Table 1 can be obtained for the entire Guanabara Bay basin from the individual value for each sub-basin.

Table 6.1. Elements included in the CBA of the sanitation measures planned by the Guanabara Bay Recuperation Programme. Emphasis is on the riverwater quality state change.

ELEMENTS TO CBA	
Population density	Inhab/km^2
Human Development Index (HDI)	HDI >0.80 (high); HDI 0.500 - 0.800 (medium) and HDI <0.500 (low)
Biogeochemical fluxes	BOD, TN, TP, etc. (t km^{-2} day^{-1})
Current pollution level	Pristine, low, high and extreme
Planned sanitation measures	Ocean outfalls, stabilization ponds etc.
Costs of the planned sanitation measures	US$
Cost *per capita*	US$/inhab
Cost *per capita* /revenue *per capita*	Ratio (non-dimensional)
Forecast of state change	Modeling of the remaining biogeochemical load effects on the riverwater quality
Standard of sustainability	Natural indicators (e.g., biogeochemical fluxes) for 'drinking water' use after conventional treatment
Natural background level	Original state of the riverwater
Physical natural capital depreciation (PNCD)	Estimation of the environmental costs for the remaining biogeochemical loads
Pressures on other environmental resources	Pressures on the wetlands and on Guanabara Bay
Benefits	Qualitative approach

Although most of the elements listed in Table 6.1 have been already discussed or are self-explanatory, some considerations are still necessary:

a) Physical natural capital depreciation (PNCD)

The capital of an economy is its stock of actual goods with the potential to produce in the future more goods and services. The capital of an economy should include the natural resources of a given region, once they have the potential to generate more goods and services in the future, both as source of raw materials and as receptors of effluents and wastes generated by human activities. Therefore the impoverishment of natural resources must be viewed as an uninvestment and should be discounted from the incomes generated by production as a "depreciation of the natural capital" (El Serafy 1991).

One reason that depreciation exists is because of a reduction over time in the physical ability of capital to generate consumable services. This loss in physical ability – physical depreciation – may also lead to a loss in the value of the capital stock – value depreciation. That is, value depreciation may be caused by physical depreciation. However, value depreciation can also arise for other reasons. For example, the value of capital can fall due to a change in tastes for those consumption items produced by the capital or simply because of a change in interest rates. Thus, the value of total depreciation could be considered as Value depreciation = physical depreciation – capital gain or + capital loss (Peskin 1989, 1991). We will only consider the physical depreciation (PNCD), hence capital (in financial terms) gains and/or losses are already included in conventional accounts.

In this study we propose to estimate PNCD through the estimation of the environmental costs associated to the remaining biogeochemical loads in the river waters. This is done by estimating the costs of the necessary measurements to reach the natural background concentrations of local fluvial waters, i.e., to attain the original state of the river water quality. The estimated values of NCD shall be included into the "satellite accounts" to correct the Gross Internal Product (GIP) of the Rio de Janeiro state for the environmental costs and benefits: 'Satellite Accounts' = GIP - Σ Costs of sanitation measures - Σ NCD.

b) Pressures on other environmental resources

The priority in the study is to consider the pressures on the wetlands and on Guanabara Bay proper. Pressures on wetlands are mostly due to the implementation of flood-control measures along the lower part of river basins (e.g., ponds, dredging, canals). In general, these measures are planned to work together with water treatment systems. But no policy specifically for protection and/or management of wetlands exists for the area, neither is any consideration given on the impact of external factors (e.g., sea level change) and other ongoing projects on development and management. These pressure are also due to the input of substances directly through rivers and residual from the outfall inputs due to sea currents and other dilution agents. The quantification of these pressures is underway but analysis of such pressures are still preliminary and its inclusion in the present model is only qualitative, indicating either its presence as significant or not, for each studied catchment.

c) Benefits

Forecasted benefits are related to the use of the Guanabara Bay water system. Improving the quality of incoming fluvial waters is a key step to the improvement of the water quality of Guanabara Bay. For many small communities better quality of fluvial waters for domestic supply would be highly beneficial. The potential for other uses such as aquaculture and recreation is not considered. Even for Guanabara Bay, the impact of improving water quality in fisheries and recreation is considered only under qualitative terms.

A basic principle of CBA is that all benefit types should have standing, whether they are quantifiable or not. The key issue is how to treat non-quantifiable elements. There are several options. One that has found favor among economists is a value-of-information approach. This involves estimating the net benefits for the quantifiable elements and asking how large the non-quantifiable elements would have to be to reverse the conclusion of the analysis. If the non-quantifiable elements were all on the benefits side and the net benefits were positive, information on the non-quantifiable benefits would have no value for the decision. If the net benefits were negative, the non-quantifiable elements would have to be at least as large to reverse the outcome of the analysis. The analyst or decision-maker could make a judgment about whether the non-quantifiable elements were likely to be greater than this amount (an easier judgment than one about the possible size of the non-quantifiable benefits: Kopp *et al.* 1997).

For instance, with respect to health benefits in the Guanabara Bay sanitation programme, the effects of water and soil contamination by bacteria, viruses etc. on human health is well known. Statistical data show that the population health is improved after the implementation of sanitation measures. That is, the costs with illness treat are reduced over time. How much? To answer to this question good statistical data on these costs are necessary. But, it is not so evident. For that reason, to estimate the approximated rates of illness reduction observed over time in areas with sanitation controls may be a sufficient approach to the benefits of sanitation programmes.

References

Barbier, E.B. 1993 Sustainable use of wetlands valuing tropical wetland benefits: economic methodologies and applications. *Geographical Journal* **159**, 22-32.

Bidone, E.D., Silva Filho, E.V., Guerra, T., Barroso, L.V., Ovalle, A.R.C. 1999 Natural and cultural nutrient levels in rivers of coastal lagoon catchments, State of Rio de Janeiro, Brazil. Pages 89-106 in

Knoppers, B.A., Bidone, E.D. and Abrão, J.J. (eds): *Environmental Geochemistry of Coastal Lagoon Systems of Rio de Janeiro, Brazil.* PGG-UFF.

Bidone, E.D., Castilhos, Z.C. and Guerra, T. 2000 Carvão e Meio Ambiente: integração dos estudos através de uma abordagem (sócio) econômico-ambiental in Carvão e Meio Ambiente, Centro de Ecologia da UFRGS, EDUFRGS, 1006 p., Porto Alegre, RS, 271-439.

Bidone, E.D. 2000 Análise econômico-ambiental aplicada à contaminação das águas fluviais de pequenas bacias costeiras do Estado do Rio de Janeiro. Pages 371-394in Esteves, F.A. and Lacerda, L.D. (eds): *Ecologia de Restingas e Lagoas Costeiras.* EDUFRJ, Rio de Janeiro.

Billen, G. 1993 The Phison River system: a conceptual model of C, N and P transformations in the aquatic continuum from land to sea. Pages 141-161 in Wollast, R., Mackenzie, F.T. and Chou, L. (eds): *Interactions of C, N, P and S biogeochemical cycles and global change.* NATO ASI Series I: Global Environmental Change Vol. 4, Springer-Verlag Berlin Heidelberg, Germany.

Campos, E.D. and Bidone, E.D. 2000 Potential Ecological Risk Index for heavy metals: assay at Guanabara Bay, Rio de Janeiro, Brazil. *XXV International Conference of Heavy Metals in the Environment,* August 2000, Ann Arbor, Michigan, USA.

Castilhos, Z.C., Bidone, Z.C. and Hartz, S. 2001 Bioaccumulation of Hg by Tucunaré (*Cichla ocellaris*) from Tapajós River Region, Brazilian Amazon. A field dose-response approach. *Bull Environ Contam Toxicol* (in press: may 2001).

Costanza, R. (ed.) 1991 *Ecological economics, the science and management of sustainability.* Columbia University Press, 515 pages.

El Serafy, S. 1991 The environment as capital. Pages 168-175 in: Costanza, R. (Ed): *Ecological economics, the science and management of sustainability.* Columbia University Press.

Heal, G. 2000 Valuing ecosystem services. *Ecosystems* 3: 24-30.

Håkanson L. 1988 Pages 240-257 in Seeliger, U., Lacerda., L.D. and Patchineelam, S.R. (eds): *Metals in coastal systems of Latin America.* Springer-Verlag.

Hueting, R. 1991 Correcting national income for environmental losses: a practical solution for a theoretical dilemma. Pages 194-213 in Costanza, R. (ed.): *Ecological economics, the science and management of sustainability.* Columbia University Press.

JICA - Japan International Cooperation Agency 1994 *The study on recuperation of the Guanabara Bay ecosytem. Main Report.* March 1994.

Kjerfve B., Ribeiro, C.H.A., Dias, G.T.M., Filipo, A.M. and Quaresma, V.S. 1998 Oceanographic characteristics of an impacted coastal bay: Baia de Guanabara, Rio de Janeiro, Brazil. *Continental Shelf Research* 17(3): 1609-1643.

Kopp, R.J., Krupnick, A.J. and Toman, M. 1997 Cost-Benefit Analysis and regulatory reform: an assessment of the science and the art. *Resources for the Future, Discussion Paper* 97-19, January 1997, Washington, USA, 61 pages.

Pearce, D.W. and Turner, R.K. 1990 *Economics of natural resources and the environment.* Harvester Wheatsheaf, London, UK, 378 pages.

Pernetta, J.C. and Milliman, J.D. 1995 *LOICZ implementation plan*, Report No. 33 IGBP, Stockholm.

Peskin, H.M. 1989 A proposed environmental accounts framework. Pages 65-78 in: Environmental accounting for sustainable development. UNEP – World Bank Symposium.

Salomons, W. 2000 Human dimensions of land-based fluxes to the coastal zone. Pages 5-12 in: Lacerda, L.D., Kremer, H.H., Salomons, W., Kjerve, B. and Marshall Crossland, J.I. (eds): South American River Catchment/Coastal Zone Interaction and Human Dimensions. Meeting report of the first LOICZ SAmBas workshop held in Bahia Blanca, Instituto Argentino de Oceanografia, 11-13 November 1999.

Turner, R.K., Adger, W.N. and Lorenzoni, I. 1998 Towards integrated modelling and analysis in coastal zones: principles and practices. *LOICZ Report & Studies* 11, LOICZ, Texel, the Netherlands, 122 pages.

WCED – World Commission on Environment and Development 1987 Our common future – The Brundtland Report.

World Bank 1992 World development report: development and environment. New York: Oxford University Press.

6.5 Integrated management of the Uruguayan coastal zone of of the Rio de la Plata

Adriana Jorajuria
Programa ECOPLATA, Pza. Cagancha 1335, of. 217, 11200 Montevideo, Uruguay

The ECOPLATA Program is an inter-institutional agreement for joint execution of activities in support of IMCZ with the participation of the Ministry of Housing, Territorial Planning and Environment (MVOTMA); the National Institute of Fisheries (INAPE, MGAP); the Oceanographical, Hydrological and Meteorological Service of the Navy (SOHMA, Ministry of Defense); the College of Sciences; and the College of Social Sciences of the University of the Republic.

The main objective is to contribute to the integrated management of the Uruguayan coastal zone of the Río de la Plata, through activities in pilot areas. It includes design and execution of management policies on the basis of a preliminary diagnosis. Planned actions should promote the conservation and sustainable use of coastal resources, with participation of the various governmental institutions that are responsible for management of the natural resources and their conservation, and other relevant organizations.

The proposed actions should resolve conflicts on the use of coastal resources, both in the terrestrial fringe and the aquatic section of the project's area. The identified conflicts of use result from activities that compete among themselves such as fishing, tourism, housing, industry and agriculture. These activities contribute to resource degradation as a consequence of overfishing, water-course pollution, solid residues accumulation, erosion and loss of agricultural lands' nutrients. Planned actions include some to protect areas that are presently relatively pristine, and corrective actions in areas where resource degradation and habitats alteration are occurring.

The involvement of several governmental institutions with national and local level responsibilities, the University of the Republic, non-governmental institutions and others that are directly involved in the use of coastal resources constitutes an innovative aspect of the project in the Uruguayan conditions.

Concentrated action in pilot areas is intended to demonstrate the contribution of technical and scientific information to integrated coastal zone management. The concentration of inter-institutional and multidisciplinary efforts in a restricted area and the selection of the pilot zones with most potential will provide results in a short period and will enable the replication of similar efforts in other parts of the project's area.

The open character of the project, which can be observed by the population, is complemented with training activities, public participation in resources management, education and information dissemination. This hopefully will ensure an improved attitude in relation to resources management and the environment.

Area of the Study

The study area includes 452 km on the Río de la Plata coast (Figure 6.6).

- **Terrestrial** – a 10 km corridor between the coast and National Routes No. 21, 22, 8 and 9, with its eastern political boundary set in Punta del Este, Maldonado Department and its physical boundary at Maldonado Creek.

- **Aquatic** – The exclusive jurisdictional zone is stated in "The Boundary Treaty of the Río de la Plata and its Maritime Front": 2 miles wide from Km 0 of the Rio de la Plata to Colonia del Sacramento City, Colonia Department, and from there seven miles stretching as far as Punta del Este, Maldonado Department.

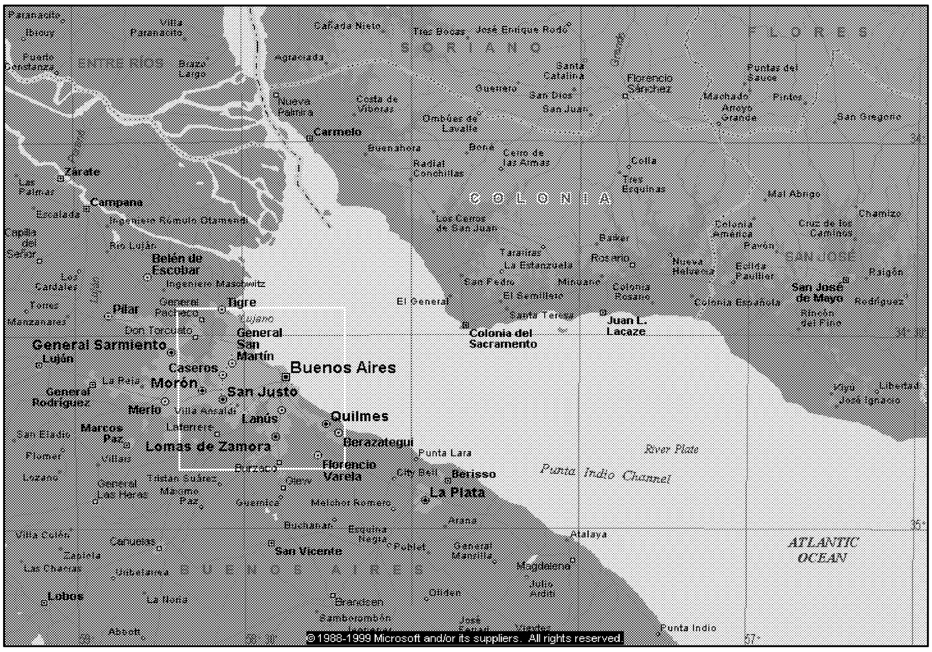


Figure 6.6. The Rio de la Plata estuary, including the study area.

The terrestrial area is characterized by a great diversity of coastal environments. Sandy beaches are dominant with bars and coastal dunes, slopes and ravines developed over diverse geological structures.

A preliminary environmental diagnosis identified processes that affect the sustainability of the coastal resources:

- Beach erosion
- Ravine erosion
- Interference to the natural processes of morphological evolution and sediments transport
- Unlawful extraction of sand and other materials for construction

Zoning and degree of environmental impact

For the purpose of zoning and ranking of environmental impact in the areas, "pressure indicators" were applied, that show the presence of activities that can generate certain level of environment impact and "state indicators", that show five *categories of environmental impact*:

- **Low:** minimal impacts or reduced damage to the environment
- **Moderate:** moderate impacts mostly related to discrete activities or less intensive use
- **Medium:** impacts with certain degree of area significance and moderately intense activities
- **High:** significant impact across large area
- **Very high:** very significant impacts over large areas and little possibility of reversion

Applying these indicators, the Uruguayan coastal zone of the Río de la Plata presented the following level of environmental impact:

• Nueva Palmira - Punta San Carlos	**Low**
• Punta San Carlos - Juan Lacaze	**Medium**
• Juan Lacaze – Kiyú	**Moderate**
• Kiyú - Arroyo Mauricio	**Medium**
• Arroyo Mauricio – PuntaTigre	**Low**
• Punta Tigre - Punta Espinillo	**High**

Punta Espinillo - Punta Lobos	**Moderate**
Punta Lobos - Punta Sarandí	**Very high**
Punta Sarandí - Arroyo Carrasco	**High**
Arroyo Carrasco - Arroyo Pando	**High**
Arroyo Pando - Arroyo Solís Chico	**Medium**
Arroyo Solís Chico - Arroyo Solís Grande	**Moderate**
Arroyo Solís Grande - Arroyo Zanja Honda	**Medium**
Arroyo Zanja Honda - Punta Fría	**Very high**
Punta Fría - Arroyo Potrero	**Low**
Arroyo Potrero - Punta Ballena	**Moderate**
Punta Ballena - Punta del Este	**Medium**
Punta del Este - Arroyo Maldonado	**Medium**

Zoning and ranking of separate sectors of the coast also identified:

I) Human intervention considered irreversible:
- Sand extraction from dune fields and coastal strings
- Rectification of mouths of rivers and streams
- Afforestation
- Urbanization
- Engineering structures

and

II) Sensitive coastal areas:
- *Micropogonias furnieri* nursery and feeding zones;
- "Espartillar" or crab community area
- *Mytilus edulis platensis* exploitation area (mussel artisanal fishery)
- Flooding areas of wetlands
- Protected native woodlands.

In the aquatic zone, the diagnosis identified the degree of contamination of streams, rivers and bays that flow into the Río de la Plata:

Montevideo Bay
Río Santa Lucía
Arroyo Carrasco;
Arroyo Pando.

The real pollutant charge of these bodies will be analyzed during the present phase of the project.

From the analysis of the physical and chemical characteristics of the Río de la Plata and its tributaries, it was concluded that there is a need to:
- Strengthen and broaden the network of coastal monitoring stations;
- Determine the sediments' granulometry and pollutant loads (organic and inorganic);
- Establish the pollutant loads of tributary streams and rivers and link it to the industries in the basin or small catchment;
- Establish "Quality Standards", according to the sub-systems of the Río de la Plata (river, estuary, ocean) to control the evolution of the quality of the system.
- Study the coastal zone of the Santa Lucía River.

The physical characteristics diagnosed generated diverse charts. These charts were cross-linked to get a unique "Environmental Impact" chart. This chart was cross-linked to the socio-demographic diagnosis to select three pilot areas:

- Saline Front
- Santa Lucía (Punta Espinillo – Playa Pascual)
- Arroyo Carrasco – Arroyo Pando

In the Santa Lucía and Arroyo Carrasco – Arroyo Pando pilot areas, three working groups were established with the participation of ECOPLATA scientists and technicians, stakeholders, technicians of the local government and the coastguards, who defined the themes: (i) environment quality; (ii) physical planning and (iii) artisanal fisheries, with participation of local stakeholders. These working groups are part of two ECOPLATA teams, one for each pilot area, formed by representatives of each Institution of ECOPLATA. The working groups are now implementing studies of the water quality of the three streams of the pilot areas: Santa Lucía River and the Carrasco and Pando streams, evaluating the solid wastes in the beaches and developing a proposal for the use of the coastal area.

In the Saline Front, information needed to support fishing activities was gathered:

- Primary productivity estimates in the saline front;
- Physical and chemical factors and their influence in the reproduction of the croaker (*Micropogonias furnieri*);
- Detection throughout the year of the saline front, where reproduction of the croaker takes place, to support the artisanal fishermen;
- Identification of croaker populations for management of the fishery;
- Development of pressure indicators on the croaker fishery;
- Characterization of the fishing settlements in Pajas Blancas and Santa Catalina and their impact on the environment.

Analysis of these elements will help to establish management measures that will support the artisanal fishermen.

7. Regional Assessment Tables

Regional Assessment Table 1: Ecuador coast, *by R. Martinez Güingla.*

Table RA1.1. Ecuador coast: major coastal impacts/issues and critical thresholds.

Overview and qualitative ranking: Impact code and relative class of importance: 1 = minimum, 10 = maximum

Coastal impact/ issue	Local site/region	Critical threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category	References/ data source
Eutrophication	Esmeraldas, Chone rivers; Guayas River/ Gulf of Guayaquil	Oxygen level (DO >4.0 mg l^{-1}). Nutrients at background levels. Organic pollution = zero	• Esmeraldas: 1° N – 79°40'W. OD= 0.9 -6.7 mg.l^{-1} , BOD. N=10.35 µgat l^{-1} NO_3, 0.36 µgat l^{-1} NO_2; 2.35 µgat/l PO_4 Coliformes Fecales (1980)= 210-240000 NMP 100ml^{-1} • Chone River estuary: OD= 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..Total coliforms = 930 NMP 100ml^{-1} • Gulf of Guayaquil: Estero Salado: OD= 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. Total coliforms = 0-240 NMP 100ml^{-1}. Total coliformes >2400 NMP 100 ml^{-1} .	• Esmeraldas River7 • Chone River = 8 • Guayas River/ Gulf of Guayaquil = 6	PMRC (1993a,b); INOCAR (1998a,b)
Contamination	Esmeraldas, Chone River and Guayas River/Gulf of Guayaquil	• Pesticides = 0 • Heavy metals at background levels • Industrial discharges to Guayas River and Estero Salado reached 25,480 m^3 day $^{-1}$ (mean) in 1996.	• Esmeraldas: Cu = 0.1- 7.2 µg l^{-1} • Heptacloro= 0.005 ppb; DDT = 0.017 ppb • Heavy metals in sediments: 87.4 ppm Zn, 2.31 ppm Cd, 43.75 ppm Cu. Cu and Cd ingested in 250 g of oysters and mussels reach 6.5 mg l^{-1} y^{-1}, 0.384 mg l^{-1} respectively. • Guayas River: coliforms= 93,000 NMP 100ml^{-1}	• Esmeraldas=7 • Chone R. = 8 • Guayas River/ Guyaquil Gulf= 6	PMRC (1993a,b); INOCAR (1998a,b)
Sedimentation and erosion	Esmeraldas, Chone rivers and Guayas River/Gulf of Guayaquil	Lack of vegetation protecting the coastline. Between 1969 and 1996 mangrove area reduced by 23.6% in Gulf of Guayaquil In the Chone River estuary mangroves reduced by 80% from 1969 to 1991 (3973ha to 785 ha)	Esmeraldas River estuary: suspended solids up to 210 mg l^{-1} Chone River estuary: High sedimentation rates and bank erosion due to clear cutting of mangroves. Guayaquil Gulf: 0-3,039 mg l^{-1} (rainy season) and 0-4,132 mg l^{-1} (dry season) of suspended solids.	Esmeraldas: Erosion = 7 Chone River: Erosión = 8 Sedimentación = 9 Gulf of Guayaquil: Erosión = 7 Sedimentation = 8	PMRC (1993a,b); INOCAR (1998a)
Coastal fisheries a. Direct effects b. Indirect effects (sediment)	Esmeraldas, Chone rivers and Guayas River/ Gulf of Guayaquil	Decreasing fisheries due to illegal use of pro (net mesh of 1.5 cm.)		Esmeraldas = 7 Chone River = 7 Gulf of Guayaquil = 8	INOCAR (1998a)

Table RA1.2. Ecuador coast: DPSIR matrix characterising major catchment based drivers/pressures and a qualitative ranking of related state changes impacting the coastal zone versus catchment size class.

State change dimension: 3 = major; 2 = medium; 1 = minor; 0 = no impact; ? = insufficient information. Time scale: p = progressive; d = discrete (Area 1-3 refers to West Coast sub-regions - see chapters 1 and 2.3).

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		
Agriculture	▪ Increased surplus of inorganic nutrients ▪ Increase of organic pollutants ▪ Pesticides use ▪ Soil erosion ▪ Water extraction **Area 1**: Esmeraldas River **Area 2**: Chone River **Area 3**: Gulf ofGuayaquil	**?** **Area 3: 1**	**Area 1: 0** **Area 2: 2** **Area 3: 1**	**Area 1: 1** **Area 2: 2** **Area 3: 2**		▪ Local contamination ▪ Human Dimension: Health of communities. ▪ Sedimentation ▪ Human Impacts: Artisanal Fisheries	**p**
Forestry	▪ Deforestation. (mangrove, tropical bosque) ▪ Change in soil quality ▪ Soil erosion ▪ Habitat loss ▪ Ecosystem alteration	**Area 3: 2**	**Area 1: 1** **Area 2: 3** **Area 3: 3**	**Area 1: 2** **Area 2: 3** **Area 3: 3**		▪ Increase sediment load ▪ Human Impacts: Artisanal Fisheries	**p**
Navigation	▪ Waste effluent ▪ Dredging	**?**	**Area 3: 1**	**Area 3: 2**		▪ Increase sediment load ▪ Hydrodynamic changes. ▪ Human impacts: artisanal fisheries.	**d**
Urbanization	• Domestic and industrial waste increase • Increase surface run-off • Deforestation		**Area 1: 1** **Area 2: 2** **Area 3: 2**	**Area 1: 2** **Area 2: 2** **Area 3: 2**		• Contamination • Increase sediment loads.	**p**

Table RA.1.2 Ecuador coast continued

Damming	▪ Changes in hydrobiological cycle ▪ Decrease in sediment transport ▪ Loss of runoff		**Area 1: 0** **Area 2: 0** **Area 3: 1**	**Area 1: 0** **Area 2: 1** **Area 3: 2**		▪ Reduce in sediment transport ▪ Change in patterns of salinity ▪ Human impact:s: artisanal fisheries ▪ Change in stratification ▪ Human impacts: loss of amenity values.	d
Marine Aquaculture	• Increase load of organic material and nutrients • Water extraction • Destruction of mangrove		**Area 1: 2** **Area 2: 3** **Area 3: 2**	**Area 1: 2** **Area 2: 3** **Area 3: 3**		• Contamination ▪ Increased sediment loads	p
Fisheries	• Increase load of organic material and nutrients. • Harvesting	?	**Area 1: 2** **Area 2: 3** **Area 3: 2**	**Area 1: 2** **Area 2: 3** **Area 3: 3**		• Contamination ▪ Increase sediment loads ▪ Decreased catch	p
Oil and gas exploitation	▪Domestic waste ▪Perforation mud discharge ▪Gases and oil emission		**Area 1: 2** **Area 2: 1** **Area 3: 2**	**Area 1: 3** **Area 2: 1** **Area 3: 3**		• Contamination ▪ Destruction of habitat ▪ Narcotization and inhibition of reproduction in microorganisms	p
Industries	Increased load of heavy metals Increasde sediment load Increased load of hydrocarbons Water extraction and generation of heat	?	**Area 1: 1** **Area 2: 1** **Area 3: 2**	**Area 1: 2** **Area 2: 1** **Area 3: 2**		• Increased contamination by heavy metals • Increased sediment load • Reduction of fisheries • Threat to human health. • Reduction of amenity value	p

Table RA1.3. Ecuador coast: the link between coastal issues/impacts and land-based drivers.

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
			Category		
Erosion and sedimentation	Damming (Daule Peripa)	• **Gulf of Guayaquil:** Area inundated 27,000 ha; storage volume $6x10^9$ m^3. Natural flux 860 m^3/s, proposed flux 100 m^3 s^{-1}.	8	Increasing	CAAM (1996)
	Deforestation	• **Esmeraldas River** • **Chone River** • **Gulf of Guayaquil:** Annual mangrove deforestation rate of 1.3% in 1995 in relation to the mangrove cover in 1969	7 10 8	Increasing	INOCAR (1998a)
	Navigation	• **Gulf of Guayaquil:** Costal erosion due to wates from large ships	7	increasing	INOCAR (1998a)
Contamination	Agriculture	• **Gulf of Guayaquil:** Increasing use of fungicides to 1994 (1196 t)	7	Increasing	CAAM (1996)
	Mariculture	• **Esmeraldas River** • **Chone River:** Shrimp farms discharge of nutrients and organic matter estimated between 3.3 and $3.5x10^6$ m^3/day^{-1} • **Gulf of Guayaquil:** 72,978 ha occupied by shrimp farms	7 10 8	increasing	INOCAR (1998a); PMRC (1993b)
	Urbanization (Municipal waste)	• **Esmeraldas River** • **Chone River** • **Gulf of Guayaquil:** 30,160 t yr^{-1} of BOD5	9 9 8	increasing	PMRC(1993a)
	Industrial	• **Esmeraldas River** • **Chone River** • **Gulf of Guayaquil**	2 4 8	increasing	PMRC (1993a)
	Petroleum activities	• **Esmeraldas River** • **Chone River** • **Gulf of Guayaquil:** 200,000 gallons oil yr^{-1}	7 4 7	stable	CPPS (2000); PMRC (1993a)
	Minerals	• **Gulf of Guayaquil**	7	stable	PMRC (1993a)
Decreasing fishery	Fisheries	• **Gulf of Guayaquil:** Overfishing; 460 industrial boats in 1997	7	stable	INOCAR (1998a)

Table RA1.4. Ecuador coast: the link between coastal issues/impacts and land-based drivers.
Overview and qualitative ranking on local or sub regional or country scale: Category: 1 = low, 10 = high.

Coastal impacts/issues	Drivers	Sub regional (i.e. by country or considering open versus enclosed seas)		Trend-expectation	References/ data sources
		ECUADOR	**Category**		
Erosion and Sedimentation	Deforestation and impacts from El Niño	1,246 km of intense coastal erosion	8	increasing	CPPS (2000).
Contamination	Agriculture	Between 1994 and 1995 about 43,248 kg ha^{-1} of fertilizers were used per year and 1,495 t yr^{-1} of pesticides in coastl agriculture areas	7	stable	CPPS (2000)
	Aquaculture	147,427 t of shrimps produced in 1997	8	stable	INOCAR (1998a)
	Municipal Waste	128,400,000 m^3 yr^{-1} of domestic effluent: Organic load of 48,280 t yr^{-1}	8	increasing	CPPS (2000)
	Industries	In 1994 total industrial effluent was $55.2x10^6$ m^3	6	increasing	CPPS (2000)
	Oil production	1,350 m^3/year	6	stable	CPPS (2000)
Decrreasing fishery	Fisheries	Sardine and shrimp fleets operate in the Gulf of Guayaquil and along the Manabí and Esmeraldas rivers, respectively. The combined effect is an intensive exploitation resulting in significant biomass decrease from 1988 to 1997.	7	increasing	

Table RA1.6. Ecuador coast: scientific and/or management response to coastal impact/issues 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**
Gulf of Guayaquil	Monitoring of quality of water in the estuary of the Gulf (INOCAR)	Marine-coastal Environmental Education Program (PEAMCO). Handling of Coastal Resources Program (PMRC).		Priority area for National Policy on Biodiversity Ministry of the Environment. Marine-coastal Environmental Education Program(PEAMCO).		Strategic Regional Program for the Protection of the Coastal - Marine and Freshwater associated to the activities developed in land. CPPS- Integrated Management of the Coastal Area of the Southeast Pacific.
Chone River		Marine-coastal Environmental Education Program (PEAMCO). Handling of Coastal Resources Program (PMRC)		Marine-coastal Environmental Education Program(PEAMCO).		Strategic Regional Program for the Protection of the Coastal - Marine and Freshwater, associated with the activities developed inland. CPPS - Integrated Management of the Coastal Area of the Southeast Pacific.
Rio Esmeraldas		Marine-coastal Environmental Education Program (PEAMCO). Handling of Coastal Resources Program (PMRC)		Priority region for the application of the National Stategy and Policy on Biodiversity by the Ecuador. Ministry of the Environment.. Marine-coastal Environmental Education Program(PEAMCO).		Strategic Regional Program -for the Protection of the Coastal - Marine and Freshwater associated to the activities developed in land. CPPS - Integrated Management of the Coastal Area (MIZC) of the South-east Pacific.

Note: The criteria used here only consider responses to problems in the river affecting the coastal zone.

Table RA1.7. Ecuador coast: hot spots of land-based coastal impact and gaps in understanding, and a preliminary 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		Hot spot regional scale	
	Key issue, trend and gaps	Scientific approach	Key issue, trend and gaps	Scientific approach	Key issue, trend and gaps	Scientific approach
Esmeraldas River **Chone River** **Gulf of Guayaquil**	• Temporal and spatial variability of physico-chemical and biological properties. • Rates of erosion. • Promote biodiversity conservation.	• Biogeochemical studyes and of the trophic food chain • Permanent water quality monitoring program • Monitoring program of heavy metals and hydrocarbons in bivalves • Water circulation study and its interaction with ocean circulation • Sediment load analysis, soil composition, relief and precipitation • Creation of a taxonomic centre for the Gulf of Guayaquil species		• Investigation and handling of the contamination in the Gulf of Guayaquil.		

References to tables:

PMRC 1993a. Estudio de la calidad del agua costera ecuatoriana. Programa de Manejo de Recursos Costeros PMRC. Ministerio de Agricultura y Ganaderia, Guayaquil. { HYPERLINK http://www.pmrc.org.ec }, { HYPERLINK "mailto:pmrc@gye.satnet.net" }

PMRC (1993b)a. Plan de Manejo de la ZEM Bahía – San Vicente - Canoa. Programa de Manejo de Recursos Costeros., Ministerio de Agricultura y Ganderia, Gayaquil, 43 pages.

INOCAR (1998a) Informe Técnico del Instituto Oceanográfico de la Armada.(INOCAR). Proyecto Autoridad Portuaria de Guayaquil (APG), Guayaquil, 286 pages.

INOCAR (1998b) Acta Oceanográfica del Pacífico, Vol. 9 No.1. 1998. ISSN No.1390 129X. Instituto Oceanográfico de la Armada. (INOCAR). E-mail: { HYPERLINK mailto:inocar@inocar.mil.ec }.

CAAM (1996) Sistemas Biofísicos en el Gulf of Guayaquil. Comisión Asesora Ambiental de la Presidencia de la República, 97 pages.

CPPS (2000) Informe Comisión Permanente del Pacífico Sur (CPPS). Secretaría General. Quito, Ecuador. Estado del medio ambiente marino y costero del Pacífico Sudeste, 40 pages.

CPPS (1998) Informe Final Comisión Permanente del Pacífico Sur (CPPS). Pages 71 – 79 in: Segunda reunión del grupo de trabajo de evaluación y ordenación Pesquera en el Pacífico Sudeste y de especies transzonales y altamente migratorias. Callao-Perú 27 al 30 de Abril de 1998. { HYPERLINK mailto:cppsmaster@hotmail.com } , { HYPERLINK http://www.cpps.org }

Regional Assessment Table 2: Magdalena River, Colombia, *by J.D. Restrepo*

Table RA.2.1. Magdalena River coastal zone, Colombia: Major coastal impacts/issues and critical thresholds in the– Overview and qualitative ranking. Impact code and relative class of importance: 1 = minimum, 10 = maximum

Coastal impact/issue	Local site/region	Critical threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category	References/ data source
Eutrophication and pollution	Magdalena River lagoon-delta complex/ Caribbean Coast of Colombia	Biological communities near the delta show signs of mortality. Declining yield trend in fish resources, with total catches from more than 63700 tons yr^{-1} in 1978 to 7850 tons yr^{-1} in 1998.	No distance – system functions already affected by excess nutrient supply; (Drainage basin management - regulation of discharges and effluents - needed)	9	INVEMAR (1997); Beltran *et al.* (2000); INVEMAR (2000)
Water discharge and sediment load diversion	Channelization of the lower Magdalena River and partial diversion of the river flow	Observed coral reef mortality (El Rosario Island-Caribbean Coast of Colombia)	Currently no distance but potential for mitigation; (diversion of river discharge will allow recovery of coral reef ecosystems)	10	Vernette (1985); Restrepo and Kjerfve (2000a)
Hyper-salinization of mangrove soils	Magdalena River/ lagoon-delta complex/ Ciénaga Grande de Santa Marta	Mortality of mangrove forest over 39-year period (272 km^2)	Distance down to zero but slightly growing; re-diversion of fresh water into the lagoon-delta complex has allowed partial recovery of mangrove	8	Cardona and Botero (1998)
Erosion (Coastal Sediment Budget)	Magdalena River delta	Observed coastal erosion of 17 m yr^{-1} due to the construction of jetties in the Magdalena mouth.	Apparently no distance to the critical need of sediment accretion for coastal stability	8	Correa (1996); Martínez (1993)

Table RA.2.2. Magdalena River, Colombia: DPSIR matrix characterizing major catchment based drivers/pressures and a qualitative ranking of related state changes having impact on the coastal zone versus catchment size class.

State change dimension: major; medium; minor; no impact;? = insufficient information
Time scale: p = progressive (continuos); d = direct (spontaneous)

Driver	Pressures	State change (qualitative index)	Impact on the coastal system	Time scale
		MAGDALENA CATCHMENT (medium size catchment)		
Agriculture	• Soil conservation. • Poor agricultural practices.	**medium**	Lost of coastal ecosystems due to accelerating upland erosion rates and eutrophication.	**p**
De-forestation	Suspended sediment loads are now an order of magnitude greater than 60 years ago.	**major**	Increased suspended sediment loads on coastal ecosystems – water quality/turbidity.	**p**
Navigation and Diversion	• Channel construction and dredging in the lower Magdalena River.	**major**	• Discharge of suspended sediment load into coastal ecosystems.	**p**
	• Jetty construction in the Magadalena delta mouth.	?	• Imbalance in the coastal sediment budget.	**p**
Urbanization (point-source effluents)	• Toxic contaminants (chlorinated and phosphorylated organic compounds). • Higher levels of nutrients. • Inputs of untreated waters. • Active elements, metals, and pesticides are known to have increased several-fold since the 1970s.	**medium to major**	Contamination and eutrophication; Fish, invertebrate and avian bio-diversity and biomass are much lower than 10 years ago.	**p**

Table RA.2.3. Magdalena River, Colombia: the link between coastal issues/impacts and land based drivers.
Overview and qualitative ranking on local or catchment scale: ⇑ increasing, = stable

Coastal impacts/issues	Driver	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ Datasources
		River	Category (1 low – 10 high)		
Eutrophication and pollution	Agriculture	Magdalena River	8	⇑	Colciencias-Fen (1989)
	Deforestation	Magdalena River	10	⇑	Colciencias-Fen (1989)
	Urbanization (Point Source Effluents)	Magdalena River	10	⇑	HIMAT-INGEOMINA (1991); Cardona and Botero (1998)
Water discharge and sediment load diversion	Diversion	Magdalena River	10	=	Vernette (1985); Restrepo and Kjerfve (2000a)
Erosion (coastal sediment budget)	Navigation	Magdalena River delta	8	⇑	Correa (1991); Martínez (1993)
Hyper-salinization of mangrove soils	Diversion	Magdalena lagoon-delta complex	9	=	Cardona and Botero (1998)

Table RA.2.6. Magdalena River, Colombia: scientific and/or management response to coastal impact/issues on catchment, sub regional and regional scale.
n.a. = not applicable

River catchment	RESPONSE catchment scale		RESPONSE Sub regional/ Country Scale		RESPONSE Regional scale	
River	Scientific	Management	Scientific	Management	Scientific	Management
Magdalena River	Water discharge data (1940-2000). Sediment load data (1972-2000) Source: IDEAM (Colombia) Heavy metals 1980-1990 Source:HIMAT-INGEOM 1999; Bustos (1999).	Quality criteria for waste water in the tributary basins. Source: Ministry of the environment,. Colombia.	In general: Monitoring programs through hydrological and geological institutes. Source: IDEAM HIMAT- INGEOMIN		n.a.	n.a

Table RA.2.7. Magdalena River, Colombia: 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)

n.a. = not applicable

River catchment	Hot spot - catchment scale		Hot spot Sub-regional/ country scale		Hot spot regional scale	
River	Key issue, trend and gaps	Scientific approach	Key issue, Trend and gaps	Scientific approach	n.a.	n.a.
Magdalena River and tributaries			*Magdalena Delta*	*Magdalena Delta*		
	Temporal variability of physical water properties (nutrients and pollutants)	Statistical analysis of time series	Fluvial fluxes into the Caribbean Sea	Analysis of fluvial fluxes to the Caribbean Sea and their interannual variability		
	ENSO-related variability	Relationships between time series variability and the ENSO cycle				
	Geology and landforms	Collection, synthesis and analysis of the information	Coastal dynamics analysis and recent delta front evolution	Temporal analysis		
	Mechanical erosion rates	Analysis of physical properties in the basin (precipitation, soil composition, relief, tectonics, water and sediment discharges)	Temporal variability of physical water properties in the river mouth (nutrients and pollutants)	Statistical analysis of time series.		
	Land-use and land use change in the catchment	Available GIS data bases and satellite image processing	State of the coastal ecosystems adjacent to the Magdalena River mouth and its channel, El Dique			
	Population trend in the basins and socio economic developments	Demographic analysis on population data from the drainage basin for the past five decades (needs inclusion of human development indicators)				

Regional Assessment Table 1.3. North-eastern Brazil tectonically passive coast, by *R. V. Marins, G.S.S. Freire, L.P. Maia and L.D. Lacerda*

Table RA3.1. North-eastern Brazil coastal zone: major coastal impacts/issues and critical thresholds.
Overview and qualitative ranking. Impact code and relative class of importance: 1 = minimum, 10 = maximum

Coastal impact/issue	Local site/region	Critical threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category	References/ data source
Erosion (coastal geomorphology)	Jaguaribe River estuary at Fortins	For coastal stability a sustained delivery of 0.5-2.0x10^6 t yr^{-1} of sediments is necessary	Present sediment delivery is from 10-50% of the critical load. Strong seasonal variation occurs.	10	Maia (1992); Valentini (1996); Morais and Pinheiro (1999)
Sediment depletion/ sorting	Jaguaribe River delta flood plains, mangroves and mud flats; Pacoti River estuary	Supply of about 1mm.yr^{-1} of fine sediments to keep mangrove and mud-flat communities	Not known, needs measurements of sedimentation rates of local mangroves. However, erosion and siltation can be seen in many mangrove areas.	7	Patchineelan & Smoak (1999); Ellison (1994)
Nutrient depletion	Estuary and adjacent coastal zone of the Jaguaribe River mouth	Chlorophyll *a* concentrations ranges from 0.05 to 0.5 mg.m^{-3}. Primary production of about 0.02 to 0.2 gC.m^{-2} d^{-1}, characterises a typical oligotrophic water mass. NO_3 and PO_4 concentrations at the surface are about 0.2 and 0.25 µM.	Regional oligotrophy may increase, but no site-specific historical trend study is available for the area.	7	Ekau and Knoppers (1999); Medeiros *et al.* (1999)
Altering food webs and trophic status	Estuaries of metropolitan rivers of Fortaleza, Cocó River and Ceará River	Existing ecological communities, presently very poorly known	Totally unknown but algal blooms occur typically during the rainy season.	6	Soares Filho and Alves (1996)
Increasing marine sand supply	Jaguaribe and Pacoti river estuaries	Benthic and mangrove community siltation. Critical threshold >100 t.yr^{-1}	Unknown, indication of occurrence due to dying mangroves.	6	Freire (1989)
Eutrophication	Cocó and Ceará rivers and adjacent beaches	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}	Estuaries of affected rivers present dissolved oxygen 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}.	6	Marins *et al.* (2001); Mavignier (1992); Almeida *et al.* (2000)

Table RA3.2. NE Brazil: DPSIR matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related state changes impacting the coastal zone versus catchment size class.

State change dimension: major; medium; minor; no impact; ? = insufficient information
Time scale: p = progressive (continuos); d = direct (spontaneous)

Driver	Pressures	State change (qualitative index)	State change (qualitative index)	Impact on the coastal system	Time scale
		Small size basins	Medium size basins		
Damming	Sediment trapping Altering nutrient balance* Altering water balance Decrease of flow transport capacity	**major**	**(major)**	• Sediment depletion/sorting • Depletion of nutrients* • Stable water flux • Erosion • Increasing marine sand supply	**p**
Agriculture	Decrease of water volume and flow transport capacity due to water withdraw for irrigation Facilitating soil erosion Pollutant emission Altering nutrient fluxes	**medium**	**(medium)**	• Sediment depletion • Enrichment of nutrients* • Stable water flux	**p**
Sand mining	Sediment remobilization Sediment withdraw Altering river morphology (banks and bottom)	**medium**	**(medium)**	• Sediment depletion • Sediment sorting • Altering flow patterns • Altering ecological conditions	**p**
Aquaculture	Changes in hydrochemistry Increasing nutrient load	**medium**	**(minor)**	• Altering food webs and trophic status	**d/p**
Urbanization	Pollutant emission Altering nutrient fluxes	**major**	**(no impact)**	• Altering food webs and trophic status	**p**
Deforestation	Facilitating soil erosion Altering sediment balance	**medium**	**(minor)**		**p**

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

Table RA3.3. NE Brazil: the link between coastal issues/impacts and land-based drivers.

Overview and qualitative ranking on local or catchment scale: ⇑ - increasing, = stable

Coastal impact/ issues	Drivers	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ data sources
		River	**Category (1 low – 10 high)**		
Erosion	Damming	Jaguaribe	10	⇑	Morais and Pinheiro (1999); Maia (1992)
Sediment depletion and sorting	Damming	Jaguaribe	6	⇑	Morais and Pinheiro (1999); Maia (1992)
	Sand mining	Jaguaribe Pacoti	4	⇒	Freire (1989)
Nutrient depletion	Damming	Jaguaribe	9	⇑	Medeiros *et al.* (1999)
Altering food webs and trophic status	Damming	Jaguaribe	2	⇑	Soares Filho and Alves (1996)
Eutrophication	Agriculture	Jaguaribe Acarau	3	⇑	Marins *et al.* (2001)
	Urbanisation	Ceará Cocó	8 10	⇑ ⇑	Mavignier (1992); Ameida *et al.* (1999)
	Aquaculture	Jaguaribe			
	Industrialisation	Ceará	3	⇑	Marins *et al.* (2001)
Sedimentation due to increasing marine sand supply	Agriculture	Jaguaribe Pacoti	6 3	⇑ ⇒	Morais and Pinheiro (1999); Freire (1989)
	Damming	Jaguaribe	8	⇑	Morais and Pinheiro (1999)

Table RA3.6. NE Brazil: scientific and/or management response to coastal impact/issues 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
Jaguaribe River	11 pluviometric stations along 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 born sediments (Marins *et al.* 2001) Water balance model developed but needs testing for robustness (SRH 1998). Survey of soil, geology and ground water resources (CPRM 1996).	ICZM at national (Brazil) level. Local catchment-under-management plan associated with dam development, water diversion and agriculture. PRODETUR program.	Survey of major drivers and impacts at 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).	ICZM plan in function. PRODETUR-CE Tourism development program PROURB-CE Urban development plan.	n.a.	n.a.
Cocó River	Monitoring of water quality including trace metals and Hg (Almeida *et al.* (2000).	Creation of an Ecological Park preserving the mangroves, by Fortaleza Municipality. Monitoring of water flow and quality by SEMACE. PROURB-CE Program.				
Ceará River	Monitoring of water quality including trace metals and Hg (Marins *et al.* 2001).	Maranguapinho Ecological Corridor, a joint preservation and reforestation program by the four municipalities of the basin. PROURB-CE Program.				
Pacoti River	Monitoring of water quality including trace metals and Hg (Lacerda et 2001). Monitoring of sediment flux, nutrients and marine born sediments (Freire (1989).	Creation of an Environmental Protection Area, including the mangrove forests of the river PROURB-CE Program.				

Regional Assessment Table 4: South-eastern Brazilian coast (Rio de Janeiro) *by E.D. Bidone*

Table RA4.1. South-eastern Brazilian coast (Rio de Janeiro): major coastal impacts/issues and critical thresholds in Latin American Coastal Zones.
Overview and qualitative ranking: * Impact category: 0= none; 10 = maximum

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	Rivers of small watersheds (with slopes changing drastically within few kilometers from high relief – 1,000m to 1,500m – to coastal plains) along the south-eastern and southern Brazilian coast, draining into bays and lagoons	Ocurrence of anoxia or low oxygen in the rivers in lowlands of watersheds, estuary zones, lagoons and bays. Nutrient concentration levels (in mg l^{-1} from n=197 samples) in rivers at the threshold: $N\text{-}NO_3$= 0.42 (0.11-0.76); $N\text{-}NH_4$= 2.52 (1.49-4.0); $P\text{-}PO_4$= 0.78 (0.34-1.30)	The nutrient concentration levels are at or higher than threshold	10	Bidone *et al.* (1999); Knoppers *et al.* (1999); Bidone (2000)
Erosion	Paraíba do Sul River delta	Not known	Suspended load of less than 60,000 t yr^{-1}	8	Salomão *et al.* (2001)
Contamination (nutrients N-P-C, microbiological. HPA's. heavy metals etc.)	Rio de Janeiro metropolittan area	• Nutrients • Microbiological: <500 colis NMP 100 ml^{-1} • Heavy metals. HPA's and others toxic contaminants: WHO, USEPA etc. standards.	• The nutrient concentration levels are at or higher than threshold • Microbiological: at the or higher than threshold • Toxics: at or higher than threshold	10	Bidone *et al.* (1999); Knoppers *et al.* (1999)
Sedimentation (in lowland sectors of the watersheds and estuarine zones. lagoons and bays. Overall in urban areas)	Rio de Janeiro metropolitan area	• Large rainfall or storms (~ 80mm or more). • Suspended solids concentrations <100 mg l^{-1}. • Sedimentation rate in lagoons ~0.1cm yr^{-1}.	Potential events occurring in summer/rainy season (December-March). Catastrophic effects on slopes/upper sectors of the watersheds in urban areas) (emphasis Rio de Janeiro city). In the rainy season concentration levels of SS can be higher than 1000 mg l^{-1}.	9	Knoppers *et al.* (1999);, Esteves and Lacerda (2000)

Table RA4.2. SE Brazil: DPSIR matrix characterizing major catchment based drivers/pressures and a qualitative ranking of related state changes impacting the coastal zone versus catchment size class.

State change dimension: 3 = major; 2 = medium; 1 = minor; 0 = 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	Domestic waste		**2**		**3**	• Eutrophication • Contamination	**p**
Industrialization	Industrial waste		**3**		**3**	• Contamination	**p**
Deforestation	Sediment budget alteration Soil exposition		**3**		**3**	• Sedimentation/ sediment accretion • Catastrophic slope erosion in urban areas	**p/d**

Table RA4.3. SE Brazil: the link between coastal issues/impacts and land based drivers in Latin American coastal zones.
Overview and qualitative ranking on local or catchment scale:

Coastal impact/issues	Drivers	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ data sources
		Rio de Janeiro metropolitan area	Category		
Eutrophication	Urbanization (diffuse source of domestic effluents)	Nutrient concentration levels in rivers and anoxia. at the or higher than threshold	10	Increasing	Bidone *et al.* (1999); Bidone (2000); Knoppers *et al.* (1999)
Contamination	Urbanization (domestic effluents) and industrialization (industrial effluents)	N-P-C, microbiological, HPA's. heavy metals etc.)	10	Increasing	Bidone *et al.* (1999); Bidone (2000); Knoppers *et al.* (1999)
Erosion	Deforestation	Catastrophic effects on slopes/upper sectors of the watersheds in urban areas in rainy station Sedimentation/Sediment accretion in bays. coastal lagoons and estuary zones	10 10	Increasing Increasing	Bidone *et al.* (1999), Bidone (2000), Knoppers *et al.* (1999)

Regional Assessment Table 5: Patos Lagoon basin and estuary (southern Brazil), *by U. Seeliger*

Table RA5.1. Patos Lagoon and estuary: major coastal impacts/issues and critical thresholds; overview and qualitative ranking.

Impact code and relative class of importance: 1 = minimum, 10 = maximum

Coastal impact/issue	Local site/region	Critical threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category	References/ data source
Eutrophication	Patos Lagoon estuary	a. Chlorophyll *a* b. Sediment and water column contamination by phosphorus in enclosed bays c. Point source ammonium contamination of water column by domestic/industrial waste	a. 0.6 – 76.8 µg Chl-a l^{-1} b. 0.73-8.55 mg kg^{-1} P-Total; up to 12 µM P-PO_4 in the water column c. Up to 45 µM N-NH_4 in the water column	7	b. Baisch 1997; Baumgarten *et al.* 1995 c. Almeida *et al.* 1993
Pollution	Patos Lagoon estuary	a. Point source Pb and Cd contamination of water column by harbor activities. a. Point source phenol contamination of water column by harbor activities. a. Nonpoint source pollution of water column by oil.	a. Pb up to 20 µg l^{-1}; Cd up to 6.5 µg l^{-1} b. Phenol up to 30 µg l^{-1} c. Oil up to 30mg l^{-1}	5	a/b/c. Niencheski and Baumgarten 1997
Sedimentation	Patos Lagoon estuary	a.Natural sediment removal to coastal nearshore waters.	a. Annual sediment removal of about 2,500,000 m^3	3	a. Calliari 1980
Dredging	Patos Lagoon estuary	a. Dredge material disposal in nearshore waters.	a. Over 60 dredgings between 1980-95; means per location in the estuary ranged 1,200 to 1,800,000 $m^{3.}$	5	SUPRG 1996
Marsh losses	Patos Lagoon estuary	a. Filling of intertidal and shallow waters for urban development.	a. 10% losses of the total salt marsh area of lower estuary.	5	Seeliger and Costa 1997
Water use	Patos Lagoon watershed	a.Increment in water demand for domestic and industrial use over the last 35 years. b.Increment in water demand for irrigated rice cultivation over the last 35 years.	a. Increase of 0.46- 0.76 km^3 yr^{-1} b. Increase of 3.89 to 9.31 km^3 yr^{-1}	7	Seeliger and Costa 1997
Pesticides	Patos-Mirim complex watershed	a. Excessive application of pesticides over vast areas of agricultural lands (e.g. 890,000 ha of rice plantations).	a. Not quantified	5	Seeliger and Costa 1997

Table RA5.1 continued

Toxic algae	Patos Lagoon and coastal nearshore	a. Blooms of *Gyrodinium aureolum*, *Dinophysis acuminata* and recent introduction of *Alexandrium tamarense* in the coastal nearshore. b. Blooms of *Mycrocistis aeruginosa* in limnic waters and in the estuary.	a. *Gyrodinium aureolum* = up to 200 cells l^{-1}; *Alexandrium tamarense* = up to 10^6 cells l^{-1}, 180 cysts cm^{-3} of sediment. b. Up to 9,000 μg Chl-a l^{-1}; microcystin concentration up to 1.1 μg mg^{-1} dry weight.	5	a. Odebrecht *et al.* 1995; Persich 2001 b. Odebrecht *et al.* 1987; Yunes *et al.* 1996.
Biodiversity loss and community changes	Patos Lagoon and coastal nearshore	a. Changes in zooplankton community structure; anatomical anomalies in some species. b. Overexploited *Netuma* spp stocks. c. Decline of up to 90% in abundance of viviparous sharks (*Rhinobathos horkelii; Galeorhinus galeus*).		5	a. Montu and Gloeden 1982 b. Haimovici *et al.* 1997
Circulation changes	Patos Lagoon and coastal nearshore	a. Changes in plankton community structure. b. Variability in shrimp production. c. Salt water balance.		?	a. Muelbert & Weiss 1991; Sinque and Muelbert, 1997. b. Castelo & Möller 1978. c. Costa *et al.*, 1988; Fernandes and Niencheski 1998

Table RA5.2. Patos Lagoon and estuary: DPSIR matrix characterizing major catchment based drivers/pressures and a qualitative ranking of related state changes impacting the coastal zone versus catchment size class.

State change dimension: 3 = major; 2 = medium; 1 = minor; 0 = 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		
Navigation	• Dredging • Increase in runoff • Increase in sediment transport • Waste effluent • Introduction of exotic species	**?**	**1**		**2**	• Sedimentation • Pollution • Changes in communities	**p**
Urbanization and industry	• Increase in water and sediment P e N levels • Increase in sediment heavy metal levels	**1**	**2**		**3**	• Eutrophication • Pollution • Changes in communities	**p**
Agriculture	• Freshwater diversion • Increase in agrotoxins • Increase in sediment transport • Land fill and canalization	**1**	**2**		**2**	• Salinization • Pollution • Sedimentation • Marshland losses • Shallow waters filling	**p**
Fisheries	• Harvesting	**0/1**	**1**		**3**	• Losses in biodiversity • Estuarine habitat destruction • Death of marine mammals	**p**
ENSO	• El Niño (increase in rainfall, freshwater input, and suspended matter to the estuary) • El Niño (increase in nearshore phytoplankton production; estuarine fish community changes) • La Niña (decrease in rainfall, freshwater input and suspended matter to the estuary; salinization)	**3**	**3**		**3**	• Eutrophication • Salinization • Communities changes • Changes in productivity • Decrease in pink shrimp recruitment into the estuary (El Niño) • Recruitment variability of fishery resources (ENSO)	**d**

Table RA5.6. Patos Lagoon and estuary: scientific and/or management response to coastal impact/issues on catchment, sub regional and regional scale.

River catchment	**RESPONSE catchment scale**		**RESPONSE Sub regional/ country scale**		**RESPONSE Regional scale**	
River	Scientific	Management	Scientific	Management	Scientific	Management
Patos Lagoon estuary	(1) Over 500 scientific papers published on structural/functional aspects of Patos Lagoon estuary and adjacent coast. (2) Monitoring of physico-chemical parameters. (3) Establishment of Brazilian LTER site.	(1) Regulation of estuarine fisheries. (2) Regulation of water use in estuary of the Rio Grande. (3) Estuary Management Program supported by Interamerican Bank for Development.				

Table RA5.7. Patos Lagoon and estuary: Hot spots of land based coastal impact and gaps in understanding, and 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**		**Hot spot regional scale**	
River	Key issue, trend and gaps	Scientific approach	Key issue, trend and gaps	Scientific approach	Key issue, trend and gaps	Scientific approach
Patos Lagoon estuary and nearshore zone	Changes in biodiversity and occurrence of harmful algae	Animal and plant community monitoring; Experimental evaluation of sensitivity of organisms				
Patos Lagoon estuary	ENSO-induced changes of hydrology	Biological and physical studies based on long-term ecological researches				
Patos Lagoon estuary and nearshore	Impact of UV radiation increases	Experimental evaluation of organisms sensitivity; UV radiation monitoring and public awareness				
Patos Lagoon estuary	Habitat degradation of shallow waters and marshes	Remote sensing; monitoring				

Regional Assessment Table 6: Rio de La Plata, *by J. Cantera*

Table RA6.1: Major coastal impacts/issues and critical thresholds in Rio de la Plata area.

Overview and qualitative ranking.
Impact code and relative class of importance: 1 = minimum, 10 = maximum

Coastal impact/issue	Local site/region	Critical threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category	References/ data source
Erosion	Uruguayan coast	Dune destruction Loss of beaches	Unknown	6	ECOPLATA (1999)
Eutrophication (habitat loss)	Uruguay River Montevideo Bay Samboronbon Bay Buenos Aires coast Paraná River	Frequent algal blooms Wetlands destroyed Low oxygen in estuaries and lagoons Nitrogen concentration very high Fish mortality near beaches	Increased nutrient load is changing the ecosystem. Fresh water inflow is increasing in last years	9	Kurucz *et al.* (1997)
Coastal pollution	Parana River Uruguay River Montevideo Bay Tributaries of the Uruguayan and Buenos Aires coast (Riachuelo, Santa Lucia, Carrasco, Reconquista rivers)	Urban and agricultural wastes inputs uncontrolled and sewage discharges without treatments	Pollutants reaching threshold values. Heavy metals (mg kg^{-1}). Cr = 0.75-57; Pb = 0.7-141; Cd = 4-231; Cu =109 Pesticides 10-250 ng l^{-1} (DDT) High heavy metal levels in biota (g kg^{-1}): Hg = 11-254; Pb = 34; Cd = 0.5-3.7; Hydrocarbons = 0.1-50. Some pollutants in fishes.	10	Moyano *et al.* (1992, 1993); AGOSBA-OSN-SIHN (1994) Moyano (1991); CARU (1993); ECOPLATA (1999) Marcovecchio and Moreno (1992, 1993) Segneur *et al.* (1991)
Biodiversity changes	Location not specified	Species lost. High mammal and fish mortality.	Unknown	8	
Fisheries decreasing	Maritime Front Inner part of Rio de la Plata	Stocks over-exploited. High pollution or marine transport in spawning and nursery areas.	Very near; fisheries decrease drastic during recent years.	8	Graña and Pineiro (1997); Acuña *et al.* (1997); INAPE reports; INIDEP reports
Algal blooms	Montevideo area Maritime Front	Several times a year there are cyanobacteria and dinoflgellate blooms.			Mendez *et al.* (1993, 1994, 1996)

Table RA6.1 continued

Increase in introduction of exotic species	Location not specified	*Vibrio chloreae* Bivalves Other poorly-known groups		6	GEF project text
High sedimentation	Parana River Uruguay River Turbidity-saline front	$79x10^6$ t yr^{-1} $11x10^6$ t yr^{-1} Maximum sedimentation zone. Sedimentation affects navigation channels necessitating dredging.		10	Lopez (1997)
Changes in land and aquatic uses	Location not specified	Wetlands destroyed to exploit areas for agriculture.		7	GEF project text

Table RA6.2 Rio de la Plata: DPSIR matrix characterizing major catchment based drivers/pressures and a qualitative ranking of related state changes impacting on the coastal zone *versus* catchment size class.

State change dimensions: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		
Agriculture	Waste/nutrient (excess fertilizer) effluent Increasing sediment transport Water extraction Excess of biocides	**medium** **major** **minor** **minor**	**medium** **major** **minor** **minor**		**major** **major** **medium** **minor**	Eutrophication; Contamination; Siltation Algae blooms Anoxia Decreasing light for photosynthesis Decreasing ecological flow Contamination	**p** **p** **p** **p** **p** **p** **d** **p**
Damming	Nutrient and sediment sequestration Changing hydrological cycle	**?**	**?**		**medium**	Coastal erosion; Nutrient depletion; Decreasing ecological flow	**d**
Deforestation	Sediment budget alteration Organic matter inputs	**minor** **minor**	**major** **medium**		**major** **major**	Siltation; Sediment accretion Decreasing oxygen concentration	**p**
Navigation	Waste effluent Dredging Channels	**medium** **major** **medium**	**major** **major** **minor**		**No impact** **No impact** **No impact**	Contamination; siltation Re-suspension of sediments Interfering life cycles of fishes	**d** **d** **p**
Urbanization (point source effluents)	Domestic pollution Industrial pollution	**medium** **major**	**major** **major**		**major** **major**	Decreasing of oxygen concentration; Coliform contamination Heavy metals, hydrocarbon pollution	**d/p** **d** **p** **d**
Fisheries	Over-exploitation	**major**	**medium**	**minor**	**minor**	Decreasing biodiversity and stocks	**p**

Table RA6.3. Rio de la Plata basin: the link between coastal issues/impacts and land based drivers.

Impact category: 1 = low; 10 = high

Coastal impact/issues	Drivers	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ data sources
			Category		
Erosion	Damming	80% runoff reduction	9	Stable	
	Deforestation	TSS concentration	9	Increasing	
	Diversion	?….	6		
Eutrophication	Agriculture	Residual nutrient reduction	9	Increasing	
	Municipal waste	Local urbanisation areas increasing	10	Increasing	
Water pollution	Municipal and industrial waste	Industrial areas established in the river border	10	Increasing	

Table RA6.6. Rio de la Plata basin: scientific and/or management response to coastal impact/issues on catchment, sub regional and regional scale.

n.a. = not applicable

River catchment	Response catchment scale		Response Sub regional/ Country scale		Response Regional scale	
	Scientific	Management	Scientific	Management		
Rio Uruguay	CARU Studies 1997,1998 Data Source: INAPE, INIDEP, SOHMA	Administrative Commission of the Uruguay River (CARU) Programa de calidad de aguas en el Río Uruguay SOHMA, DINAMA, IMM	CARU studies 1997,1998. Source: INAPE, INIDEP, OHMA Medicion de caudales Rios Parana y Uruguay		n.a.	n.a
Rio Parana	Environmental stress of Parana River. Flood plain interactions in the Parana River.	?				
Río de la Plata	ECOPLATA Project Gestión Integrada de la zona costera Uruguaya del Río de la Plata	DINAMA, IMM INAPE University de la República	GEF: Environmental Protection of Río de la Plata Program. Transboundary Diagnostic Analysis. Monitoring GOOS. Mareographic Web. Algal blooms. Monitoring of *Vibrio cholerae* Meso-scale atmospheric modelling.	Plan de Investigación Pesquera Strategic Action Plan of Administrative Commission of the Rio de la Plata and Technical Commission of the Maritime Front 2000-2004		
Uruguayan coast and small streams	ECOPLATA Project	IMM MVOTMA		ECOPLATA Project Gestión Integrada de la zona costera Uruguaya del Río de la Plata		
Argentinian coast and small streams	Monitoring of Sanboronbon Bay	Environmental management of the Cuencas of Matanza and Riachuelo.	National Environmental System	Atlas of areas of coastal zone sensitivity in Argentina		

Table RA6.7. Rio de la Plata basin: hot spots of land-based coastal impact and gaps in understanding, and a preliminary 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		Hot spot Regional scale	
	Key issue, trend and gaps	**Scientific approach**	**Key issue, trend and gaps**	**Scientific approach**	**Key issue, trend and gaps**	**Scientific approach**
Rio de la Plata			Water circulation	Model applications *In-situ* measurements Remote sensing		
			Water pollution Sediment pollution Pollution from hazardous substances	Pollution in Uruguayan Coast Pollution in Argentinean coast Campaigns to study common zone		
			River and marine biodiversity Exotic species Red tides	Binational strategy for aquatic and marine biodiversity		
			Population biology of fisheries resources	Biology studies of main commercial species		
			Pollutants accumulation in trophic chain	Studies of pollutants in high levels of trophic chain		
			Social situation	Social diagnostics		
			Legal situation	Study of existent legal instruments		
			Economic situation	Study of existing economic instruments		

Regional Assessment Table 7: Argentine (tectonically passive) coast *by P.J. Depetris*

Table RA7.1 Argentine coast: major coastal impacts/issues and critical thresholds, overview and qualitative ranking.

Impact code and relative class of importance: 1 = minimum, 10 = maximum.

Coastal impact/ issue	Local site/region	Critical threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category	References/ data source
Erosion (coastal geomorphology)	SW of Buenos Aires Province, Mar del Plata, Patagonian coastline	Unknown. Presently, there is a significant retreat of the coastline and strong evidence of erosion.	Current sediment delivery is probably 70-80% of the critical load.	7	Cionchi *et al.* (1993); López and Marcomini (1998); Violante *et al.* (2001); Isla (1997)
Sediment depletion/sorting	Northern Patagonian rivers (Colorado, Negro, and Neuquén)	Several dams affect each basin, retaining sediment and nutrients. Critical bedload is possibly ca. 10^5 t yr^{-1}.	Still undetermined. Probably the net effect of damming is a reduction of 20-40% of sediment supply.	6	Depetris *et al.* (in prep.); Isla and Bujalevsky (1995); Pasquini *et al.* (1997)
Nutrient depletion or eutrophication	Estuaries of northern Patagonia rivers (Colorado, Negro, and Neuquén)	Current total POC flux is ca. 4.1×10^4 t yr^{-1}; total PN flux is ca. 1.1×10^4 t yr^{-1}; total PS flux is ca. 2.0×10^4 t yr^{-1}.	Historical evolution unknown. Nutrients are depleted in reservoirs.	5	Depetris *et al.* (in prep); Gaiero *et al.* (1999)
Eutrophication and/or pollution	Small rivers in the Buenos Aires Province coastal zone	Unknown. Critical threshold is still beyond reach but human impact is discernible.	Unknown. Processes are basically not chronic although they are critical in several areas along the coastline.	4 - 5	Bilos *et al.* (1998); Manassero *et al.* (2000); Ronco *et al.* (1995); Manassero *et al.* (1998).
Pollution	Northern Patagonian rivers (Colorado, Negro, and Neuquén). Austral Patagonia	Unknown. Critical threshold is still beyond reach but human impact is discernible.	Unknown. Processes are basically not chronic although they may be acute in several areas.	4 - 5	Gaiero *et al.* (1999); Gil *et al.* (1999); Gaiero *et al.* (in press); Harvey and Gil (1988); Amin *et al.* (1996).

Table RA7.2. Argentine coast: DPSIR matrix characterizing major catchment based drivers/pressures and a qualitative ranking of related state changes impacting the coastal zone *versus* catchment size class.

n.p. = not present, 1= minor, 2= medium, 3= major, p= progressive, d = discrete

Driver	Pressures	State change (qualitative index)	State change (qualitative index)	Impact on the coastal system	Time scale
		Small size basins	Medium size basins		
Damming	Sediment trapping Altering nutrient balance Altering water balance Decrease of flow transport capacity	n.p.	(3)	Sediment depletion/sorting Depletion of nutrients Stable water flux Erosion Increasing marine sand supply	**p**
Agriculture	Decrease of water volume and flow transport capacity due to water withdrawal for irrigation Facilitating soil erosion Pollutant emission Altering nutrient fluxes	2	(2)	Sediment depletion Enrichment of nutrients Stable water flux	**p**
Sand mining	Sediment remobilization Sediment withdrawal Altering river morphology (banks and bottom)	1	(2)	Sediment depletion Sediment sorting Altering flow patterns Altering ecological conditions	**p**
Aquaculture	Changes in hydrochemistry Increasing nutrient load	n.p.	n.p.	Altering food webs and trophic status	**d/p**
Urbanization	Pollutant emission Altering nutrient fluxes	3	(0)	Altering food webs and trophic status	**p**
Deforestation	Facilitating soil erosion Altering sediment balance	2	(1)		**p**

Table RA7.3 Argentine coast: the link between coastal issues/impacts and land based drivers. Overview and qualitative ranking on local or catchment scale:
⇑ - increasing, ⇒ stable.

Coastal impact/issues	Drivers	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ data sources
		River	Category (1 low – 10 high)		
Erosion	Poor management practices	Buenos Aires Province coastline	8	⇑	e.g., Cionchi *et al.* (1993); López and Marcomini (1998); Violante *et al.* (2001); Isla (1997)
Sediment depletion and sorting	Damming	Colorado, Negro, Chubut	5	⇑	e.g., Isla and Bujalevsky (1995); Pasquín *et al.* (1997)
	Sand mining	Negro	4	⇒	e.g., Cionchi *et al.* (1993); Pasquini *et al.* (1997)
Nutrient depletion	Damming	Chubut , Colorado, Negro	8	⇑	Depetris *et al.* (in prep.); Gaiero *et al.* (1999); Gaiero *et al.* (in press)
Altering food webs and trophic status	Damming	Chubut	1	⇑	Depetris *et al.* (in prep.); Gaiero *et al.* (1999); Gaiero *et al.* (in press)
Eutrophication	Agriculture	Negro, Chubut	3	⇑	Depetris *et al.* (in prep.); Gaiero *et al.* (1999); Gaiero *et al.* (in press)
	Urbanisation	Chubut	7	⇑	Depetris *et al.* (in prep.); Gaiero *et al.* (1999); Gaiero *et al.* (in press)
	Industrialisation	Chubut	2	⇑	Depetris *et al.* (in prep.); Gaiero *et al.* (1999); Gaiero *et al.* (in press)

8. References – Regional Assessment Synthesis and Tables

Acuña, A., Arena, G., Berois, N., Mantero, G., Masello, A., Nion, H., Retta, S. and Rodríguez, M. 1997 Capítulo 7 – La Corvina (*Micropogonias furnieri*): Ciclo Biológico y Pesquerías en el Río de la Plata y su Frente Oceánico. Pages 191-224 in: *El Río de la Plata, una Revisión Ambiental - Un Informe de Antecedentes del Proyecto Ecoplata.* Projecto ECOPLATA, Montevideo.

AGOSBA-OSN-SIHN 1994 Río de la Plata, Calidad de las Aguas Franja Costera Sur (San Isidro-Magdalena). *Informe de Avance Argentina.* 115 pages plus appendices.

Almeida, M.M.M., Silva, F.J.A. and Araújo, L.F.P. 1999 Avaliação qualitativa da águas do principal rio da região metropolitana de Fortaleza. Pages 2154-2158 in: *Anais do 20º Congresso Brasileiro de Engenharia Sanitária e Ambiental*, Rio de Janeiro.

Almeida, M.T.A., Baumgarten, M.G.Z. and Rodrigues, R.M.S. 1993 Identificação das possíveis fontes de contaminação das águas que margeiam a cidade do Rio Grande - RS. *Documentos Técnicos (Rio Grande)* **6**: 1-30.

Amin, O., Ferrer, L. and Marcovecchio, J. 1996 Heavy metal concentrations in littoral sediments from the Beagle Channel, Tierra del Fuego, Argentina. *Environmental Monitoring and Assessment* **41**: 219-231.

ANEEL 2000 Agencia Nacional de Energia Eletrica. Descargas medias de Longo Período, Bacia Atlântico NO/NE. http://www.anel.gov.br

Baisch, P. 1997 Metais pesados. In: Tagliani, P.R.A. and Asmus, M.L. Coords: *Estudo de Impacto Ambiental (EIA) do Porto de Rio Grande, RS* - Relatório Final. Rio Grande, FURG.

Barcellos, C. and Lacerda, L.D. 1994 Cadmium and zinc source assessment in Sepetiba Bay and basin. *Environmental Monitoring and Assessment* **29**: 183-199.

Barcellos, C., Lacerda, L.D. and Ceradini, S. 1997 Sediment origin and budget in Sepetiba Bay (Brazil) - an approach based on multi-element analysis. *Environmental Geology* **32**: 203-209.

Baumgarten, M.G.Z., Niencheski, L.F.H. and Kuroshima, K.N. 1995 Qualidade das águas estuarinas que margeiam o município do Rio Grande (RS, Brasil): nutrientes e detergentes dissolvidos. *Atlântica (Rio Grande)* **17**: 17 - 34.

Behrendt, H. 2001 Estimation of the nutrient inputs into river basins – experiences from German rivers (this report).

Behrendt, H., Huber, P., Kornmilch, M., Opitz, D., Schomoll, O., Sholz, G. and Uebe, R. 1999 Nutrient emissions into river basins of Germany. *UBA-FB 99-087/e Report No.* **296 25 515**, Federal Envirobnmental Agency, Berlin, Germany, 288 pages.

Beltrán, I.C., Estrada, M., Valderrama, M., 2000 Pland de Ordenación: Manejo y aprovechamiento sostenible pesquero y acuícola de la Cuenca del Río Grande de la Magdalena. Technical Report, INPA, Bogotá, Colombia, 37 pages.

Bezerra, E. 1996. *A Barragem do Castanhão e a Transposição do Rio São Francisco.* Universidade Federal do Ceará, Fortaleza, 53 pages.

Bidone, E.D. 2000 Análise econômico-ambiental aplicada a contaminação das águas fluviais de pequenas bacias costeiras do Estado do Rio de Jnaeiro. Pages 371-394 in: Esteves, F.A. and Lacerda L.D. (eds): *Ecologia de Restingas e Lagoas Costeiras*, NUPEM/UFRJ, Rio de Janeiro.

Bidone, E.D., Silva Filho, E.V., Guerra, T., Barroso, L.V. and Ovalle, A.R.C. 1999 Natural and cultural levels in rivers of small coastal watersheds, S-SE, Brazil. Pages 89-103 in: Knoppers, B.A., Bidone, E.D. and Abrão, J.J. (eds): *Environmental Geochemsitry of Coastal Lagoons Systems, Rio de Janeiro, Brazil. Ser. Geoquímica Ambiental* **6**, Universidade Federal Fluminense.

Bilos, C., Colombo, J.C. and Rodríguez Presa, M.J. 1998 Trace metals in suspended particles, sediments and Asiatic clams (*Corbicula fluminea*) of the Río de la Plata estuary, Argentina. *Environmental Pollution* **99**: 1-11.

CAAM 1996 *Sistemas biofísicos en el Golfo de Guayaquil.* Comisión Asesora Ambiental de la Presidencia de la República.. 97 pages.

Calliari, L.J. 1980 Aspectos sedimentológicos e ambientais da região sul da Lagoa dos Patos. *Tese de Mestrado.* Porto Alegre, Universidade Federal do Rio Grande do Sul.

Cardona, P. and Botero, L. 1998 Soil characteristics and vegetation structure in a heavily deteriorated mangrove forest in the Caribbean coast of Colombia. *Biotropica* **30**: 24-34.

Campos, J.N.B., Souza Filho, F. and Araújo, J.C. 1997 Errors and variability of reservoir yield estimation as a function of variation of annual inflows. Pages 1-7 in: Proc. 27th IARH Congress, San Francisco.

Caribe Colombiano, sector Bocas de Ceniza-Parque Tayrona. *Technical Report* CIOH, Cartagena, Colombia.

CARP-CTMFM 1999 *Protección Ambiental del Río de la Plata y su Frente Marítimo.* Proyecto Gef, PNUD. Montevideo.

CARU 1993 Informe de avance. Programa de calidad de aguas y control de la contaminación del Río Uruguay. Etapa I. *Serie técnico científica* vol. **2** n° 1, 86 pages.

CARU 1997 Impacto de Zonas Costeras. Módulo: Salto-Concordia. Informe Técnico DINAMA, SOHMA y SHIN.

CARU 1999 Impacto de Zonas Costeras. Módulo:Fray Bentos -Gualeguaychú. Informe Técnico SOHMA y SHIN.

Castello, J.P. and Möller, O.O. Jr. 1978 On the relationship between rainfall and shrimp production in the Patos Lagoon estuary (Rio Grande do Sul, Brazil). *Atlântica, Rio Grande* **3**: 67-74.

Cavalcante, A.A. 2000 Impactos ambientais na região do baixo curso do Rio Jaguaribe, CE. *MSc Dissertation. Universidade Estadual do Ceara, Fortaleza*, 317 pages.

Cionchi, J.L., Alvarez, J.R., Del Río, J.L. and Ferrante, A. 1993 El efecto antrópico en el retroceso de la linea de costa del Partido de General Pueyrredón (Provincia de Buenos Aires). *XII Congreso Geológico Argentino y II Congreso de Exploración de Hidrocarburos Actas* **VI:** 318-322.

Correa, I.D., 1990 Inventario de erosión y acreción litoral (1793-1990) entre los Morros y Galerazamba, Departamento de Bolívar, Colombia. *Technical Report, IGAC*, Cartagena, Colombia, 142 pages.

Costa, C.S.B., Seeliger, U. and Kinas, P.G. 1988 The effect of wind velocity and direction on the salinity regime in the Lower Patos Lagoon estuary. *Ciência e Cultura* **40(9)**: 909-912.

Costanza, P. 1992 Assessing and communicating data quality in policy-relevant research. *Environmental Management* **16**: 121-131.

CPPS 1998 Informe Final Comisión Permanente del Pacífico Sur (CPPS). Pages 71–79 in: Segunda reunión del grupo de trabajo de evaluación y ordenación Pesquera en el Pacífico Sudeste y de especies transzonales y altamente migratorias. Callao-Perú 27 al 30 de Abril de 1998. http://www.cpps.org

CPPS 2000 Informe Comisión Permanente del Pacífico Sur (CPPS). Secretaría General. Quito, Ecuador. Estado del medio ambiente marino y costero del Pacífico Sudeste, 40 pages.

Depetris, P.J., Gaiero, D.M., Probst, J.L. and Kempe, S. in preparation. Patagonia's riverine nutrient fluxes.

Dias, G.T. and Silva, C.G. 1984 Geologia de depósitos arenosos costeiros emersos - Exemplos ao longo do litoral fluminense. Pages 47-60 in Lacerda, L.D., Araujo, D.S.D., Cerqueira, R. and Turcq, B. (eds.): *Restingas: Origem, Estrutura, Processos.* EDUFF, Niteroi, 474 pages.

ECOPLATA 1999 *El Río de la Plata, una Revisión Ambiental – Un Informe de Antecedentes del Proyecto Ecoplata.* Montevideo.

Echevaria, J. and Sarabia, J. 1993 *Mangroves of Perú.* Pages 53-65 in: Lacerda, L.D. (ed): *Conservation and sustainable utilization of mangrove forests in Latin America and Africa regions: Part I.* ISME Mangrove Ecosystems Reports, N°2, Inter. Soc. Mangrove Ecosystems, Okinawa.

Echezuría, H., Córdova, J., González, M., Méndez, J. and Yanes, C. Geoenvironmental characterization of the Orinoco Delta: a process approach. (Volume 2, this report).

Ekau, W. and Knoppers, B. 1999a Sedimentation processes and productivity in the continental shelf waters off East and North-East Brazil. Brazilian-German Joint Oceanographic Projects II, 1994/95. *Archive of Fishery and Marine Research* **47** (2-3): 109-340.

Ekau, W. and Knoppers, B. 1999b Sedimentation processes at the East and Northeast Brazil shelf . *Geo-Marine Letters* 19 (3): 171-218.

Ekau, W., Westhaus-Ekau, P. and Medeiros, C. 1999. Large scale distribution of fish larvae in the continental shelf waters off North-East Brazil. *Archive of Fishery and Marine Research* **47** (2-3): 201-210.

Escobar-Nieves, A. 1988 Condición bacteriológica de las ostras del manglar (*Crassostrea rhizophorae* Guilding) en la Ciénaga Grande de Santa Marta. *Anales del Instituto de Investigacion Marina de Punta de Betín* **18**: 137-152.

Espinoza, G., Pinazi, P., Contreras, L. and Camus, P. 1995 *Pefil Ambiental de Chile.* Comissión Nacional del Medio Ambiente, Santiago.

Esteves, F.A. and Lacerda L.D. 2000 *Ecologia de Restingas e Lagoas Costeiras*, NUPEM/UFRJ, Rio de Jneiro. 394 pages.

EULA, 1999. *Analisis de vulnerabilidad y Adaptación en Zonas Costeras y Recursos Pesqueros ante Cambio Climáticos VIII Region- Chile.* Centro EULA Universidad de Concepción, Concepción..

Fernandes, E.H. and Niencheski, L.F.H. 1998 Um modelo de caixas simplificado para o estudo dos processos de transporte na região estuarina da Lagoa dos Patos (RS – Brasil). *Atlântica, Rio Grande*, **20**: 75-85.

Forte, F.G. 1996 Taxas de Sedimentação na Baía de Sepetiba, Rio de Janeiro. *Msc Thesis., Universidade Federal Fluminense*, 72 pages.

Freire, G.S.S. 1989 Etude hydrologique e sedimentologique de l'estuaire du Rio Pacoti (Fortaleza – Ceará-Brésil). *These de Doctorat. Faculte dês Sciences et dês Techniques, Universite de Nantes, Nantes*, 229 pages.

Freire, G.S.S. and Hazin 2000 *Programa REVIZEE: Programa de Avaliação do Potencial Sustentável dos Recursos Vivos na Zona Econômica Exclusiva.* DEGEO/UFC, Fortaleza, 101pages.

Gaiero, D.M., Probst, J.L., Depetris, P.J. and Leleyter, L. 2001 Heavy metal transfers from Patagonia to the South Atlantic Ocean. (Volume 2, this report).

Gaiero, D.M., Probst, J.L., Depetris, P.J., Leleyter, L. and Kempe, S. in press. Riverine transfer of heavy metals from Patagonia to the Southwestern Atlantic Ocean. *Regional Env. Change.*

Garzón-Ferreira and Kielman, M. 1993 Extensive mortality of corals in the Colombian Caribbean during the last two decades. Pages 247-253 in: *Proc. Colloquium on Global Aspects of Coral Reefs, Health Hazards and History*. RSMAS, University of Miami, Miami.

Gil, M.N. and Esteves, J.L. 2000 Argentina estuarine systems: Bahia Nueva, Golfo Nuevo, Patagonia. Pages 45-50 in: Smith, S.V., Dupra, V., Marshall Crossland, J.I. and Crossland, C.J. (eds): Estuarine Systems of the South American region: carbon, nitrogen and phosphorus fluxes. *LOICZ Reports and Studies,* No. **15**, LOICZ, Texel, The Netherlands, 87 pages.

Gil, M.N., Harvey, M.A. and Esteves, J.L. 1999 Heavy metals in intertidal surface sediments from the Patagonian coast, Argentina. *Bull. Environ. Contam. Toxicol.* **63**:52-58.

Goniadzki, D. 1999 *Hydrological warning and information system for the Plata basin, Buenos Aires.* Instituto Nacional del Agua y del Ambiente, 70 pages.

Graña, F. and Piñeiro, D. 1997 Capítulo 8 – Pesca artesanal en Pajas Blancas: La percepción de los pescadores sobre la corvina y su ambiente. Pages 229-245 in: *El Río de la Plata, una Revisión Ambiental - Un Informe de Antecedentes del Proyecto Ecoplata.*

Haimovici, M., Castello, J.P. and Vooren, C.M. 1997 Chapter 9: Fisheries. Pages 183-196 in Seeliger, U., Odebrecht, C. and Castello, J.P. (eds): *Subtropical Convergence Environments: the coast and sea in the southwestern Atlantic.* Berlin, Springer-Verlag.

Hajek, E.R., Gross, P. and Espinoza, G. 1990 *Problemas Ambientales de Chile.* Volume **1**. Pontificia Universidad Católica de Chile, Santiago.

Harvey, M.A., and Gil, M.N. 1988 Concentrations of some trace elements in Recent sediments from the San José and Nuevo gulfs, Patagonia, Argentina. *Marine Pollution Bulletin* **19**(8):394-396.

INOCAR 1998a *Informe Técnico del Instituto Oceanográfico de la Armada* (INOCAR). Proyecto Autoridad Portuaria de Guayaquil (APG), Guayaquil, 286 pages.

INOCAR 1998b Acta Oceanográfica del Pacífico, Vol. 9 No.1. 1998. ISSN No.1390 129X. *Instituto Oceanográfico de la Armada* (INOCAR).

INVEMAR, 1997. Evaluación de los principales recursos pesqueros de la Ciénaga Grande de Santa Marta, Costa Caribe de Colombia. INVEMAR-COLCIENCIAS-GTZ-PROCIENAGA. *Technical Report*, Vol. **2**, Santa Marta, Colombia, 327 pages.

INVEMAR, 2000. Proyecto de monitoreo de las condiciones ambientales y de los cambios estructurales y funcionales de las comunidades vegetales y los recursos pesqueros durante la rehabilitación de la Ciénaga Grande de Santa Marta: Un enfoque de manejo adaptativo. Fase I: 1999-2000. Technical Report, Santa Marta, Colombia, 62 pages.

Isla, F.I. and Bujalesky, G.G. 1995 Tendencias evolutivas y disponibilidad de sedimento en la interpretación de formas costeras: Casos de estudio de la costa argentina. *Revista de la Asociación Argentina de Sedimentología* **1-2**: 75-89.

Isla, F.I., 1997 Seasonal behaviour of Mar Chiquita tidal inlet in relation to adjacent beaches, Argentina. *J. of Coastal Research* **13(4)**:1221-1232.

Jaramillo, E. 2001 The sand beach ecosystem of Chile. Pages 219-227 in Seeliger, U. and Kjerfve, B. (eds): *Coastal Marine Ecosystems of Latin America.* Springer Verlag, Berlin.

Jimenez, J. and Maia, L.P. 1999 Aeolian dune migration, NE Brazil. *Sedimentology* **46**: 689-701.

Jorajuria, A. 2001. Integrated management of the coastal zone of the Uruguayan coast of the Rio de La Plata.(this report)

Kellogg, J.N. and Mohriak, W.U. 2001 The tectonic and geological environment of coastal South America. Pages 1-16 in: Seeliger, U. and Kjerfve, B. (eds): *Coastal Marine Ecosystems of Latin America.* Springer Verlag, Berlin.

Kjerfve, B., Lacerda, L.D. and Dias, G.M.T. 2001 Baía de Guanabara, Rio de Janeiro, Brazil. Pages 107-130 in: Seeliger, U. and Kjerfve, B. (eds): *Coastal Marine Ecosystems of Latin America.* Springer Verlag, Berlin.

Kjerfve, B., Lacerda, L.D. and Diop, S. 1997 *Mangrove Ecosystems Studies in Latin America and Africa.* UNESCO, Paris, 349 pages.

Kjerfve, B., Ribeiro, C.H.A., Dias, G.T.M., Filipo, A.M. and Quaresma, V.S. 1998. Oceanographyc characteristics of an impacted coastal bay: Baia de Guanabara, Rio de Janeiro, Brazil. *Continental Shelf Research* **17**: 1609-1643.

Kjerfve, B., Seeliger, U. and Lacerda, L.D. 2001. A summary of natural and human-induced variables in coastal marine ecosystems of Latin America. Pages 341-353 in: Seeliger, U. and Kjerfve, B. (eds): *Coastal Marine Ecosystems of Latin America.* Springer Verlag, Berlin.

Knoppers, B.A., Bidone, E.D. and Abrão, J.J. 1999 *Environmental Geochemsitry of Coastal Lagoons Systems, Rio de Janeiro, Brazil. Ser. Geoquímica Ambiental* **6.** Universidade Federal Fluminense, Niteroi, 199 pages.

Kremer, H.H. and Köhn, J. 2000 Specifying user needs for global change science in coastal zones. Pages 159-198 in Pacyna, J., Kremer, H.H., Pirrone, N. and Barthel, K.G. (eds): *Socioeconomic aspects of fluxes of chemicals into the marine environment – workshop report.* Kjeller, Norway 8-10 March 1999. European Commission EUR 19089.

Kunkel, R. and Wendland, F. 1999 Das Weg-/Zeitverhalten des grundwasserburtigen Abflusses im Elbeeinzugsgebeit. *Schriften des Forschungszentrums Julich: Reibe Umwelt/Environment*, Bd. **19**, 122 pages.

Kurucz, A., Masello, A., Méndez, S., Cranston, R. and Wells, P.G. 1997 Capítulo 3 – Calidad Ambiental del Río de la Plata. Pages 71-82 in: *El Río de la Plata, una Revisión Ambiental - Un Informe de Antecedentes del Proyecto Ecoplata*, Montevideo.

Kuylenstierna, J.C., Rodhe, H., Cinderby, S. and Hicks, K. 2001 Acidification in developing countries: ecosystem sensitivity and the critical load approach on a global scale. *Ambio* **30**: 20-28.

Lacerda L.D. *1998 Biogeochemistry of trace metal and diffuse pollution in mangrove ecosystems.* International Society for Mangrove Ecosystems, Okinawa, Japan, 65 pages.

Lacerda L.D. and Salomons W 1998 *Mercury contamination from gold and silver mining. A chemical time bomb.* Springer Verlag, Berlin, 146 pages.

Lacerda, L.D. 1993 Conservation and sustainable utilization of mangrove forests in Latin America and Africa regions: Part I. *ISME Mangrove Ecosystems Reports*, N°**2**, International Society for Mangrove Ecosystems, Okinawa, 272 pages.

Lacerda, L.D. and Howarth, R.W. 1991 Editorial, "Biogeochemistry in the Humid Tropics". *Biogeochemistry.* **14**: 89-90.

Lacerda, L.D., Carvalho, C.E.V., Rezende, C.E. and Pfeiffer, W.C. 1993 Mercury in sediments from the Paraíba do Sul River continental shelf, SE-Brazil. *Marine Pollution Bulletin* **26**: 220-222.

Lacerda, L.D., Conde, J.E., Alarcón, C., León, R.A., Kjerfve, B. and Polania, J. (in press). American mangroves. In: Lacerda, L.D. (ed). *Mangrove Ecosystems: function and management.* Springer Verlag, Berlin.

Lacerda, L.D., Huertas, R., Moresco, H.F., Carrasco, G., Vianna, Lucas, R. and Pessi, M. 1998 Trace metal concentrations and geochemical partitioning in Carrasco Wetlands, Montevideo, Uruguay. *Geochimica Brasiliensis* **12**(1/2): 63-74.

Lacerda, L.D., Marins, R.V. and Barcellos, C. 2001 Anthropogenic fluxes of trace metals of environmental significance to Sepetiba Bay, SE Brazil. (Volume 2, this report).

Lacerda, L.D., Marins, R.V., Barcellos, C. and Knoppers, B.A. 2001 River basin activities, impact and management of anthropogenic trace metal and sediment fluxes to Sepetiba Bay, Southeastern Brazil. Pages 208-218 in: B. von Bodungen and R.K. Turner (eds): *Science and Integrated Coastal Management,* Dahlem University Press, Dahlem.

López Laborde, J. 1997 Capítulo 1 – Marco geomofológico y geológico del Río de la Plata. Pages 1-14 in: *El Río de la Plata, una Revisión Ambiental - Un Informe de Antecedentes del Proyecto Ecoplata.* Montevideo.

Lopez, J.L., Saavedra, I.I. and Dubois, M. 1998 *El Orinoco, aprovechamiento sustentable.* Instituto de mecanica de Fluidos, Facultad de Ingenieria, Universidad Central de Venezuela.

López, R.A. and Marcomini, S.C. 1998 Manejo costero asociado a la erosión de playas en la Provincia de Buenos Aires. *Actas X Congreso Latinoamericano de Geología y VI Congreso Nacional de Geología Económica* **I**: 373-377.

Magro, M., Cergole, M.C. and Rossi-Wongtschowski, C.L.D.B. 2000 *Síntese de Conhecimentos dos Principais Recursos Pesqueiros Costerios Potencialmente Explotáveis na Costa Sudeste-Sul do Brasil: Peixes*. Ministerio do Meio Ambiente, Brasília, 143 pages.

Maia, L.P. 1992 Controle tectônico e evolução geológica da região da desenbocadura do Rio Jaguaribe. *MSc Thesys*, Univ. Fed. Pernambuco, Recife, 126 pages.

Manassero, M., Camilión C., Ronco, A., 1998 Sedimentologia y geoquímica de metales pesados en sedimentos de fondo de arroyos de la vertiente del Río de la Plata, Pcia. De Buenos Aires. **VII** *Congreso Argentino de Sedimentología. Actas*, pages 69-79.

Manassero, M., Camilión C. and Ronco, A., 2000 Environmental sedimentology and geochemistry of heavy metals from bottom sediments in coastal streams from the Río de la Plata SW sector, Buenos Aires province, Argentina. *VIII Reunión Argentina de Sedimentología.* **Resúmenes**, 104-105.

Mancera-Pineda, J.E. and Vidal, L.A. 1994 Florecimiento de microalgas relacionado con mortandad masiva de peces en el Complejo Lagunar Ciénaga Grande de Santa Marta. *Anales del Instituto de Investigacion Marina de Punta de Betín* **23**:103-117.

Marcomini, S.C., López, R.A., 2000 Evaluación de la recarga artificial de playas. *VIII Reunión Argentina de Sedimentología.* **Resúmenes**, 108-109.

Marcovecchio, J.E. and V.J. Moreno 1992 Evaluación del contenido de metales pesados en peces de la Bahía Samborombón. *Publ. Com. Téc. Mix. Fr. Mar.* **12(A)**: 139-146.

Marcovecchio, J.E. and Moreno, V.J. 1993 Cadmium, zinc and total mercury levels in the tissues of several fish species from La Plata River Estuary, Argentina. *Environmental Monitoring and Assessment* **25**(2): 119-130.

Marins, R.V., Lacerda, L.D., Mounier, S. and Freire, G.S.S. 2001 Hidroquímica e concentração de mercúrio em rios metropolitanos de Fortaleza, Ceará. In: *Annais do VIII Congresso Brasileiro de Geoquímica, Curitiba* (in press).

Martínez, J.O. and Molina, A. 1992 Geomorfología y aspectos erosivos del litoral Caribe colombiano, sector de Bocas de Ceniza-Parque Tayrona. *Technical Report, CIOH*, Cartagena, Colombia, 89 pages.

Mavignier, A.L. 1992. Estudo físico, químico e bacteriológico do Rio Cocó. *MSc Dissertation*, Universidade Federal do Ceará, Fortaleza, 107 pages.

McManus, J.W., Nañola, C.L., Reyes, R. and Kesner, K. 1992 Resource ecology of the Bolinao coral reef system. *ICLARM Stud. Rev.* No. **22**, 117 pages.

Mechoso, C.R. and Pérez Iribarren, G. 1992 Stream flow in southeastern South America and the Southern Oscillation. *Journal of Climate* **5**: 1535-1539.

Medeiros, C., Macêdo, S.J., Feitosa, F.A.N. and Koening, M.L. 1999 Hydrography and phytoplankton biomass and abundance on North-East and East Brazilian shelf. *Archive of Fishery and Marine Research* **47** (2-3): 133-151.

Méndez, S., Brazeiro, A., Míguez, A. and Franco, J.M. 1994 Altos niveles de toxina paralizante de moluscos en Uruguay asociados a la presencia de *Alexandrium tamarensis*. Abstract of poster paper. COI – Taller Regional de Planificación Científica sobre Floraciones Algales Nocivas.

Méndez, S.M. and Ferrari, G. 1994 Control de floraciones algales nocivas en Uruguay. In: COI – Taller Regional de Planificación Científica sobre Floraciones Algales Nocivas. *Workshop Report* N° 101.

Méndez, S.M., Brazeiro, A., Ferrari, G., Medina, D. and Inocente, G. 1993 Mareas Rojas en el Uruguay. Programa de control y actualización de resultados. *INAPE, Inf. Téc.* N° **46**, 31 pages.

Méndez, S.M., Severov, D., Ferrari, G. and Mesones, C. 1996 Early spring *Alexandrium tamarense* toxic blooms in the Uruguayan waters. Pages 113-116 in Yasumoto, T., Oshima, Y. and Fukuyo, Y. (eds): *Harmful and Toxic Algal Blooms*, Intergovernmental Oceanographic Commission of UNESCO, Paris.

Milliman, J.D. and Meade R.H. 1983 Worldwide delivery of river sediments to the ocean. *Journal of Geology* **93**:1-21.

Milliman, J.D. and Syvitski, J.P.M. 1992 Geomorphic/tectonic control of sediment transport to the ocean: the importance of small mountainous rivers. *Journal of Geology* **100**: 525-544.

MMA 1996b *Perfil dos estados litorâneos do Brasil: Subsídios para a Implantação do Programa Nacional de Gerenciamento Costeiro.* Ministério do Meio Ambiente Recursos Hídricos e da Amazônia Legal. Programa Nacional de Gerenciamento Costeiro, Brasília, DF, 301 pages.

MMA, 1996a *Macrodiagnóstico da Zona Costeira do Brazil.* Ministerio do Meio Ambiente, Brasília, 277 pages.

Monestier, H. and Míguez, J.C. 1993 Evolución de caudales del Río Uruguay. *Revista de Ingeniería* **15**:5-14.

Montú, M. and I. Gloeden. 1982 Morphological alterations in *Acartia tonsa* (Saco da Mangueira, Lagoa dos Patos, Brasil). *Arquivos de Biologia e Tecnologia* **25**(3/4):361-369.

Morais, J.O. and Pinheiro, L.S. 1999 The impacts of the Jaguaribe River flow on the erosion and sedimentation of Pontal de Maceió – State of Ceará, NE Brazil. *Abstract.* VII Congresso da ABEQUA, Porto Seguro.

Moyano, M., J. Blanco, A. Caballero, H. Moresco, and M. Rosadilla 1992 Diagnóstico primario de la contaminación química en las costas de Montevideo. Pages 93-99 in UNESCO and IOC (COI), (eds): *Comunicaciones de las Jornadas de Investigación Científica en Materia de Contaminación de las Aguas.* UNESCO and OIC (COI), Montevideo, Uruguay.

Moyano, M., Moresco, H., Blanco, J., Rosadilla, M. and Caballero, A. 1993 Baseline studies of coastal pollution by heavy metals, oil and PAHs in Montevideo. *Marine Pollution Bulletin* **26**: 461-464.

Muelbert, JH and Weiss, G. 1991 Abundance and distribution of fish larvae in the channel area of the Patos Lagoon estuary, Brazil. In: Larval fish recruitment and research in the Americas: proceedings of the thirteenth annual fish conference. *NOAA Tech. Rep. NMFS* **95**: 43-54.

Muller, G., Irion, G., Morais, J.O. and Tintelnot, M. 1999 Heavy metal concentrations in fine-grained sediments in the lower course of Brazilian rivers between the state of Piauí and Espírito Santo. Pages 1-6 in: *Proc. III Inter. Symp. Environmental Geochemistry in Tropical Countries*, Nova Frigurgo, Universidade Federal Fluminense.

Myers, N., Mittermeir, R.M., Mittermeir, C.G., Fonseca, G.A.B. and Kent, J. 2000 Biodiversity hotspots for conservation priorities. *Nature* **403**: 853-858.

Nagy, G.J. 1989 Bilan des connaissances sur l'hydrologie et l'hydrodynamisme sédimentaire du Río de la Plata. Aports de la télédétection et conséquences sur l'environment biologique. *Thesis D.E.A. Océanologie, Serv. Sédimentologie, Dep. Océanologie et Océanographie. Univ. Bordeaux-I, Bordeaux.*

Nagy, G.J. 2000 Uruguay estuarine systems: the frontal zone of the Rio de La Plata. Pages 40-43 in Smith, S.V., Dupra, V., Marshall Crossland, J.I. and Crossland, C.J. (eds): Estuarine systems of the South American region: carbon, nitrogen and phosphorus fluxes. *LOICZ Reports and Studies*, No. **15**, LOICZ, Texel, the Netherlands, 87 pages.

Naylor, R.L., Goldburg, L.M., Primavera, J., Lubchenco and Troell, M. 2000 Effect of aquaculture on fish supply. *Nature* **405**: 1017-1024.

Newman-Leitão, S, Gusmão, L.M.O., Silva, T.A., Nascimento-Vieira, D.A. and Silva, A.P. 1999 Mesoplankton biomass and diversity in coastal and oceanic waters off North-Eastern Brazil. *Archive of Fishery and Marine Research* **47** (2-3): 153-165.

Niencheski, L.F.H. and Baumgarten M.G.Z. 1997 Nutrientes, óleos e fenóis. In: Tagliani, P.R.A. and Asmus, M.L. (coords): *Estudo de Impacto Ambiental (EIA) do Porto de Rio Grande, RS - Relatório Final.* Rio Grande, Fundação Universidade do Rio Grande.

Odebrecht, C., Rörig, L., Garcia, V.T. and Abreu, P.C. 1995 Shellfish mortality and a red tide event in southern Brasil.. Pages 213-215 in Lassus, P., Arzul, G., Erad, E., Gentlen, P. and Marcalliou, C. (eds): *Harmful Marine Algal Bloom.* Lavoisier, Intercept Ltd.

Odebrecht, C.; Seeliger, U.; Coutinho, R. and Torgan, L. 1987 Florações de *Microcystis* (cianobactérias) na Lagoa dos Patos, RS. Pages 280-287 in: *Anáis do I Simpósio Brasileiro de Ecossistemas da Costa Sul e Sudeste.* Academia de Ciências do Estado de São Paulo, São Paulo.

OECD (Organisation for Economic Co-operation and Development) 1993 OECD core set of indicators for environmental performance reviews. OECD Environment Monographs No. 83, OECD Paris, 39 pages.

OSPAR 2000 OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic. Quality Status Report 2000. Region II–Greater North Sea. OSPAR Commission, London, xiii+136 pages.

Paolini, J., Herrera, R. and Nemeth, A. 1983 Hydrochemistry of the Orinoco and Caroni rivers. *Mitt. Geol.-Palaont. Inst. Univ. Hamburg* **55**: 223-236.

Paredes, J.F., Paim, A.J. and Legeckis, R. 1983 Sao Francisco River: hydrological studies in the dammed Lake Sobradinho. *Mitt. Geol.-Palaont. Inst. Univ. Hamburg* **55**:193-202.

Parra, O. and Habit, E. 1998 *Documento de Sintesis. Estudio de Base para la Evaluación de Impacto Ambiental en la Cuenca del Rio Itata.* Centro EULA, Universidad de Concepción, Concepcion.

Pasquini, A.I., Depetris, P.J., Probst, J.L. and Kempe, S. 1997 The effects of natural events and man-made factors on runoff and sediment transport of Patagonian rivers: Colorado, Negro and Chubut rivers. *LOICZ Meeting Report* **29**: 84-85.

Persich, G. 2001 Germinação, crescimento, identificação genética e perfil de toxinas do dinoflagelado tóxico Alexa*ndrium tamarense* Balech do sul do Brasil. *Tese de Doutorado. Programa de Pós-Graduação em Oceanografia Biológica/FURG, Rio Grande.*

Peters E.C., Gassman, N.J., Firman, J.C., richmond, R.H. and Power, E.A. 1997. Ecotoxicology of tropical marine ecosystems. *Environmental Toxicology and Chemistry* **16**: 12-40.

PMRC 1993a *Estudio de la calidad del agua costera ecuatoriana.* Programa de Manejo de Recursos Costeros PMRC. Ministerio de Agricultura y Ganaderia, Guayaquil. www.pmrc.org.ec.

PMRC 1993b *Plan de Manejo de la ZEM Bahía – San Vicente - Canoa.* Programa de Manejo de Recursos Costeros., Ministerio de Agricultura y Ganderia, Gayaquil, 43 pages.

Rabalais, N.N. 2001 Changes in Mississippi River nutrient fluxes and consequences for the northern Gulf of Mexico coastal ecosystem. (Volume 2, this report).

Rebouças, A.C. 1999 Água doce no mundoe no Brasil. Pages 327-367 in: Rebouças, A.C., Braga, B. and Tundisi, J.G. (eds.): *Águas Doces no Brasil – Capital Ecológico, Uso e Conservação.* Escrituras Editora, São Paulo.

Restrepo, J.D. and Kjerfve, B. 2000a Water and sediment discharges from the western slopes of the Colombian Andes with focus on Rio San Juan. *Journal of Geology* **108**: 17-33

Restrepo, J.D. and Kjerfve, B. 2000b Magdalena River: interannual variability (1975-1995) and revised water discharge and sediment load estimates. *Journal of Hydrology* **235**: 137-149.

Richey, J.E., Saliti, E. and Santos, U. 1985 Biogeochemistry of the Amazon river: An update. *Mitt. Geol.-Palaont. Inst. Univ. Hamburg* **58**:245-258.

Ronco, A., Sobrero, M., Alzuet, P., Bulus Rossini, G. and Dutka, B. 1995 Screening for sediment toxicity in the río Santiago basin: a baseline study. *Environmental Toxicology and Water Quality* **10**(1): 35-39.

Salomão, M.S.M.B., Molisani, M.M., Ovalle, A.R.C., Rezende, C.E., Lacerda, L.D. and Carvalho, C.E.V. 2001 Particulate heavy metal transport in the lower Paraíba do Sul River basin, southeastern Brazil. *Hydrological Processes* **15**: 587-593.

Salomons, W., Turner, R.K., Lacerda, L.D. and Ramachandran, S. 1999 *Perspectives on Coastal Zone Managment.* Springer Verlag, Berlin, 386 pages.

Seeliger, U. and Costa, C.S.B. 1997 Chapter 10: Human and natural impacts. Pages 197-203 in Seeliger, U., Odebrecht, C. and Castello, J.P. (eds): *Subtropical convergence environments: the coast and sea in the southwestern Atlantic* . Springer-Verlag, Berlin, 308 pages.

Seeliger, U. 1997 *Coastal plant communities in Latin America.* Academic Press, San Diego, 432 pages.

Seeliger, U., Lacerda, L.D. and Patchineelam, S.R. 1988 *Metals in coastal environments of Latin America.* Springer Verlag, Berlin, 297 pages.

Seeliger, U., Odebrecht, C. and Castello, J.P. 1997 *Subtropical convergence environments: the coast and sea in the southwestern Atlantic.* Springer Verlag, Berlin, 308 pages.

Silva, N.S., Guzman, D.Z. and Veldenegro, A.M. 2000 Chile estuarine systems: Aysen Sound. Pages 55-64 in Smith, S.V., Dupra, V., Marshall Crossland, J.I. and Crossland, C.J. (eds): Estuarine systems of the South American region: carbon, nitrogen and phosphorus fluxes. *LOICZ Reports and Studies* No. **15**, LOICZ, Texel, the Netherlands, 87 pages.

Sinque, C. and Muelbert. J.H. 1997 Ichthyoplankton. Pages 51-56 in Seeliger, U., Odebrecht, C. and Castello, J.P. (eds): *Subtropical convergence environments: the coast and sea in the southwestern Atlantic* . Springer-Verlag, Berlin, 308 pages.

Smith, S.V., Dupra, V., Marshall Crossland, J.I. and Crossland, C.J. 2000 Estuarine systems of the South American region: carbon, nitrogen and phosphorus fluxes. *LOICZ Reports and Studies,* No. **15**, LOICZ, Texel, the Netherlands, 87 pages.

Soares Filho, A.A. and Alves, M.I.M. 1996 Peixes do estuario do Rio Jaguaribe (Ceará-Brasil): Aspectos fisioecológicos. *Ciência Agronômica* **27**: 5-16.

SRH. 1998 Secretaria de Reucrsos Hídricos, Estado do Ceará. Bacias Hidrográficas. Tabelas fluviometricas e pluviométricas. http://www.shr.gov

SUPRG 1996 *Arquivos da Superintendência do Porto de Rio Grande.* Rio Grande (RS).

Talaue-McManus, L., Kremer, H.H. and Marshall Crossland, J.I. 2001 SARCS/WOTRO/LOICZ: Biogeochemical and human dimensions of coastal functioning and change in Southeast Asia. Final report of the SARCS/WOTRO/LOICZ project 1996-1999. LOICZ *Reports & Studies* No. **17**, LOICZ, Texel, the Netherlands, ii+277 pages.

Turner, R.K, Adger, N.W. and Lorenzoni, I. 1998 Towards integrated modelling and analysis in coastal zones: principles and practices. *LOICZ Reports and Studies* No. **11**. LOICZ, Texel, the Netherlands, 122 pages.

Turner, R.K. and Bower, B.T. 1999 Principles and benefits of integrated coastal zone management (ICZM). Pages 13-34 in Salomons, W., Turner, R.K., Lacerda, L.D. and Ramachandran, S. (eds): *Perspectives on Coastal Zone Managment.* Springer Verlag, Berlin.

Tutivén, I.U. 2000 Ecuador estuarine systems: Gulf of Guayaquil. Pages 51-54 in: Smith, S.V., Dupra, V., Marshall Crossland, J.I. and Crossland, C.J. (eds): Estuarine systems of the South American region: carbon, nitrogen and phosphorus fluxes. *LOICZ Reports and Studies*, No. 15, LOICZ, Texel, the Netherlands, 87 pages.

Valentini, E. 1996 Um modelo de balanço sedimentológico para o litoral do Ceará. Pages 251-259 in: *Anais do II Encontro Nacional de Engenharia de Sedimentos, Rio de Janeiro.*

Veiga, M.M. 1997 *Introducing new technologies for abatement of global Mercury pollution in Latin America.* UNIDO/CETEM, Rio de Janeiro, 94 pages.

Vernette, G. 1985 Le plataforme continentale caribe de Colombie (du débouche du Magdalena au Golfe de Morrosquillo): importance du diapirisme argileux sur la morphologie et la sedimentation. *PhD Dissertation, Universite de Bordeaux, Talence,* 387 pages.

Violante, R.A., Parker, G. and Cavallotto, J.L. 2001 Evolución de las llanuras costeras del este bonaerense entre la bahía Samborombón y la laguna Mar Chiquita durante el Holoceno. *Revista de la Asociación Geológica Argentina* **56**(1): 51-66.

Watras, C. and Huckabee, H. 1994 *Mercury pollution: Integration and synthesis.* Lewis Publ. Boca Raton, 727 pages.

Weibezahn, F.H., Alvarez, H. and Lewis, W.M. 1990 *The Orinoco River as an ecosystem.* Impressos Rubel CA, Caracas 430 pages.

Wells P.G. and G.R. Daborn. 1997 *The Río de la Plata. An Environmental Overview.* An EcoPlata Project Background Report. Dalhousie University, Halifax, Nova Scotia. 248 pages.

Yunes , J.S, Salomon, P.S., Matthiensen, A., Beattie, K.A., Raggett, S.L. and Codd, G.A. 1996 Toxic bloom of cyanobacteria in the Patos Lagoon estuary, southern Brazil. *Journal of Aquatic Ecosystem Health* **5**: 223-229.

Appendix I Meeting Report

The South American Basins (**SAmBas**) assessment and synthesis was carried out in two phases. A first, general workshop (**SAmBas 1**) was held in Bahia Blanca, Argentina in November 1999, in association with the 4th LOICZ Open Science Meeting. A second workshop, SAmBas 2, held in Fortaleza, Brazil in May 2001 refined the assessment and focussed on the human dimension. SAmBas 2 also worked towards a sound scientific basis on which to develop project proposals addressing indicators for coastal monitoring as well as river-based and coastal management issues. The SAmBas network was expanded in this second phase involving new participants from the west coast of South America and socio-economic experts.

SAmBas 1

SAmBas I was held in Bahia Blanca, Argentina, on 11-13 November 1999, with participants staying on for the subsequent 4th LOICZ Open Science Meeting. There, international exchange with other basins-related studies was continued and a working group on basins issues in island-dominated regions was set up. This resulted in the LOICZ Caribbean Basins study, CariBas, and a desk study on the South Pacific region. The island working group recommended to investigate closer links to initiatives of UNESCO/IOC, namely the C-GOOS (Coastal module of the Global Ocean Observing System) and the ICAM (Integrated Coastal Area Management) programme. Terms of reference, participants, the agenda and important acronyms are given in the appendix to this report jointly with SAmBas 2 information.

Following the official opening of this first SAmBas workshop by Prof. Gerardo Perillo and Prof. Wim Salomons, Dr Hartwig Kremer provided the background to the global **LOICZ Basins** project, its goals and perspectives, then Wim Salomons followed with a detailed outline of the scientific approach taken in assessment and synthesis of the "human dimensions" of flux changes to the coastal sea. In order to achieve the integration needed in such a regional assessment, the group made reference to the LOICZ Integrated Modelling Guidelines (Turner *et al.* 1998, www.nioz.nl/loicz/) which stresses the applicability of the Drivers, Pressures, State, Impact, Response framework, DPSIR. This was introduced by OECD in the early 90's and subsequently developed further within LOICZ (particularly the Basins program) as a means of standardise cross disciplinary regional analysis. It ultimately allows combination of results from the natural and social sciences as well as investigation of feedback from and to policy/management.

In two working groups led by Profs. D. de Lacerda and B. Kjerfve relying mainly on existing data, the drivers–pressures–state and state change information was reviewed and compiled for countries such as Colombia, Venezuela, Brazil, Uruguay (partly) and Argentina. Key aspects addressed:

- major coastal issues in the South American coastal zone;
- material flow to the coastal zone of water, sediments, nutrients and priority substances (past, current, future trends);
- socio-economic drivers which have changed or will change these material flows; and
- indicators for impacts on coastal zone functioning from which to derive an approximation of distances of system states and fluxes from "critical thresholds" for coastal functioning.

Horizontal flux and retention models as applied in Europe (MONERIS) were presented and considered for application in the region, and case studies with similar key questions e.g., the Mississippi system. Emphasis was also directed towards the development of classifications and qualitative ranking for river catchment-coastal system classes and the degree of pressures, observed change and expected trends in systems of various catchment size. It was pointed out, however, that this aspect needed further work and would become a major objective of the second phase workshop to be conducted after 1 or 1.5 years, when this first regional assessment would be refined to enable better comparability with **LOICZ Basins** analysis elsewhere and to improve the set of potential entry information for the LOICZ typology effort.

Key outcomes and findings from the workshop:

The regional assessment conducted in Bahia Blanca provided a comprehensive overview of the current understanding of catchment–coastal sea interaction in South America. Using geomorphologic and hydrologic characteristics, the working groups provided an initial classification of the river systems into four catchment size sub-categories (large, medium, small active and small passive). Drivers, pressures, state changes and especially potential coastal impacts were reviewed and analyzed against these sub-categories. Information was provided to the best currently available level.

The DPSIR scheme was evaluated and applied to standardize the descriptive approach and enable cross-regional comparison. Scales varied from catchment via country to sub-regional level, acknowledging that the large stream systems inherently provide a sub-regional perspective of coastal issues due to catchment size and run off and – regarding the response – the transboundary issues involved.

A first set of qualitative typological classes of drivers and changes was developed and again reviewed against the catchment size based sub-classes of river–coast systems. The information compiled in this process will be developed further to an "expert-classification" of the regional systems and their change under various forcing in a second step (SAmBas 2). Ultimately the DPSIR-based ranking is expected to form an interface to the joint LOICZ/BAHC typology, a tool continuously developed for interregional and global comparison of scenarios, visualization and upscaling. Among the features considered were:

- Coastal geomorphology
- Coastal habitats/biodiversity
- Climate influence
- People relationships (demography and drivers)
- Catchment size and seasonal runoff features
- Land use and cover characteristics

It was agreed to provide a regional synthesis in the format of a LOICZ Reports & Studies Volume, by distilling the information from an improved set of **LOICZ Basins** assessment tables. Those are to be produced based on the global set of first regional workshops by the **LOICZ Basins** principal network members. **SAmBas 1** provided an important starting point for this development.

Products from **SAmBas 1** (as approved in the closing plenary discussion):
- A multiauthor LOICZ Meeting Report providing a first regional picture, designed along the DPSIR framework and setting the stage for the refined synthesis and proposal development in a second workshop. The refined regional assessment is to become an entry into the first global LOICZ synthesis book at end 2002;
- A first indication of information needs and gaps in understanding, such as descriptions of systems along the west coast and, more generally, the socio-economic dimensions as well as a list of sites with negative trend expectations - "hot spots". This information, together with suggestions on templates for future project design will form the basis of the terms of reference for the second regional assessment workshop. (Combination and potential for a final link to similar activities in the Caribbean under the LOICZ frame – CariBas – were considered)

The workshop was hosted by the Instituto Argentino de Oceanografia in Bahia Blanca, Argentina. LOICZ is grateful for this support and indebted to Dr Gerardo Perillo and Institute staff, and to the resource scientists for their contributions to the success of the workshop. LOICZ gratefully acknowledges the efforts and work of the participants not only for their significant contributions to the **SAmBas** goals, but also for their continued interaction beyond the meeting activities.

SAmBas 2

An introduction to the Land Ocean Interactions in the Coastal Zone, LOICZ, core project of the International Geosphere Biosphere Project, IGBP, given by Dr Hartwig Kremer provided the background of the second global **LOICZ Basins** assessment of catchment/coastal sea interaction and human dimension studies in South America. Developments made in the methodology since **SAmBas 1** in 1999 were presented, in particular the standardised regional assessment tables developed for global application in the **LOICZ Basins** core project. The strong focus on driver/pressure and response aspects characterising the evaluation of changes reflected the increasing recognition of community issues in the LOICZ work.

Major thrust for the **LOICZ Basins** project came from the recommendations and commitment of participants of the 4th LOICZ OSM.

Profs Drude Lacerda and Bjoern Kjerfve summarised the key findings of the first meeting (see above and Meeting Report No. 37 – LOICZ 2001) and the IOC representative Julian Barbière outlined the relevance of the **LOICZ Basins** approach and findings for the global efforts of UNESCO/ IOC in their Integrated Coastal Area Management, ICAM and C-GOOS initiatives. The results generated on regional levels and in particular the pilot studies to be addressed in future research under the aegis of a continued LOICZ would certainly prove valuable sites within IOC's networks. IOC will support further development of **SAmBas**-related project proposals in South America.

A detailed introduction provided the background and scientific rationale of the key questions leading through the set of seven assessment tables. Dr Kremer, Prof. Lacerda and Dr Horst Behrendt (member of the **LOICZ Basins** task team) explained the input expected for each of the tables and how to process available information for upscaling from local to regional (sub-continental) scales. Critical loads and thresholds were emphasised. These allow determination of the current state of coastal systems in the context of expected trends of change and, where information is sufficient, the derivation of semi-quantitative measures of critical loads status and metrics needed for sustained system functions.

Presentations of catchment–coast biogeochemical and socio economic information
The key LOICZ questions posed were:

- 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?

Site descriptions and regional synthesis were provided for river/coast systems in various sub-regions, including:

Pacific coast
Southern Pacific Coast (Chile)
Central Pacific Coast (Chile/Peru/Ecuador)
Northern tropical Pacific Coast (Colombia/Ecuador)

Caribbean coast

North East Brazil (sub tropical Atlantic)

Central Brazilian coast (Guanabara and Sepetiba Bay)

La Plata region Atlantic coast (SE Brazil, Uruguay, Argentina)

SE Atlantic, Argentina – Patagonia

In two breakout groups addressing separately the Atlantic and Pacific coasts of South America, the draft versions of assessment tables produced prior to the meeting were revised and amended taking into consideration both the results of the **SAmBas I** workshop and new information. Gaps from the first phase were the lack of information on west coast systems and on socio-economic issues. Special attention was paid to indicators and critical loads. While there is some information on fluxes and land-use patterns, in some cases covering more than five decades of data-sampling, indicators reflecting human development and its influence on water and material transports are rather scarce. However, methods and potential solutions for this problem were discussed in detail (see Bidone and Lacerda, this report).

The participants identified demonstration sites for continued **SAmBas** work that could be subject of a future interdisciplinary investigation. Following the same sequence of sub-regions as given above those are:

- the Bio Bio, Guayas and Chaira rivers in Chile and Ecuador;
- the San Juan and Patia rivers in Colombia;
- the Magdalena River system in Colombia;
- the Ceará, Jaguaribe and São Francisco rivers, Guanabara and Sepetiba bays and the Patos Lagoon estuary and wider la Plata region;
- Rivers in Patagonia, to address the serious issues of erosion driven by damming and urbanisation in an area with relatively low population density.

Outcomes and Wrap-up

- Assessment tables including the latest information available to the participants (Appendix III) were produced, covering sites as well as sub-regional and regional scales. Trend information on future changes and the current status of response were included where possible. Limited critical load/threshold information was provided for some sites.
- The meeting agreed to produce a multi-author LOICZ R&S, providing first regional pictures designed along the DPSIR framework. Expansion of the extended executive summaries submitted so far (see contributed papers) to full scientific publication for joint publication in the peer-reviewed journal "Regional Environmental Change" by Springer publishers were welcomed by the participants.
- The **SAmBas** network has encouraged the development and design of regional proposals for holistic future work. This work (and task proposals) will be promoted through LOICZ working closely with UNESCO/IOC. Earlier work conducted along these lines such as the SARCS/WOTRO/LOICZ project in South East Asia and the European **Basins** follow up project "**EuroCat"** will provide a sound template for the draft of a "SAmCat". Prof. Lacerda agreed to coordinate this effort in the region. The meeting agreed further to pursue formal and/or operational links to ongoing international efforts such as the ICAM (Integrated Coastal Area Management) and GOOS (Global Ocean Observation System) of UNESCO/IOC, providing ways for global application and use of the outcomes.

SAmBas and the LOICZ IPO expressed their special thanks to Prof. Drude Lacerda and his team for the excellent organization, support and hosting of this second phase of SAmBas. Financial support from the Brazilian Science Foundation, CNPq, UNESCO/IOC and LOICZ was gratefully acknowledged.

Appendix II Participants and contributing authors - LOICZ SAmBas I and II

ARGENTINA

Pedro J. Depetris (SAmBas I&II)
Universidad Nacional de Córdoba
Facultad De Ciencias Exactas, Fisicas y Naturales;
CIGES-FCEFyN,
V. Sarsfield 299,
5000 Cordoba, Argentina
Phone: +54-351-4332114
Fax: +54-351-4332097
pdepetris@com.uncor.edu
pdepetris@powernet.com.ar

Diego M.Gaiero (SAmBas I)
Universidad Nacional de Córdoba
Facultad De Ciencias Exactas, Fisicas Y Naturales;
CIGES - Centro de Investigaciones Geoquímicas y de Procesos de la Superficie
Avda. Vélez Sarsfield 299,
5000 Córdoba, Rep. Argentina
Phone: +54 (0)351 433 2114,
Fax +54 (0)351 433 2097
dgaiero@gtwing.efn.uncor.edu

Jorge Marcovecchio (SAmBas I)
Laboratorio de Quimica Marina, Instituto Argentino de Oceanografia (IADO), Florida, 4000, Edificio E1,
8000 Bahia Blanca, Argentina.
Phone: + 54 291-486-1112,
Fax: + 54 291-486-1112
jorgemar@criba.edu.ar

BRAZIL

Cristovam Barcellos (SAmBas I)
Fundação Oswaldo Cruz,
Rio de Janeiro, RJ, Brazil
christovamb@hotmail.com

Norton Mattor Gianuca
Universidade do Rio Grande,
Departamento de Oceanografia,
Caixa Postal, RS, 96201-900, Brazil
Phone: +55-053-2336522,
Fax: +55-053-2336601
docngian@super.furg.br

RozaneValente Marins (SAmBas II)
Laboratório de Geologia Marinha e Aplicada,
Universidade Federal do Ceará, Campus do Pici,
Fortaleza, Ceará, 60455-9790, Brazil
Fax. +55 85 268 3205
rmarins@ufc.br

BRAZIL

Edison D. Bidone (SAmBas II)
Departamento de Geoquimica
Universidade Federal Fluminense
Niteroi, Rio de Janeiro 24020-007
Brazil
Phone: +55 21 7174189
Fax: +55 21 6207025/7174189
geobida@vm.uff.br

Rozane Marins (SAmBas II)
Dept. Geologia
Universidade Federal do Ceará, Campus do Pici
Bl. 912, Fortaleza, CE, 60455-970,
Brazil
Phone: +55 85 288 9868
Fax: +55 85 268 3205
rmarins@ufc.br

Mauricio Mussi Molisani (SAmBas II)
Departamento de Geoquimica,
Universidade Federal Fluminense
Niteroi, Rio de Janeiro 24020-007
Brazil
Phone: +55 21 7174189
Fax: +55 21 6207025/7174189
mussi@geoq.uff.br

Heloísa Helena Moreira Paraquetti (SAmBas II)
Departamento de Geoquimica, Universidade Federal Fluminense,
Niteroi, Rio de Janeiro, 24020-007
Brazil
Phone: +55 21 7174189
Fax: +55 21 6207025/7174189
paraquetti@ig.com.br

Luiz Drude de Lacerda (SAmBas I&II)
Currently:
Rua Joaquim Nabuco 275, apto. 102, Meireles,
Fortaleza, CE, 60125-120
Brazil
Phone: +55 852683205
Fax: +56 852683205
ldrude@fortalnet.com.br

permanent address:
Dept. Geoquímica, Universidade Federal Fluminense,
Niteroi,
Rio de Janeiro, 242020-007

Luiz Parente Maia (SAmBas II)
Dept. Geologia, Universidade Federal do Ceará,
Campus do Pici
Bl. 912, Fortaleza, CE, 60455-970
Brazil
Phone: +55 85 2889868
Fax: +55 85 2873360
Parente@ufc.br

José Pedro Rebes Lima (SAmBas II)
Dept. Geologia, Universidade Federal do Ceará,
Campus do Pici
Bl. 912, Fortaleza, CE, 60455-970
Brasil

Phone: +55 85 2889868
Fax: +55 85 2683205
rebes@ufc.br

Ulrich Seeliger (SAmBas II)
Dept. Oceanografia, Universidade Federeal do Rio Grande,
Av. Italia KM8,
96201-900 Rio Grande – RS.
Brasil
Phone: +55 53 2336583
Fax: +55 53 2336600
uli@ecoscientia.com.br

Cesar Serra B. Costa (SAmBas II)
Dept. Oceanografia, Universidade Federeal do Rio Grande,
Av. Italia KM8,
96201-900 Rio Grande – RS.
Brazil
Phone: +55 53 2336583
Fax: +55 53 2336600
uli@ecoscientia.com.br

George Satander de Sá Freire (SAmBas II)
Dept. Geologia, Universidade Federal do Ceará,
Campus do Pici,
Bl. 912, P.O. Box 6011, Fortaleza, CE, 60455-970,
Brazil
Phone: +55 85 2889868
Fax: +55 85 2873360
freire@ufc.br

Renato Sales (SAmBas II)
Universidade de São Paulo,
Avenida Angelica 1106, Ap.141
CEP 1228-100, Sao Paulo,
Brazil
Phone: +56 11 3666 3081
Fax: +56 11 381 358 19
rivabendesales@uol.com.br

Wilson Thadeu Valle Machado (SAmBas II)
Departamento de Geoquimica, Universidade Federal Fluminense
Niteroi, Rio de Janeiro, 24020-007
Brazil
Phone: +55 21 7174189
Fax: +55 21 6207025/7174189
wmachado@geoq.uff.br

CHILE
Giovanni Daneri (SAmBas II)
Director, Centro de Ciencias y Ecologia Aplicada (CEA)
Universidad del Mar
Carmen 446, Cerro Placeres
Valparaíso, Chile
Phone: +56 (0)32 501846
Fax: +56 (0)32 798731
gdaneri@udelmar.cl

Hugo Salgado (SAmBas II)
Departamento de Economía,
Universidad de Concepción, Casilla 1987, Correo 3,
Concepción,
Chile
Phone: +56 41 203207 – 204 200 – 204 503
Fax: +56 41 254 591
husalgad@udec.cl

COLOMBIA
Leonor Botero (SAmBas I)
Jefe, Programa Nacional de Ciencia y Tecnología del Mar,COLCIENCIAS
Trans. 9 A # 133-28, Santafé de Bogotá,
Colombia
Phone: +57-1 216 9800,
Fax: + 57-1 625 1788
lbotero@colciencias.gov.co

Jaime Polania (SAmBas I)
Instituto de Estudios Caribeños, Universidad Nacional de Colombia sede San Andres,
Carretera circunvalar de San Luis,
sector Free Town 52-44, San Andres Isla,
Colombia
Fax: +57-8 513 1281
jhpolanv@bacata.usc.unal.edu.co

Juan D. Restrepo (SAmBas II)
Currently: Ph.D. Candidate, Marine and Geological Sciences
University of South Carolina
Columbia, SC 29208
USA
Phone: +1 803-777-4529
Fax: +1 803-777-4600
restrepo@geol.sc.edu
permanent address:
Area de Ciencias del Mar,
Universidad EAFIT,
Medellin,
Colombia, A.A. 3300

ECUADOR
Rodney Martínez Güingla (SAmBas II)
Subdirector Cientifico
Instituto Oceanográfico de la Armada del Ecuador, INOCAR
P.O. Box 5940, Guayaquil
Ecuador
Phone: +593 44811085;
+593 4808618 (domicilio)
Fax: +593 4485166
cdmbac@inocar.mil.ec

FRANCE
Julian Barbière (SAmBas II)
Intergovernmental Oceanographic Commission (IOC)
UNESCO, (ICAM and GOOS initiatives)
1 rue Miollis
F-75732 Paris Cedex 15
France
Phone: +33 1 45 68 40 45
Fax: +33 1 45 68 58 12
j.barbiere@unesco.org

Jean Benaim (SAmBas II)
RCMO, Universite de Toulon, La Garde
BP 132
F-83957 Toulon Cedex,
France
Phone: +33 494 142 306
Fax: +33 494 142 168
benaim@univ-tln.fr

Stephane Mounier (SAmBas II)
RCMO, Universite de Toulon, La Garde,
BP 132,
F-83957 Toulon Cedex,
France
Phone: +33 494 142 492
Fax: +33 494 142 057
mounier@univ-tln.fr

GERMANY
Horst Behrendt (SAmBas I&II)
Institute of Freshwater Ecology and Inland Fisheries,
Dept of Flatland Rivers and Shallow Lakes
Müggelseedamm 310,
D-12587 Berlin,
Germany
Phone: +49 30 641 816 83
Fax: +49 30 641 817 99
behrendt@igb-berlin.de

Frederico Foders (SAmBas I)
Kiel Institute of World Economics
Duesternbrooker Weg 120
D-24105 Kiel
Germany
Phone: +49-431-8814-285 /281
Fax: +49-431-85853
ffoders@ifw.uni-kiel.de

NIGERIA (during SAmBas I at GKSS, Germany)
Olasumbo Martins (SAmBas I)
College of Evironmental Resources Management
University of Agriculture
P.M.B. 2240, Abeokuta
Ogun State, Nigeria
martins@skannet.com

NETHERLANDS
Hartwig Kremer (SAmBas I&II)
LOICZ International Project Office, Netherlands
Institute for Sea Research,
P.O. Box 59,
NL-1790 AB Den Burg, Texel,
The Netherlands
Phone: +31 222 369 427
Fax: +31 222 369 430
loicz@nioz.nl
kremer@nioz.nl

Wim Salomons (SAmBas I)
Free University Amsterdam
Institute for Environmental Studies
De Boelelaan 1115
1081 HV Amsterdam
The Netherlands
Phone: + 31-50 5349165,
Fax: + 31-50 5349931
wim.salomons@home.nl

URUGUAY
Jaime R. Cantera K. (SAmBas II contr.)
Freplata Project, Administracion Nacional de Puertos,
Rambla 25 de Agosto de 1825, No 160
Piso 5 Oficina 502
11.000 Montevideo
Uruguay
freplatajc@netgate.com.uy

Adriana Jorajuria (SAmBas I)
Proggrama ECOPLATA,
Pza. Cagancha 1335, of. 217,
11100 Montevideo
Uruguay
Phone: +598 2 900 2602
Fax: +598 2 901 1800
joca@gcien.edu.uy

USA
Jeremy D. Bartley (SAmBas II)
Kansas Geological Survey, University of Kansas,
1930 Constant Avenue
Campus West
Lawrence, Kansas 66047-3720
USA
Phone: +1 785 864 2112
Fax: +1 785 864 5317
jbartley@kgs.ukans.edu

Björn Kjerfve (SAmBas I&II)
Marine Science Program,
University of South Carolina,
Columbia, South Carolina 29208
USA
Phone: +1-803-777 2572
Fax: +1-803-777 4600
Email: bjorn@geol.sc.edu

William K. Michener (SAmBas II)
LTER Network Office, Department of Biology
University of New Mexico
Albuquerque, NM 87106
USA
Phone: +1 505-272-7831
Fax: +1 505-272-7080
wmichene@LTERnet.edu

Nancy N. Rabalais (SAmBas I)
Louisiana Universities Marine Consortium
8124 Hwy 56
Chauvin, LA 70344
USA
Phone: +1-504-851-2800, 2836
Fax: +1-504-851-2874
nrabalais@lumcon.edu

VENEZUELA

Heriberto Echezuría (SAmBas I)
PDVSA-Intevep, Petróleos de Venezuela S.A.,
Apartado 76343,
Caracas 1070 A
Venezuela
Phone: + 58-2-9087407/6065137,
Fax: +58-2-9087756
echezuriah@pdvsa.com

Appendix III Workshop Agenda

South American Basins II (SAmBas II), Fortaleza, Brazil, 2-5 May 2001.

(for SAmBas I agenda refer to LOICZ Meeting Report No. 37, LOICZ IPO, Texel, The Netherlands)

Wednesday 2nd May
9:00 – 9:30 Registration
9:30 – 10:00 Opening Session:

Local Host and IGBP/LOICZ, IPO	Prof. Drude Lacerda, Dr Hartwig Kremer
Regional task leaders	Prof. Drude Lacerda, Prof. Björn Kjerfve;
IOC/UNESCO representative	Dr Julian Barbiere

10:00 – 11:00 Introduction (Prof. Drude Lacerda, Dr Hartwig Kremer)

- **LOICZ Basins**: background, approach, results of other regional **Basins** activities (briefly), products, timelines and outlook
- Status and achievements of South American **Basins**
- Links to international organisations here: IOC/UNESCO.

11:00 – 11:15 Coffee Break

11:15 – 11:45 1. Plenary Session on Typology and upscaling

- Introduction (if possible online) in the LOICZ Typology and LOICZVIEW software
- Parameterisation and ranking of BASINS information for upscaling and comparison

11:45 – 12:30 2. Plenary Session on Coastal Issues, Drivers, Pressures and State/State-Changes in South America – overview of SAmBas I results and gaps:

- The regional assessment of SAmBas I;
- what are gaps and needs to refine the synthesis? – brief introduction into assessment tables;
- Discussion

12:30 – 14:00 Lunch (same time each working day)

14:00 – 15:30 3. Working groups on Coastal Issues, Drivers, Pressures and State/State-Changes in South America –assessment tables 1-7 (with 10 minutes plenary introduction).

The Groups will workshop through the regional assessment tables distributed prior to the workshop; new information, rank-orders, refined regional synthesis and gaps will be addressed along the following steps:

- Background of the tables, how they have been developed;
- how to fill in the tables and synthesise on various scales, subject to what has been provided to the meeting in preparation;
- organisation of breakout groups (along division of the coastal zone by sub-regions);

Assessing and ranking Issues/Impacts (critical thresholds) based on coastal change in the region (Assessment Table 1).

Key questions:

- What are the major **Impacts** (Coastal issues) on the coastal zone and do we know anything on
- How close they are to a **critical threshold** of system functioning?

Assessment, synthesis and ranking of (maximum 10) major **Driver/Pressure** settings generating the coastal **Impact**/Issues (Assessment Table 2)

Key questions:

- What are major (max. 10) catchment-based driver/pressure settings causing coastal change?

- Can we identify spatial scales on which certain driver/pressure settings dominate coastal issues (e.g. land-based coastal impact the level of which is determined by the size of the catchment)?

Assessment, synthesis and up-scaling of links between coastal issues/impacts and land based pressures and drivers on catchment, sub regional and full regional scale (Assessment Tables 3 - 5).

Key questions:
- What are the major Driver/Pressure settings causing coastal impact observed and what are the future trends (expert judgement) on local or catchment level?
- on sub-regional (or island) level?
- on full regional or sub-continental level?
- Can we derive a first expert typology of catchment-coast interaction and human dimensions in South America?

15:30 – 15:50 Tea Break (same time each working day)

15:50 – 17:00 4. Working groups on Coastal Issues, Drivers, Pressures and State/State-Changes in South America – Assessment Tables 1-7 continued:

Assessment of scientific and/or management **Response** on the various scales. Identification of major regional hot spots and gaps in understanding to be addressed by further investigations in an holistic multidisciplinary scientific project (Tables 6 – 7).

Key questions:
- Given the issues identified, what is the current status of response taken on scientific or policy/ management levels on local, sub-regional and regional scales?
- What are major gaps in our current understanding of river catchment – coastal sea interaction and which hot spots should be addressed in a future integrated scientific effort/proposal including natural science and socio economic disciplines?

17:00 – 17:30 5. Plenary Session on Coastal Issues, Drivers, Pressures and State/State-Changes in South America – reporting back from the working groups
- chairs/rapporteurs give a short report
- discussion

Thursday 3rd May

09:00 – 10:45 1. Plenary Session – Socio economic aspects of catchment – coastal sea interaction – the human dimensions of land-based coastal change:
- presentations from the socio-economics experts

11:00 – 11:45 2. max. 3 breakout groups (Chairs & Rapporteurs: TBA):
- revisit the tables against the new information on human dimensions (drivers, feed-back, critical loads and indices of change and trends)

11:45 – 12:30 3. Plenary: Reporting back of the working groups: Response, research needs and potential methodologies (available data) in view of human dimensions
- the first full regional assessment results and ways ahead
- drawing a qualitative and/or semi-quantitative picture of change and impact affecting South American catchment-coast systems;
- leading to the proposal development

14:00 – 14:45 4. Plenary discussion on hot spots and proposal
- Discussion – response success and failure, classes of change, where to set up pilot sites,
- Links and synergies with IOC C-GOOS and ICAM,
- potential templates for project design (other **Basins** studies such as **EuroCat**, SWOL),

- plenary approval on suggested sites and studies.

14:45 – 15:30 5. Breakout groups **SAmBas** proposals (Chair & Rapporteur: TBA):

- developing/refining the suggestions for demonstration project/s and drafting a first design for the "**SAmCat**" studies.

15:50 – 16:30 6. Breakout groups continued:

- developing/refining the suggestions for demonstration project/s and drafting a first design for the studies

16:30 – 17:00 7. Reporting back from the drafting process

Friday 4th May

09:00 – 09:15 1. Morning Plenary

- first 15 minutes: short recall of the previous day (e.g., presentation of tables short explanations).

09:15 – 12:30 2. Breakout groups **SAmBas** proposals (Chair & Rapporteur: TBA):

- finishing the first draft of a design for the future **SAmCat** study.

14:00 – 14:45 3. Afternoon Plenary

- review and discussions on the first draft proposals from the working groups.

14:45 – 16:30 4. Breakout groups **SAmBas** proposals continued (Chair & Rapporteur: TBA):

- refining the first draft for the future study

16:30 – 17:00 5. Plenary

- Reporting back and discussion on potential funding agencies and funding mechanisms to be considered

Saturday 5th May: Proposals, study design, implementation and workshop results

09:00 – 10:45 1. Plenary:

- Chairs and rapporteurs to report back from the working groups and presenting of the study proposals, discussion (also with IOC representatives)
- Discussion:
  What, Why (Regional and Global Relevance), Where, How, (incl. Structure),Who, (identify coordinators and get commitment to finish and submit proposal/s), Funding, Timelines.

11:00 – 12:30 2. Final Plenary

- Approval of products, proposal suggestions, commitments and timelines by the plenary
- Strengthening the South American **Basins** Network
- Conclusion (synthesis and proposals) and Outlook
- Closure of the meeting

Afternoon - departure of participants (key persons local and external to continue drafting the report).

Appendix IV Terms of Reference

LOICZ South American Basins (SAmBas) II

South American River Catchment–Coastal Zone Interaction and Human Dimensions

Fortaleza, Universidade Federal do Ceará, Brazil, 2-5 May 2001

(for TOR of SAmBas I, see LOICZ Meeting report No. 37, LOICZ IPO, Texel, The Netherlands)

Introduction - the LOICZ Basins background

Discussion on global change issues in coastal zones and integrated coastal management focuses increasingly on the interplay between river catchments and the coastal sea. Coastal zone processes and issues are considered to be a systemic i.e., receiving, part of a water continuum. The International Geosphere Biosphere Programme, IGBP, has responded by concentrating effort on the human dimension of global change issues within the whole water cascade. Parts of this issue is being addressed by LOICZ through the **LOICZ Basins** core project. This workshop aims to refine results and undertakings developed in the earlier **SAmBas 1** workshop, held in Bahia Blanca (November 1999) and to extend the basin assessments and develop appropriate regional research proposals.

Specific Workshop Objectives

1. Review, complete and/or develop further, the **system state reports** of river catchment – coastal sea interactions developed in Bahia Blanca 1999 which set up a first qualitative or semi-quantitative system to **categorise** key pressures and state change settings, providing an **indexed data entry** for upscaling purposes (see 2);
2. **Scale up the information** to regional and global levels via developed index system by identifying and clustering areas of similar change features.

   Due to the large differences in coastal change, uses, management status and legislation among the different countries participating in South American **LOICZ Basins**, upscaling in a typology approach may not be a simple exercise. Identifying **simple proxies for coastal change** observed and adapting and optimising them to the regional reality should also constitute a major objective of the present workshop.
3. Provide the regional data and information base for **an inter-regional/global LOICZ Basins project synthesis** by late 2001, aiming to summarize the available regional information to a first *global LOICZ Basins synthesis.*
4. Review, based on earlier and new assessment information, the set of pilot areas discussed in Bahia Blanca and identify possible new ones. This is aimed at **developing proposals** for specific case studies that integrate natural and socio-economic sciences and elaborate on the "human dimensions" of global change in the catchment – sea water continuum;
5. **Strengthen a regional South American LOICZ Basins network** to continue the science and synthesis and to strengthen existing and seek new **links** to other regional and international projects and organisations e.g., UNEP, GIWA, **UNESCO/IOC (GOOS and ICAM)** and START. This will be facilitated through the LOICZ platform; but will only be possible with the involvement of national scientific programs and agencies.

Focus of workshop:

To achieve the objectives outlined the workshop will follow the framework of the DPSIR scheme. The process of *assessment, analysis, categorisation and indexing* will make use of a tabulated approach which is also being applied in other regional **LOICZ Basins** studies to assist global evaluation.

For clarification of nomenclature in the DPSIR scheme as a descriptive framework:
Catchment-based activities (land use and land use change) with consequences for the coastal zone are **(DRIVERS)** such as:

- Effects of damming and other huge constructions;
- River diversion and effects of irrigation and water supply activities (abstraction);
- Influence of industrial, agricultural and domestic wastes (urbanisation);
- Mining activities;

DRIVERS cause **PRESSURES** on ecosystem and social system functioning, affecting and changing the **STATE** of the coastal environment due to natural and anthropogenic forcing. This follows the guidelines of the LOICZ research approach, considering:

- Water, nutrient and sediment transportation throughout the catchments as key indicators for change across the boundaries of the water pathway. (Indicators are designed to give an overview of the environmental status and its development over time and finally allow the development of the critical load information and index systems linked to pressures);
- Geomorphologic settings, erosion, sequestration (retention times in catchments); and
- Economic fluxes relating to changes in resource flows from coastal systems, their value and changes in economic activity

IMPACTS, which are observed effects on coastal systems and how they are expressed, i.e., habitats, biodiversity, social and economic functioning and resource and services availability and use. These translate into the coastal **ISSUES** from which the assessment process embarks. And finally the

RESPONSE, reflecting action taken at management and policy levels to either protect against change, ameliorate adverse effects and ensure sustainable use of system's resources.

Products and Expectations

- ♦ The South American **LOICZ Basins** workshop in May 2001 will provide the information needed for the LOICZ *regional synthesis* and outcomes will be included in a LOICZ R&S series volume addressing the following**:**

1. Coastal impact/issues (environmental and socio economic focus)
    1.1 Development of qualitative indices
    1.2 Categorise the relevance of Impacts
2. Drivers
3. Pressures
    3.1 Development of qualitative indices
    3.2 Categorise the relevance of Pressures
4. States, State changes (fluxes, materials cycles)
5. Response
    5.1 Socio-economic and political/legal settings
    5.2 Changes of these settings
6. Regional up-scaling
    6.1 Typology development – Driver/Pressure/State/Impact/Response scenarios employing indices of the various aspects;
    6.2 Typology of the regional features;
7. Trend analysis
    7.1 Defining change - the "Delta" - of key parameters and derive first trend prediction;
8. Gaps
    8.1 Data and information gaps;
    8.2 Efforts/commitments needed to fill these gaps.

- ♦ Draft of a *research proposal* aimed at integrated cross-disciplinary, pilot studies complementing those under development within the other regional **LOICZ Basins** efforts.
  (As outlined earlier, a key criterion for selection is the potential for up-scaling, i.e., to represent a certain type of catchment - coastal sea interaction that is characteristic for a sub-region).

- Information flow into the first *global LOICZ BASINS Synthesis*, providing input for the current LOICZ Synthesis.

Workplan (tentative)

- The workshop is to be held 2-5 May 2001 in Fortaleza, Brazil;
- Background documents, (**SAmBas I** report (LOICZ Meeting Report No. 37) and LOICZ R&S No. 11 (Turner *et al.*) on Integrated Modelling and the DPSIR (see LOICZ web-page http://wwwnioz.nl/loicz/ for downloading) and a set of **LOICZ Basins** regional assessment tables (including guidelines).
- Participants are asked to **start filling the tables along the key questions** outlined prior to arrival to enable targeted synthesis work during the first half of the meeting. A draft program for the workshop will be circulated by email as well as further background information on the key questions. **LOICZ Basins** regional assessment tables will be provided with some completed examples.
- A participants list will be circulated prior to the meeting.
- The meeting will agree on timelines and approve the schedule and contents for publication and confirm the schedule of drafting (about 4 months).
- Pilot areas will be identified at the meeting and drafting of the proposals will be a participant task during the meeting – subject to agreement by the meeting.

Participants

Attendance will be limited to a maximum of 20 to 25 South American scientists, plus LOICZ resource scientists and local organisers. **Invitation and support will be based on expression of interest and agreement to this TOR.**

Concluding Note

Access to socio-economic information and input to the analysis and development of pressure–state–response indices usually turns out to be a major challenge and gap in networking. This should be a priority issue in further development. **The network is therefore encouraged to identify expertise in their region and encourage participation by such experts**.

In the process of verifying and approving demonstration sites for which to draft project proposals, emphasis will have to be put on the potential to up-scaling and management relevance as well as on broader contribution to global projects such as those coordinated by UNESCO/ IOC.

Appendix V List of important acronyms and abbreviations

ANEEL	Brazilian National Electric Energy Agency
BAHC	Biospheric Aspects of the Hydrological Cycle
BID	Inter-American Development Bank
CAAM	Environmental Advisory Commission to the Presidency of the Republic of Uruguay
CariBas	Caribbean Basins Programme
CARU	Uruguay/Argentinean Administrative Commission of the Uruguay River
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CNPq	National Research Council of Brazil
CONICET	National Scientific Investigation Research Council
CPPS	Permanent Commission for the South Pacific, Ecuador
DINAMA	National Environmental Directory, Uruguay
DPSIR	Driver-Pressure-State-Impact-Response Framework
EuroCat	European Catchment Project/part of the "European Land Ocean Interaction Studies", ELOISE cluster, DG Research
GEF	Global Environmental Facility
GOOS	Global Ocean Observing System
IAI	Inter American Institute for Global Change
ICAM	Integrated Coastal Area Management
ICZM	Integrated Coastal Zone Management
IDEAM	Institute of Hydrology, Metereology and Environmental Studies of Colombia
IGBP	International Geosphere-Biosphere Programme; A Study of Global Change
ILTER	International Long-Term Ecological Research Network
IMM	Montevideo Municipality
INAPE	National Institute of Fisheries, Uruguay
INIDEP	National Institute of Fishery Research and Development, Argentina
INOCAR	Oceanographic Institute of the Navy, Ecuador
INGEOMINAS	National Institute of Mining and Geology, Colombia
IOC	Intergovernmental Oceanographic Commission (UNESCO, Paris)
IVEMAR	Institute of Marine Research, Punta Betin, Colombia
JOPS	Brazilian-German Joint Oceanographic Programmes
LOICZ	Land Ocean Interactions in the Coastal Zone
LTER	Long-Term Ecological Research
MONERIS	Modelling Nutrient Emission in River Systems
MVTOMA	Ministry of Housing, Land Planning and the Environment, Uruguay
OSM	LOICZ Open Science Meeting
PAB	Policy Advisory Board
PMRC	Coastal Resources Management Program, Ecuador
PNGC	National Coastal Management Programme - Brazil
SAmBas	South American Basins Programme
SARCS	South Asia Committee for START
SOHMA	Uruguayan Navy Oceanographic, Hydrographic and Metereological Service
START	Global change system for Analysis, Research and Training
SWOL	SARCS/WOTRO/LOICZ – South East Asian LOICZ core project 1996-99
UFC	Universidade Federal do Ceará
UNDP	United Nations Development Program
UNEP	United Nations Environment Programme
UNESCO	United Nations Education and Cultural Organization
WOTRO	The Netherlands Foundation for the Advancement of Tropical Research
WP	Work Package