Caribbean Basins

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

with a desktop study of Oceania Basins

by

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Cover: The cover shows images of the Caribbean (B. Kjerfve) and Oceania (Rand McNally) and the DPSIR framework cycle (from Turner *et al.* 1998).

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1. Executive Summary

by Björn Kjerfve

Integrated coastal zone management is focused on impacts and solutions for local or regional sections of coasts. Land Ocean Interaction in the Coastal Zone (LOICZ) is a core project of the International Geosphere-Biosphere Project (IGBP). The Basins core project of LOICZ is developing a global evaluation of the importance of coastal oceans as receiving bodies of land- based changes material fluxes. CariBas is the LOICZ-Basins project focused on the Caribbean.

The Caribbean is an enclosed tropical sea covering 1,943,000 km². The countries of the Caribbean region range from small, low islands to continental, mountainous lands. There are vast differences in rainfall patterns, climate, landform and land use, which result in great diversity. The coastal zone of the Caribbean supports more than 100 million people in more than 25 countries and territories, with an anticipated population doubling time of 30 years at the current rate of growth. Population growth in almost all of the Caribbean threatens to overwhelm any attempt to implement rational coastal management, putting the coastal zones of the Caribbean under siege. Intense housing, industrial and tourism developments compete for the limited available space and attention from local governments and authorities. The Caribbean is culturally diverse, but with a shared history that unites the islands and the countries.

It is widely believed that much of the Caribbean region is in fairly pristine condition, and that where there are problems, they are of recent origin. Nothing could be further from the truth. Few forests in the Caribbean are "virgin", and the land has all been modified by man for at least the past 500 years. Each country has, either consciously or *de facto*, made decisions about how its lands are managed. The consequences of these decisions have left some countries wealthy and prosperous and others in poverty.

The Caribbean coastal environments consist of a myriad of interlinked open marine and coastal ecosystems in a geographically diverse setting, with mangrove wetlands, seagrass beds and coral reefs as the dominant coastal habitats, each exhibiting high productivity and rich biological diversity. Mangroves have been significantly encroached upon, cut back and filled in, especially during the past century. Virtually all of the coral reefs of the Caribbean are either in critical or threatened condition. Poor land-use practices, population growth and technological development are the major causes. With respect to each of the three important and dominant coastal ecosystems in the Caribbean, i.e. mangroves, seagrasses and coral reefs, the message is that these systems need to be managed together. The state of coastal ecosystems and their variability at 21 coastal Caribbean sites has been documented and is being monitored by the Caribbean Coastal Marine Productivity (CARICOMP) project, with standardized environmental, oceanographic and meteorological measurements made regularly at most sites for more than a decade.

River drainage basins are for the most part of comparatively small size because of the predominance of island areas, and thus impacts are characterized by a short response time from basin development activities to coastal responses as compared to the larger basins of South America. However, the Caribbean is also the receiving basin of one world class river, the Magdalena River of Colombia, by far is the largest river of Colombia and the Caribbean with a drainage basin of 257,000 km². Since changes in fluxes are mostly due to activities in river catchments, the catchment-coastal sea system is treated as one unit. Practically, this requires considerations of tourism, fisheries, agriculture, mining, urban development, industry and transport, as well as morphological modifications to the catchment, including construction of dams, irrigation and flow diversion. Changes in land cover in the Caribbean occur mostly on a short time-frame due to the relatively small size of most of the catchments, where the buffer capacity of the river catchment system is less effective than larger catchments.

Integration of natural and social science considerations requires a common framework for assessment and analysis. The LOICZ-Basins project has adopted the Driver-Pressure-State-Impact-Response (DPSIR) framework to integrate the results from the natural and social sciences with feedback to and from policy and management. The project therefore deals with the impact of human society on the material transport to the coast, including water, sediments, nutrients, heavy metals and man-made chemicals, assesses their impact on coastal systems and tries to develop rational management options.

Application of the DPSIR concept to the Caribbean indicates that sedimentation/erosion is by far the most significant impact/issue for the region as a whole, followed by pollution, eutrophication and salinization, and loss of biodiversity. Many drivers contribute to the generation of the impact/issues, including in order of importance deforestation, tourism, urbanization/industry, agriculture, and damming/diversion of rivers and navigation. The principal pressures are increased sediment load, nutrient input, siltation, sewage input, poor land management practices, construction and dredging, water damming and water diversion, all exaggerated by changes in the hydrological cycle and tropical storms/hurricanes.

Detailed pilot study reports are presented for six different watershed-coastal marine ecosystems in the Caribbean:

(i) Caroni River Basin, Trinidad, Republic of Trinidad and Tobago
(ii) the Buccoo Reef/Bon Accord Lagoon system, Tobago, Republic of Trinidad and Tobago
(iii) Kingston Harbour, Jamaica
(iv) Parque Nacional Morrocoy, Venezuela
(v) Magdalena River, Colombia
(vi) La Estrella River Basin-Cahuita Reef System, Costa Rica.

The DPSIR concept is applied separately in a synthesis-table format to each of the mentioned six systems and also to the Meso-American Barrier Reef of Mexico, Belize, Guatemala and Honduras. The DPSIR concept is also applied in table format to the Caribbean region as a whole. In addition, the report provides an overview of Caribbean economies with a focus on tourism, which dominates the Caribbean economy, and a description of approaches and analytical tools for integrated assessments of Caribbean river basins.

2. CariBas - The Caribbean Basins Perspective

Björn Kjerfve, William J. Wiebe, Juan Restrepo, Hartwig Kremer and Wim Salomons

2.1 Background to LOICZ-Basins

Integrated coastal zone management is principally focused on impacts and solutions for local or regional sections of coasts. However, transboundary fluxes of water, energy and matter into the coastal systems, both from the ocean and the land, are far-field effects with the potential to impact coastal systems. Such impacts may be direct and/or indirect and need to be considered and managed. Trans boundary fluxes affect the ecological health, resource use, and social value of coastal systems. Management and sustainable utilization of coastal systems often fail to consider anthropogenic activities occurring in drainage basins and river catchments, often long distances from the coast. Socio-economic driving forces acting on river basins may be completely different than those acting within coastal areas. Although coastal environmental legislation has been strengthened globally during recent decades, potential environmental and socio-economic benefits of such legislation are in many cases negated by detrimental benefits generated within river basins (Salomons *et al.* 1999).

Land Ocean Interactions in the Coastal Zone (LOICZ) is a core project of the International Geosphere-Biosphere Project (IGBP). It is a global change synthesis experiment consisting of more then 150 individual projects world-wide. It attempts to improve our understanding of the contribution of the coastal zone to global change and document how coastal systems respond to changing pressures on a spectrum of scales. LOICZ-Basins is a core project of LOICZ to develop a global evaluation of the importance of coastal oceans as receiving bodies of land-based changes in material fluxes in different regions. The priority focus is on transport of water, sediments, carbon, nitrogen and phosphorus.

To consider the impact of changes that have taken place, are taking place or and likely to happen in Caribbean river catchments and the downstream impact on the coastal systems, LOICZ organized two workshops (the first in Trinidad in 2000, followed by a second in Miami in 2001) to address these issues. This report is the result of those workshops.

Coasts worldwide are subject to many pressures which are expected to increase, and the Caribbean is no exception. River transport of heavy metals, nutrients, and PCB's will continue to be of concern and the delivery of pathogens may increase with increasing population. Physical changes to the rivers, e.g., construction of dams, irrigation and flow diversion, alter the natural flow of water, nutrients and sediments to the coast. Not only is water lost to irrigation and evaporation, but the natural hydroperiod is usually also altered. What used to be strong variability of discharge has become a more steady flow, which has an enormous impact on the natural ecological function and productivity of the downstream courses of rivers. Assessment of water, sediment, chemical and nutrient discharges is for the most part poorly known for the Caribbean region and will require an investment in river and coastal ocean monitoring. In addition, the increase in economic activities from tourism, fisheries and urbanization will provide challenges for coastal zone managers and policy makers. To solve management issues rationally requires an integrated approach blending both natural and socio-economic sciences (Turner *et al.* 1998; Salomons *et al.* 1999). Although numerous studies have been conducted to address directly these issues, they have seldom considered integration of natural and social sciences.

The integration of natural and social sciences requires a simple common framework for assessment and analysis. For such integration, the LOICZ Basins studies have adopted the Driver-Pressure-State-Impact-Response (DPSIR) framework (Figure 2.1), since it enables results to be combined from the natural and social sciences as well feedback from and to policy/management options.

The LOICZ approach focuses on changes in biogeochemical cycles as major indicators. The LOICZ-Basins project therefore deals with the impact of human society on the material transport to the coast, including water, sediments, nutrients, heavy metals and man-made chemicals, assesses their impacts on coastal systems and tries to develop rational management options. Since the changes in fluxes are mostly due to activities in river catchments, the catchment-coastal sea system is treated as one unit. Practically, this requires considerations of tourism, fisheries, agriculture, mining, urban development, industry and transport, as well as morphological modifications to the catchment, including construction of dams, irrigation and flow diversion.

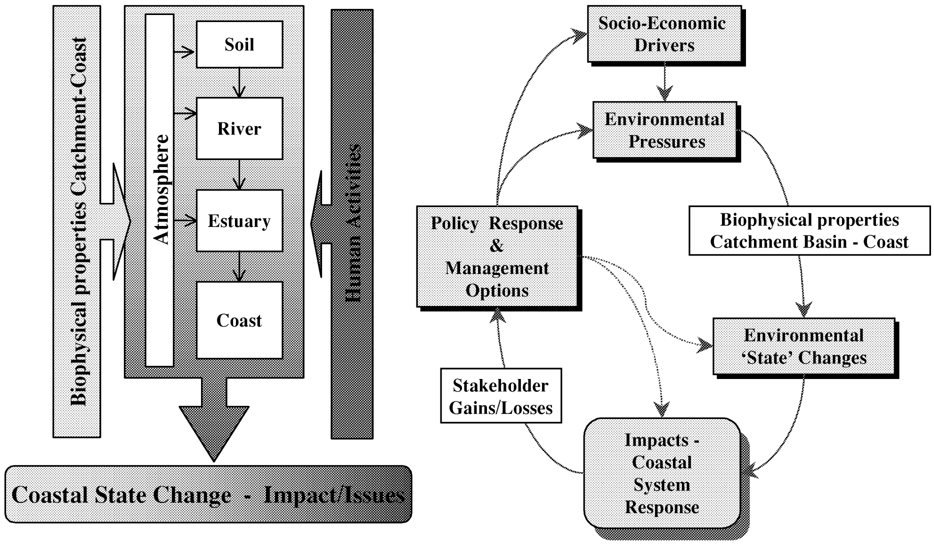

Figure 2.1 The catchment (island)-coastal zone system and the DPSIR framework.

The critical load and threshold concept has been adopted. In the LOICZ-Basins studies these concepts have been extended to the marine environment. In a systems approach it can be used for cost-benefit analyses of management options. 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 Observation System, C-GOOS (now COOP, the Coastal Ocean Observing Panel) of UNESCO's IOC.

LOICZ-Basins employs different approaches to identify targets and indicators for coastal responses:

1. A simple "policy-oriented" approach considers the critical loads which have been agreed upon in international treaties.

2. An "ecosystem" approach uses historical data to evaluate the response coastal systems to changing loads and identifies indicators, attempting to distinguish between natural and anthropogenic changes.

3. A "regional management" approach, based on consultation with local authorities, identifies criteria for indicators or critical loads, and incorporates social and economic factors along with scientific data.

The indicators and targets are used to derive critical concentrations. This critical load, or the critical outflow of the catchment, is a combination of inputs by socio-economic activities and transformations in the river catchment and coastal system. When the links and the transformations of the loads have been established, it is possible to simulate scenarios for cost-benefit analysis and trade-offs, integrating approaches from the natural and social sciences, including economists, scientists, and stakeholders from industry, government, non-governmental organizations, user groups and citizens.

The LOICZ-Basins approach must:

(i) determine the time delay between changes in land-based material flows, the causes for their delays, and their impacts on the coastal system;

(ii) generate better understanding of the complexities of coastal environments and from this derive critical loads; and

(iii) incorporate the diversity of interests of stakeholders affected by transboundary issues.

Changes in land cover in the Caribbean occur mostly on a short time frame due to the relative small size of most of the catchments, where the buffer capacity of the river catchment system is less effective as compared to larger catchments.

2.2 Biogeochemical fluxes and regional variability

Water flows from the mountains to valleys through rivers, over land and and as groundwater to the sea. How the water flows and what it carries depends on the meteorology, climate, geography, geology, economics and politics of each country. The status of each country is intrinsically tied to its history and the development and progression of governments over the last several hundred years. Within the context of biogeochemical fluxes from the land to the sea, each country has, either consciously or *de facto*, made decisions about how its lands are managed. The consequences of these decisions have left some countries wealthy and prosperous and others in poverty.

Biogeochemical fluxes are of particular interest to LOICZ. Although they would mostly flow from land to sea, there are a number of cases where the transport direction is reversed. Factors that can affect the movement of organic matter and inorganic nutrients into the coastal zone and their subsequent fates are listed in Table 2.1.

Table 2.1. Fluxes from land to sea and from sea to land.

	A. Land to Sea	B. Sea to Land
Natural	River discharge Groundwater Sediment Nutrients Humics and organics Storm debris Earthquake debris Volcanic debris	Energy and debris from hurricanes Cold water and nutrients from upwelling Wave action Salt and salt aerosols Dust
Anthropogenic	Sediment (increase from land use and decrease from dams) Nutrients and organic matter from agriculture and sewage Coliform bacteria Herbicides and pesticides Heavy metals Oil and chemicals	Oil and chemical spills Chronic input of oil and chemicals Sewage from ships Ballast water with exotic organisms Debris from ships Brackish infiltrations of groundwater reservoirs by water extraction

Perhaps the most important feature of the tropical landscape in coastal ecosystems is how interdependent the different components are, particularly, but not exclusively, in a downstream direction. Food production and ecosystem management on Yap has been described as a series of nature-integrated systems that are managed to provide sequential filtration of sediment and nutrients from the land to the sea, in order to maintain clear water for the coral reefs. Boto and Robertson (1990) concluded that mangrove forests would generally benefit from increases in inorganic nutrients and that the sediments had a high capacity to denitrify, since one hectare of forest could process sustained inputs of 300 kg of N and 30 kg of P annually. In the Caribbean and elsewhere, mangrove forests are unfortunately often the first coastal system to be destroyed. Seagrasses in the shallow subtidal zone are vulnerable to eutrophication; plankton reduce light and epiphytes cover the grass blades. The result is that the grasses decline and allow nutrients to flow to the reefs, where they stimulate massive algal growth that smother the reefs. Virtually all of the coral reefs of the Caribbean region are either in critical condition (loss in 10-20 years) or threatened (loss in 20-40 years). Poor land-use practices, population growth, and technological development are the major causes. These three important and dominant coastal ecosystems in the Caribbean, i.e. mangroves, seagrasses, and coral reefs, need to be managed together.

The countries of the Caribbean region range from small, low islands to continental, mountainous lands. Some have numerous watersheds of a variety of sizes, while others have no rivers, and essentially constitute a single watershed. For example, Jamaica, Costa Rica, Columbia, and Venezuela have many watersheds, while Barbados, Bonaire and Aruba have no rivers and essentially constitute a single watershed. There are vast differences in rainfall patterns, climate, landform and land use, which result in great diversity and make it difficult to make generalizations about the region.

The state of coastal ecosystems and their variability at 21 coastal Caribbean sites, with local institutions taking part in the Caribbean Coastal Marine Productivity (CARICOMP) project, has been documented by Kjerfve (1999). Standardized environmental, oceanographic and meteorological measurements are made regularly at most of the CARICOMP sites, and the resulting data are provided to the Data Management Center at the University of the West Indies in Kingston, Jamaica.

There clearly is a shared history that unites the islands and the countries of the Caribbean. An understanding of the present status of the coastal systems in the Caribbean requires at least a brief review of its history.

2.3 Historical perspective - human impacts on Caribbean marine environments

It is widely believed that much of the Caribbean region is in fairly pristine condition, and where there are problems, they are of recent origin (e.g., Hughes 1994). Nothing could be further from the truth. The destruction of the Caribbean marine mega-vertebrates was virtually complete by 1800 and that over-fishing in Jamaica was obvious by the mid-19th century (Jackson 1997). There is widespread evidence throughout the Caribbean region that man has altered the environment via the use of fire for millennia. The Spanish explorer, Balboa, crossed the isthmus of Panama with horses and cannons in 1509. Today, this would be impossible unless his troops could follow a highway. The reason Balboa could make the journey was that the indigenous people maintained the area as a savannah by burning. Today, few forests in the Caribbean are considered "virgin". The land has all been modified by humans, unless it was too harsh or too wet for intervention.

Following the period of "Discovery", the Caribbean region was swept by waves of invasion, wars and eventually genocide of the indigenous people. Subsequent importation of laborers from Africa, India and elsewhere for exploitation of natural resources resulted in massive land clearing. Today, the most serious problems in the Caribbean coastal zone result from inadequate management of the land, caused in large part by the rapidly increasing population (Mosher 1986). Rivers flow with nutrients, producing algal blooms; sediments reduce light penetration and smother seagrasses and corals; pesticides and herbicides poison the animals and plants (Wishart *et al.* 2000). Land is cleared without regard for its intrinsic value, its effects downstream, or the long-term effect on people; Salvador, Honduras and Nicaragua suffered dramatically from bad land-use practices as the result of Hurricane Mitch in 1998, when as many as 12,000 individuals died (mostly in Honduras and Nicaragua). Even so, the lotic ecosystems of the Caribbean are less degraded than those in the "First World" (Wishart *et al.* 2000).

Development is the major threat to river and coastal conservation in the Caribbean region. Pressure to "develop" from wealthy nations, The World Bank, the IMF and multinational companies contributes directly to environmental degradation (Wishart *et al.* 2000, Goodwin *et al.* 1987). There have been several regional programs undertaken to try to develop better management of coastal natural resources in the past few years (UNEP 1983, 1985), but water quality within the coastal zone continues to decline. It is paradoxical that while it takes money to implement programs, and thus funds raised from development are essential, the developments themselves create problems.

Rapidly increasing populations, mostly along the coast of islands and in coastal urban centers, exacerbate the degradation of water quality. Population growth in almost all of the Caribbean Basin threatens to overwhelm any attempt to implement rational coastal management. Fortunately, within the past two decades, governments, non-governmental organizations, individual scientists and lay environmentalists have begun to realize the absolute need to develop the environment in ways that will preserve what remains and repair what is damaged. LOICZ recognizes the need to link natural and social sciences, but it remains unclear how successful this approach can be in the face of the demographics.

2.4 Caribbean geographic setting and oceanography

The Caribbean (Figure 2.2) is an enclosed tropical sea, measuring 1,943,000 km², completely located within the area defined by latitudes N8°- 22°and longitudes W 59°-89°, and it occupies 0.38% of the surface of the earth. It is a deep sea with a maximum depth of 7,686 m in the Cayman Trench, which defines the plate boundary of the North American and Caribbean plates (Heyman and Kjerfve 2001). Three deep basins are located within the Caribbean. Relatively shallow water depths define the rim of the Caribbean basin with the North Atlantic Ocean. Only a few relatively narrow channels into the Caribbean exceed 1,000 m in depth and limit deep water exchange with the Atlantic. Another notable bathymetric feature is the shallow ridge which extends from Honduras to Jamaica, including Pedro and Roslind banks, with typical water depths from 10-100 m.

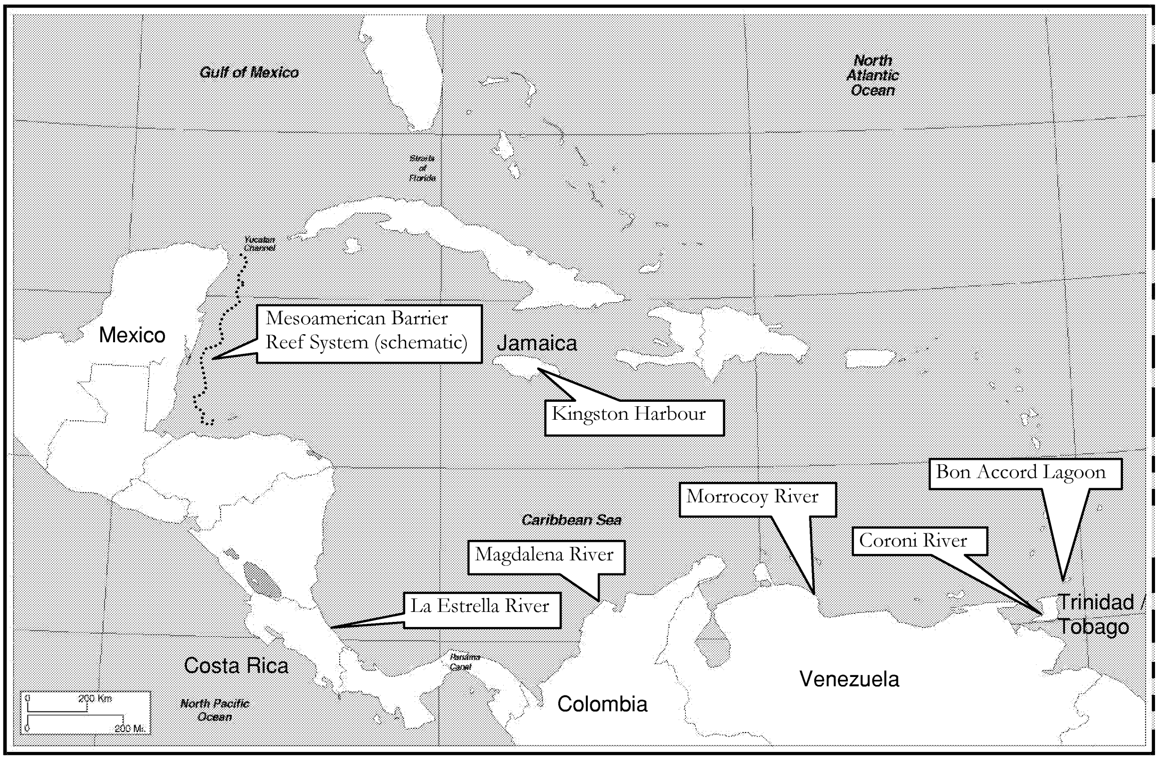

Figure 2.2 The Caribbean Sea and island systems.

The Caribbean coastal environments (Kjerfve 1999) consist of a myriad of interlinked open marine and coastal ecosystems in a geographically diverse setting. The Caribbean is bordered by the South American continent in the south, the Central American isthmus in the west, the larger islands of the Cuba, Hispaniola, and Puerto Rico in the north, and thousands of smaller islands primarily in the east, but scattered around all coasts. River drainage basins are for the most part of comparatively small size because of the predominance of island areas, and thus impacts are characterized by a short time response between basin development activities to coastal responses as compared to the larger basins of South America. However the Caribbean is also the receiving basin of at least one world class river, the Magdalena River of Colombia, which is responsible for massive inputs of freshwater equal to 228 km3 yr-1 and sediment equal to $144x10^6$ t yr^{-1} and other substances (Restrepo and Kjerfve 2000). The Magdalena River is by far the largest river of Colombia and the Caribbean, with a drainage basin of 257,000 km^2 and it drains directly into the western Caribbean at Barranquilla.

The entire coastal zone of the Caribbean supports over 100 million people in more than 25 countries and territories, with an anticipated population doubling time of 30 years at the current rate of growth (Population Reference Bureau 1996). Under pressure of rapidly increasing human population, urbanization and demands for resources, the coastal zones of the Caribbean are under siege. Intensive housing, industrial and tourism developments compete for the limited available space and attention from local governments and authorities.

The Caribbean is culturally diverse. It also supports a variety of tropical coastal and marine habitats and exhibits high productivity and rich biological diversity (Kjerfve 1999). The coastal habitats include rivers, estuaries, coral reefs, mangroves, sea grass beds, muddy bottoms, sandy beaches, nearshore cays and offshore atolls, rocky shores and open ocean environments. Most of the Caribbean supports commercial harvests of shrimp, lobster, conch and a variety of finfish. In addition to the commercial species, the Caribbean provides feeding and breeding habitats for rare and endangered megafauna, such as marine turtles, dolphins, whale sharks and manatees (Heyman and Kjerfve 1999). Numerous coastal and marine reserves and parks already exist and many more are currently being developed with intense scrutiny from both local governments, international banks and organizations, and grass-roots support through non-governmental organizations. Such parks and reserves are likely to play a critical role in protecting both productivity and marine biodiversity in the Caribbean, and thus contribute to the integrated coastal zone management of the region as a whole (Heyman *et al.* 2001).

Mangrove wetlands, seagrass beds and coral reefs dominate the land-sea margin in the Caribbean (Kjerfve 1999). These ecosystems have among the highest biological diversity of all marine habitats. We exploit them for food, building materials and firewood while at the same time they represent the infrastructure for villages and towns, tourism and industrial developments. Too often the coastal ecosystems are modified, impacted, or destroyed by different forms of development, including development within the drainage basins of island and continental regions, which on a relatively short time-scale reach the coastal zone through water and sediment runoff. Within the Caribbean, there is a clear consensus that coastal marine systems are impacted and changing for the worse. The ultimate causes are exponential population growth and anthropogenically-driven changes in the coastal zone and in the upstream watersheds. Because the underlying causes for this decline are diverse, there is no general agreement on how the ecosystems can be stabilized and restored to their former state, or what constitutes sustainable development. And that further raises the question, restored to what state? We now know that the Caribbean was significantly impacted by humans long before it was colonized by Europeans in the early 1500's.

With new data from ocean drifter buoys, satellite altimeters, SeaWiFS satellite images, field observations and numerical simulation modelling (Carton and Chao 1999; Murphy *et al.* 1999; Andrade and Barton 2000), it is apparent that surface currents in the Caribbean Sea are dominated by meso-scale eddies, large anticyclonic eddies to the north and smaller cyclonic eddies to the south. The prevalence and energetics of these eddies alter the concept of the Caribbean Current as a sluggish, slow-flowing east-to-west conduit of water. The eddies have chaotic characteristics and systematically propagate from east to west, squeeze through the lesser Antilles as eddies associated with the Guyana Current pass through the openings between islands and re-form inside the Caribbean. The eddies advect towards the Yucatan Channel, which they mostly reach within 12 months. The eddies provide the connectivity from upstream to downstream reefs and coastal areas and serve as the dispersal mechanisms of pelagic and coastal larvae (Cowan *et al.* 2000), and can in a matter of days transport surface waters hundreds of kilometers, and not necessarily in the direction of the mean flow.

The climate of the Caribbean is everywhere tropical but highly variable. It is controlled by the position of the Intertropical Convergence Zone (ITCZ), which migrates north in July into the Caribbean and southward onto continental South America in December. The ITCZ, in part, controls the easterly and north-easterly trade winds, which in turn interact with mountainous islands and continental mountain ridges (Nieuwolt 1977), which may result in orographically-induced rainfall. The trade winds blow most strongly from December to May. During the winter and early spring months, the Caribbean regularly experiences northerly or north-westerly winds associated with the passage of a North American frontal system, which quickly sweeps through the Caribbean.

Caribbean precipitation is greatest in the watersheds of the Gulf of Honduras and in Nicaragua, where easterly waves bring intense rainfall. Precipitation reaches 4,000 mm annually and exceeds 6,000 mm in the Sarstún watershed of southern Belize. In contrast, the climate is completely arid on the Guajira Peninsula of Colombia and along the western coast of Venezuela, where the precipitation in many places seldom exceeds 200 mm annually. Many of the islands of the Caribbean also suffer from low rainfall and thus lack of potable water.

Rainfall maxima occur in May-June and in September-October, especially in the western Caribbean. High rainfall is accompanied by low pressure in the equatorial Atlantic, enhanced convergence, and much cloudiness (Hastenrath 1984). An atmospheric inversion layer occurs only 30-40% of the total number of days between July to October in the western Caribbean (Nieuwolt 1977). Hence, the chance of rainfall in late summer is increased. Tropical storms also bring significant rainfall to the region between August and November, giving rise to a bimodal rainfall distribution in much of the region.

Although El Niño-La Niña cycle has been correlated with weather patterns worldwide (Kousky *et al.* 1984; Ropelewski and Halpert 1987; Rogers 1988; Hanson and Maul 1993; Waylen and Caviedes 1996). Ropelewski and Halpert (1987) suggested that there is only a weak relationship between precipitation and ENSO in the Caribbean. This region, in fact, exhibits the lowest coherence of 17 regions worldwide between precipitation and ENSO. For example, only 35% of the precipitation variability at Kingston, Jamaica, is explained by the SOI variability (Thattai *et al.* submitted). The exception is the northern parts of South America, which exhibits a very strong negative rainfall correlations with El Niño. However, for most parts, excluding the Caribbean coasts of Colombia and Venezuela, the precipitation variability in the Caribbean does not depend strongly on ENSO.

Tropical storms and hurricanes regularly enter and cross the Caribbean from east to west, mostly from August through October. The occurrence of tropical storms and hurricanes in the Atlantic Province is strongly modulated by the presence of El Niño or La Niña conditions (Fitzpatrick 1999). During El Niño years, excessive vertical shearing of the horizontal winds over the western tropical Atlantic and the Caribbean reduce hurricane activity (Rappaport 1999), whereas during La Niña years tropical storms occur more frequently.

A large portion of the central and northern Caribbean is frequently impacted by tropical storms and hurricanes, more than 100 storms per century (Gentry 1971). During the past 25 years, three super hurricanes have wreaked particular havoc in the Caribbean. Hurricane Allen in 1980, with a central pressure of 899 hPa, brought death and destruction to Hispaniola and Jamaica. Hurricane Gilbert, in 1988, was the most intense storm with a central pressure of 889 hPa and destroyed coastal development and ecosystems in Jamaica and on the northern coast of the Yucatan Peninsula. Hurricane Mitch in 1998 began in the western Caribbean, made landfall in the Bay Islands of Honduras, dropped more than 750 mm of rain in a few days over parts of Honduras and Nicaragua, resulting in flooding, hillside collapse and the death of more than 9,000 people, the deadliest of Caribbean hurricanes in recorded history (Thattai *et al.* submitted). Whereas waves in the Caribbean usually are less than 1.5 m high and with a period less than 7 secons, coastal hurricane waves are known to exceed 12 m under the influence of hurricane forcing (Kjerfve *et al.* 1986).

Tides throughout the Caribbean are microtidal with an approximate tidal range of 0.2 m. They are mostly mixed mainly semidiurnal in both the eastern and western parts of the Caribbean, but a central region from Puerto Rico to the coast of Venezuela experiences pure diurnal tides (Kjerfve 1981). Although the astronomical tides are weak, tidal currents can nevertheless be strong in reef passages and near river mouths, and may play a significant role in the dispersion of sediment, nutrients, pollutants and larvae. The dominant semidiurnal (M2) and diurnal (K1) tidal constituents progress from east to west and rotate in an anticyclonic sense (Kjerfve 1981). Meteorological tides at times completely dominate the astronomical tides.

2.5 Coastal issues and impacts in the Caribbean coastal zone (tabulated).

Table 2.2. Major coastal impacts/issues and critical thresholds of fluxes to coastal zones – Overview and qualitative ranking.
Impact code and relative class of importance e.g., 1- 10

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. The Magdalena River / Delta Lagoon complex and areas of the Caribbean Coast of Colombia. b. The Caroni River of Trinidad. c. Aroa-Yaracuy River. d. Rio Cobre and Kingston Bay Basin, Jamaica. e. La Estrella River and the Cahuita reef on the Caribbean Coast of Costa Rica. f. Northern part of the Caribbean: Chetumal Bay Basin; Belize, Sibun and Monkey Rivers of Belize; El Porvenir and Motogoa Rivers of Guatemala; and the Cahmelecon, Ulua, and Aguan Rivers of Honduras	Some measurements in coral reefs such as water turbidity levels, trace metals (e.g., Hg), live coral cover, coral disease infection rate and macro-algal cover may be used as good indicators of pollution and tracers of urban and industrial sources.	Biological communities near the coast show signs of mortality. Declining yield trends in fish resources: fisheries and oyster harvesting in the Gulf of Paria have declined by more than 50% and on the Magdalena delta/lagoon complex total catches have declined from 63700 t/yr in 1978 to 7850 t/yr in 1998. High levels of heavy metals have been observed in coral reef communities. Low water quality, increased turbidity and reef mortality and deterioration observed in El Rosario Islands (Colombia), Cahuita Reef (Costa Rica), fringing reefs off the Yucatan Peninsula, Mexico and islands of Honduras, and barrier reefs off Belize and Guatemala.	8	Abarca and Ruepert 1992; Boodoosingh, 1992; Guzman and Jimenez 1992; Bastidas *et al.* 1999; INVEMAR, 1997; Lapointe 1997; Sale *et al.* 1999; Beltran *et al.* 2000; INVEMAR, 2000a; Kramer and Kramer 2000; Wilkinson 2000.
Eutrophi-cation	a. The Magdalena River and associated delta/lagoon complex. b. Northern Caribbean basins including Belize, Sibun and Monkey rivers, Belize; El Porvenir and Motogoa rivers, Guatemala; and the Cahmelecon, Ulua, and Aguan rivers, Honduras. c. Caroni River, Trinidad. d. La Estrella River and the Cahuita reef on the Caribbean coast of Costa Rica. e. Rio Cobre basin and Kingston Bay, Jamaica.	Redfield ratio (C:N:P) and macro-algal cover can be used as preliminary indicators.	The lagoon system in the Magdalena delta is already affected by excess nutrient supply (no distance). Bacterial contamination of fisheries in the Gulf of Paria (Caroni River, Trinidad) has resulted in economic losses of 50%. Macroalgal cover exceeds 60% in barrier reefs of the Meso American Barrier Reef System (Belize, Honduras, and Guatemala). High algae cover in the Cahuita reef of Costa Rica. Nitrate and phosphate concentrations in barrier reef waters of Belize and Honduras of 1.0uM and 0.1 uM. High levels of eutrophication (sewage input) in the Kingston Bay have altered seagrass ecosystems.	7	Boodoosingh 1992; Cortes 1993; Lapointe, 1997; Sale *et al.* 1999; Beltran *et al.* 2000; INVEMAR 2000a; Kramer and Kramer 2000; Wilkinson 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
Sedimen-tation	a. Channelization of the lower Magdalena River (El Dique delta) and partial diversion of the river flow. b. Caroni River, Trinidad c. Aroa-Yaracuy River d. La Estrella River/Cahuita reef e. Increased water discharge and sediment load from the Belize, Sibun, and Monkey rivers of Belize, El Porvenir and Motogua rivers of Guatemala and Chamalecon, Ulua and Aguan rivers of Honduras.	Sediment load estimates before urban expansion can be used as a good indicator of critical threshold (analysis of interannual variability of sediment loads and their relationship with demographic indices). Live coral cover, macro-algal cover and biodiversity indices may be used as indicators of coral reef responses to sediment discharge: -Live coral cover > 10% -Biodiversity > 70% -Macro-algal cover >60%	Observed coral reef mortality at El Rosario Islands, Caribbean Coast of Colombia (live coral cover is less than 25%). Decline of oyster harvest by 50% in the coast of Trinidad (Caroni River Basin). Live coral cover is down to 5% and biodiversity has been reduced to 20% in the coral reefs along the coast of the Aroa-Yaracuy River mouth. General reef deterioration and coral mortality in the Cahuita reef of Costa Rica (live coral cover is 11%). Habitat degradation and loss of biodiversity at coral reefs of the Meso American Barrier Reef System: live coral cover of 28% in Belize and 21% in Honduras. Macro-algal cover is 36% and 53% in Belize and Honduras, respectively.	10	Vernette 1985; Boodoosingh 1992; Bastidas *et al.* 1999; Sale *et al.* 1999; INVEMAR 2000a; 2000b; Kramer and Kramer 2000; Wilkinson 2000.
Salinization	• Magdalena River / Lagoon Delta Complex: Cienga Grande de Santa Marta.		Mortality of mangroves in the Cienaga Grande de Santa Marta (Magdalena delta) due to salinization has reached 272 km^2 over a 39-year period. Rediversion of fresh water into the lagoon system has allowed partial recovery of mangrove.	7	Cardona and Botero 1998; INVEMAR 2000b.
Biodiversity loss and/or decreasing biological productivity	a. Magdalena River and associated channels (El Dique Delta). b. Aroa-Yaracuy River. c. Trinidad, Eastern Caribbean. d. Meso American Barrier Reef (Belize, Honduras and Guatemala Basins).	Biological productivity (e.g., fishery stocks) and biodiversity indicators characterize threshold levels. At the Magdalena delta front, sustainable annual catches reaches about 64,000 ton/yr.	Fisheries stocks at the Magdalena River mouth decreased approximately 90% during the last two decades. Overall reduction in biodiversity of 35% along the coast of the Aroa-Yaracuy river mouth. Various reports on biodiversity loss along the coast of Trinidad , Kingston Bay, and the Meso American Barrier Reef.	6	Bacon 1993; Losada and Klein 2000; Sale *et al.* 1999; Beltran *et al.* 2000; INVEMAR 1997, 2000b; Kramer and Kramer 2000.

Table 2.3. DPSIR matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related state changes having impact on the coastal zone.

State change dimension: major; medium; minor; 0 = no impact; ? = insufficient information
Time scale: p = progressive (continuous); d = direct

Driver	Pressures	State change (qualitative index) Large Basins Passive coast	State change (qualitative index) Small Basins Passive coast	Impact on the coastal system	Time scale
Urbanization and industry	Increasing sediment load. Increase of nutrient and pollutants rich waste effluents.	**medium-major**	**medium-major**	• Eutrophication • Pollution due to heavy metals • Loss of biodiversity, biomass and productivity • Habitat destruction (mangrove and reef deterioration and mortality)	**p**
Agriculture	Poor agricultural practices result in poor soil conservation. Increasing sediment load and water extraction. Freshwater diversion. Nutrient and pesticide inputs. BOD effluent increase.	**medium**	**medium-major**	• Lost of coastal habitats due to increasing upland erosion rates. • Eutrophication • Biodiversity loss • Pollution with heavy metals and pesticides	**p**
Damming	Changes in the hydrological cycle. Nutrient and sediment load sequestration. Siltation	**minor**	**minor**	• Nutrient depletion • Coastal erosion • Salinization • Changes in flora and fauna distributions • Morphodynamic changes on the coast.	**d**
Deforestation	Increasing suspended sediment loads to the coastal zone. Increasing organic and nutrient inputs.	**minor**	**minor-medium**	• Increased suspended sediment load on the coastal ecosystems. • Mangrove and coral reefs siltation.	**p**

Driver	Pressures	State change (qualitative index) Large Basins Passive coast	State change (qualitative index) Small Basins Passive coast	Impact on the coastal system	Time scale
Navigation	Increasing coastal engineering structures (jetties, channels). River diversion and changes in material fluxes on the coastal zone. Dredging.	**major**	**minor-medium**	• Increasing pollution and sedimentation. • Unbalance in the coastal sediment budget. • Discharge of suspended sediment load into coastal ecosystems.	**d**
Tourism	Sediment and sewage inputs. Increasing shoreline engineering constructions. Habitat changes and deterioration.	**medium**	**medium-major**	• Habitat reduction and alteration. • Loss of mangrove and reef deterioration. • Loss of biodiversity. • Litter and solid contamination.	**p**

Table 2.4. The link between coastal issues/impacts and land based drivers – 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
		River/system	Category (1 low – 10 high)		
Pollution	Urbanization and industry	▪ Magdalena River	10	⇑	HIMAT-INGEOMINAS 1991; Bone *et al.* 1993; Cardona and Botero 1998; IMA 1999; INVEMAR 2000b.
		▪ Gulf of Paria, Trinidad, Eastern Caribbean	6	⇑	
		▪ Rio Cobre, Kingston, Jamaica	2	⇑	
		▪ Aroa-Yaracuy River	8	⇑	
		▪ Golfo Triste, Venezuela	8	⇑	
		▪ Chetumal Bay, Mexico	8	⇑	
		▪ Belize City	6	⇑	
		▪ Bahia de Amatique	4	⇑	
		▪ Manabique, Guatemala	7	⇑	
		▪ Roatan, Honduras	6	⇑	
	Agriculture	▪ Magdalena River	8	⇑	Colciencias-Fen 1989; Bone *et al.* 1993; ProAmbiente 1998; IMA 1999.
		▪ Gulf of Paria, Trinidad, Eastern Caribbean	6	⇑	
		▪ Rio Cobre Basin		⇑	
		▪ La Estrella River, Costa Rica	2	⇑	
		▪ Aroa-Yaracuy River	9	⇑	
		▪ Golfo Triste, Venezuela	8	⇑	
		▪ Sibun, Belize	8	⇑	
		▪ Stann and Monkey Basins, Belize	5	⇑	
		▪ Sarstoon and Motagua Basins, Guatemala	3	⇑	
		▪ Chamalecon, Ulua, and Aguan rivers, Honduras	6	⇑	
			5	⇑	
	Tourism	▪ Cancun, Cozumel, and east coast of Yucatan, Mexico.	10	⇑	Sale *et al.* 1999; INVEMAR 2000b; Sealy and Bustamante 2000.
		▪ Roatan, Honduras			
		▪ El Rosario Islands, Caribbean coast of Colombia	7	⇑	
		and El Dique delta.	6	⇒	

Table 2.4 continued.

Coastal Impact/ Issues	Drivers	Local catchment (allowing within and between catchment comparison) River/system	Category (1 low – 10 high)	Trend expectations	References/ Data sources
Eutrophication	Agriculture	▪ Magdalena River	8	⇑	Colciencias-Fen 1989; Bone *et al.* 1993. ProAmbiente 1998; IMA 1999.
		▪ Gulf of Paria, Trinidad, Eastern Caribbean	2	⇑	
		▪ Rio Cobre, Jamaica	6	⇑	
		▪ La Estrella River, Costa Rica	9	⇑	
		▪ Aroa-Yaracuy River	8	⇑	
		▪ Golfo Triste, Venezuela	8	⇑	
		▪ Sibun, Belize	5	⇑	
		▪ Stann and Monkey Basins, Belize	3	⇑	
		▪ Sarstoon and Motagua Basins, Guatemala	6	⇑	
		▪ Chamalecon, Ulua, and Aguan rivers, Honduras	8	⇑	
	Urbanization	▪ Magdalena River	10	⇑	Colciencias-Fen 1989; Bastidas *et al.* 1999; Losada and Klein 2000; IMA 1999.
		▪ Gulf of Paria, Trinidad, Eastern Caribbean	2	⇑	
		▪ Kingston Harbor, Jamaica	10	⇑	
		▪ Aroa-Yaracuy River	8	⇑	
		▪ Golfo Triste, Venezuela	8	⇑	
		▪ Chetumal Bay, Mexico	8	⇑	
		▪ Belize City	6	⇑	
		▪ Bahia de Amatique	4	⇑	
		▪ Manabique, Guatemala	7	⇑	
		▪ Roatan, Honduras	6	⇑	
	Tourism	▪ Cancun, Cozumel, and East Coast of Yucatan, Mexico.	10	⇑	Sale *et al.* 1999; INVEMAR 2000b; Sealy and Bustamante 2000.
		▪ Roatan, Honduras			
		▪ El Rosario Islands, Caribbean Coast of Colombia and El Dique delta.	7 6	⇑ ⇒	

Table 2.4 continued.

Coastal Impact/ Issues	Drivers	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ Data sources
		River/system	Category (1 low – 10 high)		
Sedimentation	Deforestation	▪ Magdalena River ▪ Gulf of Paria, Trinidad, Eastern Caribbean ▪ Aroa-Yaracuy River ▪ Golfo Triste, Venezuela ▪ Sibun, Belize ▪ Stann and Monkey Basins, Belize ▪ Sarstoon and Motagua Basins, Guatemala ▪ Chamalecon, Ulua, and Aguan rivers, Honduras	10 6 8 8 5 3 6 8	⇑ ⇑ ⇑ ⇑ ⇑ ⇑ ⇑ ⇑	Colciencias-Fen 1989; Bone *et al.* 1993. IMA 1999.
	Navigation	▪ Magdalena River mouth (Bocas de Ceniza) ▪ Kingston Harbor, Jamaica	8 2	⇑ ⇑	Correa 1996; Martinez and Molina 1992; Martínez 1993.
	Damming/ Diversion	▪ Magdalena River and El Dique Canal	10	⇒	Vernette 1985; Restrepo and Kjerfve 2000
Salinization	Damming/ Diversion	▪ Magdalena delta and lagoon complex (Cienaga Grande de Santa Marta) ▪ Gulf of Paria, Trinidad, Eastern Caribbean	9 2	⇒ ⇑	Phelps 1997; Cardona and Botero 1998; INVEMAR 2000b.

Coastal Impact/ Issues	Drivers	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ Data sources
		River/system	Category (1 low – 10 high)		
Biodiversity loss and/or decreasing biological productivity	Urbanization and industry	▪ Gulf of Paria, Trinidad, Eastern Caribbean ▪ Aroa-Yaracuy River ▪ Golfo Triste, Venezuela	4 10 10	⇑ ⇑ ⇑	Bastidas *et al.* 1999; Phelps 1997; Losada and Klein 2000.
	Deforestation	▪ Kingston Harbor, Jamaica	4	⇑	
	Agriculture	▪ Gulf of Paria, Trinidad, Eastern Caribbean	4	⇑	Phelps 1997.
	Damming/ Diversion	▪ Magdalena delta and lagoon complex (Cienaga Grande de Santa Marta mangrove system) ▪ Magdalena River-El Dique Canal and El Rosario Islands (coral reefs)	9 10	⇒ ⇒	Vernette 1985; Cardona and Botero 1998; INVEMAR 2000b; Restrepo and Kjerfve 2000.
	Fishing	▪ Kingston Harbor, Jamaica ▪ La Estrella River/Cahuita Reef	6 2	⇑ ⇑	Mug 2000.
	Tourism	▪ La Estrella River/Cahuita Reef ▪ Aroa-Yaracuy River ▪ Golfo Triste, Venezuela	2 10 10	⇑ ⇑ ⇑	Bastidas *et al.* 1999; Phelps 1997; Losada and Klein 2000; ProAmbiente 1998; Mug 2000.

3. Outlook and future project options

by P.R. Bacon and H.H. Kremer

The findings and "hot spots" identified in this first CariBas assessment can be utilised to develop an approach which recognizes the local and regional specifics but links into the broader catchment – coast research frame coming up or running under the global LOICZ project. These projects are the regional catchment studies such as the EU-funded EuroCat (http://www.iia-cnr.unical.it/EUROCAT/project.htm) and the recently started AfriCat pilot studies (funded by START). The objective is to look in higher detail into the interaction of certain socio economic drivers such as damming, deforestation or urbanisation and how they affect the water cascade and the coastal zone, recognizing changes in both the anthropogenic and global pressures, e.g., climate change. A potential CariCat would have to address these issues in an almost totally man-influenced area with growing pressures from tourism and climate change and to consider both mainland coasts and islands.

Introduction

The LOICZ-Basins approach (http://w3g.gkss.de/projects/loicz_basins) has been concerned, *inter alia*, with how 'changes' in land-use alter the fluxes and retention of water and particulate matter in the coastal zone.

Two problems are associated with this approach in the Caribbean:

a. Except in a few cases, data does not exist on previous fluxes, particularly on fluxes prior to human intervention in catchments – so 'changes' cannot be assessed in any quantitative way since there is no baseline.
b. On the other hand, analysis of 'change' in comparison to these so called "pristine" conditions is largely irrelevant for people issues nowadays, although it is of scientific relevance in the broader context of global earth system functions assessment.

Taking into account that it is highly unlikely (i) that there will be a return to earlier conditions or (ii) that the economic activities that produced changes in the river catchments or islands will cease, return to a pre-human settlement situation is most unlikely to be a management option. It seems more rational to identify those environmental quality targets and criteria that can be linked to human and environmental health and sustainable economic growth. CariCat would then have two major objectives: to provide the regional information into the broader Earth System Science (e.g., in a continued future LOICZ) context and to give the scientific information necessary to support decision-making for coastal management under various use and global change scenarios. The latter would need to encompass sub-regional and even local scale issues.

To accomplish this complex task it is important to improve our understanding of how existing catchment activities affect present processes that determine land-based fluxes and their impact in the coastal zone. It is of great scientific value, and of developmental importance, to quantify the type and scale of current catchment activities and to accurately establish the relationships between these activities and impacts on coastal ecosystems and resources. Drawing on these relationships, one can embark on the development of future scenarios by taking into account various economic options and aspects of global change forecast and likely to affect the region.

A regional CariCat project proposal could examine these aspects in three phases.

Phase 1. Land use and ecological impact

The first phase of the proposed project would be concerned with an inventory of current land use in selected river catchments throughout the Caribbean region and the elucidation of cause-effect relationships responsible for negative coastal resource impact.

Using the LOICZ-Basins approach, this investigation will treat the river catchment (or island) and its associated coastal zone as one system (Figure 3.1). In this system the change in the coastal zone is the result of local human activities, for which the actual impact depends additionally on its biophysical properties. Hence on a global scale coastal zones will show differences in their responses to a similar human activity. The regional system itself is subject to outside (long-term) pressures and drivers, which include climate change and global socio-economic trends and changes. To elucidate these intricate internal and external relationships, one focus will be on the horizontal flux of substances within the catchment (island) coastal zone system.

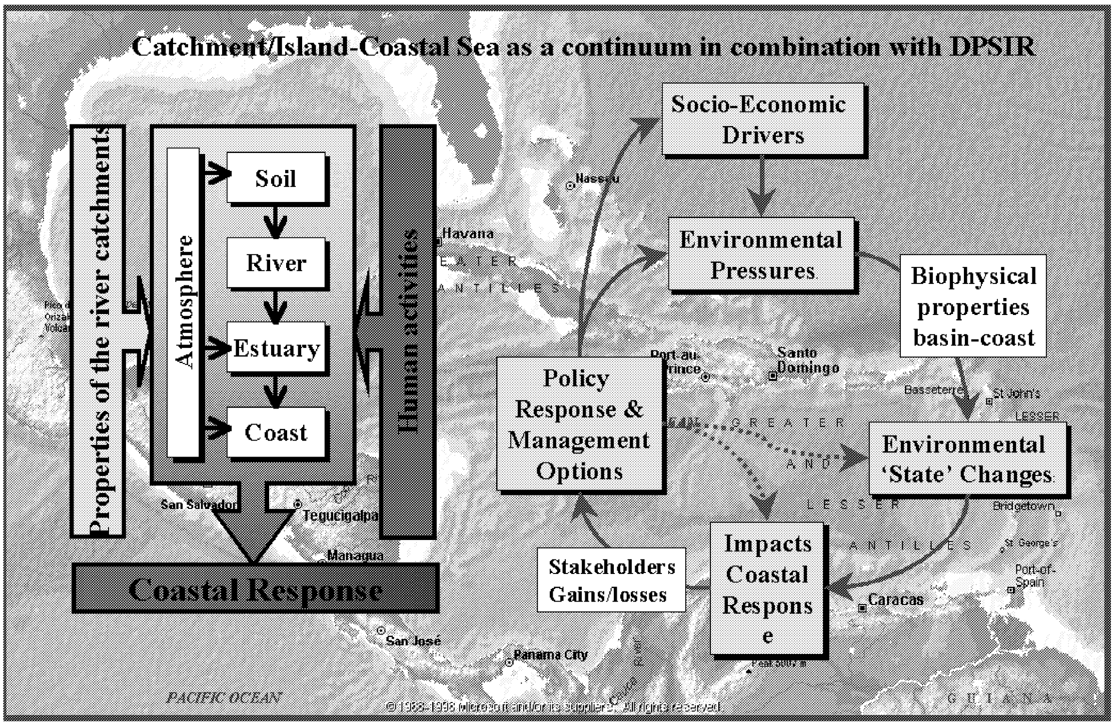

Figure 3.1. The LOICZ-Basins approach.

The systems approach hence requires an integration of the natural and social sciences to address issues like critical concentrations and loads as well as resilience and carrying capacity. In LOICZ-Basins the DPSIR framework, originally developed by the OECD, is adapted for this integration. In workshops around the globe this approach is used to analyse the system, show deficiencies in knowledge and come up with project proposals. Within the DPSIR framework the next two phases will particularly concentrate in the Impact and Response sections.

Phase 2. Evaluation of economic impacts

The second phase of the proposed project will carry the LOICZ Synthesis into a study of comparative resource economics. This is considered to be the most relevant and challenging phase of the project, as it is expected to contribute to our understanding of the 'human dimension' of fluxes to the coastal zone. The main objective of this phase will be to make a macro-economic analysis of the impacts of the catchment economy on the coastal zone economy at selected study sites.

Phase 3. Management implications and response options

The final phase of the proposed project will be concerned with the management implications of the research findings. It will be an important, but minor, aspect of the proposal, largely concerned with formulating a range of management responses or questions for follow-up research.

Although not wishing to pre-empt the findings of Phases 1 & 2, it is likely that the project will demonstrate some negative economic consequences for coastal resource use as a result of specific catchment/island activities. If this is demonstrated, some important technical and economic and response questions may need to be formulated such as –

a. Is the scale of coastal zone degradation (as a direct result of land-based fluxes) sufficient to require mitigation by modification of specified land-use practices?
b. Will modification of land-use practices be technically feasible?
c. Will modification of land-use practices be economically feasible?
d. What economic instruments can be used to force appropriate changes in land use?
e. What type(s) of public education and community participation will be needed to bring about appropriate land-use change?
f. What national (or River Basin Authority) strategy can be formulated to achieve the desired changes in land-use practice (scenarios, response options and institutional dimensions)?

The collection of baseline data demonstrating a clear cause-effect relationship (as far as possible), coupled with a compelling economic analysis, and generic-level answers to these key questions (a-f above) will set the stage appropriately for the underlying aim of LOICZ projects. This is to motivate the human populations in selected river catchments to ensure that their land-use practices do not impact negatively on the livelihood of neighbouring coastal resource users.

The proposed project seeks to provide a good scientific and economic database and understanding of the land-based fluxes situation in selected river catchments, that can be used by governments to address the problems identified in follow-up projects. The project findings will be geared towards eventual action to solve problems in the coastal zone.

Design of a potential CariCat project

Structure

It is anticipated to have 5 to 6 regional catchment- or island-based case studies with different characteristics with regard to coastal zone systems, habitats, their change and its drivers and pressures. Each case study will however be representative for a broader region and the methodology applied aims to make intercomparison and up-scaling to the Caribbean region possible. The sites currently proposed for case studies are those already under study in the Caribbean region (see chapters 2, 4).

To make the project manageable the effort is divided into workpackages. It is realised that not in all case studies all the necessary expertise will be available. Hence each workpackage will have an overall scientific co-ordinator who has responsibility for contents and deliverables and will initiate (if deemed necessary) capacity building across the sites and beyond. At case study level the site manager will take responsibility for the regional workpackages as a whole. The workpackage co-ordinators and the site managers constitute the management team.

Workpackages - General Remarks

Significant parts of this assessment and synthesis will focus on improved understanding of how present activities in the catchment determine land-based fluxes and their impacts in the coastal zone. Emphasis will be on quantifying the type and scale of this relationship accurately and to elaborate on the implications for coastal resource use.

However, for purposes of modelling and forecasting (Figure 2, right side) addressing the temporal scale of 'change' is also of scientific relevance. This is particularly important under the anticipated unfavourable conditions that the economic activities in the river catchments/islands causing coastal change are unlikely to cease, thus continuing along past detrimental trends.

Analysis in this project will consequently include information on previous fluxes where available, although due to the general scarcity of this information due to human intervention in catchments will be encompassed rather than fully pristine conditions.

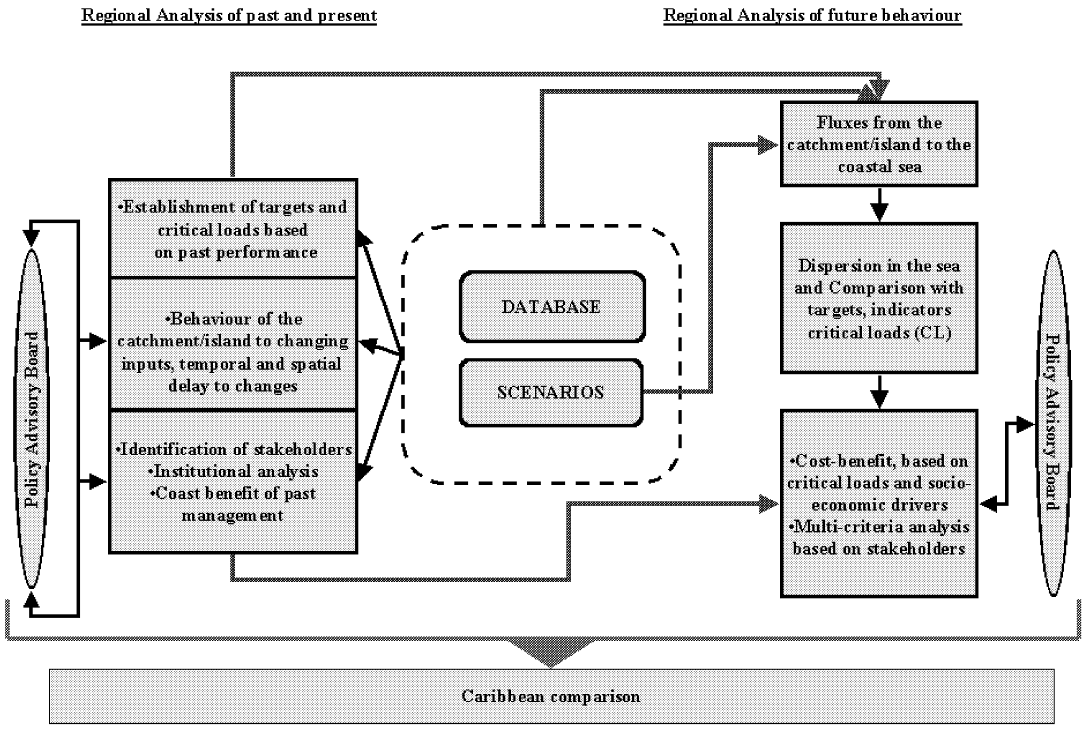

Figure 3.2. The CariCat workplan.

As outlined above, the project database will be concerned with an inventory of land-use, coastal change (biophysical, geomorphologic, ecological), the 'human dimension' of fluxes to the coastal zone in the form of comparative resource economics and ultimately the management implications of the findings, which will be communicated also to the coastal user community through advisory boards. This will form the basis for the scenario simulation including the different quality targets for coastal ecosystems and thresholds for system functioning.

The workpackages (WP) will comprise:

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 Caribbean level

Establishing the databases (WP 1) (monitoring data, geographical and socio-economic data) will largely rely on geographical information systems which may also provide the basis for the presentation of all of the spatial data and the results. This will also take into consideration existing data and information provided through the CARICOMP network and other regional projects.

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

WP 3 deals explicitly with the development of plausible scenarios of future change. These scenarios can be based on readily available global scenarios but scaled down to the Caribbean and then to the site studies and the sub-regions they should represent. The socio-economic analysis of the scenarios and present functioning of the coastal zone can draw on experiences (as appropriate) from earlier LOICZ work such as the Southeast Asian core project SWOL (dealing with input output modelling and rapid assessment of sectoral residual production of nutrient fluxes to coastal zones – LOICZ R&S No 17, 2001) and links to related global activities carried out in the LOICZ framework. In addition, the project can adapt and use as appropriate methodologies of the EuroCat (European Catchments) project such as the software package DEFINITE. The package can be used to undertake both cost-benefit analysis and multi-criteria analysis, the latter allowing the inclusion of costs and benefits, which cannot be expressed in monetary terms. To model catchment fluxes the project may consider to use the experiences made on models including point and diffuse sources as well as land cover. In this context the model MONERIS, Modelling Nutrient Emissions in River Systems, can be evaluated and adapted from European to Caribbean application.

In this 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 Caribbean level.

It is considered recommendable to set up a Policy Advisory Board (PAB) 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 PAB.

Products
The project will provide a better understanding of the functioning and change of Caribbean coastal systems under natural and human forcing based on an integrative coupling of biogeochemistry and socio-economic sciences. 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 are expected to comprise.:

- Catchment/island case studies in peer-reviewed articles;
- Regional synthesis for evaluation in the global LOICZ network and the IGBP II and IHDP (International Human Dimensions Programme on Global Change) integrated earth system science framework;
- Protocols for integrated assessment, modelling and forecasting for dissemination in training workshops.

Links
In implementing the recommendations of the Basins/Islands working group held at the 4th LOICZ Open Science Meeting, Bahia Blanca, Argentina, 1999, the CariBas synthesis implements and concludes a first assessment and synthesis of Caribbean coastal change and land-based drivers initiated by LOICZ in late 2000. The Caribbean activities associated and part of this project in the LOICZ framework were/are supported by LOICZ, the UNESCO/IOC and the IAI. Close watching briefs should be established with other ongoing regional activities such as the UNEP regional seas project, the GEF Meso American Reef project and in particular with IOCARIBE, the regional sub-commission of UNESCO/IOC, and its activities including the coastal GOOS and ICAM projects. Links and synergies with global change science conducted under the aegis of the Inter American Institute of Global Change (IAI) are to be investigated and mutual agendas being sought.

4. CONTRIBUTED PAPERS

4.1 Environmental modifications and impacts on the Caroni River basin, Trinidad

Rahanna Juman, Peter Bacon and Lloyd Gerald

Trinidad is the most southerly of the Caribbean islands, located in the delta of the Orinoco River in northern South America, from which it is separated by the Gulf of Paria. Trinidad is a high island, with three roughly parallel mountain ranges and two flat, alluvial plains. It is located approximately 10° N of the equator in a humid, tropical region dominated by the north-east trade winds.

The Caroni River basin, the hydrometric area that encompasses the Caroni Swamp, is situated in the north-western section of Trinidad (Figure 1) and covers a total of about 883.4 km^2, equivalent to 22% of the land surface area of the island.

The Caroni and associated rivers discharge into the Caroni Swamp, the largest mangrove area in Trinidad, situated on the eastern coast of the Gulf of Paria. The swamp is important economically for oyster and fish harvesting, for hunting and for ecotourism. Major commercial fisheries are based on demersal stock in the adjacent eastern Gulf of Paria.

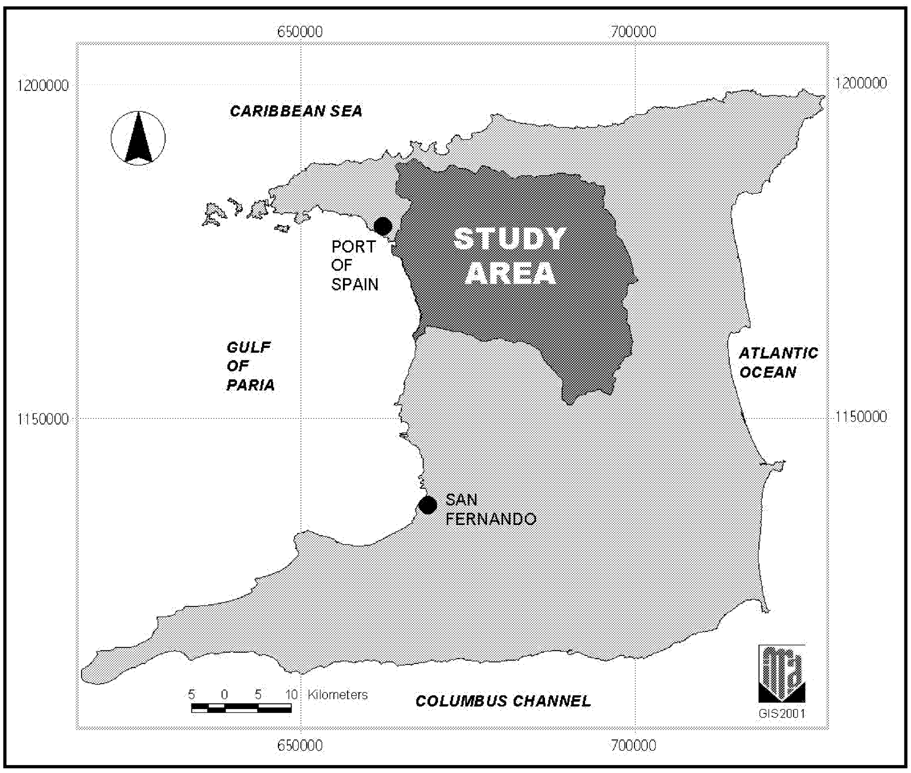

Figure 1. Location map of the Caroni River basin, Trinidad

Description of the river basin

The Caroni River basin falls within the physiographic regions of the Northern Range, which rises to nearly 940 m, and the Central Range, which bisects the island obliquely from east to west and rises in places to over 300 m in the Northern Basin (Bacon 1970). The Caroni River, which is the largest river in Trinidad, drains the northern and central ranges to the west and has a catchment area of about 600 km^2. The major part of the Caroni River water supply comes from perennial tributaries of the northern and central ranges.

Twelve rivers flow into the Caroni River on its northern side from the Northern Range, and six rivers flow in from the southern side from the Caroni Plain and the northern side of the Central Range (Figure 2). A list of the major tributaries in the Caroni Basin and their characteristics is provided in Table 1.

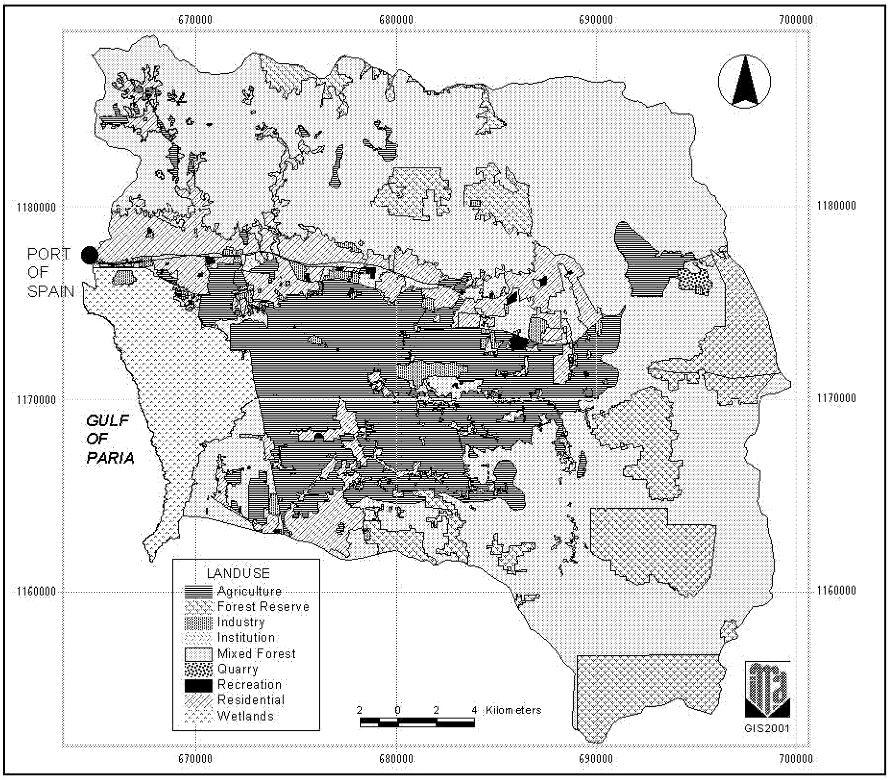

Figure 2. Land use/ land cover in the Caroni River basin.

Table 1. Tributary characteristics in the Caroni River basin.

	Area of catchment[1] (km²)	**Length[1] (km)**	**Slope[1] (m km⁻¹)**	**Flow rates [2] (m³ s⁻¹)**
Northern Range Tributaries				
San Juan	59.1	19.0	5.1	0.660
St Joseph	47.5	17.9	6.9	0.386
Tunapuna	16.6	9.3	21.9	
Tacarigua	49.4	20.5	9.0	0.473
Arouca	47.2	19.9	11.7	
Oropuna	19.1	12.0	4.3	
Mausica	17.2	13.0	20.7	
Carapo	14.2	7.0	5.8	
Arima	29.5	18.6	12.1	
Guanapo	47.2	19.9	10.2	
El Mamo	15.6	9.8	11.4	
Aripo	43.7	22.0	17.1	
Central Range Tributaries				
Tumpuna	56.4	28.4	2.7	
Talparo	35.3	16.5	2.8	
Cumuto	52.1	22.6	2.3	
Guatapa jaro	18.3	8.0	3.3	
Arena 1	19.1	9.7	6.1	
Arena 2	11.4	8.4	4.6	

Sources: [1] NEDECO 1983 ; [2] Phelps 1997.

The northern tributaries contribute the major part of the Caroni River water supply while draining the rainforest-covered mountains of the Northern Range, which is composed of indurated metamorphic rocks that include marmorolized, silicified and schistose limestones, mica schists, and slaty shales. Tributaries from the Central Range that contribute to the Caroni outflow drain mainly soft, massive, arenaceous, yellow-white limestone hills (Bacon 1970) on which agriculture has largely replaced native forest. The lower course of the Caroni River flows through the Caroni plain from an elevation of less than 30 m across broad alluvial valleys. After meandering westward through this basin, the river at one time separated into a number of distributaries in the Caroni Swamp, but the drainage pattern was modified by channelization.

A dam constructed within the Caroni River basin created the Caroni-Arena reservoir, situated between the Arena Forest Reserve to the north and the Tumpuna Forest reserve to the south and covering an area of about 573.1 ha. There are also several minor diversion structures which channel water for domestic and agricultural/irrigation use. Water is diverted from the Caroni and its tributaries for industrial, domestic, and agricultural purposes. Further diversion and river-training works are associated with flood-control structures, particularly in the lower reaches of the main river.

A large number of light industrial and agricultural plants discharge wastewater directly into the Caroni River and some of its tributaries. The river is also used as a receiving body for secondarily treated sewage effluent. The land-use/land-cover throughout the Caroni River basin is diverse, as indicated in Figure 2.

The gently sloping foothills of the northern and central ranges and the non-flood-prone areas of the Caroni floodplain are used extensively for built development, both industrial and residential. The housing and built development sector extends from the eastern boundary of Port of Spain continuously along what is known as the "East-West Corridor" and covers an area of about 8,724 ha. Increased competition for lands in the flatter areas of the basin has led to built development on the fertile lowlands and additional development on steeper slopes. The river basin contains some of the most fertile land in the country (Brown *et al.* 1966).

The Caroni River basin is the most populated region of the country, with 33% of the national population. The area has a population density of 439 persons km^{-2}, higher than the national average. There was rapid population growth in the Caroni River basin between 1970 and 1990, mainly because of migration from less developed rural regions to Port of Spain and its environs (Table 2).

Table 2. Population data for the Caroni River basin compared with the national average.

Year	Caroni River Basin	Trinidad and Tobago
1960	269, 534	827,597
1970	329,590	940,719
1980	No data	No data
1990	415,636	1,125,128

Source: Central Statistical Office

Residential areas are concentrated along the east-west corridor within the basin (Figure 2) and the spread of urbanization has resulted in the expansion of built development to the valleys and hillsides, threatening traditional agricultural activities. Much of the hillside development in the river basin is unplanned and on state land. In 1980, 106 squatter settlements were identified in Trinidad, with St George County showing the larger percentage, followed by Caroni County.

In 1980, 76% of the lands in the river basin were under agriculture (Deonarine 1980). Crops were cultivated on some 57,270 ha, of which 60% was devoted to traditional export crops such as sugarcane, coffee, cocoa and citrus. Sugarcane occupied some 14% of these lands, while domestic food crops were produced on less than 10%. In the 1990's, a decline in domestic agriculture was noticed (from 1994 aerial photographs) and only 15,799 ha of the river basin is currently estimated to be under agriculture. There is still increasing pressure to convert agricultural lands to other profitable uses. Current agricultural activities, including livestock production, are shown in Figure 2.

A wide variety of pesticides, herbicides, fungicides and fertilizers have been used for agricultural activities in the river basin. High levels of contamination and some bio-magnification in fish and other aquatic species has been found, as shown in Table 3.

Table 3. Pesticides Residues in the Caroni River basin (Deonarine 1980).

Donawa study, 1976

Species	Chlorinated hydrocarbons	Wet weight
T. mossambica (Tilapia) 1973	DDT	0.001 ppt
	Dieldrin	0.001ppt
	DDE	0.002 ppt
Centropomus (Brochet)	Dieldrin	0.002 ppt
T. mossambica (Tilapia) 1974	DDE	0.002 ppt
	DDT	0.002 ppt
	Lindane	0.009 ppt
	Dieldrin	0.001 ppt
	DDT	0.006 ppt
	Dieldrin	0.003 ppm

Deonarine study, 1980

Species	Chlorinated hydrocarbons	Wet weight
Arius sp.	Arochlor 1254	59.2 ppb
	pp DDT	0.8 ppb
	Dieldrin	2.0 ppb
Lutjanus griseus	Arochlor 1254	127.2 ppb
	pp DDT	1.3 ppb
	pp DDE	0.3 ppb
	Dieldrin	0.5 ppb
Mytella guayanensis	Arochlor 1254	46 ppb
	pp DDT	1.1ppb
	OpDDD	0.3 ppb
	op DDE	0.6 ppb
	Dieldrin	0.6 ppb
Aratus pisonii	Arochlor 1254	96 ppb
	Dieldrin	5.0 ppb

Industrialization has always been a prominent feature of the Caroni River basin. According to 1976 statistics, the basin housed 264 industries. In 1990 surveys, 355 industries were recorded, and these occupied about 1,172 ha of the land in the river basin. Industrial activities in the river basin are shown in Figure 2, and the types of major industries and their wastes are listed in Table 4.

Table 4. List of major industries in the Caroni River basin and their wastes.

Type of Industry	Waste
Cigarette	Tobacco, dust, wash water, human
Soaps, detergents, cleaning compounds, sanitary chemicals	Wash water, human
Canned food, milk processing, dried food, processed foods, snack foods, baked food, frozen food and snacks	Scum, vegetable matter, oil, baking powder, wash water, human
Meat processing and packaging; animal slaughtering	Wash water, grease, blood, animal entrails, hair, offal, human
Soft drinks	Wash water, coke residue, human
Sugar and distilleries	Alcohol, molasses, wash water, human
Livestock, hatcheries, poultry farms	Wash water, grease, blood, animal entrails, hair, offal, human
Hot asphaltic concrete production; concrete products; mastic alphalt mix	Equipment wash, cooling water, human
Car assembly; auto body works; mufflers	Paint fillers, wash water, human
Paints	Paint residues, wash water, human
Batteries	Acid, lead oxide paste, wash water, human
Plastics; pipes; fittings	Powdered waste, plastic residue, human
Metal structures and frames, welded wire, metal, furniture, tools, moulds	Acid, paint, grease, oil, iron phosphates, cooling water, wash water, human
Paper and paper products	Dextrine, cornflour, wash water, human
Printing and painting ink	Oils, chemicals, resins, dye wash, human
Styrotex	Detergent, wash water, human

Sources: Deonarine 1980, Siung-Chung *et al.* 1997

Quarrying activities have also occurred within the Caroni River basin, covering an area of about 220.7 ha. Significant deposits of limestone and non-hydrocarbon minerals are found in the Northern Range and northern basin, and in 1991, 57 sand and gravel quarries and 18 limestone quarries were recorded for this area of Trinidad. The impact of quarrying on rivers and streams in the Caroni River basin has been studied in two University of the West Indies (UWI) undergraduate projects, but no published reports appear to be available.

More than 60% of the land in the river basin is under forest, with 11,560.8 ha designated as Forest Reserve. There are sixteen forest reserves within the basin, with the Central Range Forest Reserve being the largest, covering 2,423 ha.

The coastal systems

The Caroni Swamp is situated on the west coast of Trinidad, south-west of Port of Spain (Figure 3). It is the second largest wetland in Trinidad, consisting of 5,611 ha of mangrove and herbaceous marsh, interrupted by numerous channels and lagoons. This is developed on late Pleistocene and Recent peat and river-borne sediments derived from the Caroni River Basin. Below the peat deposits of the Caroni Swamp are Pliocene clays overlying Mio-Pliocene conglomerates. Strong faulting in the latter and in the underlying Cretaceous rocks suggests that a graben with an east-west axis determined the position of this sedimentation area (Bacon 1970).

The Gulf of Paria is a semi-enclosed sea between Trinidad and Venezuela, bordered on the north by the Caribbean Sea and on the south-east by the Atlantic Ocean. It is shallow, with an average depth of about 25 m and a maximum depth of 300 m in a trench to the north. The eastern side, adjacent to the Caroni Swamp, is shallower, with large areas of mudflat exposed at low tide. During the dry season the Guiana Current forces the main flow through the gulf from the Atlantic, which develops into a clockwise gyre within the gulf. Water quality and flow pattern are dominated during the wet season by a large input of freshwater from the Orinoco delta distributaries. This leads to stratification, with denser saline water below the fluvial discharges (Gopaul and Wolf 1996).

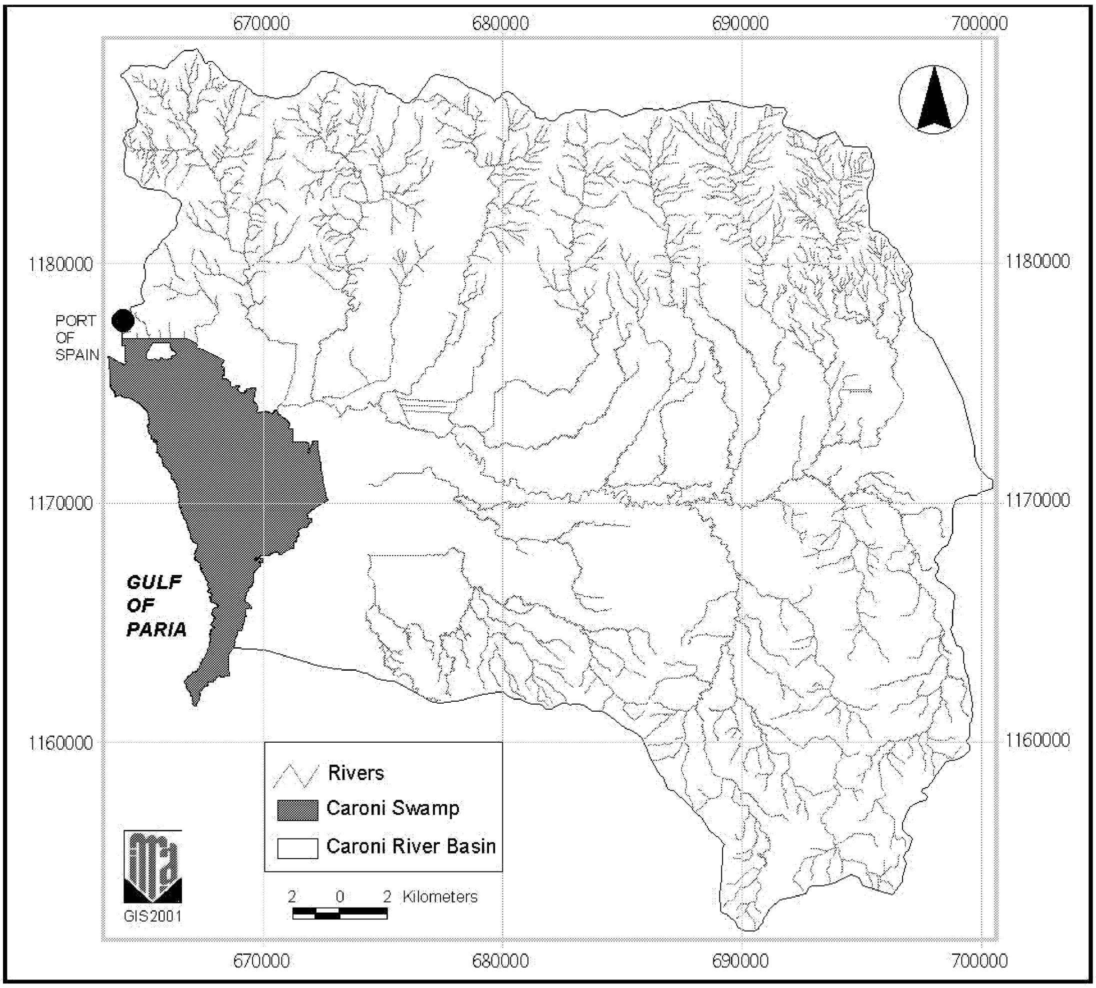

Figure 3. Map of the surface hydrology of the Caroni River basin.

The eastern borders of the Caroni Swamp are occupied by the remnants of once-extensive marshes. In the 1970s these were predominantly freshwater habitats, but freshwater diversion and saltwater encroachment have changed them to saltmarsh ecosystems in the last two to three decades. In their present saline, and frequently hypersaline, condition, these marshes are of considerable importance as waterbird-feeding habitat and consequently as bird-watching sites.

The Caroni Swamp is bounded on the north by the Caroni River, on the east by the Uriah Butler Highway, on the west by the Gulf of Paria, and on the south by the Madame Espagnole River. Under natural conditions, the swamp received freshwater inflow to its northern half from sediment-laden overflows from the Caroni River, and along its eastern boundary from overflows further upstream, while the Guayamare River and Cunupia River entered the swamp close to its southern boundary. However, the original drainage pattern in the swamp has been modified by attempted reclamation, under the Cipriani Reclamation Scheme 1921-1922, which was initiated to facilitate rice cultivation. Flood protection works which began in the 1950s have resulted in an overall reduction of freshwater inflow into the swamp (Phelps 1997).

This loss of freshwater inflow has further reduced freshwater storage in the swamp and caused salinity levels to increase. The swamp also receives water polluted with sewage, wastewater from industry and agriculture runoff (Phelps 1997). Table 5 provides information on the water chemistry in the Caroni River basin.

Table 5. Water chemistry information sources for the Caroni River basin.

Source	Type of information
Siung-Chang *et al.* 1987	Organic pollution of the Caroni River, Biological Oxygen Demand (BOD)
Environmental Management Authority 1997	Physicochemical ranges, coliform levels, existing and potential sources on pollution in the Caroni River basin
Bacon *et al.* 1997	Salinity records for Caroni Swamp 1966-1968, 1995 to 1997.
Phelps 1997	Discharge rates of rivers
Institute of Marine Affairs 1999	Chemical analysis of the rivers in the Caroni River basin; physical parameters, nutrients, heavy metals.

The Caroni Swamp has an estuarine environment under which salinities in the main channels fluctuate from >36.0 to <10.0 psu in response to seasonal rainfall. Tidal change is approximately 1 m, with semi-diurnal periodicity. As indicated above, the original pattern of creek channels and open lagoons has been modified by attempted reclamation, although the breakdown of embankments is allowing the swamp to return to its earlier state.

Approximately 60% of the mangroves found in Trinidad occur in Caroni Swamp. These are in the form of mangrove woodland of the *Rhizophora-Avicennia-Laguncularia* association. *Rhizophora mangle* is the dominant species, with a few small stands of *R. racemosa* and *R. harrisonii.* The more landward areas are dominated by *A. germinans,* with isolated patches of *A. schaueriana.* *Laguncularia racemosa* is ubiquitous, but nowhere common. The eastern, landward borders of the swamp are occupied by saline marshes, dominated by sedges, *Eleocharis* spp., in association with grasses and the fern *Acrostichum aureum.*

A wide variety of estuarine invertebrates is present, including commercially important resource organisms such as the mangrove oyster, *Crassostrea rhizophorae*, mussels, *Mytella guyanensis & M. falcata*, clams, *Phacoides pectinatus*, conch, *Melongena melongena,* and shrimp, *Penaeus* spp. Some 190 species of birds have been reported in Caroni Swamp, including resident and nesting waterbirds, plus migratory species and a number of forest and pasture birds that roost in the mangrove (Bacon 1970).

Socio economic importance

Very little data is available on the social and economic interactions between local communities and coastal ecosystems in the Caroni Hydrometric Area. One early study by Ramdial (1975) gave data from 1974 on the nature and extent of resource use in the Caroni Swamp (see Table 6). Oyster-harvesting (La Croix 1971; Chin Yuen Kee 1978) is shown in Table 7.

Oyster collecting was an important economic activity up to the 1990s when a serious decline in stocks was noticed. In August 1992, a countrywide ban on oyster sales was introduced because of the threat of cholera, which had been reported in neighboring Venezuela. The ban remained in force for two and a half years, during which time the generally unsanitary nature of the swamp environment received a great deal of press coverage. Oyster collectors and vendors suffered severe economic losses during this period, and oyster sales have never returned to their former level. There have been no recent attempts to assess the oyster stocks or the extent of their utilization.

Table 6. Estimated use of the Caroni Swamp (Ramdial 1975).

Employment Full-time	240 persons	Oyster vendors (27%), fish vendors (11%), taxi-drivers (15%), crab vendors (9%), boat operators (3%), conch vendors (3%), shrimp vendors (1%)
Part-time	105 persons	Taxi-drivers (13%), fish vendors (9%), oyster vendors (5%), boat operators (2%), conch vendors (1%) crab vendors (1%)
Number of people interviewed Bird-watching residents Bird-watching tourists Sport fishermen Hunters	486 620 379 63	
Values ($TT) Recreational resources Fin and shellfish harvest Total annual return Value of swamp (calculated) Opportunity cost	1,038,500.00 981,450.00 2,020,020.00 4,000.00 per acre 1,398,330.00	

Number of oyster vendors – 154		
Estimated Production of Main Oyster Beds- 56, 620 kerosene tins		
Total fixed and variable cost and returns/ annum for boat owners in the wholesale trade		
Capital cost	$TT 193.33	
Operating cost	$TT 597.00	
Gear	$TT 14.58	
Total cost fixed and variable	$TT 804.91	
Revenue	624 tins @ $4.00 per tin	$TT 2,296.00
	Net profit	$TT 1,691.09
	Income/month	$TT 141.00
Total fixed and operating cost and returns/ annum for a collector who himself is a retailer.		
Capital cost	$TT 20.00	
Operating cost	$TT 694.58	
Revenue	$TT 2,912.00	
Net profit	$TT 2,217.00	
Income/month	TT 185.00	

Table 7. The Caroni Swamp oyster trade (La Croix 1971)

The Caroni Swamp Forest Reserve, which covers approximately 2,833 ha, was proclaimed in 1936, and a further area of 136 ha was designated a Wildlife Sanctuary in 1953 for breeding Scarlet Ibises, the national bird of Trinidad and Tobago. Later extensions to the Sanctuary brought the total to 200 ha (Bacon & ffrench, 1972). Fishing, oyster collecting, and hunting had been permitted in all areas except the Wildlife Sanctuary. In 1987, the major part of Caroni Swamp, south of the Blue River, was declared a Prohibited Area (Forests Act, chap 66:01). This meant that all fishing, oyster collecting, and other extractive activities (mangrove bark, stakes, poles) became illegal and, with the exception of licensed tour guides, local communities were no longer able to use the resources of the Caroni Swamp. A Master's degree study from UWI on community use and exploitation of Caroni Swamp has not yet been completed, but has shown that prohibition in the Swamp has caused a marked decline in resource use since 1987.

Consequences of temporal changes

Because of their leeward situation, the Caroni Swamp and eastern Gulf of Paria are little affected by hurricanes and tropical storms, except as a result of increased river flow following associated heavy rains. Fluctuations in total annual rainfall are thought to influence ambient salinities in the Swamp channels, but this response is difficult to separate from the effects of freshwater reduction through diversion.

Data showing these increases in salinity in the interior of Caroni Swamp over the last two decades, coupled with observations of erosion and retreat of the coastal mangrove fringe, may be a signature of sea-level rise around the Trinidad coast.

Significant changes have been observed in ambient salinity conditions, plankton composition, biomass of the rhizofauna, and waterbird populations. Salinity change, coupled with habitat perturbation, has been implicated in breeding failure by the scarlet ibis, *Eudocimus ruber*, in recent years. Several aquatic plant and animal species have been lost from the eastern marsh area, probably as a result of reduction of freshwater inputs to the Caroni Swamp.

Salinity and nutrient content of waters in the swamp are strongly affected by conditions in the Gulf of Paria. During the dry season, oceanic water from the Central Atlantic flows strongly through the gulf, its presence noticeable in the large populations of jellyfish, such as *Stomolophus fritillarius*, that enter the Caroni Swamp with the tides at this time. During the wet season, Orinoco floodwaters dominate the gulf and bring more estuarine conditions to its eastern coastline. It is thought that the eastern gulf and the Caroni Swamp may be impacted by pollutants carried into the gulf from the Orinoco River basin and by petroleum hydrocarbon residues generated by the local oil industry. Data are poor on contamination levels at the study site, but some monitoring is in progress.

Agard (1992) reported the first appearance of *the Indo-Pacific* Green-lipped Mussel, *Perna viridis,* in the eastern Gulf of Paria in 1990 and its rapid invasion of Caroni Swamp. This species was probably brought to the Gulf of Paria by ships docking at Port of Spain or Point Lisas, a few kilometers to the south of the swamp. The impact of this exotic species on the benthic fauna of the study site has not been assessed.

There is little likelihood of significant changes occurring in land-use patterns and activities in the Caroni River basin and along the Gulf of Paria coast in the near future. Although agricultural expansion is unlikely, some change and diversification in cropping patterns can be expected with the continuing decline in the importance of sugarcane. Urbanization is increasing rapidly, and that trend seems unlikely to abate in the immediate future. Industrial activity is expected to increase significantly on the Trinidad west coast, immediately south of the Caroni Swamp, as oil and gas exploration and refining are expanding rapidly.

The Government of Trinidad and Tobago has shown interest in the conservation of the Caroni Swamp. Recently it commissioned studies on the feasibility of enhancing freshwater input in order to restore marsh habitats in the eastern swamp. A recently prepared water resources management plan includes consideration of freshwater allocation to support wetland needs at Caroni. The government has established a National Wetlands Committee, which is seeking to have the Caroni Swamp declared a Ramsar Site, and a Caroni Lagoon and Bird Sanctuary Management Committee with immediate concern for the conservation of the swamp through regulation of resource users. Unfortunately, little attention is being paid to reducing the high pollutant loading of rivers and streams throughout the Caroni River Basin, although the Water and Sewerage Authority has a number of initiatives concerned with water quality enhancement.

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4.2 Environmental overview of Buccoo Reef and the Bon Accord Lagoon, Tobago

Rahanna A. Juman and Peter R. Bacon

Introduction

The Buccoo Reef/Bon Accord Lagoon system, (11° 10' N, 60° 57' W) on the leeward coast of south-western Tobago (Figure 1), is the best example of contiguous coral reef, seagrass bed and mangrove swamp in the country. This coastal area has no riverine inflow, merely ephemeral streams and surface drains. There is no drainage basin, but rather a drainage area, based on the surface hydrology of the coralline limestone beds, which are highly fractured and faulted, facilitating chemical dissolution. The high porosity and transmissivity of this coral-algal limestone makes it unsuitable for liquid effluent/sewage disposal.

Buccoo Reef has been recognized as an important socio-economic asset for the country. It is one of the largest tourist attractions in Tobago, with more than 50,000 visits to the reef per annum, and the annual income generated by the reef tour trade exceeds TT $1 million. The major land-use activities within the drainage area of this ecosystem complex is built development, which includes housing and resort development, and some agriculture. Buccoo Reef and Bon Accord Lagoon have been impacted by eutrophication, mainly through sewage pollution, and the Reef has been physically damaged by tourist-related activities such as reef walking, anchor damage, and boat groundings.

The Buccoo Reef/ Bon Accord Lagoon system is 300 km^2 in area and has a resident population of 46,654 (Central Statistical Office 1990).

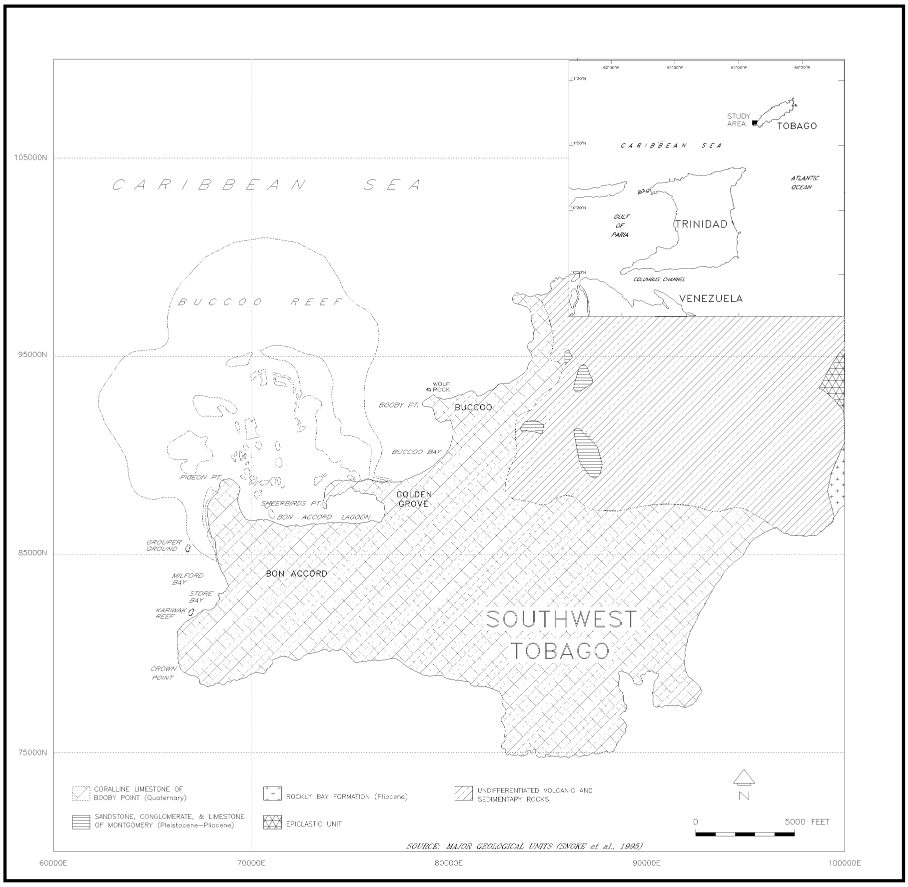

Figure 1. Location map of the Buccoo Reef/ Bon Accord Lagoon system. The predominant geological provinces are indicated, with bricked patterns indocating limestone pavement and the striped pattern indocating either volcanic or sedimentary basement.

Climate

Tobago experiences a humid, tropical seasonal climate with dry (January-April) and wet (May-December) seasons and a mean annual ambient temperature of 25.7ºC (Berridge 1981). Seawater temperature is generally constant to depths less than 20 m, ranging from 24ºC in the dry season to 27ºC in the wet season. South-western Tobago receives little precipitation, with a maximum of 1016 mm during the wet season and a minimum of 381 mm during the dry season (Berridge 1981). The wet season coincides with the overhead passage of the Inter-Tropical Convergence Zone (ITCZ). A summary of climate and weather in Trinidad and Tobago can be obtained from Henry (1990).

Tobago lies south of the hurricane belt and, thus, only occasionally experiences tropical storms and hurricanes. The last major hurricane was Flora in 1963, which caused extensive damage to the mangroves in the Bon Accord Lagoon (Kenny 1976). Daniel and Maharaj (1987) discuss all tropical cyclones affecting Trinidad and Tobago from 1725-1986. The North-east Trade winds prevail during the wet season, while the stronger northern winds prevail during the dry season (Kenny 1976). Winds were on average 5 m s^{-1}, with maximum wind speed recorded at 10 m s^{-1} (IMA 1993).

Circulation within the coastal zone

Water circulation within the coastal area of this drainage area is wind-driven, mainly by the northern and north-eastern winds. Residual currents within the lagoon move westerly at a speed of 10-11 cm s^{-1}, resulting in a flushing time of 2-3 days (IMA 1993). Residual currents over the Reef move in a westerly and northwesterly direction at a speed of 20-60 cm s^{-1}, resulting in a flushing time of 3-16 hours (IMA 1993). During the North American winter months, the area experiences strong oceanic swells from the north, and these invariably cause some surface movement, even in the sheltered Bon Accord Lagoon. This results in an increase in levels of turbulence and, consequently, of turbidity in the water (Kenny 1976).

The Buccoo Reef/Bon Accord Lagoon area experiences a mixed, semi-diurnal tide. Mean spring tide range is approximately 0.9 m, while the mean neap tide range is approximately 0.4 m. Salinity and turbidity of the water are strongly influenced by the Orinoco River discharge during the wet season, which has a marked effect on the water quality at Buccoo Reef, where lower mean salinity (34 psu) and higher turbidity (15 m visibility) are common during the wet season (Laydoo *et al.* 1998)

The major ocean current that influences Tobago is the Guiana current. The northward-flowing component of this current moves along the east coast of Trinidad, flows through the Tobago Sound, the channel that separates Trinidad and Tobago, and continues north east along the south coast of Tobago (Van Andel and Postma 1954).

The largest contribution of freshwater input around Tobago comes from the Orinoco River (IMA 1996). Muller-Karger and Castro (1993), using Coastal Zone Color Scanner (CZCS) imagery, found that the Orinoco discharge has a profound effect on the pigment concentrations around Tobago, and during July-November, the plumes surround the island. The effects of the Amazon River are less clear, but Muller-Karger and Castro (1993) suggest that some of the pigments observed in Tobago waters may be the result of eddies generated in the region of the North Brazil Current.

Geology

Buccoo Reef represents a Holocene formation (ca 15,000-18,000 years B.P.) lying on a Pleistocene carbonate platform that characterizes the adjacent terrestrial geology of south-western Tobago, from Little Courland in the north to Little Rockly Bay in the south. This low-lying region is a coralline limestone formation (Quaternary), which is porous and re-crystallized, and consists of broken fragments of corals and mollusks (Maxwell 1948). The algal-limestone within south-west Tobago is highly fractured and faulted and facilitates chemical dissolution (IMA 1996). These geological properties, together with wave action, make the coastal areas very unstable. The high porosity and transmissivity of the coral-algal limestone terrain renders it unsuitable for liquid effluent/sewage disposal. Geological studies have shown that south-western Tobago is susceptible to earthquakes and ground motion. In addition, loose alluvial and coastal sands and gravels are susceptible to liquefaction and ground settlement (IMA 1996).

Drainage area

The drainage area for the Buccoo/Bon Accord Lagoon falls in the South-western Coast Hydrometric area No.15. The immediate drainage area is bounded to the east by Grafton and Shirvan roads, to the south by Milford Road and to the north-west and west by the coastline running diagonally from Mt Irvine Bay to Bon Accord Lagoon, and to the west from Pigeon Point to Milford Bay at the western end of Milford Road (Figure 2).

Hydrology and land use within the drainage area

There are no rivers within this drainage area; several ephemeral streams and surface drains transport runoff from a cattle farm and sewage treatment plants (STP's) into Buccoo Bay and Bon Accord Lagoon (Figure 2). Groundwater seepage or runoff into the Bon Accord Lagoon and Nylon Pool areas has not been investigated. Groundwater has never been tested for nutrients, pesticides or heavy metals.

Figure 2. Land uses within the Buccoo Reef / Bon Accord Lagoon drainage area.

South-west Tobago consists of four main hydrogeological units. The most significant of these is the fissured coral-algal limestone platform, as it represents the only unit with significant groundwater resources (IMA 1996). Three main wells are drilled for groundwater exploratory purposes in this limestone unit, two of which are located within the Buccoo Reef/Bon Accord Lagoon drainage area. One well is located in the Bon Accord/Canaan area. It is 30.5 m deep, with a surface cover of 18 m of limestone, then clay, silts, marls and sandy layers from 18-22 m, under which lie volcanics. Specific capacity of this well measures 0.108 $m^3\ h^{-1}\ m^{-1}$ (per metre of drawdown). The other well, near Pigeon Point, is 185 m deep, with a surface cover of 14 m of limestone, then clay, silts, marls and sands from 14-16 m, below which lie volcanics. This well is an observation/monitoring well, with a specific capacity of 0.038 $m^3\ h^{-1}\ m^{-1}$ (per metre of drawdown) (Water Resource Agency 1989).

Based on the stratigraphy of the three wells, the surface limestone unit thins toward the west-north-west. Consequently, wells within the drainage area can become artesian (IMA 1996). The intermediate sands, silts, marls and clays below the limestone contain intergranular sand aquifers. However, these are isolated and lenticular. The reef system is thought to be impacted by groundwater intrusion/ upwelling.

Town and Country Planning Division (TCPD) reported in 1991 that some 73% of the total land area in Tobago was covered with natural vegetation, 17% was cultivated, and the remaining 10% was built development (TCPD 1991). However, existing land-use data for south-west Tobago (TCPD 1996; IMA 1996) showed that the predominant land-use in this region is built development, accounting for some 2416 ha or 38% (Table 1).

Table 1. Existing land use, south-west Tobago (TPCD 1996; IMA 1996).

Use	Area (hectares)	Percentage of total area
Built development	2415.84	38
Coconut	693.67	11
Other agriculture	179.7	3
Forest	509.19	8
Disrupted forest	1132.06	18
Lastro / scrub/ bamboo	579.88	9
Grasslands	651.52	10
Mangroves	156.79	3
Total	6318.74	100

Over the last decade, south-west Tobago has been experiencing rapid growth and development in the tourism and related service sector. Resort development (hotels and guest-houses) is predominant. Data from TCPD indicated that there are some 1654 hotel rooms in this region, with another 1372 rooms approved but not yet built. Residential development is concentrated in particular areas, including Coral Gardens, Milford Courts and Bon Accord Housing Development, all of which are within the Buccoo/Bon Accord drainage area (IMA 1996).

The most suitable soils for commercial agriculture are located in south-west Tobago, but very little agriculture occurs in this area. Agriculture as an economic activity has been on the decline, a trend that is expected to continue if not addressed. An 18 % decline in the area under crop production has been recorded between 1963-1982 (IICA 1994). Agricultural lands have been replaced to a large extent by built development, particularly resort development (IMA 1996).

State of the coastal ecosystems

Buccoo Reef and Bon Accord Lagoon are located on the leeward coast of south-west Tobago and are characterized by contiguous reef, seagrass beds and mangrove swamp. The reef system is approximately 7 km^2 in area and consists of five emergent reef platforms which arc seaward of the reef lagoon from Pigeon Point in the west to Sheerbird's Point on the east, and are known as Pigeon Point Reef, Western Reef, Northern Reef, Outer Reef and Eastern Reef (Laydoo *et al.* 1998) (see Figure 2).

The reefs are generally characterised by a narrow seaward reef crest and a more extensive back reef, towards the reef lagoon. The reef crest coincides with a conspicuous breaker zone. Due to the turbulent nature of this zone, the faunal composition of the reef crest is limited to wave-resistant corals such as *Montastrea annularis* and elkhorn coral, *Acropora palmata* (Kenny 1976).

The fore-reef slopes gently to a depth of 20 m west of the reef flats, 15 m to the east, and over 30 m to the north (Laydoo 1985). The fore-reef was formerly characterised by large scleractinian coral colonies, with *A.*

palmata common on the upper fore reef area, as rubble and as standing dead skeletons. Large colonies of brain corals, *Colpophyllia* spp. and *Diploria* spp., starlet coral, *Siderastrea siderea*, and the star corals, *Montastrea cavernosa* and *M. annularis*, dominated the lower fore-reef. Colonies of leaf coral, *Agaricia* spp., gorgonians and sponges were also common in the lower fore-reef. Recent surveys conducted on Buccoo Reef reported a large number of dead standing *A. palmata.* Many *M. annularis* colonies have not recovered from an extensive bleaching event in 1998, (Reia Guppy, pers. comm., January 2000).

Smaller coral communities throughout the back-reef lagoon were characterised by one to a few species, dependent on location. Hudson (1984) identified four types of these coral communities. To the south, and in the Bon Accord Lagoon, patches of finger coral, *Porites porites* occurred, in association with coral rubble encrusted with the calcareous green alga, *Halimeda* spp. In coral patches on the western flank of the back-reef, thickets of staghorn coral, *Acropora cervicornis,* were found, while colonies of *A. cervicornis* and fire coral, *Millepora* sp., were found on the eastern margin.

Coral patches in the northern areas of the back-reef lagoon were mainly large boulder-like formations of star coral, *M. annularis* and the brain corals, *Diploria labyrinthiformis* and *D. strigosa*, in association with sea fans, *Gorgonia ventalina*, and other octocorals. Numerous reef fish species were commonly encountered at this location, which is popularly known as the Coral Gardens, the most popular glass-bottom boat tour site on the reef.

In terms of species diversity, Buccoo Reef was reported to slightly less diverse than other reefs around Tobago. A total of 97 coral and 117 reef fish species were recorded for reef localities around Tobago, compared with 42 coral and 70 reef fish species for Buccoo Reef (Kenny 1976; Ramsaroop 1981; Laydoo 1985; IMA 1994). Juman (2001) recorded 102 reef fish species on Buccoo Reef. This lower diversity may be a result of the stressed marine environment at Buccoo Reef, due primarily to its close proximity to the Orinoco River delta in Venezuela (IMA 1994). This natural stress is absent or not as evident at other reef localities in Tobago such as Speyside, Arnos Vale and Man-of-War Bay, and in the Caribbean in general. The existence of a stressed natural environment at Buccoo Reef has important management implications, since the reef's plant and animal communities will be much more sensitive and susceptible to human activities that result in direct or indirect negative impacts on the quality of the reef environment (IMA 1994).

Studies of water quality in the Buccoo Reef/Bon Accord Lagoon have all indicated sewage pollution with high faecal coliform levels in the area (Laydoo and Heileman 1987; Thames 1992; IMA 1994). Nutrient enrichment due to high nitrate and phosphate concentrations has had a negative effect on the reefs and seagrass beds (CARICOMP database; Juman 2001).

The seagrass community in the shallow inshore region of Bon Accord Lagoon covers an area of approximately 54 ha and is one of the largest remaining communities in the country. The seagrass beds extend in some places to a depth of approximately six metres, in three main areas: north of Sheerbird's Point in the back-reef area, south of Sheerbird's Point and in the lagoon extending from east of Gibson's Jetty towards Pigeon Point. Turtle grass, *Thalassia testudinum,* is the dominant seagrass species in the lagoon (Figure 3). Smaller areas of *Halophila decipiens* and *Halodule wrightii* are interspersed among the turtle grass. The dominant algal species were from the following genera- *Acanthophora*, *Bryopsis, Padina, Dictyota*, *Halimeda* and *Caulerpa* (Alleng and Juman, in press). Finger corals, *Porites porites,* also occur in the lagoon, among the seagrass beds.

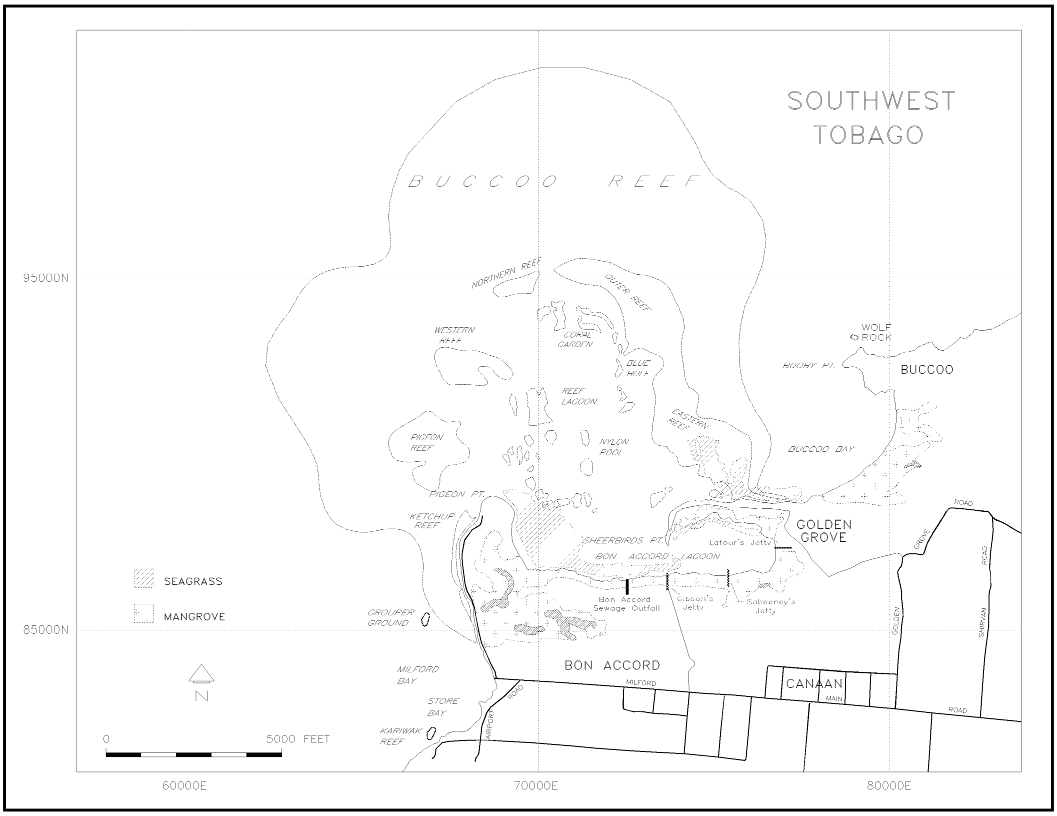

Figure 3. Map of the Buccoo Reef/ Bon Accord Lagoon ecosystems.

Overall in the Bon Accord Lagoon, seagrass standing crop varied between 2.9 tonnes dry weight in the wet season and 6.0 in the dry season. Mean annual productivity was estimated at 4.2 g dry wt m^{-2} d^{-1}, giving a total production of 682.0 kg dry wt d^{-1} and an annual production of 249 metric tonnes dry wt, which included 18 crops of leaves (Juman 2001). Seagrass beds within the lagoon are subjected to nutrient enrichment, and in many instances algal standing crop is exceeding that of seagrasses (Juman 2001).

The mangrove forest in the Bon Accord Lagoon is a fringe forest, dominated by red mangrove, *Rhizophora mangle*. The forest is approximately 89 ha, of which 9 ha are ponds, and extends between 20 to > 70 m in width. The seaward side of the forest is subjected to tidal flushing twice a day. There is no riverine inflow into the swamp. Two drains, Latour's and Bon Accord sewage outfalls, carry land-based runoff through the mangroves into the lagoon.

Mangrove above-ground biomass in Bon Accord Lagoon was estimated at 14.13± 8.1 kg (dry wt.) m^{-2}, giving a standing crop of 11,318.1± 6,488.1 tonnes for the lagoon. Productivity, as indicated by litter-fall rate, was estimated at 1269.5 g (dry wt) m^{-2} yr^{-1} (Juman 2001). The Bon Accord Lagoon is therefore a very productive system, producing 2.8 tonnes dry wt of litter-fall daily (1017 tonnes dry wt annually) and 11.8 kg dry wt of decomposed leaf material daily (Juman 2001). Most of the organic carbon produced by the mangrove swamp is washed into the lagoon by the tides, semi-diurnally.

While 102 species of fish were recorded on the reef by visual and net surveys, 33 species were recorded over the seagrass beds using beam trawls and 25 species were recorded in the mangrove lagoon using net surveys (Juman 2001). Some species were common to all three ecosystems.

Coastal resource use

Buccoo Reef is one of the largest tourist attractions in Tobago. Guided tours by locals to the reef date back to the 1930s, and this industry now has more than 12 glass-bottom boats. The major tourist-oriented activities on the reef are: glass-bottom tours to the outer reef flat, Coral Gardens and Nylon Pool; reef-walking and snorkelling on the shallow back-reef areas of the outer reef flats; and occasionally sport-diving at fore-reef sites. A user-impact survey conducted in 1991 indicated a maximum of 9 boats visiting a location on the reef at peak time. The reef tour-boats were anchored or adrift (IMA 1996). At times there were over 200 people at a particular site. Estimated visits to the reef were in excess of 50,000 per annum to 1994 (IMA 1994), with about 34,302 persons visiting the reef in 1995 (IMA 1996). Annual income generated by the reef tour trade exceeds TT$1 million (IMA 1994). Tourist-related activities on the reef have resulted in physical damage to the reef. Corals have been trampled by reef walkers and crushed by falling anchors and boat groundings (Kenny 1976).

Fishing is the mainstay of many coastal villages in Tobago (IMA 1996) and is largely an artisanal activity. A survey in 1991 recorded 32 landing beaches in Tobago, 10 of which have facilities, including storage for nets and equipment. There was a total of 840 registered fishermen, 275 boats and 9 major landing sites (IICA 1994).

Five of the nine landing sites in Tobago are situated on the leeward coast, including Pigeon Point, Swallows, Buccoo, and Plymouth. Some 450 fishermen and 206 boats operate from these beaches. Table 2 gives an idea of the number of fishermen and the fish species landed at sites within the Buccoo/ Bon Accord area.

Table 2. Number of fishermen and fish species landed in 1993 at major landing sites in the Buccoo/ Bon Accord area (IMA 1993)

Landing site	# of fishermen	Species caught
Pigeon Point	150	Tuna, shark, flying fish, oceanguard, wahoo, dolphin fish, bonito and albacore
Swallows	150	Kingfish, snapper
Buccoo Bay	100	Tuna, shark, flying fish, oceanguard, wahoo, dolphin fish, snapper, plume

Source: Division of Agriculture, Fisheries, Marine Resources of the Tobago House of Assembly, 1993 as adapted from IICA 1994.

The fleet of boats consists mainly of small, open-decked vessels known as pirogues and bumboats. The average size is between 7-9 m and the boats are equipped with outboard engines of 15-74 horsepower. As a result, most of the boats operate inshore within the country's territorial water, which extends 12 nautical miles (IMA 1996). The main fishing methods employed include banking, trolling, fish pots and pelagic nets. In addition, some fisherman spearfish and use long-lining and turtle nets. Fishermen in Pigeon Point do fish-potting all year round, the main catches being groupers and snappers. Even though Buccoo Reef is a protected area, some fishing activity occurs on the reef.

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4.3 Environmental overview of Kingston Harbour, Jamaica

Dale Webber and Trion Clarke

Introduction

Jamaica is the largest and most populous of the English-speaking Caribbean islands. Its interior consists mainly of porous limestone, while the coastal regions are mainly alluvial plains. The main mountain range runs from east to west through the centre of the island. All of the island's main rivers originate in the higher altitudes of this range and flow either southward or northward to the Caribbean Sea, which surrounds the island.

Kingston Harbour is situated on the south coast of Jamaica at 17^0 58' N, 76^0 48' W (Figure 1). It has a total surface area of approximately 51 km^2. It is a natural harbour, bounded on the north, east and west by the mainland and partly enclosed by the Palisadoes spit on the south. The Palisadoes spit was formed by deposition of sediment from the Hope and Yallahs rivers. The entrance to the open sea is by a narrow channel at the south-west corner. The harbour extends approximately 16.7 km in an east-west direction and between 2.8 and 6.5 km in a north-south direction. It has a total surface area of approximately 51 km^2, with an inner lobe, which encompasses the eastern closed portion, and an outer lobe which covers the western portion and extends to the mouth (Williams 1997). The harbour has been in a state of increasing eutrophication for decades, with the most rapid deterioration occurring in the last twenty-five years, coinciding with a rapid increase in the population. The total drainage basin of the harbour is 715 km^2. Activities in the drainage basin and coastal marine regions have profound impacts on the harbour. Unfortunately, many of these activities are expected to increase or at least remain constant.

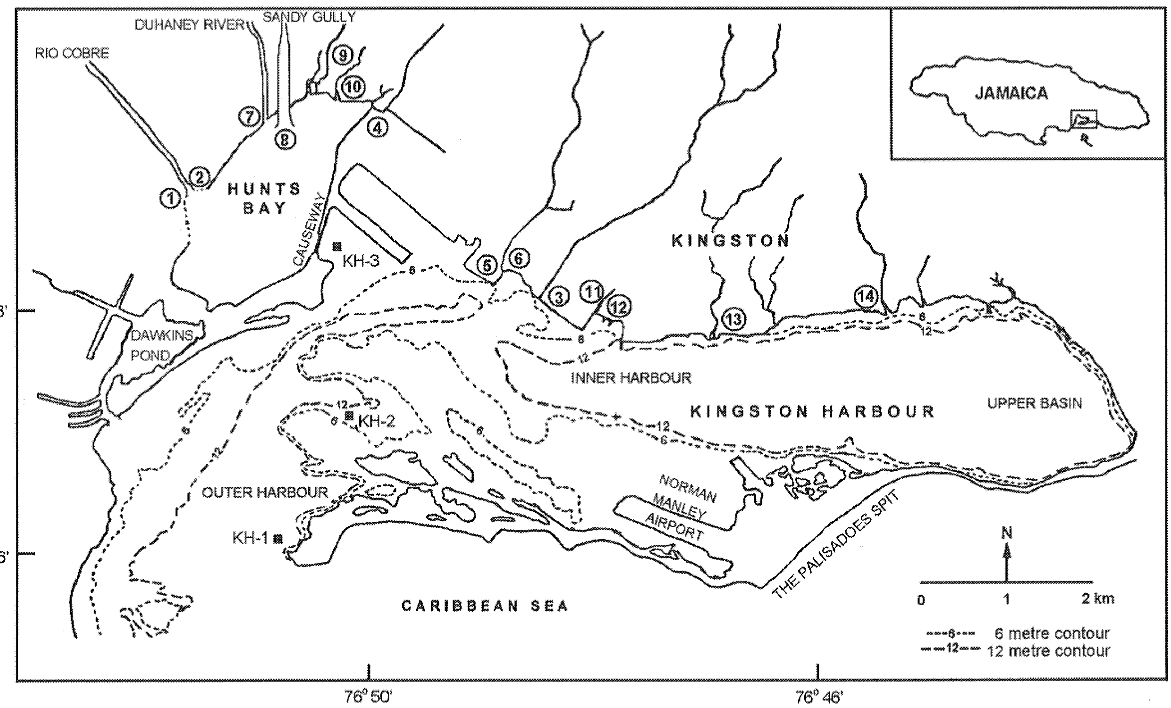

Figure 1. Location and map of Kingston Harbour, Jamaica.

Sewage is the most important contributor of pollution to the harbour, regardless of the nature of the pollutant. The Greenwich and Western sewage treatment plants are the two most significant point sources of pollution to the harbour. Sewage accounts for 68% of inorganic phosphorus, 45% of the inorganic nitrogen, and up to 70% of total suspended solid inputs to the harbour.

The Rio Cobre, which drains the largest of the drainage basins, is the second largest point source of pollution to the harbour. The significance of its contribution is dependent on rainfall, increasing with flow. Industries and groundwater are major non-point sources of pollution during low-flow periods.

The activities within Kingston Harbour presently account for 3.1% of Gross Domestic Product of the country. This is comparable to the largest of the drainage basins, which accounts for 2.4% of GDP.

Studies within the harbour have resulted in considerable data being collected. However, there are still several gaps in the data, mainly in the quantitative relationship between the generation of pollutants on land and their transportation to the coast. There is still the need for substantial research. The quantification of the relationship between land-based activities and coastal impacts will be vital in the on-going management efforts by the relevant authorities in Jamaica.

Hunt's Bay, a semi-enclosed body located at the north-western corner of Kingston Harbour, is a manmade estuarine coastal lagoon of approximately 3.6 km^2. The bay is a shallow basin with an average depth of about 2.4 m. It has been identified as the most polluted portion of Kingston Harbour (Wade 1976; SENTAR 1993). Hunt's Bay was separated from the main body of the harbour by a land-fill causeway in 1969. This reduced the avenue of water exchange to a narrow gap of just over 200 meters, resulting in Hunt's Bay becoming a large sediment trap (CIMAB 1997).

To the south-west of the harbour lies a region called Hellshire. The Hellshire coastline consists of, among other features, the most popular recreational beaches within an hour's travel of Kingston. Water leaving Kingston Harbour flows westward along the Hellshire coast, considerably influencing the quality of the coastal waters (Webber and Roff 1996).

Industrial uses

Kingston Harbour is regarded as one of the finest natural harbours in the world. Its utilization for navigation dates back to the seventeenth century, coinciding with the occupation of the island by the British in 1655. The approaches to Kingston Harbour were protected by a number of forts and cannon turrets, some of which are still in evidence along the shore. The harbour is Jamaica's main shipping port, with 65% of the ships that visit Jamaica docking there, due to the industrial operations along the shore. Kingston wharf was the main loading pier for passenger as well as freight vessels up to the 1960s, but passenger shipping declined with the popularization of air travel. The harbour is now used mainly for freight shipping, with the Newport West/Gordon Cay docks being among the busiest transhipment ports for containerized traffic in the Caribbean. It offers approximately 3000 m of government berthing in addition to a number of private industrial berths. There are gypsum and cement loading piers and oil bunkering berths in the eastern section, along a shipping channel which is dredged annually to allow for large vessel traffic. The only regular commercial passenger vessel nowadays is a ferry that crosses the harbour between Kingston and Port Royal on the western end of the Palisadoes spit.

Dredging and land-fill operations have had a profound effect on the structure of the shoreline. The main structural changes have been related to the use of the harbour shores for docking. The major works have been:

- The construction of the ESSO Oil Refinery compound, Newport West and Newport East dockyards (1963-68).
- The construction of the Hunt's Bay causeway (1969).
- The construction of the Gordon Cay trans-shipment port (1973-78).
- The reclamation and filling of much of Dawkins Pond (1969-77).
- The construction of a navigable channel connecting Dawkins Pond and the outer harbour (1970).
- Filling of the shore adjacent to the cement factory (1965-78).
- Extension of Gordon Cay transhipment port (1995-8).
- Extension of the airport runway (1996 - 2000).

The harbour was one of the island's main fishing sites, as it had a wide range of pelagic fish. The mangroves that bordered the shores were important nurseries. This gave rise to a number of fishing villages developing at different points along the shores. The main ones were the Greenwich Farm and Port Royal villages, with smaller ones in Port Henderson and along the Hunt's Bay causeway. The villages remain, but the fishing is done mainly outside the harbour, since fish stocks have declined due mainly to the deterioration of water quality in the harbour.

A number of industries are sited along the shores of the harbour, including an oil refinery, a flour mill, a cement plant and two power plants. Destruction and clearing of mangroves has been widespread. The construction of the international airport on the southern shore had a particularly significant impact on the fauna and flora of the region.

Academic and military uses

One of the first marine laboratories in the Caribbean was established on the north-western shore in the 1890's because of the rich diversity of environments and biota that the harbour provided (Wade 1976). Since the establishment of the University of the West Indies' marine laboratory in Port Royal in 1955 and the establishment of the Jamaica Maritime Training Institute, the harbour has been used as a major center of research and instruction in the Caribbean. Additionally, the main Jamaica Defence Force Coastguard base is located in Port Royal, close to the harbour entrance.

Recreational Uses

Until 1976, Kingston Harbour was the most intensively used recreational facility in Jamaica, offering the greatest range of attractions of any single environment in the island. There were three public beaches and several private beaches, including those of two hotels along its shores. There were three pleasure boat marinas and a number of lay-by ramps for launching small boats. Swimming, water-skiing, sailing and line-fishing were listed among the activities (Wade 1976).

This situation has changed drastically in the last quarter of a century. Increased eutrophication and increased utilization of coastal land for industrial and residential development have led to the loss of all but one of the beaches. Recreational activities are limited to those that severely limit actual contact with the water of the harbour. While marinas still exist, most of the sailing actually takes place outside the harbour. One very popular international event, the 'cross-the-harbour' race, which involved swimming from the Kingston waterfront to Port Royal, had to be discontinued in the 1980s because of the low water quality.

Drainage basins

Kingston Harbour receives water from several land-based sources. The city of Kingston, adjoining the harbour, is Jamaica's capital and largest city, with a population of over 600,000. The city represents a dynamic coastal metropolis. It lies within, and is surrounded by several drainage basins. The harbour receives discharge from all drainage systems within and surrounding the Kingston Metropolitan Area (KMA) (Wilson-Kelly 1998). The residential area of Portmore, with a population of over 165,000, is located on the north-western side of the harbour. A large portion of Portmore was constructed on landfills. Kingston and Portmore together account for more than one third of the country's population, whereas the KMA accounted for only 18% in 1950. Table 1 shows the populations of the KMA and Portmore since 1960.

Table 1. Population of KMA and Portmore since 1960 (Source: STATIN 1995).

Year	**1960**	**1970**	**1982**	**1991**	**1995**
KMA	376, 500	437, 700	524, 600	562, 100	570, 790
Portmore	0	5, 100	73, 426	100, 200	165, 341

The most densely populated part of Kingston lies within a 2-km band on the shore of the harbour, stretching from the 'inner city' slums in the east to the Harbour View housing development in the west. North of this densely populated area, the population spreads over the plains of Kingston and St Catherine to the hills of St Andrew. All these communities, including those farther from the coast, impact the harbour, as they are connected to the harbour by their drainage systems.

Wilson-Kelly (1998) identified five distinct drainage areas (Figure 2), covering 715 km². The largest of the drainage basins (Drainage area 1, Figure 2) is the area drained by the Rio Cobre. It is a watershed drainage system, 567 km² in area. The Rio Cobre drains a large portion of St Catherine, Jamaica's largest parish, which is dominated by plantation agriculture, mainly sugarcane and citrus (Figure 3). In its northern region, this basin extends to the island's main mountain chain. The Rio Cobre flows through an active flood plain, the St Catherine Plain, before emptying into the western side of Hunt's Bay. Several population centres such as Linstead, Bog Walk and the island's original capital, Spanish Town, are found within this drainage basin. In addition, a number of food-processing industries and an alumina-processing plant are located within this basin. The Rio Cobre is a source of water for irrigation of agricultural land in addition to potable water for many of the residents of the watershed.

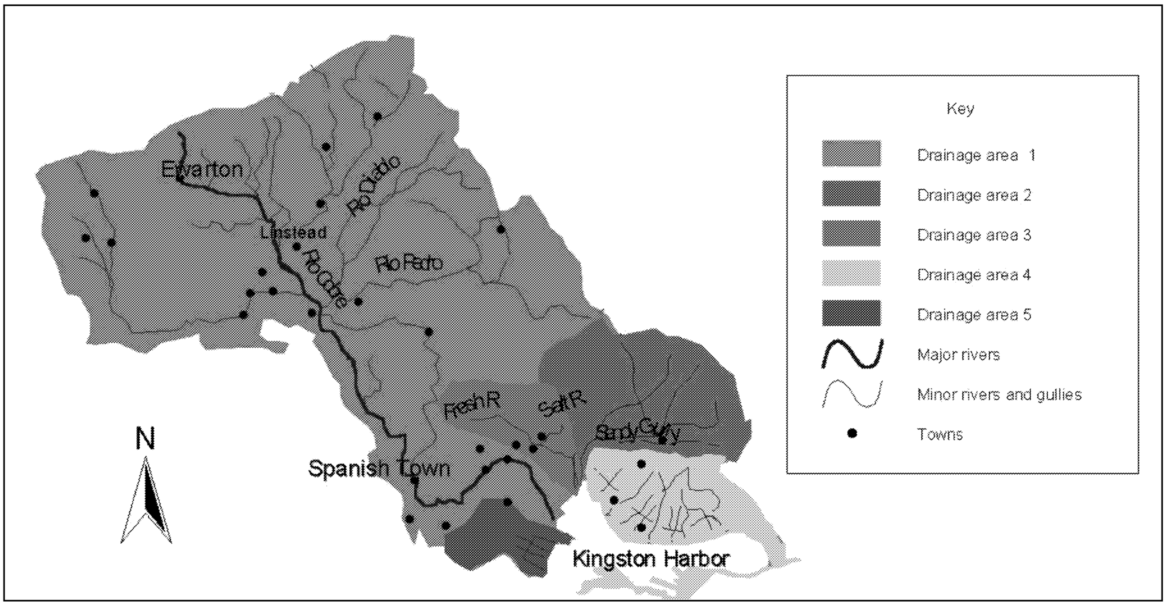

Figure 2. Drainage areas associated with Kingston Harbour.

The population of this drainage basin has rapidly increased over the years (Table 2), though the range of activities has been constant. An increase in housing developments has led to significant migration to areas such as Spanish Town and Linstead. The major shift in activity occurred in the 1960s, when bauxite mining and alumina production were added to the traditional activities. The activities contribute significantly to the national Gross Domestic Product (GDP) (Table 3).

Table 2. Population of Drainage Area 1 since 1970 (Source: STATIN).

Year	1970	1982	1991
Population	61,090	122,901	150,624

Urbanization and mining have taken their toll on the natural forests that originally existed in this watershed. Deforestation is expected to continue as urbanization and expansions in mining continue.

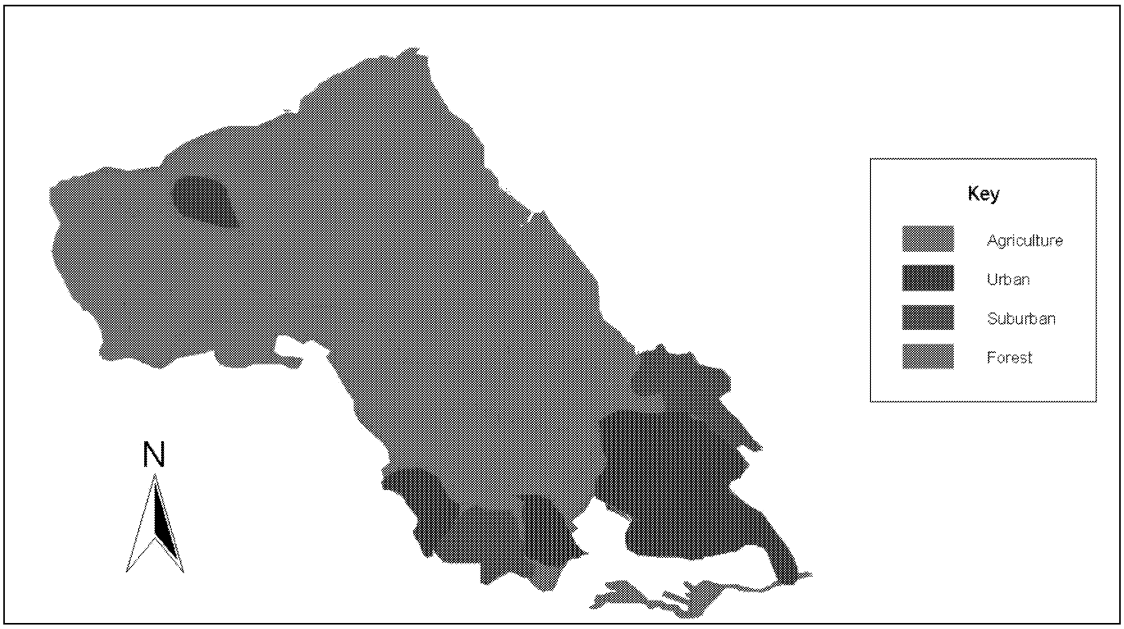

Figure 3. Land use within the drainage basins.

Table 3. Estimated annual value of Drainage Basin 1 as income generated (based on 1995 figures).

Component	**US $ million**	**% of GDP**
Export agriculture	6.2	0.15
Sugarcane	4.6	0.11
Livestock	0.4	0.01
Bauxite and Alumina	39.3	0.95
Sugar, molasses and rum	37.3	0.90
Food	12.2	0.30
Total Income	100	2.42

This drainage basin contributes the highest volume of water and sediment loads to the harbour. As mentioned earlier, much of this basin is agricultural land. The removal of the natural vegetation to allow for cultivation, coupled with farming on slopes without terracing, results in considerable loss of topsoil. Much of this topsoil is transported by the river to the harbour (Table 4). The Rio Cobre is prone to rapid swelling when there is heavy rain. The Rio Cobre is estimated to discharge more than $2x10^9$ m^3 yr^{-1} of water into the harbour.

Table 4. Summary of estimated average sediment load to Hunt's Bay (long tons) (from CIMAB 1997).

Source	**Silt / clay**	**Sand / gravel**	**Total**	**Percentage**
Rio Cobre	1,120,000	280,000	1,400,000	97.4
Sandy Gully	20,000	0	20, 000	1.4
Duhaney River	17,000	0	17,000	1.2
Total	1,157,000	280,000	1,437,000	100

The Rio Cobre also transports pesticides from the agricultural lands along its course. The banana, coffee, sugarcane, citrus and vegetable farmers in the river basin have been using organochlorines and other classes of pesticides fairly heavily since the 1950s (Henry 1985). Residues of seven insecticides introduced into the harbour via the Rio Cobre have been found in the water and sediment as well as in organisms such as fish and oysters (Mansingh and Wilson 1995). The Rio Cobre has been estimated to deliver 32% of the Biological Oxygen Demand (BOD) loading to Kingston Harbour, 15% of the nitrogen loading and 9% of the phosphorus loading (SENTAR 1992).

Drainage area 2 (Figure 2) is the Sandy Gully system. The largest individual area of drainage in the parish of St Andrew, it is composed of a network of man-made storm drains that empty into Sandy Gully via nine other gullies. Sandy Gully is essentially a dry course, but heavy rainfall results in heavy flows of relatively short duration. The waters are conveyed to the northern section of Hunt's Bay. The area drained by this system is estimated at 26 km^2 (SENTAR 1993). This drainage basin is dominated by residential development. The sedimentary material conveyed by this system is derived from the alluvial Liguanea Plain and residue from the southern slopes of the Liguanea and Red Hills. The wide, lower course of Sandy Gully acts as an effective sediment trap, the coarser sediment particles being deposited in channels prior to arrival in Hunt's Bay. The finer particles are carried farther along the gully and tend to accumulate in Hunt's Bay close to the mouth of the gully. Sandy Gully has also been used as an illegal dump by many of the residents along its course. Rubbish and sewage placed in the gully are transported into Hunt's Bay when the flow is strong enough.

Drainage area 3 (Figure 2) lies to the immediate west of the St Andrew area and is comprised of two rivers (the Fresh and Salt rivers) and a gully that join to form one freshwater system known as the Duhaney River, with a watershed area of approximately 104 km^2. The Duhaney River enters Hunt's Bay to the east of the Rio Cobre, and is predominantly spring-fed with a relatively uniform discharge throughout the year. The sedimentary contribution is mainly silt and clay from the agricultural and residential areas along its course (Table 4). The Duhaney River discharges approximately 8.8×10^7 m^3 of water annually into Hunt's Bay. The Duhaney River has considerably less impact on Kingston Harbour than the Rio Cobre as relates to water discharge, but contributes 13% to the BOD and nitrogen loading to the harbour.

Drainage area 4 (Figure 2) is comprised of 15 gullies, each being its own drainage system. Together they drain approximately 30 km^2 of the southern sections of Kingston and St Andrew. Most of the fifteen gullies drain densely populated residential areas and areas of intense industrialization. Seven of the gullies receive some industrial effluent, while two of the gullies are known sewage discharge points.

Drainage area 5 (Figure 2) is located in the densely populated residential area of Portmore. It consists of a network of man-made canals and drainage systems that ultimately empty into the western corner of Kingston Harbour. These canals convey mainly domestic waste and sewage from the residences. The discharge point of at least one sewage plant lies in this area. Hunt's Bay receives input from an area of 660 km^2, which is 92% of the total drainage area of the entire harbour. Since Hunt's Bay has a surface area that is only 7% of the total surface area of the harbour and is also the shallowest section of the harbour, the immense pressure on this area is apparent.

Kingston Harbour receives waste discharges from a number of sources. A number of the gullies discharge industrial waste directly into the harbour. Sewage loading has been identified as the main cause of pollution since the 1960s and continues to be the main contributor to nutrient and BOD loading to the harbour, with at least 26 sewage treatment plants discharging their effluents into the harbour. Ships may also discharge sewage into the harbour. Two sewage plants - Western and Greenwich - account for 75% of the sewage pumped directly into the harbour. SENTAR (1993) reported that only 1 of 26 area package sewage treatment plants was reasonably effective in treatment, with all the rest discharging only partially treated sewage. All are prone to frequent mechanical problems, resulting in discharge of raw sewage. Sewage reaching the Western Plant receives only limited primary treatment before discharge, while the Greenwich Plant is overloaded and discharges raw sewage. The sewage inputs have resulted in high faecal coliform levels across the harbour. As early as 1967, the coliform levels were above those considered safe for swimming (Wade 1972). There has been more sewage generated and less treatment since then, with the consequent increases in bacterial levels. The bacterial population has led to high BOD across the harbour, particularly in the vicinities of sewage discharges. The result is low dissolved oxygen concentrations in the harbour. This low dissolved oxygen is one of the main reasons for the marked reduction in heterotrophic life there.

The waters that flow into the harbour convey high concentrations of nutrients in addition to suspended solids and bacteria (Table 5). While most nutrients are carried by the sewage, significant amounts come from fertilizers used in the watersheds drained by the rivers. During flood conditions both nitrogen and phosphorus inflows may increase as much as 87 times over those that occur normally (Wilson-Kelly 1998). These inflows of nutrients have caused algal proliferation. High biomass values have been reported across the harbour and 'red tides' of dinoflagellates have increased in frequency since the 1970's (Wade 1976; Simmonds 1997).

Table 5. Mean daily fluxes of total suspended solids, phosphate-P, and nitrate-N into Kingston Harbour from fluvial sources.

Entity	Low Flow	High Flow (Flood)
Total Suspended Solids	9.4×10^5 kg	1.2×10^8 kg
Phosphate- P	5.7×10^7 mol	5×10^9 mol
Nitrate- N	2.9×10^9 mol	1.4×10^{11} mol

The Palisadoes spit forms a very effective barrier between the harbour and the Caribbean Sea to the south. The retention (flushing) time of the harbour ranges between 152.5 and 176.5 days, these times coinciding with the wet and dry seasons respectively. Waters from the Caribbean Sea normally affect only the outer lobe of harbour, the inner lobe being sheltered by the Palisadoes spit. During periods of inflow, water from the Caribbean Sea flows in along the sides of the harbour mouth. Simultaneously, water from the harbour flows outward down the centre of the mouth. During outflow periods, there is flow from the harbour to the Caribbean Sea through all portions of the mouth (CIMAB 1997). Only during extreme weather conditions is there enough wave energy to cause washing of the sea over the narrow portions of the spit into the inner lobe of the harbour. This has occurred during strong tropical storms or hurricanes on the south coast. The amount of water that enters by this route is very low, as the island experiences strong storms once every ten years and hurricanes once every thirty years.

Management Efforts

Efforts have been made to place a monetary value on Kingston Harbour. The estimated contribution of Kingston Harbour was US$128 million in 1995, 3.1% of Jamaica's real Gross Domestic Product (Table 6). The cost to clean and maintain the gullies flowing into the harbour, in addition to collecting solid waste over the next twenty years, has been estimated at US $20 million annually (Pereira and Witter 1997).

Table 6. The estimated annual value of Kingston Harbour as income generated (based on 1995 figures).

Component	US $ million	% of GDP
Water transport & support services	40	0.97
Free zone manufacturing	46	1.11
Seafood production & processing	10	0.24
Waste disposal	32	0.78
Total income	128	3.10

The government of Jamaica, in response to the findings of the GEF project "Planning and Environmental Management of Heavily Contaminated Bays and Coastal Areas in the Wider Caribbean", has sought to procure funding for rehabilitation efforts. To date, only a small fraction of the funds needed to address the sewage treatment problem has been realized. The Planning Institute of Jamaica continues to solicit funds.

Activities in the drainage basins and coastal marine regions have profound impacts on the harbour. Unfortunately, many of these activities are expected to increase or at least remain constant in the future. Though some investigative work has been carried out, mainly in the harbour, there is still the need for substantial research (Table 7). Kingston Harbour, of great economic importance to Jamaica, is susceptible to damage by the actions of the populace, not just in the coastal environment, but throughout the drainage basins as well (Table 8). Pollution of this resource has resulted in the harbour's deterioration to a point that will require immense physical and financial resources to rehabilitate. The longer the delay in addressing the problem of pollution, the less value the harbour will have, and the greater the cost of rehabilitation.

Table 7. Areas that need further investigation in the efforts to manage Kingston Harbour and its drainage basins.

Drainage Basins	Kingston Harbour
• Intensity of pesticide & fertilizer use • Rate of leaching of nutrients and contaminants from soil to waterways. • Point sources of contaminants • Effect of contaminants on the biota in waterways • Socio-economic factors driving activities in the basin	• Inventory of marine flora and fauna • Rate and extent of faunal contamination • Rate of decline in bio-diversity • Effect of introduced exotic species on ecology • Fate of introduced sediment, nutrients and contaminants • Role of sediment in the release or retention of nutrients and contaminants • Development of a 3-D model to assist in management

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Table 8. Socio-economic issues and the related drainage basin and coastal marine-based drivers for Kingston Harbour.

Driver status and location - Estimation of the intensity and geographical location of the driver.
C: Coast; L: Lower basin; M: Middle basin; U: Upper basin
I: Low; II: Medium; III: major; 0: Not present; -: Not applicable. Time scale - Temporal intensity of the driver. P: Progressive; D: Discrete

Socio-economic and coastal Issues	Present problem status	Impact	Impact Intensity	Pressures	Drivers	Driver location and status				Time scale	Future trend expectation
						C	L	M	U		
Decline in Recreational use.	III	Declining water quality	III	Bacterial contamination	Urbanization	-	III	II	0	P	Increase
				Eutrophication	Urbanization	-	III	III	II	P	Increase
					Agriculture	-	III	III	III	P	Increase
					Industries	-	III	II	0	P	Increase
					Navigation	III	0	-	-	P	Increase
				Siltation	Urbanization	-	I	I	I	P	Increase
					Agriculture	-	I	III	III	P	Increase
					Industries	-	I	0	0	P	Constant
					Navigation	II	-	-	-	P	Increase
				Pesticide contamination	Agriculture	-	III	III	III	P	Constant

Table 8 continued.

Socio-economic and coastal Issues	Present problem status	Impact	Impact intensity	Pressures	Drivers	Driver location and status				Time scale	Future trend expectation
						C	**L**	**M**	**U**		
Reduction of fish stocks	III	Declining water quality	III	Bacterial contamination	Urbanization	-	III	II	0	P	Increase
				Eutrophication	Urbanization	-	III	III	II	P	Increase
					Agriculture	-	III	III	III	P	Increase
					Industries	-	III	II	0	P	Increase
					Navigation	III	0	-	-	P	Increase
				Siltation	Urbanization	-	I	I	I	P	Increase
					Agriculture	-	I	III	III	P	Increase
					Industries	-	I	0	0	P	Constant
					Navigation	II	-	-	-	P	Increase
					Deforestation	-	II	I	I	P	Increase
				Harvesting	Fisheries	II	-	-	-	P	Constant

Table 8 continued.

Socio-economic and coastal Issues	**Present problem status**	**Impact**	**Impact Intensity**	**Pressures**	**Drivers**	**Driver location and status**				**Time scale**	**Future trend expectation**
						C	**L**	**M**	**U**		
Reduction in Biodiversity	III	Declining water quality	III	Bacterial contamination	Urbanization	-	III	II	0	P	Increase
				Eutrophication	Urbanization	-	III	III	II	P	Increase
					Agriculture	-	III	III	III	P	Increase
					Industries	-	III	II	0	P	Increase
					Navigation	III	0	-	-	P	Increase
				Siltation	Urbanization	-	I	I	I	P	Increase
					Agriculture	-	I	III	III	P	Increase
					Industries	-	I	0	0	P	Constant
					Navigation	II	-	-	-	P	Increase
					Deforestation	-	II	I	I	P	Increase
		Habitat destruction	III	Siltation	Urbanization	-	I	I	II	P	Increase
					Agriculture	-	I	III	III	P	Increase
					Industries	-	I	0	II	P	Increase
					Navigation	II	-	-	-	P	Increase
					Deforestation	-	III	I	II	P	Increase
				Physical damage	Fisheries	I	-	-	-	P	Increase
					Deforestation	III	-	-	-	P	Increase
					Navigation	II	-	-	-	P	Increase

Definitions:
Problems - Recognized socio-economic consequence.
Present problem status - Assessment of the intensity of the problem.
Impacts - Perturbation of the natural environment.
Pressures - Parameters that cause the perturbation.
Drivers - Source of pressure.

4.4 Natural and anthropogenic impacts on the Parque Nacional Morrocoy, Venezuela

David Bone

Geographical Setting

Venezuela has approximately 2,875 km of continental coastline, of which 1,927 km (67%) are along the Caribbean Sea and 948 km (33%) along the Atlantic Ocean. The major shallow marine and coastal habitats are sandy beaches, rocky shores, seagrass beds, coral reefs, coastal lagoons and mangroves.

Surface temperatures along the Venezuelan coastline form cold-water plumes with a variable mixture zone. The borders of these plumes present differences in form, size, and intensity that are related to the season and wind intensity. The annual surface seawater temperature ranges between 20 and 29°C. The daily thermal variation can be as much as 2.5C degrees, with the largest variation in the first months of the year. These daily oscillations become less intense during upwelling, which also modifies the spatial-temporal temperature distribution along the coast. The yearly variations span 5C ° if the upwelling waters are taken as a reference. The oceanic waters can have variations of up to 3C°. The 2C° difference between oceanic and coastal waters is due to upwelling (Penchaszadeh *et al.* 2000). The north-south oscillation of the Intertropical Convergence Zone (ITCZ) constitutes the main cause of seasonal changes in salinity and temperature of the Caribbean Sea surface waters (Müller-Karger and Varela 1989).

The regional temperature variations follow a seasonal pattern. The waters are colder during the dry season (January-April) and warmer in the rainy season (May-December) (Fukuoka 1965; Okuda 1974). When the Trade Winds reach maximum speeds, the cold-water plumes become more intense and more detectable, decreasing surface water temperature by mixing it with deep water.

A variety of economic activities takes place along the Venezuelan coastline, including fisheries, industry and tourism. Fisheries occur mainly on the eastern coast and make up 50% of the national production. Tourism is distributed along most of the coastline. Petroleum activities (exploration, extraction, and refinery) occur mainly on the western coast, and industrial activities are located around the central coast (Penchaszadeh *et al.* 2000). Shallow marine and coastal habitats comprise sandy beaches, rocky shores, seagrass beds (mainly *Thalassia testudinum*), coral reefs, coastal lagoons and mangroves. Primary production is generally high due to the upwelling systems and additional nutrient supply by rivers and watersheds. Some of these ecosystems exist within a delicate dynamic equilibrium influenced by continental water masses, and interact by means of nutrient transfer brought about by organisms that migrate on a daily or seasonal basis from one ecosystem to another (Ogden and Zieman 1977, Zieman *et al.* 1979).

The Golfo Triste Region

Golfo Triste has been defined as the marine area to the mid-west of the coast between Puerto Cabello and Punta Tucacas the eastern meridian 67° 51' W, the north parallel 10° 52' N, and the continental coastline to the south and west. The continental shelf widens from east to west, reaching a maximum width of 20 nautical miles. The shelf presents a gentle and regular slope, except to the north, where some coralline islands are found, and reaches a mean depth of 50 m. The sea floor is sandy in nature, dominated by fine to very fine sands, but showing a clear influence of terrigenous silty sediments (Perez-Nieto *et al.* 1980). It consists of a wide coastal plain without mangroves or corals. The area is directly influenced by the Aroa and Yaracuy rivers, which have a combined catchment area of 4,720 km^2.

Heavy industrial activities (power plant, refinery, petrochemical plant, pulp-mill paper industry) have highly impacted the coastline, introducing hydrocarbons, heavy metals and organic compounds, and causing an increase in water temperature, especially in the south near the city of Puerto Cabello. Other activities include agriculture, ports and tourism.

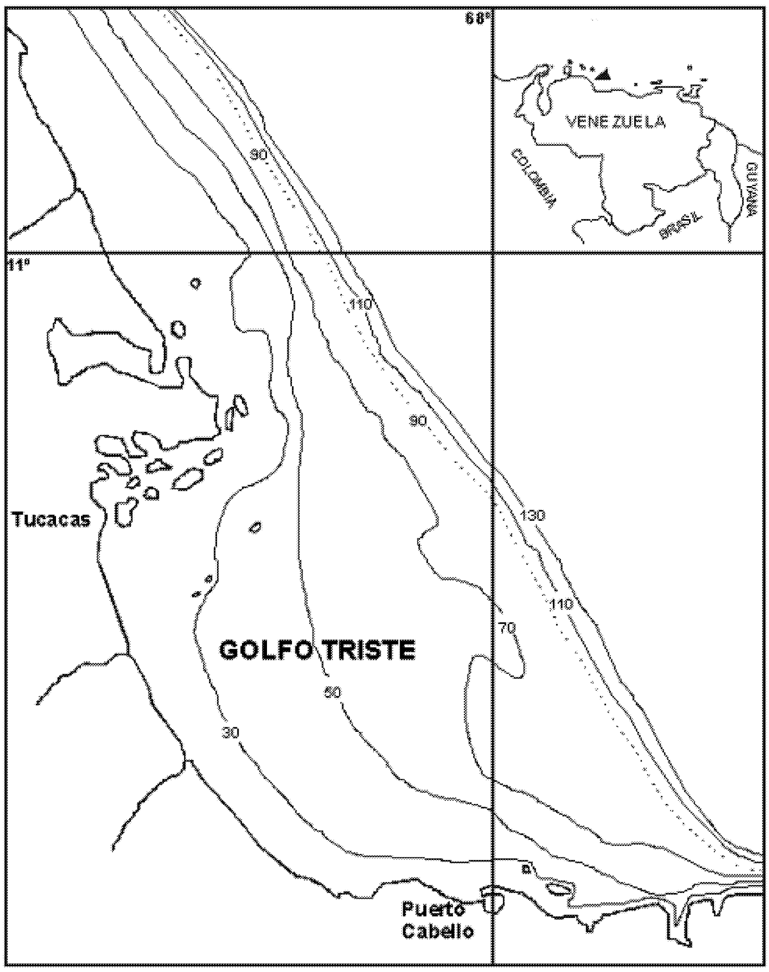

Figure 1. Map of the Golfo Triste area, showing the location of the Parque Nacional Morrocoy, and the mouths of the Aroa and Yaracuy rivers. Depth line counters are also shown.

Rivers and river basins

The Aroa and Yaracuy rivers, which have a combined catchment area of 4,720 km^2, discharge into the Golfo Triste (Figure 2). These sister basins are separated towards the south-west (SW) by the highest elevation of the area, the Sierra de Aroa (1,000 m above sea level). Population increase, from fewer than 100,000 in 1950 to over 800,000 in 1998, is related to rapid urbanization, changing from 38% in 1950 to 76% in 1990, with urban centers, including the state capital, San Felipe, in the central region of the basins.

The main economic activities are agriculture and cattle raising, which occupy 85% of the land area. The main agricultural product is sugarcane, but corn, coffee, bananas, beans, oranges and other fruits are also important, especially in the middle and lower areas of the basin. Mining activities, with copper and iron as the main products, take place in the Sierra de Aroa region.

The Yaracuy River basin has a total catchment area of 2,840 km^2. Triangular in shape, the base measures 30 km from north to south, with the apex towards the coast. The average water discharge is the most important of the area, measuring 7.9 $m^3 sec^{-1}$. The mean annual precipitation value is 1,193 mm, with a mean annual temperature of 23.7°C and 77% relative humidity. Geologically, it belongs to a recent period, the Quaternary. The lowlands near the coast are swamp-type areas, with many small lagoons and sandy bars.

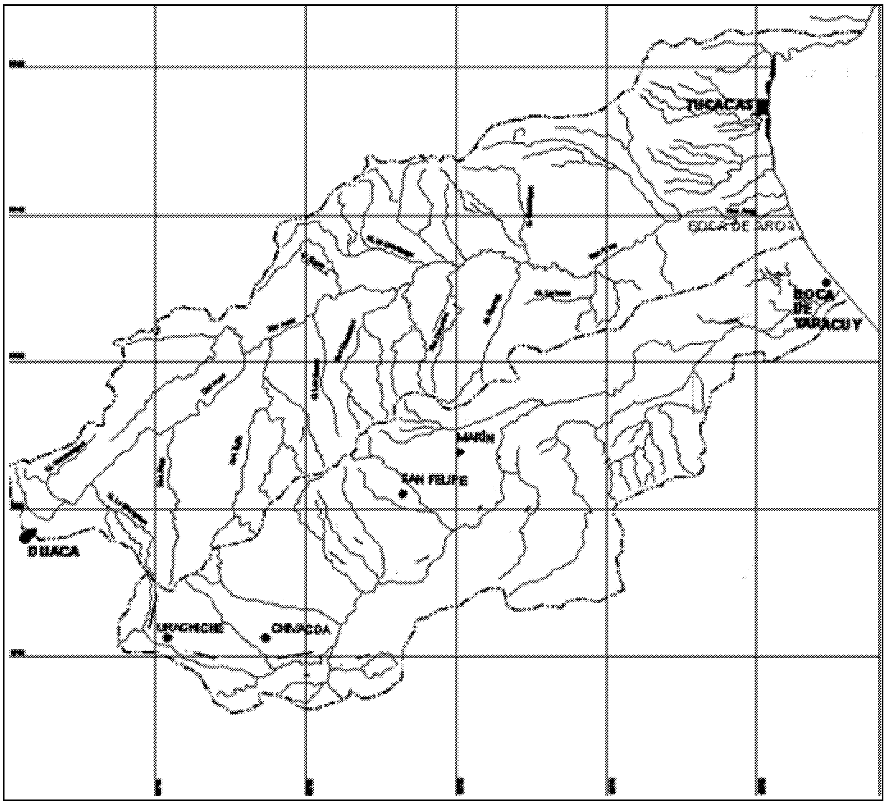

Figure 2. The Aroa and Yaracuy river basins.

The Aroa River basin is rectangular in shape, 70 km long and 28 km wide, with a total catchment area of 1,880 km^2. The average water discharge is 3.2 m^3 sec^{-1}. It is an alluvial valley sitting over sheets of a metamorphic formation from the Cretaceous. The mean annual rainfall value is the greater of the two basins, with 1,409 mm, a mean annual temperature of 24.5^o C, and 77% relative humidity. The natural vegetation is characteristic of a tropical savanna climate to the east, but most of the basin area is dedicated to sugarcane crops. Tropical forests develop around the Sierra de Aroa. In addition, cattle-raising activities take place on the lowlands.

The Aroa and Yaracuy basins provide water for agriculture, industrial and urban activities, energy generation and dam construction, and the main river courses are used for effluent discharge. Three dams have been built on these rivers: two on the Aroa, and the largest one on the Yaracuy River. The basins have also been subjected to intense deforestation, which is increasing soil erosion and deterioration of the lower reaches. These is turn have increased sediment loads, nutrient and organic matter and pollutants in the rivers, and are eventually impacting marine areas.

Coastal systems

Venezuela has two important marine continental ecosystems where the most characteristic communities of the Caribbean are very well represented: the Parque Nacional Mochima, located to the east of the country, and the Parque Nacional Morrocoy, located to the central west.

Parque Nacional Morrocoy and its surrounding areas constitute the most important and complex marine ecosystem of the continental shore, due to the existence of extensive coral reef areas, mangrove forests, and seagrass meadows, in addition to estuarine and hypersaline environments. This park is located on the central west coast, between 10º52' N and 69º16' W, covering a total area of 320 km^2 (Figure 3). The mean annual rainfall for the period 1965-95, at various continental stations near the park, ranged between 936 and 1,283 mm, with evaporation rates twice these values (> 2000 mm) (Bastidas *et al.* 1999). Mean annual surface water temperatures range from 27 to 32º C, and salinity values span from 30 to 38%. The park includes continental, insular and marine ecosystems, with two marine zones well differentiated: the seaward zone, connected to the open sea through small canals defined by a line of keys, characterized by coral reef environments, moderate swells, low turbidity and an average depth of 10 m; and the inshore zone, characterized by mangrove-seagrass communities, low wave activity, higher turbidity and shallow waters (Bone *et al.* 1998).

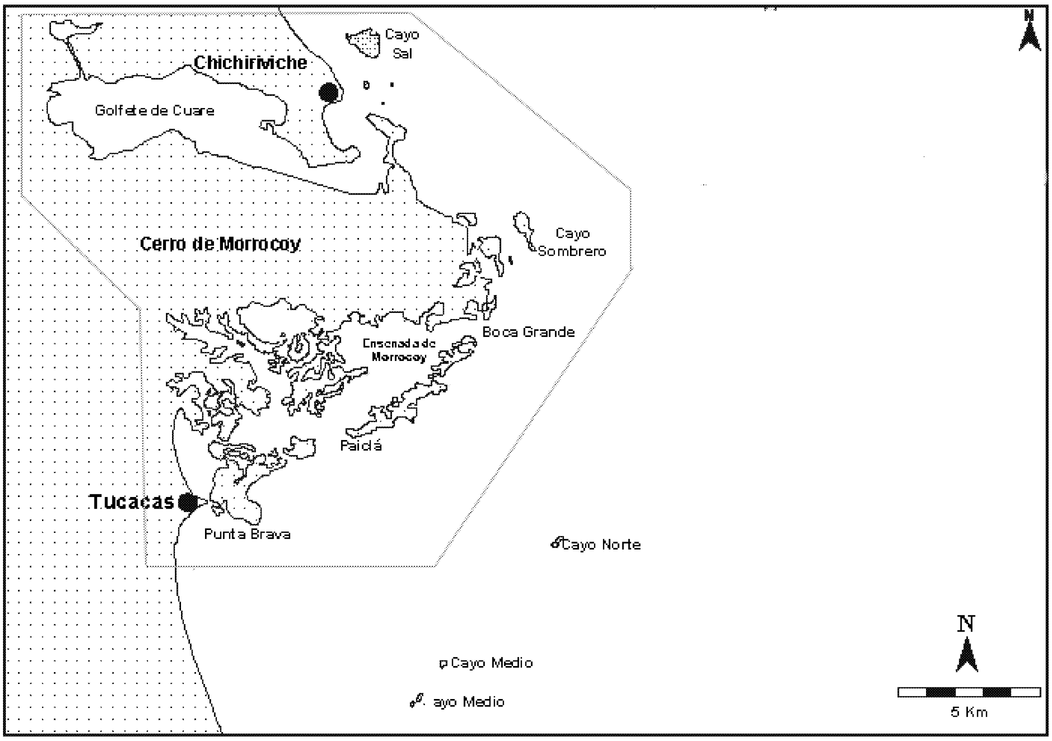

Figure 3. Map showing the Parque Nacional Morrocoy and its boundaries.

Sedimentation rates within the park are inversely related to the distance from the main terrestrial sources of sediment, probably brought about by drainage of the Aroa and Yaracuy. Urgent studies are needed, to add water quality parameters that may help in the detection of nutrient eutrophication and polluted situations (i.e., heavy metals, hydrocarbons) and to define precisely the relationship between the river activities and the deterioration of the ecosystems of the park. Evaluation of natural and anthropogenic effects on the biota and the current status of the ecological conditions of the main coastal communities is needed. Special research effort needs to be directed to the understanding of the land-coastal zone interaction, i.e., establishing the parameters that link the identified drivers to the pressures that impact the marine ecosystems.

This area has been the subject of scientific research for many years, on coral reefs (Weil 1980; Bone 1980; Alvarez 1981; Weil *et al.* 1984; Losada 1988; Bone *et al.* 1993), seagrass meadows (Babarro 1988; Bitter 1988; Rebolledo 1988; De Mahieu 1989; Losada and La Schiazza 1989; Bone 1991; Guevara 1993; Isea 1994; Perez 1995; Galindo 1997), mangroves and related communities (Martín 1978; Alvarez 1989). The information that has been amassed has contributed to our understanding of these marine ecosystems and can help us take measures to protect them.

Anthropogenic influence on the coastal area

During recent decades, the negative effects from anthropogenic activities have been reported as affecting many coastal marine ecosystems in the Caribbean. Mangrove forests have been used as a source for lumber, cleared for agriculture activities, construction and mining; seagrass meadows are being dredged for the construction of port facilities; coastal deforestation has increased the amount of siltation reaching the reef communities through runoff waters and river discharges; and fisheries are been overexploited (Rogers 1985; Ogden and Gladfelter 1986; Bone *et al.* 1993; Ginsburg 1994).

The coral communities of the Parque Nacional Morrocoy have been affected by man-made disturbances. These began towards the end of the 60s with the construction of houses and docks, and the disposal of garbage, sewage and other materials into Chichiriviche Bay. Sewage pollution caused the greatest damage (Weiss and Goddard 1977). During the 70s building spread onto all keys of the area and to many shoals, sand banks and reef flats (Bone *et al.* 1993). After heavy community pressure, the area was decreed a National Park by the Venezuelan Government in May 1974, and the buildings were completely removed within one year. Any further development of the coastal areas included within the Park limits was prohibited. Despite this protection, the damage suffered by the reefs has increased.

The reefs that were healthy in 1973 (Weiss and Goddard 1977) showed high dead-coral cover values in 1979 (Bone 1980). Other reefs of the northern areas of the park had obvious symptoms of deterioration, such as high dead-coral coverage and the smothering of many living colonies by sediments (Bone *et al.* 1993). The extent and degree of damage are probably mainly due to a high and increasing sedimentation process that began in 1972 with erosion from poorly managed development on the mainland. Sediments were carried into the marine park by rivers and by coastal currents.

A recent study compared the sedimentation rates at four localities within the park during a one-year period and found that the sedimentation rate was inversely related to the distance from the main terrestrial sources of sediment (i.e., the rivers) and ranged from 44±7 to 281±46 g m^{-2} d^{-1} for the farthest two localities (Bastidas *et al.* 1999). These results indicate that the reef environments of the Parque Nacional Morrocoy are still being affected by the long-term continuous load of sediment, probably brought about by drainage of the rivers, such as the Aroa and Yaracuy. Metal concentration in these sediments also varied inversely to the distance from terrestrial sources, ranging from 1.01-2.57 μg g^{-1} for Al, 44.6-77.9 for Zn, 19.9-41.8 for V, 18.1-35.6 for Pb, 18.1-31.9 for Cr, and 6.8-40.3 for Cu.

Heavy metal levels (Al, Fe, Mn, Zn, Pb, Cd, Cu, Ni, and Cr) have also been reported in organisms, in water and in sediment at five locations in the Park (Perez 1988). The Ministry of Environment and Renewable Resources found that the maximum heavy metal concentration registered for the superficial sediments in the park were higher than those observed in other regions of the country, and comparable with other marine-coastal areas in the world affected by domestic and/or industrial discharges (Cd, Pb, Cu, Fe, Ni, Cr) (MARNR 1994). A high count of dissolved and dispersed hydrocarbons, lubricants and grease concentrations were reported after a holiday season, which indicates a high boat activity in the marine area of the park.

Natural events also impact on the park. At the beginning of 1996 extensive bleaching events were detected, which resulted in a widespread mass mortality in several groups of marine invertebrates in the Park, but especially in corals (Laboy *et al.* in press). The report documented the changes in physicochemical parameters, nutrients, metals, oceanographic characteristics and the structure of some of the communities. Coral reef species were almost wiped out throughout the park, and other groups, including holothurians, sand dollars, sipunculans, polychaetes, sponges and gastropods, were decimated. This phenomenon was related by the authors to an upwelling event that prompted a sharp decrease in water temperature throughout the park in January 1996 and a plunge of salinity at some locations, which probably give rise to a concatenation of events, phytoplankton blooms included, that ultimately led to the widespread mortalities.

These mass mortalities serve to emphasise the dramatic effects of mounting pressures on the ailing marine ecosystems of the Parque Nacional Morrocoy. Urgent studies are needed to add new water quality parameters that may help in the detection of polluted situations (i.e., heavy metals, hydrocarbons, nutrients) and to define precisely the relationship between the river activities and the deterioration of the ecosystems of the park.

A matrix of causes and effects (Table 1) was created for the combined Parque Nacional Morrocoy (basins to coastal zone) to provide an overview of the major problems occurring in the area, drivers affecting drainage basins, the resulting pressures affecting the coast, impacts and their intensity, and time-scale.

Future research needs

Assessment of biogeochemical fluxes into these coastal ecosystems from land and sea, including nutrients, heavy metals, pesticides, hydrocarbons, sewage and other pollutants is needed. Evaluation of natural and anthropogenic impacts on the biota is also needed, and the current status of the ecological conditions of the main coastal communities should be determined. Special research efforts need to be directed to the understanding of the land-coastal zone interaction, i.e., establishing the parameters that link the identified drivers to the pressures that impact the marine ecosystems, thus, causing the problems. SeaWiFS satellite image analyses could provide a useful tool to keep track of the trends of the sediment plumes originating in the mouth of the rivers, their trajectories, marine areas being influenced, and coastal current patterns.

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Table 1. Drivers-Pressures-State Change and Impacts matrix for the Parque Nacional Morrocoy

Driver status and location - Estimation of the intensity and geographical location of the driver.
C: Coast; L: Lower basin; M: Middle basin; U: Upper basin
Impact status: I: Low; II: Medium; III: major; 0: Not present; -: Not applicable; Time scale - Temporal intensity of the driver. P: Progressive; D: Discrete

Socio-economic and coastal Issues	Present problem status	Impacts	Impact Intensity	Pressures	Drivers	Driver location and status				Time scale	Future trend expectation
						C	L	M	U		
Decline of commercial stocks (fish, oysters, lobsters, etc.)	III	Declining water quality	III	Sediments/siltation Pesticides/contamination Nutrients/eutrophication	Agriculture/ Cattle raising	-	III	II	I	P	Increasing
		Marine and terrestrial communities degradation (reefs, mangroves etc.)		Bacterial contamination Sediments/siltation Sewage/contamination	Urbanization/ Industrial	-	II	II	0	P	Increasing
				Habitat alteration	Tourism	II	-	-	-	p	Increasing
				Nutrients and sediment sequestration	Damming	-	0	I	I	D	Constant
Reduction of tourism attractions	II	Declining water quality	III	Sediments/siltation Pesticides/contamination Nutrients/eutrophication	Agriculture/ Cattle raising	-	III	II	I	P	Increasing
		Marine and terrestrial communities degradation (reefs, mangroves etc.)	III	Bacterial contamination Sediments/siltation Sewage/contamination	Urbanization/ Industrial	-	III	II	0	P	Increasing
					Tourism	II	-	-	-	P	Increasing

Table 1 continued.

Socio-economic and coastal Issues	Present problem status	Impacts	Impact Intensity	Pressures	Drivers	Driver location and status				Time scale	Future trend expectation
						C	**L**	**M**	**U**		
Loss of biodiversity	II	Declining water quality Habitat reduction	III	Sediments/Siltation Pesticides/contamination Nutrients/Eutrophication	Agriculture/ Cattle raising	-	III	II	I	P	Increasing
			II	Bacterial contamination Sediments/siltation	Urbanization/ industrialization	-	III	II	0	P	Increasing
				Sewage/contamination Reef destruction/ Extraction	Tourism	II	-	-	-	p	Increasing

Problems - recognized socio-economical consequence
Present problem status - assessment of the intensity of the problem
Impacts - perturbation of the natural environment
Pressures - parameters that cause the perturbation
Drivers - source of the pressures

4.5 River discharge, sediment load, and sediment yield estimates for the Magdalena River and other Caribbean rivers of Colombia: environmental implications

Juan Dario Restrepo and Björn Kjerfve

Introduction

Three major rivers drain into the Caribbean Sea from Colombia. They are the Atrato, the Sinú and the Magdalena. The Atrato River drains a basin area of 35,700 km^2. Although the Atrato occupies a considerable portion of the Pacific basin, the river empties into the Caribbean through the Golfo de Urabá (Figure 1). The upper and middle sections of the Atrato River are located in regions with very high annual rainfall. The meteorological station at Granja Agrícola Lloró in the upper Atrato basin, at an elevation of 120 m, has an annual rainfall rate of 12,717 mm based on data 1952-1989 (Eslava 1992). This, to the best of our knowledge, represents the highest rainfall rate anywhere in South America. Based on runoff ratios calculated from monthly meteorological data throughout the basin (Snow 1976; Eslava 1992), Restrepo and Kjerfve (2000a) calculated the water discharge for the Atrato to be 2,740 m^3 s^{-1}. Based on discharge gauging and sediment concentration measurements, the sediment load of the Atrato is estimated to be 11.26x10^6 t yr^{-1}, and the corresponding sediment yield 315 t km^{-2} yr^{-1} (Table 1). The sediment yield is comparatively low, because of the large size of the drainage basin and the extensive low-lying Urabá alluvial flood plain, where significant sediment deposition and storage occur. Several other smaller rivers also discharge into the Golfo de Urabá. These rivers have small drainage basins and high sediment yields.

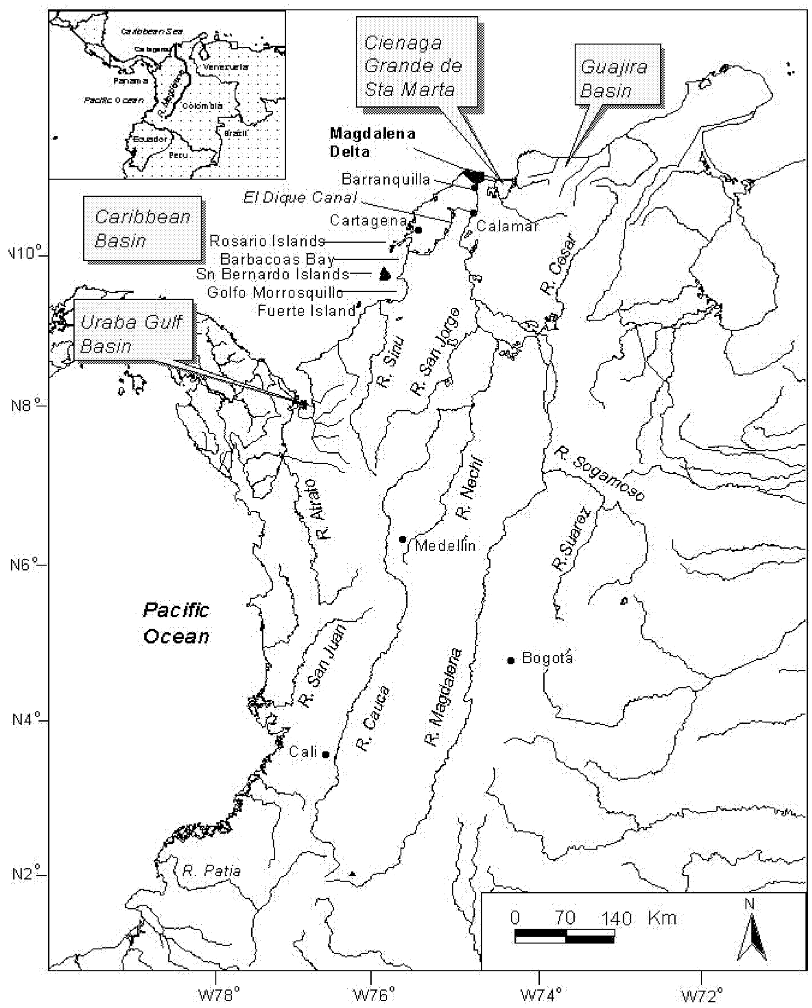

Figure 1. Map showing the rivers of Colombia draining into the Caribbean Sea and the main drainage basins.

The Sinú River empties into the Golfo de Morrosquillo (Figure 1) and drains an area of 10,180 km^2. Based on monthly data 1963-1993, the annual discharge of the Sinú is 373 m^3 s^{-1}. The sediment load is 6x10^6 t yr^{-1}, based on data 1972-1993, with a sediment yield of 589 t km^{-2} yr^{-1}at Montería.

The Magdalena River, the largest river to drain directly into the western Caribbean Sea, discharges 228 km^3 of water annually, or on the average 7,200 m^3 s^{-1} based on 21-years of daily stage data, 1975-1995 (Restrepo and Kjerfve, 2000b). Analysis of data for an additional 22 rivers in Colombia, which also drain into the Caribbean Sea, indicates that these rivers discharge a combined 338 km^3 yr^{-1} of water and deliver 168 t yr^{-1} of sediment into the Caribbean, corresponding to a sediment yield for the Colombia Caribbean drainage basins of 541 t km^{-2} yr^{-1} (Table 1).

Table 1. Drainage basin, annual rainfall, measured water discharge, sediment load, and calculated yields for the Caribbean Rivers of Colombia (modified from Restrepo and Kjerfve, 2000a).

River	Basin area (x10^3 km^2)	Annual rainfall (mm)	Water discharge (km^3 yr^{-1})	Sediment discharge (x10^6 t yr^{-1})	Sediment yield (t km^{-2} yr^{-1})	Years of data
Caribbean Coast						
Urabá Gulf						
Atrato	35.7	5318	81.08	11.26	315	1982-93
Chigorodó	.1	2485	.46	.2153	1088	1977-93
León	.7	2485	2.01	.7701	1007	1978-93
Vijagual	.04	2485	.06	.0219	548	1977-93
Grande	.07	2485	.13	.0438	626	1978-93
Zungo	.05	2485	.07	.0292	584	1977-93
Apartadó	.16	2485	.14	.0620	585	1984-93
Carepa	.15	2485	.16	.3175	2048	1978-93
Currulao	.23	2485	.31	.2373	1023	1979-93
Guadalito	.08	2485	.08	.0310	369	1979-93
Turbo	.16	2485	.12	.0730	445	1966-93
Caribbean Basin						
Mulatos	1.02	2485	.33	.2117	208	1978-93
Sinú	10.18	1750	11.76	6.1	589	1963-93
Canal Dique		1750	9.43	4.76	...	1981-93
Magdalena	257.43	1700	228.1	143.9	559	1975-95
Guajira Basin						
Piedras	.14	850	.15	...	...	1974-93
Gaira	.03	850	.08	.0014	42	1978-93
Guachaca	.26	450	.45	.0113	43	1973-93
Don Diego	.52	450	1.14	.0226	43	1973-93
Ancho	.54	450	.47	.0288	53	1971-93
Palomino	.68	450	.80	.0511	75	1973-93
Ranchería	2.24	450	.39	.1022	46	1976-93
Total Caribbean	**311.06**		**337.68**	**168.25**	**541**	

Note: Normalized sediment yield for the river basins was estimated by dividing sediment load (t yr^{-1}) by drainage basin areas (km^2). Sediment load information was gathered from IDEAM, Colombia.

The Magdalena River

The Magdalena River is 1,612 km long and drains a 257,438 km^2 basin that occupies a major portion of the Colombian Andes. It is the largest fluvial system in Colombia and originates from headwaters in the Andean Cordillera at an elevation of 3,300 m. According to Potter (1997), sediment deposits in the Magdalena Valley between the Eastern and Western Cordilleras are evidence for a Late Miocene age for most of the Magdalena River. The paleo-Magdalena, and its principal tributary, the paleo-Cauca, both developed in longitudinal tectonic lows parallel to a convergent plate margin. Thus the tectonic control and origin are evident along the Magdalena drainage basin, which is oriented parallel to the Cordilleras. The Magdalena discharges into the western Caribbean and forms a 1,690 km^2 triangular delta (Figure 1).

In South America, the primary focus with respect to rivers, river basin processes, and river fluxes has been directed towards the three largest fluvial systems, the Amazon (Meade *et al.* 1979; Meade *et al.* 1985; Richey *et al.* 1986; Richey *et al.* 1989), the Orinoco (Eisma *et al.* 1978; Depetris and Paolini 1991) and the Paraná (Depetris *et al.* 1996; Depetris and Gaiero 1998; Goniadzki 1999). However, the sediment transport of the Magdalena River is of the same magnitude as the three larger rivers, which all have significantly larger drainage basins and significantly greater water discharge (Bassin 1976; Milliman and Meade 1983; Javelaud 1987; Restrepo and Kjerfve 2000a).

Fluvial transport estimates from the Magdalena River have previously been reported as a part of global water and sediment budgets (Baumgartner and Reichel 1975; Meybeck 1976; Alekin 1978; UNESCO 1978,1979,1985,1992; Milliman and Meade 1983; Milliman *et al.* 1995). Most of these data were based on a 1971-1972 study by Netherlands Engineering Consultants (NEDECO 1973). However, the general validity of the NEDECO data set is questionable because of the short record (Milliman and Meade 1983; Restrepo and Kjerfve 2000b).

Daily water discharge measurements 1975-1995 on the Magdalena River at Calamar indicate an average discharge rate of 7,232 m^3 s^{-1}. The discharge varies considerably inter-annually. The peak flood discharge usually exceeds 12,000 m^3 s^{-1} during La Niña years. Low water discharge of 2,000-3,000 m^3 s^{-1} occurs during El Niño conditions. The Magdalena River contributes approximately 9% of the total sediment load discharged from the east coast of South America. In addition, the Magdalena River has the highest sediment yield of any medium-sized or large river along the Caribbean and Atlantic coasts. Daily load measurements 1975-1995 yielded an annual sediment load of 143.9x10^6 t yr^{-1}. The calculated sediment yield for the drainage basin area upstream of Calamar is 559 t km^{-2} yr^{-1}. The Canal del Dique (Figure 1), a 114 km long man-made channel from the Magdalena River at Calamar to Cartagena Bay constructed in 1514 by native slaves on the order of Spanish conquistadors, has a mean water discharge of 299 m^3 s^{-1} and sediment load of 4.76 x 10^6 t yr^{-1} (Restrepo and Kjerfve 2000a, 2000b).

Environmental changes and implications related to the Magdalena River

Over the last 50 years, the Magdalena River and associated coastal areas have been under increasing environmental stress. Economic development of Colombia in the 1970's and 1980's has increased demand for river control and utilization. Ongoing trends in the drainage basins include:

(1) escalating population densities in the basin and near the river mouth (the main cities of Colombia, including Bogotá, Medellín, Cali, and Barranquilla, are all located in the Magdalena basin (Figure 1);
(2) accelerating upland erosion rates due to poorly implemented agricultural practices, increasing deforestation, and active gold mining; and
(3) increasing water pollution.

All of these trends have produced impacts which severely are distorting the natural hydrography, leading to loss of critical habitat, biodiversity, and altered material transport (COLCIENCIAS-FEN 1989; HIMAT-INGEOMINAS 1991; Restrepo and Kjerfve 2000b). Although these facts are acknowledged, no quantification of the water and material fluxes by the Magdalena River has been estimated for the past century.

Sediment loads from the Magdalena River have strongly impacted the adjacent coastal ecosystems. Since 1954, the government of Colombia has dredged the Canal del Dique. Because of increased sedimentation in the bay during the 1970's, new canals were constructed from El Dique to Barbacoas Bay. Despite these efforts, the suspended sediment load into Barbacoas has reached and impacted El Rosario Islands (Figure 1), a 68 km^2 coral reef ecosystem in the Caribbean Sea of Colombia. River-derived sediment is probably responsible for most of the observed coral reef mortality, which exceeds 58% of the total reef cover (Vernette 1985; INVEMAR 2000b). Suspended sediment load from the Sinú River may currently impact the largest coral reef on the Colombian Caribbean coast, the San Bernardo and Fuerte Islands reefs, a 135 km^2 coral reef community north of the Golfo de Morrosquillo (Figure 1). Live coral cover has here, in some places, decreased by 75% since 1995 (INVEMAR 2000b).

Water diversion due to the construction of a highway in the Magdalena delta/lagoon complex, the Ciénaga Grande de Santa Marta, has resulted in hyper-salinization of mangrove soils and consequent die-off of almost 270 km^2 of mangrove forests over a 39-year period. Between 1956 and 1995, 66% of the original mangrove forest died (Botero 1990; Cardona and Botero 1998). Recent estimates indicate that for the whole Magdalena lagoon/delta complex and associated coastal zones, the mangrove area has been reduced from 62,000 ha in 1991 to 52,478 ha in 1996, almost 2,000 ha yr^{-1} (INVEMAR 2000b). Fresh water from the Magdalena River flowing to Ciénaga Lagoon was also diverted for irrigation and interrupted by dikes built along the delta distributaries to prevent flooding of farmlands. The changes in the hydrological regime have caused water quality changes in the lagoons and associated channels, resulting in low dissolved oxygen concentrations and associated fish kills and eutrophication (Botero 2002).

The Magdalena River is the major collector in Colombia of municipal and industrial wastewaters. Urban, agricultural, mining and industrial waste inputs from the Magdalena basin have aggravated the conditions of the lagoon and coastal ecosystems. Biodiversity has been reported to be considerably lower in the area affected by mangrove mortality as well as in the coastal zone (INVEMAR 2000a; Botero 2002). Declining fisheries from 63,700 t in 1978 to 7,850 t in 1998, roughly eight-fold in 20 years, indicates a strongly declining rate for the living resources, and also signifies poor environmental and water quality conditions as well as the absence of water policies and management (Beltrán *et al.* 2000).

The Magdalena River deserves international attention because it has such a significant sediment yield (the largest on the Atlantic and Caribbean coasts of South America), and a close tele-connection with the ENSO. La Niña events trigger high rain, discharge, and flooding events. The Magdalena is the most significant freshwater source for the Caribbean Sea, and the river has great environmental and economic impacts on the adjacent coastal Caribbean ecosystems.

The Magdalena River and the LOICZ approach

Consistent with the LOICZ-Basins approach, future studies should attempt to assess physical and biogeochemical fluxes into the Magdalena coastal ecosystems from both land and sea. These need to include water, sediment, nutrients, heavy metals, pesticides, organics, hydrocarbons, sewage, solid waste and pollutants, as a means of evaluating natural and anthropogenic responses to both chronic and episodic events. This will require assessment of the time progression of basin development and changes in population and land use, including an overview of the environmental resource economics and social impacts.

Since river fluxes are indicators of regional environmental change, either related to global or regional climate change or directly to human impacts on continental aquatic systems, a comprehensive analysis of drainage basin behavior appears warranted from a global change-perspective. Further, to understand the relationships between natural variabilities and the anthropogenic changes that have taken place in the drainage basins during the past century, and how these factors influence the delivery of water and sediment to coastal areas, have economic and social importance (Vörösmarty and Meybeck 2000).

A study of the natural and anthropogenic changes in the Magdalena drainage basin and their impacts on the coastal zone need to address the following questions:

- What are the key controlling factors that define the discharge of water, sediments, nutrients and pollutants through the river system and how natural and man-induced changes in the last century have altered the transport rate of river fluxes?
- Which are the factors controlling the hydrology of the basin in the presence of extensive human-induced alterations and land-use change?
- How have changes in river fluxes and human development altered the coastal ecosystems during the past five decades, and what can be expected during the next five decades?

The research associated with these questions provides a framework for quantifying and assessing the impacts of natural and man-induced basin changes in the coastal zone, serve to update GLORI (Global River Inputs to the Ocean) database, and is the basis for a new pilot project by the Colombia Government and LOICZ.

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4.6 Land use in the La Estrella River basin and soil erosion effects on the Cahuita Reef system, Costa Rica

Ana C. Fonseca E. and Jorge Cortes N.

Abstract

The fringing coral reef of Cahuita is the best developed on the south-Caribbean coast of Costa Rica. This reef has been protected to some extent since 1970 within the Cahuita National Park. At present, the reef of Cahuita is greatly deteriorated. Coral growth rates (5-6 mm yr^{-1}), live coral coverage (11%), and diversity (H'=1.44) are low. A change in coral species "zonation" is also obvious. Coral recruitment is also low and occurs only on vertical surfaces. The main problem that affects the coral reef at Cahuita is the high concentration of suspended sediment that has been increasing (from 8.4 in 1981 to 19.4 mg l^{-1} in 2000) and high rates of bottom sediment re-suspension, 20-1000 mg cm^{-2} day^{-1}. Heavy metal concentrations in coral and sediments are higher at Cahuita than at other coral reefs surveyed in Panama and Costa Rica. The reef of Cahuita has been affected mainly by the sediments, fertilizers and pesticides derived from deforestation of the main upstream river La Estrella. The 7.5 earthquake of 1991 removed high amounts of sediment from rivers and sea bottoms, however sediment loads were already high before this event. The La Estrella River mouth is about 15 km from Punta Cahuita. It has 15 tributaries and a small basin of 724.3 km^2. There is an evident cultural difference between the coastal communities and the communities along the river valleys and mountains. The main economic activities of the La Estrella River basin are agriculture, cattle ranching, forestry and tourism. The amount of sediments carried by this river, up to 5 g/l, has increased in the last 30 years. The La Estrella River is considered within the group of rivers with the most frequent flooding in the country, at least once every year. La Estrella River contains high levels of contamination by the insecticide cholorpyrifos in the biota (max: 8 $\mu g\ l^{-1}$) and by the fungicide cholorothalonil in surface water (max: 8 $\mu g\ l^{-1}$), sediments (max: 40 $\mu g\ l^{-1}$), and wells (max: 0.98 $\mu g\ l^{-1}$). Both pesticides are very toxic for aquatic organisms. At Cahuita the population is concentrated in areas around the Cahuita National Park. There are 1,009 houses of which 677 have latrines, 320 septic tanks and 12 use the river or the land for waste water drainage. Four small creeks within the Cahuita National Park contribute to the contamination of the Cahuita reef, especially Kelly Creek and Hone Creek. Tourism and fishing are important economic activities in Cahuita and they also have some degree of impact, but this has not been quantified. Line fishing is concentrated on snappers at the carbonated banks around the Park. There are 12 active fishermen which capture approximately between 2,592 and 32,400 kg y^{-1}. This fish production represents 2 to 24 % of the whole Caribbean coast of Costa Rica. The Cahuita National Park attracts 2% of the total foreign tourists coming to Costa Rica each year. About 43% of tourists consider that the major reason for visiting Cahuita is the National Park, and the coral reef is one of the main attractions of it. Taken in perpetuity the National Park has an asset value of US$27.9 million and just the coral reef is an economic asset worth at least US$1.4 million. The destruction of the Cahuita reef implies the loss of an important research, recreational and food source. The recovery of this reef is possible if tourism and fishing are monitored and regulated, and sediment loads in the rivers are reduced by covering with grass the cultivated soils, re-establishing the forest at the river edges and stopping deforestation on the highlands. Further research efforts must be devoted to the analysis of cause-effect relationships between current catchment activities and degradation of coastal ecosystems and resources.

Introduction

Costa Rica is located in the Central American Isthmus between Nicaragua and Panamá, and it meets the Caribbean Sea to the east and the Pacific Ocean to the west and south-west. The La Estrella River basin and the Cahuita National Park are located on the south Caribbean coast in Limón province, between 9º30'-10º30' N and 82º45'-83º30' W (Figure 1). Cahuita has the largest coral reef of the country. The population at Cahuita is concentrated in settlements around the Cahuita National Park, which consists of 1,100 ha of lowland rainforest and 22,400 marine ha, of which 600 ha correspond to coral reef substrate down to 15 m deep. The local coastal community subsistence economy is based on fishing and tourism. These communities depend on the good health of this reef. Since the beginning of the 20th century deforestation, land erosion and sedimentation of water courses have been major problems for the coral reef system of Costa Rica. The reef of Cahuita has been affected mainly by the sediments, fertilizers and pesticides derived from deforestation of the main upstream river La Estrella (Cortés and Risk 1984, 1985).

The La Estrella River basin drains through tertiary clastic and andesitic volcanic rocks (Dirección de Geología, Minas y Petróleo 1968), and it has very high precipitation (Instituto Metereológico Nacional 1994; Fallas 1999). Some sections of the regional rainforests of the basin were cut mainly for agricultural purposes. The exposure of these soils to the normal, high precipitation has led to extensive soil erosion and, consequently, the poor condition of rivers and seawater. Parallel to this, economic activities of the local communities are also affected by flooding of crops, contamination and death of aquatic resources (ProAmbiente 1998).

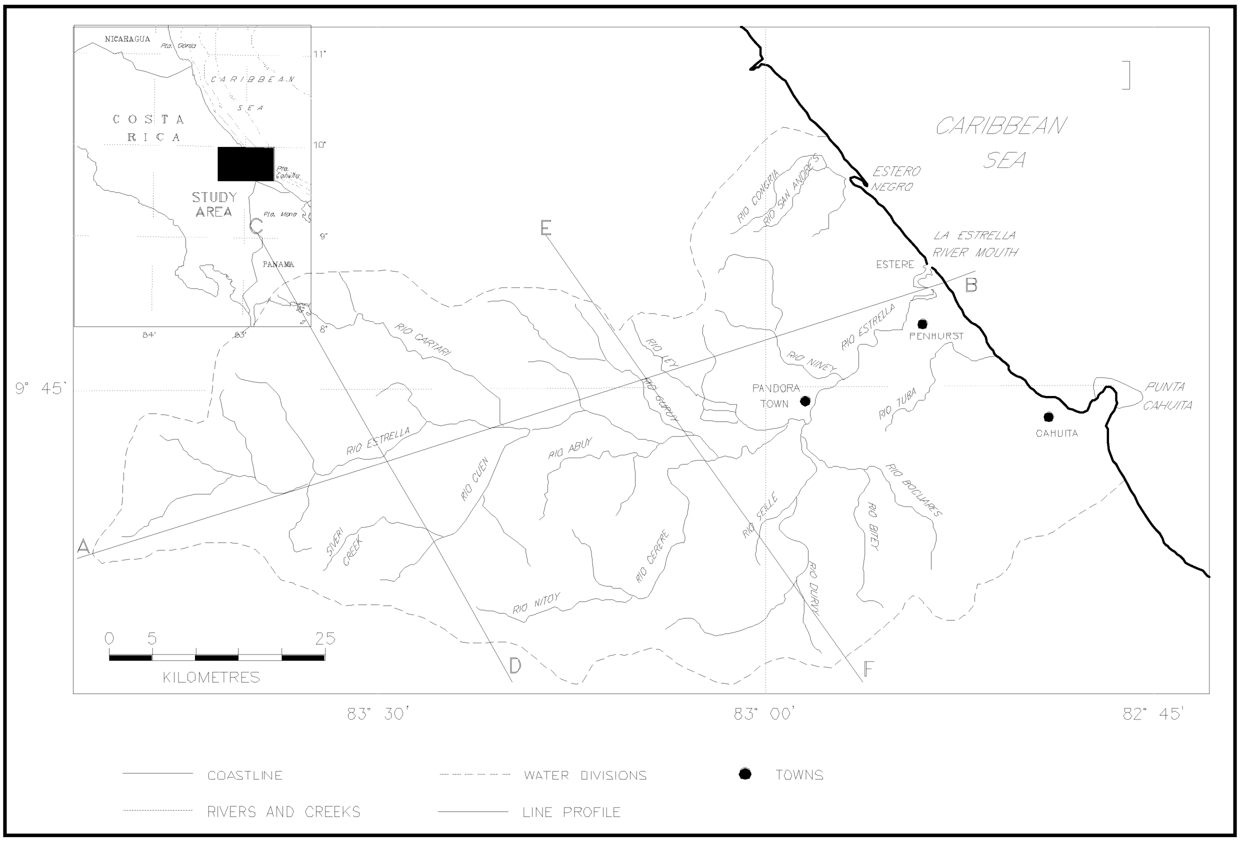

Figure 1. Location and map of the La Estrella River basin, Costa Rica.

A workshop on land management of the La Estrella River basin took place in 1999 (Fonseca 1999a). The objective of this workshop was to share, among communities and private and public institutions from La Estrella basin and Cahuita town, interests and concerns about the problem of erosion. The workshop led first to bibliographic review of the known social and physico-chemical characteristics of the La Estrella River basin and the documented effects of its contamination on the coral reef and town of Cahuita. Actions to mitigate negative impacts are urgent

La Estrella River basin

The La Estrella River mouth is about 15 km from Punta Cahuita. The river has a volume of 32.5 m^3 (Q-TEC Soluciones Ambientales 1997), and a length of approximately 67 km (Dirección General de Estadística y Censos 1988-1992). It has 15 tributaries and a small basin of 724.3 km^2. Its lower section is known as La Estrella Valley and covers 75.9 km^2 (10.5%). The middle basin contains 185.9 km^2 (25.7%), and the upper basin covers 462.5 km^2 (63.8%). In this upper section, 281.6 km^2 (60.9%) are under some kind of national environmental protection category (ProAmbiente 1998). Population in the area has been increasing at a mean rate of 314 inhabitants/year (Table 1). This area has a mean annual precipitation of 3,750 mm and a mean annual water volume of 3.8 km^3 that enters into the basin as precipitation (Fallas 1999). The drainage area is 1,005.0 km^2 and the amount of sediment carried by this river, up to 5 g l^{-1}, has increased in the last 30 years (Cortés and Murillo 1985).

Table 1. Changes in population at the La Estrella River from 1996 to 2000 (Dirección general de Estadística y Censos 1996-2000).

Year	Population
1996	4,414
1997	4,713
1998	5,090
1999	5,407
2000	5,672

In the past this basin, as well as the rest of the region, was covered by rainforest. The upper basin is still covered mostly by forest, but cattle ranching is now the main activity in the middle basin, and banana plantations cover most of the lower basin (Figure 2). There were not significant changes in soil use from 1984 to 1992. However, in 1992, forest cover decreased from 80% to 67%, agriculture increased from 5% to 10%, and pastures increased from 14% to 23% (Table 2). Banana plantations have a drainage system based on open channels, and each banana farm has its own wells for water supply from 15 to 40 m deep (Abarca and Ruepert 1992). The timbering activity is higher in the periphery of the valley's banana plantations, around the tributaries of La Estrella River, especially in the origin of the Bitey, Duruy, Mohín and Bocuares rivers and the middle section of the Cuen River. The La Estrella River has no dams (Fallas 1999).

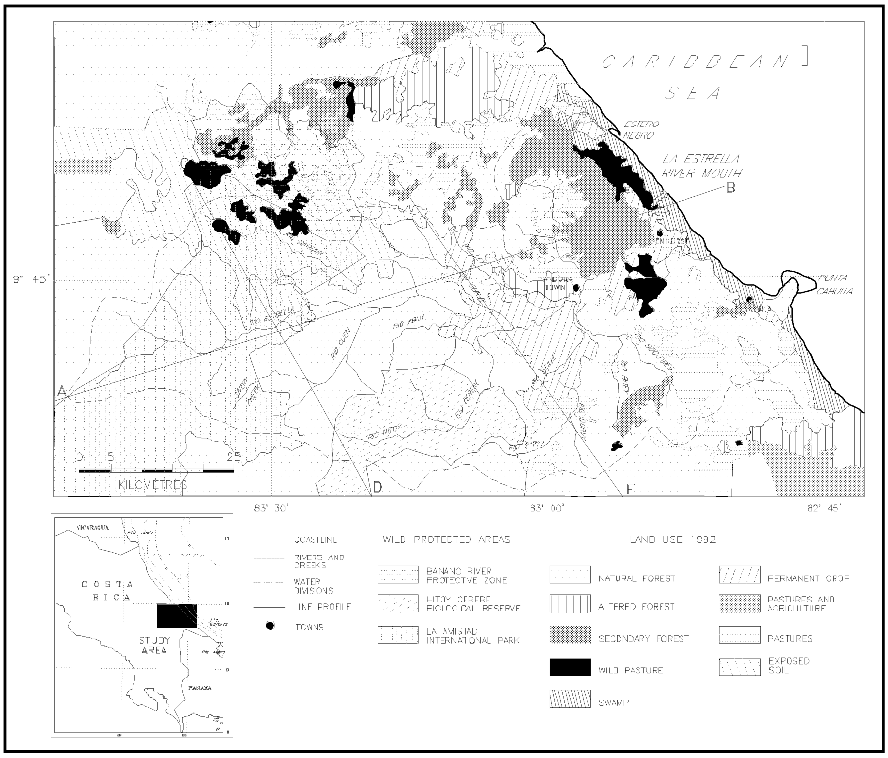

Figure 2. Land use changes in La Estrella River basin, 1984-1992.

Table 2. Land use (% soil cover) in the La Estrella River basin in 1984, 1992 and 1999.

Activity	1984	1992	Fuentes 1999
Agriculture	5	5	9.95
Pastures for cattle ranching	14	14	23.02
Forest	81	80	66.89
Exposed soil	0.24	0.25	No data
Wetland	Included as forest	0.27	Included as forest

Main environmental problems of the La Estrella River basin

The main economic activities within the La Estrella basin are agriculture, cattle ranching, forestry and tourism. The La Estrella River floods frequently, at least once every year (Comisión Nacional de Emergencias, CNE, 1993). Deforestation and floods affect regional economic activities, so that crops, cattle, pastures, infrastructure, medical services, drinkable water availability and education suffer as a result. As the quality of life is reduced, there is an increasing tendency towards more intensive land use and migration away. Consequently, the agrarian front is in constant expansion, and the upper basin is becoming more vulnerable to changes in land use (ProAmbiente 1998).

Factors that have a negative influence on the studied river basin include (ProAmbiente 1998):

- Irregular distribution of the population and increased residential areas within natural risk zones. According to risk maps of the National Emergencies Committee, 56% of the communities in the La Estrella River basin are located in high-risk areas for floods.
- Changes in land use within inappropriate zones. During the past five years, shifts in land use have occurred on several fronts against the tropical rainforest, especially in the southern sector of the upper river basin.
- Discharge of sewage water into the basin and sub-basin drainage system. The settlements within the basins have no systems for the treatment of residual waters.
- Unloading of solid waste without previous processing at non-authorized sites. There are no adequate municipal solid waste sites and services in operation in the southern Caribbean region.
- Discharge of waste products generated by agrarian activities. Deaths of river organisms are presumed to be linked to the effect of agrochemicals and sediments.
- Pressure from deforestation on the system of protected areas. From 1992 to 1997 there was an increase in the loss of forest cover especially in the upper basin of the La Estrella River, close to its limits with the Hitoy Cerere Biological Reserve, at the origin of Bitey and Mohín rivers and the middle section of the Cuen River.
- Soil instability and erosion. High precipitation, typical of the region, causes immediate erosion of the exposed soils. High expenses are incurred by the Water and Sewage National Institute (A y A) in the removal of sediment during the processing of drinkable water (A y A 1980).
- The 7.5 earthquake of 1991 caused serious landslides in the basin (CNE 1993).

Water quality of the La Estrella River

High levels of contamination have been found in the La Estrella basin, from the insecticide cholorpyrifos in the biota (max: 8 $\mu g\ l^{-1}$) and from the fungicide cholorothalonil in surface water (max: 8 $\mu g\ l^{-1}$), sediments (max: 40 $\mu g\ l^{-1}$) and wells (max: 0.98 $\mu g\ l^{-1}$) (Abarca and Ruepert 1992). The former is used inside the plastic bags for protection of bananas, and the latter is used for eradicating the Black Sigatoka fungus. Both pesticides are very toxic for aquatic organisms. The Standard Fruit Company constantly monitors water quality for sediment and pesticide concentrations, and the results are presented to the Banana Activity Control Division of the Human Environmental Protection Department of the Ministry of Health. These data are very hard to obtain as they are available only at the discretion of these institutions. However, the results of this water quality monitoring at La Estrella River since 1992 (Martín and Jackson 1998) suggest that there is no contamination in this river (0.05 μg of pesticides l^{-1}; 1 μg of sediment km^{-1}). Seawater surface currents coming from the La Estrella River mouth showed low contamination in terms of Biological Oxygen Demand (BOD) in 1996 and 1997 (Table 3; Q-TEC Soluciones Ambientales 1997). Unexpectedly, pesticides and heavy metals in the water were below the detection limits. It is possible that pesticides are not always detected, because the contamination source is not continuous, and because the La Estrella River has a high dilution capacity (Abarca and Ruepert 1992).

Further research efforts must be devoted to the long-term analysis of contaminants in water, sediments and biota of rivers, wells and channels, and the study of potential impacts of repeated or continual low-level exposures to a mixture of pesticides (Abarca and Ruepert 1992; Castillo *et al.* 1997, 2000). Removal of the following pesticides should be regarded as priority at La Estrella River (Abarca and Ruepert 1992):

1 - the nematicides Aldicarb, Oxamil and Terbufos;
2 - the fungicides Benomil, Chlorothalonil, Dyazinon, Mancozeb, Propiconazol, and Tridemorf;
3 - the insecticide Chlorpyrifos;
4 - the herbicides Glifosate and Paraquat

Table 3. Water quality on surface currents at the mouth of La Estrella River (modified from Q-TEC Soluciones Ambientales 1997).

	Unit	Mouth of La Estrella River[1]	Mouth of La Estrella River
Date	d/m/y	18-10-96	03-02-97
Time	hrs		9:15
Season			Rainy
Hydrometric station		85-02-02 Pandora	
Drainage area	Km^2	1,005.0	1,005.0
Mean volume	m^3/s	44.8*	32.5*
Color	U Pt/Co		5
Amonium	mg/L		0.14
Electric conductivity	µS /cm		271
Total OBD	mg/L		5.9
Total OQD	mg/L		
Phosphorus	mg/L		0.29
Nitrates	mg/L		3.6
Disolved oxygen	mg/L		8.0
PH	Unid		8.09
Total solids	mg/L		196
Suspended solids	mg/L		7
Suspended sediments	mL/L/hr		
Turbidity	U.N.T.		4.4
Cadmium	mg/L		
Lead	mg/L		
Chrome	mg/L		
Pesticides	mg/L	N.D	
Fecal coliforms/ 100 ml	N.M.P	430	

Note: [1] = BID/A y A. [2] = A y A; * Source: ICE, **= Source: A y A; n.d. = not detected

Social, economic, productive and environmental situation of Cahuita

Socio-economic history

Cahuita has an area of 170.41 km^2 and is located in the Talamanca canton. During pre-Columbian times, Talamanca was inhabited by indigenous groups, some located on the shore and others in the mountains. Their economy was based, until the beginning of this century, on subsistence agriculture (corn, cacao, squash, cassava, beans and tubers), fishing, hunting and collection of forest products. Banana, plantain, rice and sugarcane, pigs and poultry, were incorporated later during the colonial period. The indigenous agricultural system consisted of the rotation of annual crops. They harvested once or twice during a year, and then the soil could rest for many years. Afro-Caribbean people arrived at the end of the 18th century, coming from Nicaragua and Bocas del Toro, Panama. They founded the coastal communities at the beginning of the 19th century and were dedicated to fishing, turtle collection and associated products and some coconut and cacao production. White settlers introduced at the river valleys other agricultural practices such as extensive cattle ranching and the burning mode of agriculture, which caused heavy environmental impacts. There is a clear cultural difference between the coastal communities and those of the river valleys and mountains. Civil wars in Central America, and environmental, economic and demographic crises in other areas of Costa Rica, created a migratory process towards Talamanca, and this region became an agrarian front (ACLAC-FUDEU 1999).

Coal exploitation was established by a Costarican company in the hills along the edge of the Carbón River from 1908 to 1918 (Kutay and Rojas 1980). Banana plantations started in 1908, and by 1920, they occupied all of the Talamanca Valley, displacing indigenous peoples to the mountains (ACLAC-FUDEU 1999). From 1930 to 1940, a timber company settled in Gandoca, south from Cahuita. Gandoca, Puerto Viejo and Puerto Vargas (within the present Cahuita National Park) became important timber ports. The cacao production was established in 1933 by banana companies but without much success. Between 1978 and 1980, *Monilia* disease killed the cacao plants. The destruction of the cacao plantations affected the local economy and led to the intensification of plantain crops and timber exploitation as alternatives. In 1980, there was a new expansion of banana plantations, which caused more deforestation, indiscriminate use of pesticides, unfriendly technologies and bad working conditions. In the 1990s, banana plantations and massive tourism and migration increased in the region and cacao plantations started again in 1993. In 1984 Talamanca county had 11,013 inhabitants and the Cahuita district 2,521 inhabitants. In January 1999 the population had nearly doubled in both centres, in Talamanca to 20,683 and Cahuita to 4,141 inhabitants (ACLAC-FUDEU 1999). In the last decade of the 20th century, the ideas of sustainable development, based on ecotourism and organic farming, started to become important considerations (ACLAC-FUDEU 1999). The Cahuita National Park was created in 1970, bringing economic benefits to some people based on ecotourism. However, communities that have not directly benefited from the protected area consider the park as an obstacle to their survival strategies (ACLAC-FUDEU 1999).

Land use in Cahuita

The soil next to the sea is mostly sandy, changing to limes and clays further inland. There are drainage problems on the near slopes. Communities in Cahuita can be divided into 2 groups, depending on soil type, slopes, and, therefore, soil-use capacity (ACLAC-FUDEU 1999):

Group 1: an area of 1,182.9 ha, divided into 483 parcels and lots. It consists of alluvial plains and fossil reefs with slopes of 1 to 27% and a maximum altitude of 10 to 20 m; it is possible to find swamps with poor drainage to the coastal zone. Cattle ranching, ornamental plant culture, and permanent plantations of cacao, banana, fruit trees, roots, and tubers dominate economic activity.

Group 2: an area of 4,305.5 ha, divided into 273 parcels and lots. Slopes are steep (from 10 to 70%), with a maximum altitude of 330 m. Predominant activities are timber extraction, cattle ranching, basic grains, roots, and tuber production.

There are four small creeks within the Cahuita National Park that also contribute to the contamination of Cahuita Reef, especially Kelly Creek and Hone Creek (Table 4).

Table 4. Basins with deforestation problems within the Cahuita National Park.

	Main problems			
	Erosion	Sediment to the reef	Other contaminants to the water	Loss of species
Hone Creek	X	X	X	X
Duncan Creek			X	X
Little Hudson Creek			X	X
Kelly Creek	X	X	X	X

Source: Conversation with farmers (1999).

The coral reef of Cahuita and the impact of terrestrial runoff and other social activities

Current status of the Cahuita Coral Reef

Cahuita Reef is the largest and best studied fringing coral reef on the south Caribbean coast of Costa Rica (Wilkinson 2000). It has been adversely affected by sediments, fertilizers and pesticides resulting from deforestation around the main upstream river, the La Estrella River (Cortés and Risk 1984, 1985). Although the reef has been protected to some extent since 1970 within the Cahuita National Park, it is greatly degraded. Coral growth rates (5-6 mm yr^{-1}), live coral coverage (11%), and diversity (H'=1.44) are low. Live coral cover decreased from 40% in the late 1970s to 11% in the 1980s, and algae cover and coral rubble have increased from 60 to 89%. Over the last 20 years, live coral cover has been evenly maintained, apparently as a result of resistant survivors (Fonseca 2000; Fonseca, submitted) (Table 5). Corals present at the site are those efficient at rejecting sediments (*Agaricia agaricites*, *Siderastrea radians* and *Porites porites*), and morphological changes seem to develop as adaptations to resist the effect of sediments (vertical fronds of *Agaricia agaricites*), or as a response to limited light (shingles of *Montastraea franksi*, *Diploria strigosa* and *Porites astreoides* at 2 m depth). A change in coral species "zonation" is also obvious - species or colony morphologies usually found in deep zones are found in shallow zones. Coral colonies are generally larger than in other areas in the region. Coral recruitment is low and occurs only on vertical surfaces. Early mortality is very high (Cortés and Risk 1984, 1985; Cortés 1993, 1997).

Table 5. Substrate cover and suspended particulate matter (SPM) at the reef of the Cahuita National Park from 1981 to 1999.

	Cortés 1981	Cortés 1993	Fonseca 1999 a	Fonseca 2000
SPM (mg l^{-1})	8.4	9.1	18.0	19.4
Live coral cover (%)	40.4	11.2	11.5	13.6
Other substrate (%)	59.6	88.8	88.5	86.4

The main problem that affects the coral reef at Cahuita is the high concentration of suspended terrestrial sediment that has been increasing (from 8.4 in 1981 to 19.4 mg l^{-1} in 2000: Fonseca 2000; Table 5) and high rates of bottom sediment re-suspension, 20-1000 mg cm^{-2} day^{-1}. The minerals present in the non-carbonate reef sediments and trapped in coral heads (illite, montmorillonite, feldspar) are essentially identical to the minerals present in the La Estrella River, the mouth of which is about 15 km from Punta Cahuita. Heavy metal concentrations in coral and sediments are higher at Cahuita than at other coral reefs surveyed in Panama and Costa Rica. These metal pollutants are associated with natural (soil erosion) and anthropogenic (domestic and industrial sewage, oil, pesticides) sources (Guzmán and Jiménez 1992). There are 1,009 houses, of which 677 have latrines, 320 septic tanks, and 12 use the river or the land for wastewater drainage. Other oceanographic conditions at Cahuita (water temperature, salinity, movement and radiation) seem conducive to coral growth (Cortés and Risk 1985; Cortés 1993).

Siltation impact

Deforestation and inappropriate agricultural practices on the coastal plains and the river basins north of the reef, especially at the La Estrella basin, have been increasing over the last 30 years and are causing the siltation stress on this reef (Cortés and Risk 1985). Currents along the Atlantic coast are from north-west to south-east (Risk *et al.* 1980; Kinder 1983), and they are continuously transporting sediments in that direction. LANDSAT imagery produced at any time of the year shows sediment plumes along the coastline from Limón and south to Cahuita. Moreover, the old park ranger's house, located in Punta Vargas, originally belonged to a lumber company operating in the early 1960s in what is now the National Park. Most of the forest around this point was logged (Cortés and Risk 1984; 1985). At present, the major threat is the imminent land abandonment by the banana companies; the European countries are not buying bananas from farms that do not pay attention to ecological regulations, so banana companies are being confronted with a severe economic crisis (Villela pers. comm., 2000).

Some of the transported material settles on the reef and is intermittently resuspended. Some is trapped inside the coral skeletons, and some accumulates in the bay south of the reef. The sediment amount in old sections of the coral skeletons of Cahuita is smaller than the amount in more recent sections. Greater concentrations of acid-insoluble residues were trapped in coral heads after 1950 (>0.05%: Cortés and Murillo 1985; Cortés and Risk 1985). The category of National Park is not protecting the reef from sediment disturbance.

Tourism and fishing impact

Tourism and fishing are important economic activities in Cahuita and they also have some degree of impact, but this has not been quantified. The first inhabitants of Cahuita were artisanal fishermen who colonized the area of the present Park and then moved to the surroundings. The tourist activity has increased and is now combined with fishing.

Line fishing is permitted within the park. However, fishing is concentrated on snappers at the carbonate banks around the Park. There are 12 active fishermen, who capture approximately between 2,592 and 32,400 kg/y. This fish production represents 2 to 24 % of that of the whole Caribbean coast of Costa Rica. Their total income varies from US$7,335 to 91,698, which means that they generate an individual income of US$611 to US$2,700 (Mug 2000).

Currently, tourism is one of the main activities in the Cahuita town. Local guides offer snorkeling, boat rides, and walks through terrestrial trails. Some of these visitors walk on the reef, break corals and cause boat damage (Cortés 1993). Tourism started growing in 1976 when the bridge over La Estrella River was finished (Kutay and Rojas 1980). From 1979 to 1998, visitation to the park increased by 2881 tourists. However, from 1998 to 2000, it decreased by 14,202 tourists (Figure 3); MINAE-ACLAC pers. comm. 2001). Currently, this Park attracts 2% of the total foreign tourists coming to Costa Rica each year. About 43% of tourists consider that the major reason for visiting Cahuita is the Cahuita National Park, and the coral reef is one of the main attractions. However, some tourists leave the park disappointed with the snorkeling because of cloudy water conditions and lack of live coral. This fact, coupled with the social insecurity, may explain the visitation decrease in recent years (Blair *et al.* 1996).

Tourism provides most economic resources to Cahuita town. The annual revenue attributed to the National Park according to a cash flow valuation is US$ 1.2 million. At a 12% discount rate (representing the opportunity costs of funds, based on an 8% interest rate and 4% assumed inflation rate), the economic value of the park increases to approximately US$ 9.7 million (Table 6).

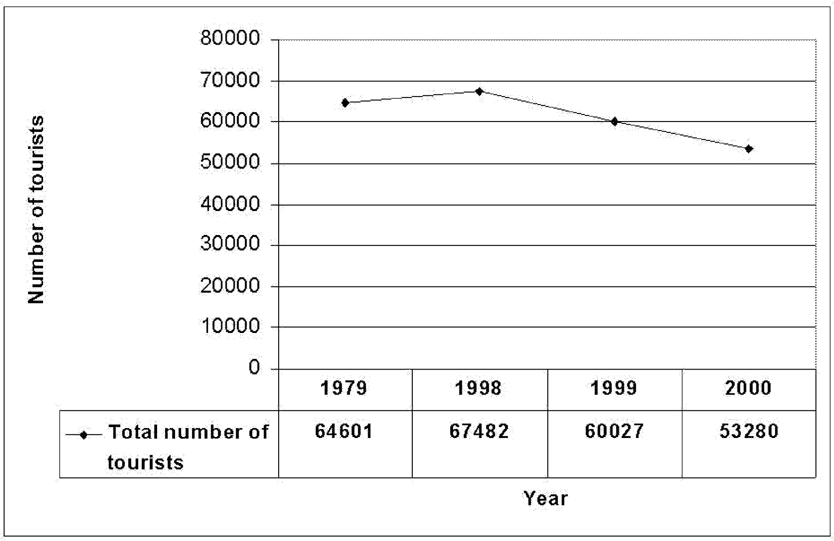

Figure 3. Changes in the number of tourists visiting Cahuita National Park from 1979 to 2000.

Table 6. Total sources of revenue at Cahuita (from Blair *et al.* 1996)

Source of revenue	Total (US$)	% attributable to National Park	National Park revenue
Direct reef revenue	71,502	100.00	$71,502
Residual park entrance revenue	22,091	100.00	$22,091
Hotel revenue	647,925	72.00	$466,506
Restaurant revenue	564,767	72.00	$406,632
Miscellaneous sources of revenue	281,080	72.00	$202,378
Total revenue/annum	1,587,365		$1,169,109
Discount rate:			12%
Value of National Park in perpetuity:			$9,742,574
Value of coral reef in perpetuity:			$595,850

A travel cost valuation results in a yearly income from daily visitor expenditures of US$1.3 million, and over US$2 million from travel expenditures. Combining these figures, visitors spend over US$3.3 million each year to see the Cahuita National Park. In perpetuity, the park has an asset value of US 27.9 million, of which the coral reef is an economic asset worth at least $11.4 million in perpetuity and a yearly value of nearly $172,000. (Table 7; Blair *et al.* 1996).

Table 7. Travel cost valuation of the Cahuita National Park (from Blair *et al.* 1996).

Home country	Travel cost (US$)	Number of tourists	Travel cost contribution (US$)	Spending contribution (US$)	Total contribution (US$)
Canada	676	1,903	220,698	130,590	351,288
Europe	1,543	2,616	692,659	224,452	917,111
United States	746	4,162	532,768	299,950	832,717
Costa Rica	30	20,072	301,079	498,850	799,929
Other	988	1,903	322,558	130,590	453,148
National Park total:			2,069,761	1,284,432	3,354,193
Coral reef total:			106,075	65,827	171,902
Value of National Park in perpetuity:			17,248,006	10,703,602	27,951,608
Value of coral reef in perpetuity:			883,960	548,560	1,432,520

Other threats and disturbances

The government approved an oil exploitation concession for a foreign company in 2000. Some mining exploration rights were also recently given. The risk of accidents during oil exploitation is very high. The effects of these accidents are devastating, including death or changes in the physiology of aquatic organisms and changes in the ecology of coastal ecosystems (coral reefs, seagrasses and mangroves). In Panama, the effects of two oil spills within 20 years were detected within days to months and sustained in some cases over years, even in common organisms resistant to previous disturbances (Jackson *et al.* 1989). The mean level of contamination by petroleum in the south Caribbean coast of Costa Rica is low (1.6 $\mu g\ l^{-1}$, between 1981 and 1985), but some sporadic events of high contamination have been detected (10 $\mu g\ l^{-1}$ in 1985) near the port of Limón, where boat transit is mostly concentrated (Mata *et al.* 1987). Recently environmentalists won the battle against any kind of oil exploitation and exploration.

Natural disturbances suffered by Cahuita Reef in the last 20 years include coral bleaching in 1983 (Cortés *et al.* 1984), *Diadema antillarum* urchin die-offs in 1983 and 1992 (Murillo and Cortés 1984) due to a water-borne pathogen (Lessios *et al.* 1984) and the 7.5 earthquake in 1991 (Cortés *et al.* 1992). The earthquake removed high amounts of sediment from exposed soils, the rivers and the sea bottom (Cortés *et al.* 1992). One of the adjustment faults runs parallel to and through the La Estrella River valley. During the earthquake, the drainage system of the banana plantations was destroyed, necessitating reconstruction (Denyer pers. comm. 2000). However, soil erosion and sediment loads were already high before this event (Cortés and Risk 1984). However, other Caribbean reefs were also affected by the above natural phenomena, and those that are not under siltation stress seem to have recovered (Cortés and Guzmán 1985; Cortés 1992).

Initiatives for the mitigation of anthropogenic impacts

Costa Rica is divided into Conservation Areas. The Amistad-Caribe Conservation Area (ACLAC) is the governmental entity responsible for the environmental management of the south Caribbean coast of Costa Rica. Most protected areas, including the Cahuita National Park, have a management plan for regulating activities within the Park. Tourism and fishing have some regulations formulated to protect the reef from overexploitation. However, their current impact has not been quantified.

The La Estrella River basin is also socially and environmentally an important site for strategic conservation and management. This basin is not a National Park, although the upper section has some low level of protection by national laws and contains an important section of the remainder primary forest of the country. The basin ranks among the main providers of drinkable water for the province of Limón. There is a commission for the management of the La Estrella and other regional river basins, which started holding meetings in 1997 and was officially created on July 28, 1999. This Commission has representatives from the Ministry of Agriculture, Ministry of Environment, Ministry of Health, Municipality of Limón, Basins Foundation of Limón, Water and Sewage National Institute (A y A), Port Administration Board for the Atlantic Basin, National Emergencies Commission, local communities, and the private sector (Standard Fruit Company). There is already a proposal for the natural resources management that includes plans to buy 5,200 ha of La Estrella River basin for protection purposes (ProAmbiente 1998).

Timbering activities are common in the basins, but the activity is performed by people from outside the area, who show little regard for the damage they cause. The cattle ranching farms have not solved the problem of erosion yet, and the soil has no consistent plant cover. The banana companies are beginning to implement measures in order to mitigate erosion, including plant coverage in the plantations, drainage canals, and natural regeneration within 15 m of river edges. However, these efforts still fall short of what is necessary under the present circumstances.

The destruction of the Cahuita reef implies the loss of an important research, recreational, and food source that affects the daily life of fishermen and tourist guides (Table 8) (Blair *et al.* 1996; ProAmbiente 1998). There is still hope for the Cahuita reef, since there is still some live coral cover, a relatively large number of coral species, and some herbivorous fish are still present (Phillips and Pérez-Cruet 1984; Fonseca and Gamboa submitted). Recovery of this reef is possible if tourism and fishing are monitored and regulated, and sediment loads in the rivers are reduced by covering cultivated soils with grass, re-establishing the forest at the river edges and stopping deforestation on the highlands (Cortés 1993). Further efforts must be devoted to the analysis of cause-effect relationships between current catchment activities and degradation of coastal ecosystems and resources. The La Estrella River basin must be included within the limits of the protected area.

One of the conclusions from the workshop held in 1999 was the need for more scientific studies on concentration of nutrients, sediments and other contaminants in the regional rivers, as well as the type and magnitude of their impact on aquatic organisms. The determination of these factors will better support the need for taking actions to mitigate negative impacts (Fonseca 1999a).

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Table 8. Qualitative analysis of the environmental and socio economic issues of the La Estrella River basin and the Cahuita reef.

Driver status and location - Estimation of the intensity and geographical location of the driver.
C: Coast; L: Lower basin; M: Middle basin; U: Upper basin
Impact status: I = Low; II = Medium; III = major; 0 = Not present, -= Not applicable. Time scale = temporal intensity of the driver: P = Progressive; D = Discrete.

Socio-economic and coastal Issues	Present problem status	Impacts	Impacts intensity	Pressures	Drivers	Driver location and status				Time scale	Future trend
						C	L	M	U		
Reduction of tourism attractions	III	Declining of water quality Reef deterioration	III III	Siltation Pesticides contamination Eutrophication	Agriculture	-	III	II	0	P	Abandon?
				Siltation	Cattle raising	-	I	III	I	P	Constant
				Siltation	Logging	-	-	I	II	P	Increasing
				Siltation Bacterial contamination Waste solids contamination	Urbanization	-	I	I	0	P	Increasing
				Harvesting	Fishing	I	-	-	-	P	Constant
				Destruction Extraction	Tourism	I	-	-	-	P	Increasing

Table 8 continued.

Socio-economic and coastal Issues	Present problem status	Impacts	Impacts intensity	Pressures	Drivers	Driver location and status				Time scale	Future trend
						C	**L**	**M**	**U**		
Reduction of commercial stock populations	III	Decline of water quality Reef deterioration	III III	Siltation Pesticides contamination Eutrophication	Agriculture	-	III	II	0	P	Abandon?
				Siltation	Cattle raising	-	I	III	I	P	Constant
				Siltation	Logging	-	-	I	II	P	Increasing
				Siltation Bacterial contamination Waste solids contamination	Urbanization	-	I	I	0	P	Increasing
				Harvesting	Fishing	I	-	-	-	P	Constant
				Destruction Extraction	Tourism	I	-	-	-	P	Increasing

Table 8 continued.

Socio-economic and coastal Issues	Present problem status	Impacts	Impacts intensity	Pressures	Drivers	Driver location and status				Time scale	Future trend expectation
						C	**L**	**M**	**U**		
Loss of biodiversity	III	Decline of water quality Reef deterioration	III III	Siltation Pesticides contamination Eutrophication	Agriculture	-	III	II	0	P	Abandon?
				Siltation	Cattle raising	-	I	III	I	P	Constant
				Siltation	Logging	-	-	I	II	P	Increasing
				Siltation Bacterial contamination Waste solids contamination	Urbanization	-	I	I	0	P	Increasing
				Harvesting	Fishing	I	-	-	-	P	Constant
				Destruction Extraction	Tourism	I	-	-	-	P	Increasing

Explanation of table headings:
Problems: recognized socio- economical consequence
Present problem status: assessment of the intensity of the problem
Impacts: perturbation of the natural environment
Pressures: parameters that cause the perturbation
Drivers: source of the pressures
Driver status and location: estimation of the intensity and geographical location of the driver
Time scale: temporal intensity of the driver
Future trend: expectation of the driver.

4.7 An overview of Caribbean economies with particular reference to the role of the tourism industry

Marlene Attzs

This paper provides a socio-economic overview of Caribbean economies in terms of, *inter alia*, general population and the main economic activities contributing to Caribbean economies. In addition, it provides more details of what is the most common economic activity in Caribbean economies – tourism. Tourism is the fastest-growing industry, not only in the Caribbean but worldwide. It is also the Caribbean industry that relies the most heavily on marine resources and, as a result, can also be affected by indiscriminate land-based activities.

An overview of Caribbean economies

Population, language, and land space

Table 1 provides data on the population, aerial size, language and political status of Caribbean countries. Caribbean, in the context of this paper, is defined as the wider Caribbean – encompassing the non-English-speaking Caribbean countries of Cuba, Dominican Republic (DR) and Haiti. These three countries are among the largest in the Caribbean, with populations in excess of 11, 8 and 7 million respectively. They also cover very wide land spaces – some 115,000 km^2 in Cuba, 48,000 km^2 in the DR and 28,000 km^2 in Haiti. Guiana, with a land space of 215,000 km^2, should also be included here.

As a result of their large population sizes compared to the other eastern Caribbean countries, plus the fact that they are Spanish-speaking territories, the combined populations of Cuba, DR, and Puerto Rico contribute to making Spanish the language spoken by the majority of Caribbean peoples–approximately 60%. French, particularly Créole, is the second most common language, spoken in Haiti, Martinique and Guadeloupe by an estimated 22% of the Caribbean population. A variant of Créole is also spoken in eastern Caribbean countries such as St. Lucia and Dominica, where English, the third language of the region (spoken by 17% of the region's population), is primarily spoken.

Economic History

Most Caribbean economies are greatly dependent on the export of natural resources. During the period of slavery, the island economies were dependent almost entirely on the production of sugarcane for their economic survival. The end of slavery resulted in, among other things, a move towards diversification of the economies, primarily still concentrating on agricultural production but in other areas, mainly on cocoa and coffee. Present economic survival continues to be dominated by natural resource exploitation – bauxite in Jamaica, Guyana and Suriname, and oil/natural gas in Trinidad and Tobago. Tourism, which is now the dominant economic activity in most of the islands of the Caribbean, is based almost entirely on the exploitation of natural resources – marine flora and fauna.

Thus, Caribbean economies are:

- mono-crop economies–one main economic activity dominates
- natural resource-based economies
- environmentally and ecologically sensitive

Vulnerability of Caribbean island states

Caribbean island states are environmentally and ecologically more vulnerable than many other developing countries. Their higher level of vulnerability can be traced back to the interaction of the following socio-economic and natural characteristics:

- Environmental/ecological vulnerability, particularly high exposure to natural hazards
- Limited land resources and difficulties in waste disposal managementGeographic remoteness and isolation
- Limited diversification and very open economies

- Weak institutional capacity and high costs of basic infrastructure
- Special social vulnerabilities

Table 1. General population statistics for the Caribbean region.

Country	Population	Area km^2	Language	Political status
Anguilla	10,000	96	English	UK Territory
Antigua & Barbuda	69,000	440	English	Independent
Aruba	67,000	194	Dutch	Netherlands Territory
Bahamas	293,000	13,878	English	Independent
Barbados	263,000	430	English	Independent
Belize	230,000	2,2700		
British Virgin Islands	19,000	153	English	UK Territory
Cuba	11,115,000	114,524	Spanish	Independent
Cayman Islands	35,000	250	English	UK Territory
Dominica	75,000	790	English	Independent
Dominican Republic	8,232,000	48,400	Spanish	Independent
Grenada	85,000 (1991)	344	English	
Guadeloupe	444,000	1780	French	French Territory
Guyana	857,000	214, 970	English	Independent
Haiti	7,533,000	27,750	French	Independent
Jamaica	2,539,000	10990	English	Independent
Martinique	392,000	1100	French	French Territory
Montserrat	6,000	102	English	UK Territory
Netherlands Antilles	198,000	800	Dutch	Netherlands Territory
Puerto Rico	3,806,000	9,104	Spanish	US Territory
St. Lucia	136,000 (1991)	620	English	Independent
St Kitts/Nevis	41,000 (1991)	2,69.2	English	Independent
St. Vincent & the Grenadines	106,000 (1991)	388	English	Independent
Suriname	443,000	163,820	Dutch	Independent
Trinidad & Tobago	1,318,000	5130	English	Independent
Turks & Caicos	15,000	430	English	UK Territory
US Virgin Islands	102,000 (1990)	342	English	US Territory

Some of these vulnerabilities are exacerbated by the current context of globalisation and erosion of trade (e.g., loss of preferential trading arrangements for bananas).

A fundamental aspect of the environmental/ecological vulnerability of Small Island Developing States (SIDS) is related to their geographical location. Caribbean SIDS are situated in the "hurricane belt," and the almost annual occurrence of this meteorological phenomenon has profound implications for all aspects of the survival of these islands. The frequency and intensity of hurricanes have increased in recent years (Table 2). The small size of the population and economy of most Caribbean island states means that when a disaster strikes, it affects a large proportion of the economy and people, and development of the countries is set back by several years. For example, the 210-miles-per-hour winds of Hurricane Luis, which struck Antigua and Barbuda in 1995, caused over EC$810 million in damages and resulted in the closing of all hotels (Table 3). This amounted to 71% of the island's GDP. This was particularly severe as 83% of its GDP is derived from tourism. Anguilla also suffered damages, estimated to be 147% of its GDP. In addition to the loss of income and employment that such disasters cause, scarce resources have to be diverted away from social essentials such as health and education, which frequently suffer during these storms, and directed to the repair of infrastructure, such as roads, power and water supplies.

Table 2. Selected hurricanes affecting the Small Island States of the Caribbean region.

Year	Name of hurricane/storm	Island(s) affected
1992	Andrew	Bahamas
1994	Debby	St. Lucia
1995	Luis and Marilyn	Anguilla, Antigua/Barbuda, St. Kitts and Nevis, Dominica, Montserrat
1996	Bertha	British Virgin Islands
1998	George	Antigua and Barbuda, St. Kitts and Nevis
1998	Mitch	Belize (flooding)
1998	Floyd	Bahamas
1999	José	Antigua and Barbuda
1999	Lenny	Entire northeastern Caribbean

Source: Caribbean Disaster Emergency Relief Agency (CDERA)

Tourism in the Caribbean

The tourism industry is the biggest industry in the Caribbean and also the fastest-growing. As a result of the increase in stay-over and cruise-ship tourists and in hotel room numbers (tables 4–8), the tourist sector has become a major source of employment as well as a contributor to the balance of payments and other macro-economic indicators across the Caribbean in terms of direct employment and GDP.

Table 3. Cost of damage to the five countries most seriously affected by hurricanes Luis and Marilyn in 1995, in relation to GDP (millions of EC dollars).

Country	1995	Storm damages (EC$ Mn)	GDP for preceding year (EC$ million)	Damage/GDP
Anguilla	1995	245	166.4	147.0%
Antigua/Barbuda	1995	810	1 143.9	71.0%
Montserrat	1995	8.0	147.3	5.4%
Dominica	1995	262	494.1	53.0%
St. Kitts/Nevis	1995	532	505.6	105.2%
St. Martin	1995	1,764		NA

Sources: CDERA: Report on the Economic Impact of the Recent Disasters in the Eastern Caribbean, 1998.
ECLAC/CDCC: Selected Statistical Indicators of Caribbean Countries Doc. LC/CAR/G.535 Vol. X, 1997.

The number of stay-over tourists the Caribbean received increased from approximately 8 million in 1990 to just over 17 million in 1999 (Table 4). A breakdown of the islands visited by the majority of tourists reveals the "leaders" in Caribbean tourism:

- For the larger island states of Cuba, Jamaica, Haiti, Puerto Rico and the DR, the data suggest that Puerto Rico has been the preferred island destination among tourists. For the period 1992–1999, Puerto Rico had, in some cases, almost 1 million more stay-over tourists than the second most visited country, the DR. Overall, tourist arrivals to Puerto Rico were between 18% and 25% of total tourist arrivals to the Caribbean between 1992 and 1999.
- Of the smaller island states, including, the OECS countries[1], Barbados, Bahamas, and Trinidad and Tobago, the Bahamas has dominated tourism since 1990, capturing 1.4 - 1.6 million tourists each year between 1990 and 1999.

[1] The countries of the Organisation of Eastern Caribbean States are: Anguilla, Antigua & Barbuda, British Virgin Islands, Dominica, Grenada, Monstserrat, St Kitts/Nevis, St Lucia, St Vincent & the Grenadines.

Table 4. Stay-over arrivals to Caribbean destinations (000s), 1990–1999.

Destination	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Anguilla	31	30	30	38	44	39	38	43	44	47
Antigua and Barbuda	206	205	218	249	263	220	228	240	234	240
Aruba	433	501	542	562	582	619	641	646	647	683
Bahamas	1,562	1,427	1,399	1,489	1,516	1,598	1,633	1,618	1,528	1,577
Barbados	432	215	386	396	426	442	447	472	512	518
Belize	216	215	246	279	314	321	349	305	288	327
Bermuda	433	385	374	413	416	388	390	380	369	354
Bonaire	41	50	51	55	56	59	65	63	62	62
British Virgin Islands	160	136	117	200	239	220	244	244	279	286
Cayman Islands	253	237	246	279	314	361	373	381	404	395
Cuba	340	424	461	544	617	763	1,004	1,170	1,416	1,603
Curacao	208	206	207	214	226	224	214	205	199	198
Dominica	45	46	47	52	57	61	63	66	66	74
Dominican Republic	n.a	n.a	1,524	1,636	1,767	1,776	1,926	2,211	2,309	2,649
Grenada	126	85	88	94	109	108	108	111	116	125
Guadeloupe	288	132	341	453	556	640	625	660	693	711
Guyana	64	73	75	107	113	106	92	76	69	75
Haiti	120	119	90	77	70	145	150	149	147	143
Jamaica	841	845	1,057	1,105	1,098	1,147	1,163	1,192	1,225	1,248
Martinique	282	315	321	366	419	457	477	513	549	564
Montserrat	19	19	17	21	21	18	9	5	8	10
Puerto Rico	n.a	n.a	2,754	2,923	3,113	3,054	3,128	3,379	3,492	3,228
Saba	5	7	18	16	14	10	10	11	11	9
St. Eustatius	n.a	n.a	13	10	11	9	8	9	9	9
St. Kitts / Nevis	76	84	88	89	94	79	84	88	93	84
St. Lucia	138	159	178	194	219	232	236	248	252	261
St. Maarten	565	548	569	520	586	480	365	439	459	445
St. Vincent and Grenadines	54	52	53	57	55	60	58	65	67	68
Suriname	29	104	30	39	42	43	53	61	55	63
Trinidad and Tobago	194	220	235	248	266	260	266	324	348	359
Turks and Caicos Islands	42	55	52	67	71	78	87	92	106	118
US Virgin Islands	370	376	487	550	541	454	373	393	422	484
Total stay-over arrivals	**7,572**	**7,270**	**12,310**	**13,340**	**14,233**	**14,469**	**14,905**	**15,859**	**16,475**	**17,016**

Source: Social and Economic Statistics, Caribbean Tourism Organization 2001.

The consistent growth in cruise-ship passengers to the Caribbean (Table 5), from 6.5 million in 1990 to almost 11 million in 1999, is also evidence of the importance of this burgeoning industry in these island states. Total cruise-ship and stay-over tourists to the region almost doubled between 1990 and 1999 – from just over 14 million in 1990 to almost 28 million in 1999 (Figure 1).

Table 5. Cruise passenger arrivals to Caribbean destinations (000s), 1990-1999.

Destination	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Antigua and Barbuda	227	256	250	238	236	227	270	286	336	328
Aruba	130	133	217	251	257	294	317	298	258	289
Bahamas	1,854	2,020	2,139	2,047	1,806	1,544	1,687	1,744	1,730	1,982
Barbados	363	372	400	429	460	485	510	518	507	433
Belize	n.a	n.a	2	6	13	8	0	3	14	34
Bermuda	113	128	131	155	173	170	182	182	188	193
Bonaire	5	13	28	17	12	11	15	20	20	17
British Virgin Islands	95	79	88	113	82	122	160	105	105	181
Cayman Islands	362	475	614	606	599	683	771	865	853	1,036
Cuba	n.a	n.a	n.a	n.a	n.a	n.a	n.a	2	n.a	n.a
Curacao	159	157	160	183	161	172	173	215	231	221
Dominica	7	65	90	88	126	135	193	231	239	202
Dominican Republic	n.a	n.a	50	28	50	31	111	271	393	283
Grenada	183	196	196	200	201	250	267	247	266	246
Guadeloupe	261	261	246	263	314	419	613	544	334	293
Haiti	n.a	n.a	n.a	n.a	n.a	225	250	238	246	243
Jamaica	386	491	650	630	595	605	658	712	674	764
Martinique	421	417	399	429	420	428	408	387	415	339
Montserrat	n.a	n.a	6	9	11	9	n.a	n.a	n.a	n.a
Puerto Rico	n.a	n.a	1,019	968	977	1,001	1,025	1,236	1,243	1,149
St. Kitts and Nevis	34	53	74	83	113	121	86	96	154	137
St. Lucia	102	153	165	154	172	176	182	310	372	351
St. Maarten	515	502	470	660	719	564	657	886	882	616
St. Vincent and Grenadines	79	88	63	69	71	85	63	31	35	48
Trinidad and Tobago	32	32	27	33	45	49	48	32	47	57
US Virgin Islands	1,120	1,221	1,277	1,209	1,241	1,171	1,316	1,619	1,616	1,403
Total cruise-ship passenger arrivals	**6,446**	**7,110**	**8,759**	**8,866**	**8,851**	**8,985**	**9,963**	**11,076**	**11,157**	**10,844**

Source: Social and Economic Statistics, Caribbean Tourism Organization 2001

Physical infrastructure to accommodate tourists also increased over the 10-year period 1990 – 1999 as the stock of hotel rooms in Caribbean tourist destinations doubled. The DR, Cuba, Jamaica, Bahamas and Puerto Rico accounted for the major share of these hotel rooms. In 1999, the DR provided almost 24% of the total hotel stock, Cuba accounted for 16%, Jamaica 11%, while the Bahamas and Puerto Rico each provided roughly 6% of the total (Table 6).

In terms of macroeconomic contribution, although there is a paucity of data for some of the island destinations, these islands are generally monocrop economies – depending on one main industry, tourism, for their economic survival (Table 7). For example, visitor expenditures accounted for 75% of Anguilla's GDP in 1998, falling to 65% in 1999. In St. Lucia, tourism accounts for approximately 55% of GDP. In Jamaica, roughly 20% of GDP comes from tourism, and for the Bahamas and Barbados, between 30 and 35% of GDP is garnered from tourism. In economies that are heavily reliant on industrial activity, such as Trinidad and Tobago, tourism accounts for a modest 3% of GDP.

A look at another macroeconomic variable, employment, reveals that as of 1996 (the last year for which data were available), tourism employed almost 125,000 persons in the Caribbean (Table 8).

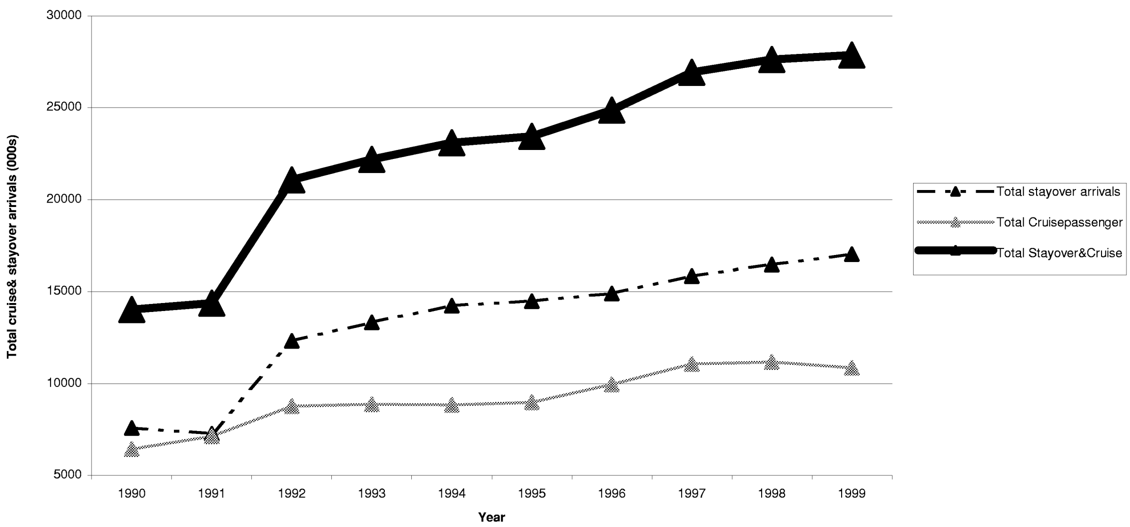

Figure 1. Total stay-over and cruise-ship arrivals in the Caribbean, 1990–1999.

Tourism in south-west Tobago: the impact of drivers on coastal resources

Tourism is the third largest economic activity in Tobago, after agriculture and fisheries. The Policy Research and Development Institute (PRDI) of the Tobago House of Assembly (THA) has noted that, "Tourism is targeted as the leading sector of the Tobago economy. Accordingly, in the MTPFT, tourism policy is intended as a major aspect of the Tobago development policy … " (PRDI 1998, p. 26). Tourism on Tobago is mainly concentrated in the south-western region. Pantin (1996) noted:

"... the existing hotel stock [in Tobago] is concentrated in the south-western region of Tobago (90%). Moreover, the vast majority of the planned increase in hotel rooms is also targeted for the very same southwestern region of the island..." *(Pantin 1996, p. 44)*

The impact of the concentration of tourism development in the south-western part of Tobago has led to, *inter alia*, increased demand for water and sewerage facilities. The current facilities are inadequate, so that inadequately treated sewage effluent is being discharged into the waters of the surrounding ecosystems. The central STP, under the control of the Water and Sewerage Authority (WASA), is designed to serve a population of 10,000 and caters to the sewerage disposal needs of the capital. Pantin (1996 p.36) notes that:

"It has a design outfall into the Scarborough harbour. ... Of the fourteen (14) package sewage treatment plants located throughout Tobago (in 1991), four (4) discharge directly into coastal waters by way of pipeline outfalls; six (6) indirectly into streams or drains discharging into coastal waters at a point less than 0 meters from the beach line; two (2) into mangrove lagoons that connect with the sea; and two (2) at a point greater than 5,000 metres from the beach line. Ten (10) plants are located within 200 metres of the coastal waters."

Table 6. Total number of hotel rooms in Caribbean destinations, 1990-1999.

Destination	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Anguilla	741	863	920	978	978	951	866	915	1,045	1,120
Antigua and Barbuda	2,752	2,752	3,317	3,317	3,317	3,317	3,185	3,185	3,185	3,185
Aruba	5,736	5,864	6,238	6,150	6,366	6,881	6,822	6,962	7,212	7,320
Bahamas	13,475	13,165	13,541	13,521	13,398	13,421	13,288	13,288	14,243	14,153
Barbados	6,709	5,387	5,902	5,580	5,685	5,084	6,315	5,349	5,752	6,585
Belize	2,115	2,784	2,913	3,325	3,504	3,708	3,690	3,905	3,921	3,963
Bermuda	4,265	4,251	4,258	4,236	4,161	4,141	4,152	4,135	3,857	3,276
Bonaire	1,038	1,038	1,038	810	831	1,052	1,128	1,069	1,086	989
British Virgin Islands	1,138	1,165	1,195	1,198	1,224	1,452	1,558	1,587	1,594	1,626
Cayman Islands	3,064	3,275	3,428	3,453	3,532	3,585	4,477	4,501	4,216	4,318
Cuba	12,868	16,638	18,682	22,561	23,254	24,233	26,878	31,837	35,708	33,000
Curacao	1,631	1,722	2,200	2,200	2,200	1,950	2,343	2,696	2,528	2,768
Dominica	531	547	603	757	757	588	764	824	824	857
Dominican Republic	n.a	n.a	24,410	26,801	28,967	32,475	35,729	38,250	42,412	49,410
Grenada	1,105	1,118	1,114	1,428	1,428	1,652	1,669	1,775	1,802	1,928
Guadeloupe	6,064	7,016	7,440	7,798	7,550	7,917	8,294	8,350	8,371	8,260
Guyana	538	538	538	538	639	639	639	730	730	730
Haiti	n.a	n.a	1,500	1,500	1,500	1,758	1,758	1,758	1,758	1,758
Jamaica	16,103	17,337	18,489	18,935	19,760	20,896	21,984	22,954	22,713	23,067
Martinique	5,802	5,658	5,730	6,960	7,220	7,210	7,300	7,400	7,400	7,341
Montserrat	710	710	710	710	710	710	n.a	n.a	n.a	243
Puerto Rico	n.a	n.a	8,415	5,851	9,519	10,251	10,245	10,849	11,828	11,635
Saba	90	100	100	100	186	186	186	186	91	87
St. Eustatius	n.a	n.a	102	139	139	139	77	77	77	62
St. Kitts and Nevis	1,402	1,392	1,330	1,600	1,593	1,563	1,610	1,729	1,762	1,754
St. Lucia	2,370	2,464	1,659	2,919	2,954	3,974	3,986	3,701	3,769	3,065
St. Maarten	3,400	3,400	3,400	3,707	3,707	3,707	3,910	4,049	4,174	3,065
St. Vincent and Grenadines	1,058	1,109	1,164	1,230	1,215	1,176	1,251	1,254	1,550	1,540
Suriname	532	n.a	n.a	n.a	967	1,024	1,088	1,276	1,276	1,276
Trinidad and Tobago	2,125	n.a	2,314	2,652	2,950	3,107	3,536	3,652	3,971	4,236
Turks and Caicos Islands	1,014	1,026	1,115	1,139	1,068	1,068	1,500	1,493	1,562	1,674
US Virgin Islands	4,520	4,739	5,049	5,405	5,461	5,154	4,087	4,401	4,929	4,849
Total Rooms	**102,896**	**106,058**	**148,814**	**157,498**	**166,740**	**174,969**	**184,315**	**194,137**	**205,346**	**209,140**

Source: Social and Economic Statistics, Caribbean Tourism Organization, 2001

These improperly functioning sewerage systems is, according to Laydoo (1987), can destroy coral reefs by:

(a) Toxicity from chlorine added to sewage as a disinfectant; and

(b) Organic enrichment of the sewage, which causes rapid increase in the biological production, eutrophication (deterioration of life-supporting quality) and depletion of oxygen in local waters. This can manifest itself in more phytoplankton in the water, decreased water transparency, organic enrichment of the sediments and obliteration of corals by competing benthic algae.

The implications of sewage pollution in the coastal waters of Tobago would be:

(a) Coral reefs, including Buccoo Reef, would lose their attraction for visitors and would no longer be a major resource from which a large number of Tobagonians could earn a livelihood; and

(b) Health risks to users of the receiving marine environment through exposure to pathogenic organisms introduced with untreated or partially treated sewage.

Table 7. Visitor expenditure as a percentage of GDP for selected Caribbean destinations.

Destination	**1998 (%)**	**1999 (%)**
Anguilla	75	65
Antigua and Barbuda	49	52
Aruba	41	42
Bahamas	34	n.a.
Barbados	36	33
Belize	16	16
Bermuda	24	n.a
British Virgin Islands	n.a	47
Cayman Islands	60	n.a
Cuba	11	n.a
Dominica	17	22
Dominican Republic	14	n.a
Grenada	28	26
Guyana	11	n.a
Haiti	n.a	n.a
Jamaica	20	21
Montserrat	25	9
Puerto Rico	4	4
St. Kitts and Nevis	31	n.a
St. Lucia	55	56
St. Vincent and Grenadines	28	29
Suriname	7	n.a
Trinidad and Tobago	3	n.a
Turks and Caicos Islands	n.a	159

Source: Social and Economic Statistics, Caribbean Tourism Organization, 2001

Broad policy recommendations

1. An attempt should be made to map the percentage of Caribbean land space dedicated to different [economic] drivers, e.g. agriculture, industry, etc.
2. Identify the socio-economic contribution of different drivers for the entire Caribbean, including the contribution of these drivers to the national economies and the share of the population employed in each economic activity.

Table 8. Employment in tourist establishments in the Caribbean* (for selected countries only).

Country	No. of rooms	No. of persons employed
Anguilla[4]	978	1064
Antigua & Barbuda	3317	3649
Aruba	6150	7995
Bahamas	13398	16078
Barbados	5685	5685
Bermuda[1]	4152	4029
Cayman Islands	4477	1569
Curacao	2696	2500
Dominica[1]	764	415
Dominican Republic	28967	34760
Grenada[5]	1085	1200
Jamaica	22954	28976
Martinique[4]	5730	2307
St. Lucia[1]	4203	5200
St. Kitts[3]	1593	1599
Trinidad & Tobago[1]	3198	4160
US Virgin Islands	4406	3570
TOTAL	**113753**	**124756**

Source: Caribbean Tourism Organization 1997.
* Caribbean Hotel Trends (CTO 1994)
[1] 1996 [2] 1995 [3] 1994 [4] 1993 [5] 1991

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4.8 Approaches and analytical tools for integrated assessments of Caribbean river basins

Liana Talaue-McManus

This section discusses conceptual project frameworks and analytical tools that have been used in the study of Southeast Asian catchments and coastal basins (Talaue-McManus *et al.* 2001; Talaue-McManus 2000; Smith *et al.* 2000). Because they provide an integration of the human dimension into the study of material fluxes into and through the coastal zone across site-specific and regional scales, their application in the Caribbean region is explored. Subsequently, the use of similar protocols at regional scales can then facilitate comparisons of estimates of material exchanges through coastal filters, and the anthropogenic drivers that influence these.

Latin America and the Caribbean share similar environmental issues with Southeast Asia, including overexploitation of land and marine resources, loss of biodiversity and habitat degradation, groundwater contamination and depletion, heavy metal contamination, and urban waste disposal (Global Environment Outlook 2000 at http://www.unep.org/Geo.2000). The presence of small-island developing states (SIDS) and the circulation patterns in the Caribbean Sea that allow for transboundary transport of pollutants and contaminants, amplify many of these issues. The major challenges for sustainable development in the region are the threats of climate change, and of tourism and pollution on major coastal and marine ecosystems (Report of the Latin America and the Caribbean Eminent Persons Regional Roundtable (18-20 June 2001) at http://www.johannesburgsummit.org). Thus, the use of analytical frameworks and tools must include, if not focus on, the quantitative assessments of the major natural (e.g. indicators of climate change) and anthropogenic drivers (e.g. tourism, other land uses and pollution) as they influence nutrient cycles and aquatic ecosystem functions in the region.

Integrated Project Framework

The SARCS/ WOTRO/ LOICZ (SWOL) regional project in Southeast Asia chose to integrate the human dimension through the assessment of economic activities and their direct contribution to biogeochemical fluxes from the catchments to the coastal waters (van Kessel *et al.* 2001). One of the major reasons for choosing economics was that it has remained as the most quantitative among the social science disciplines. Environmental impacts quantified in economic terms are also potent tools for addressing policy needs. Estimates of economic variables may then be integrated into models that attempt to describe and subsequently predict biogeochemical fluxes. In the case of the Caribbean, major demographic parameters (e.g., urban population growth), and key economic production sectors (e.g., industry, services, specifically tourism, agriculture, forestry and mining) are among the critical elements that need to be addressed in a regional project proposal.

Quantifying biogeochemical inputs from economic activities

Two approaches were used in the SWOL project to quantify waste generated by economic production sectors, including the household sector. The first was the 11-sector economic input-output model. Most economic input-output tables are produced at the national scale by economic planning bodies and would need to be recalculated at sub-regional level to reflect best economic production at the landward side of specific coastal basins. In two of the four study sites, the endogenized household sector was included as the 12th production sector.

A second approach was the rapid assessment method utilized by the World Health Organization and developed by Economopoulous (1993). It includes the enumeration of production establishments by economic activity and the conversion of waste products these generate into carbon, nitrogen, and phosphorus (San Diego-McGlone *et al.* 2000). The rapid assessment method is more amenable to spatially-based evaluation but does not take into account the interactions among production sectors as does the I-O model (McGlone and Caringal 2001).

The economic I-O and rapid assessment models could both be implemented, using government statistics that are usually compiled for each of the regional units of a country. As such, they are geo-politically based, and subsequent estimations to match scales of catchments would necessitate disaggregation of economic data (if possible). A final conversion of generated waste into dissolved inorganic nitrogen and phosphorus allows for the integration of these estimates into the budget modeling below.

Quantifying nutrient fluxes and system metabolic states

The LOICZ biogeochemical modeling guidelines were adopted in the formulation of stoichiometrically linked water-salt-nutrient budgets (Gordon *et al.* 1996). As summarized by Smith (2000), "Water and salt budgets are used to estimate water exchange in coastal systems. Nutrient budgets (as a minimum, dissolved inorganic phosphorus and dissolved inorganic nitrogen) are also developed, and departure of the nutrient budgets from conservative behavior is a measure of net system biogeochemical fluxes." An overview of the budget modelling approach, the budgets so far developed, and tutorials can be accessed through the LOICZ homepage (http://www.nioz.nl/loicz).

Other modeling approaches may be used to validate results obtained from the LOICZ budget models. Because of minimal data requirements, and the availability of some of these as secondary data, the LOICZ approach provides a sound platform for broad-scale comparisons and upscaling of non-conservative flux estimates.

The estimated DIN and DIP from economic activities can be compared with the total fluxes entering the coastal zone as estimated above. Alternatively, the concentration of DIN and DIP derived from economic activities can be compared with measured ambient concentrations in the coastal system after assuming some levels of assimilation.

Looking for transboundary environmental issues

In looking at sources and sinks of horizontal material delivery to the coastal waters, transport (and circulation) processes may link catchments and coastal basins that belong to different jurisdictional areas. Transport of water-borne pollutants to countries downstream of a source river mouth is a classic example. The introduction of noxious algal species through ballast water of ocean-going ships has been established as a transboundary phenomenon. Harder still is the transboundary trade of goods and services from the coastal zone, such as the case in the international shrimp trade and tourism. All of these examples occur in the wider Caribbean region. Transboundary issues require that analysis and mitigation be done on regional scales and thus provide a rationale for regional collaboration (Talaue-McManus 2000).

Up-scaling site-specific estimates through a typology

A major goal of the LOICZ programme is to derive global estimates of the biogeochemical fluxes of carbon, nitrogen, and phosphorus in and through the coastal zone. To upscale the site-specific budgets, a requisite step is to develop an objective classification or typology of the coastal regions of the world (Maxwell and Buddemeier 2002). Each identified type may include one or a number of well-characterized sites, the functional features for which may be used to characterize all sites belonging to this type.

A typology tool known as LOICZView, a clustering and visualization routine, has been developed by the Typology Project and may be accessed through the website of the LOICZ/UNEP-GEF Synthesis Workshops (http://www.kgs.ukans.edu/Hexacoral/Tools/). The LOICZView clustering routine may be implemented through its login site (http://www.palantir.swarthmore.edu/~maxwell/loicz/).

The approaches and analytical tools discussed above should provide scientists worldwide with a minimum set of protocols that can allow for sound comparisons of coastal systems at local and regional scales. Validation of modelling results with those of other approaches is encouraged to test further for robustness of patterns and trends.

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5. REGIONAL ASSESSMENT TABLES: SITE-SPECIFIC CARIBBEAN COASTAL ISSUES AND IMPACTS

These country tables have been compiled using available information. For each site they are in the format of the standardized LOICZ-Basins Regional Assessment (RA) Tables 1-7. In case certain tables, e.g., on sub-regional or full regional scale (tables 4, 5) are not used, the numbering still follows the sequence outlined in the methodology. For more information see Appendix I.

5.1. Caroni River, Trinidad, Trinidad and Tobago

Peter Bacon and Rahanna Juman

Table Summary

The Caroni River, with a drainage basin of 883 km^2, flows through the Caroni mangrove swamp into the Gulf of Paria. Major land use within this river basin includes urbanization, industrial development, damming, agriculture and quarrying. These activities have downstream effects on the coastal zone. Deforestation for housing and quarrying have increased the sediment load in the coastal zone. Damming and alteration of the hydrology of the swamp have resulted in reduction of freshwater flow, salinization and the loss of freshwater habitats, resulting in reduced biodiversity. Effluent from residential areas, industrial and agricultural runoff have led to increased pollution and eutrophication. These land-based activities have impacted on the quality and quantity of the coastal resources, which in turn affects human utilization of the same resources.

Within the Caroni Swamp, oyster harvesting is an important economic activity. Impacts from the catchment such as pollution have resulted in reduced oyster populations. The quality of the oyster is also affected, since these organisms bio-accumulate pollutants, bacteria and viruses. The Caroni Swamp is also an important habitat for the Scarlet Ibises and an eco-tourism site for bird-watchers. Salinization in areas of the swamp has resulted in loss of habitats for these birds as well as for other species.

Though very little fishing occurs in the swamp itself, the Caroni River flows into the Gulf of Paria, which is the most active fishing area around the island. The Gulf of Paria is a shallow basin entirely enclosed by the west coast of Trinidad and the east of Venezuela. Water entering the gulf from the Caroni River basin contains nutrients, sediment, pesticide residues and heavy metals. These pollutants have intensified the decline in fish populations, which have serious economic implications for the people of Trinidad.

Table RA5.1.1. Caroni River: major coastal impacts/issues and critical thresholds – overview and qualitative ranking.

Impact category and relative class of importance:1 = low – 10 = high.

Coastal Impact/ Issue	Critical Threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category	References/Data source
Pollution, Eutrophication, Sediment loading Salinization	Decline of fish stocks, 50% for economic loss	Currently about 30% loss	10	Boodoosingh 1992
Pollution, Eutrophication, Sediment loading Salinization	Decline of oyster harvest by 50% Bacterial contamination 5%	No distance	10	Boodoosingh 1992
Pollution, Eutrophication Habitat alteration Salinization	Loss of biodiversity, loss of species	No distance	8	Bacon 1993

Table RA5.1.2. Caroni River: 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; 0 = no impact; ? = insufficient information.
Time scale: p = progressive (continuous); d = direct (spontaneous).

Driver	Pressures	State change (qualitative index)	Impact on the coastal system	Time scale
		Small basin, passive coast		
Agriculture	• Siltation • Pesticide contamination • Freshwater diversion • Hypernutrification	**major** **medium** **minor** **medium**	Declining water quality, biodiversity loss, salinization, eutrophication	**p**
Damming	• Siltation • Flow increase	**major** **minor**	Salinization	**d**
Industries	• Contamination	**major**	Biodiversity loss, declining water quality	**p**
Urbanization (point source effluents)	• Sewage and • heavy metal contamination	**major** **minor**	Eutrophication, biodiversity loss	**p**
Quarrying	• Siltation	**medium**	Water quality decline	**p**

Table RA5.1.3. Caroni River: the link between coastal issues/impacts and land-based drivers– overview and qualitative ranking on local or catchment scale.

Impact category and relative class of importance:1 = low – 10 = high.

Coastal Impact/issue	Drivers	Impact category	Trend expectations	References/ data sources
Declining water quality	Agriculture Deforestation Industry Quarrying	8	⇑	IMA 1999
Salinization	Agriculture damming	2	⇑	Bacon 1993
Biodiversity loss	Agriculture Industry Urbanization	4	⇑	Bacon 1993; Ramnarine 1997
Eutrophication	Agriculture Urbanization		⇑	Siung-Chang 1987 IMA 1999

Table RA5.1.6. Caroni River: scientific and/or management response to coastal impact/issues on catchment, sub-regional and regional scale.

Response Catchment scale		Response Sub-regional/ Country scale		Response Regional scale	
Scientific	Management	Scientific	Management	Scientific	Management
Various studies by UWI, IMA	Designation of protected areas Caroni Swamp Management Committee	Various studies by UWI, IMA	National Wetlands Committee and Policy Specially Sensitive Areas Rules Effluent standards EMA	CARICOMP	UNEP-Regional Coordinating Unit

IMA Institute of Marine Affairs
UWI University of the West Indies, St Augustine
EMA Environmental Management Authority

5.2 The Buccoo Reef/ Bon Accord Lagoon System, Tobago, Trinidad and Tobago

Peter Bacon and Rahanna Juman

Table Summary

The Buccoo Reef/ Bon Accord Lagoon system, located on the leeward coast of south-western Tobago, is the best example of contiguous coral reef, seagrass bed and mangrove swamp in the country. Unlike the Caroni Swamp, this coastal area has no riverine inflow, but instead several ephemeral streams and surface drains transport effluent from a cattle farm and sewage treatment plants. This coastal zone does not have a well-defined drainage basin like the Caroni River but has a drainage area, based on the surface hydrology. The terrestrial geology of the drainage area is a coralline limestone formation, which is highly fractured and faulted and facilitates chemical dissolution. The high porosity and transmissivity of this coral-algal limestone makes it unsuitable for liquid effluent/sewage disposal.

The Buccoo Reef has been recognized as an importance socio-economic asset for the country. It is one of the largest tourist attraction in Tobago with more than 50,000 visits per annum and the annual income generated by the reef tour trade exceeds TT $1million. The major land use within the drainage area of this ecosystem complex is built development with include housing and resort development, as well as some agriculture. Buccoo Reef and Bon Accord Lagoon have been impacted by eutrophication mainly through sewage pollution, and the Reef has been physically damage by tourist-related activities such as reef walking, anchor damage and boat groundings.

Table RA5.2.1. Buccoo Reef/ Bon Accord Lagoon: major coastal impacts/issues and critical thresholds – overview and qualitative ranking.
Impact category and relative class of importance:1 = low – 10 = high.

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	Buccoo Reef/ Bon Accord Lagoon	Loss of bathing beach through bacterial (faecal coliform) contamination	No distance	10	IMA 1994, 1996; Laydoo *et al.* 1987
		Presence of diseased coral, reduction in coral cover, loss of biodiversity	No distance	8	CARICOMP data (IMA)
Eutrophic-ation	Buccoo Reef/ Bon Accord Lagoon	Loss of hard corals cover and biodiversity	No distance	10	CARICOMP data (IMA)
		Reduction in fish stocks	Not known	?	Juman 2001
		Reduced seagrass productivity/ biomass	No distance	9	
Sediment loading	Buccoo Reef/ Bon Accord Lagoon	Loss of biodiversity	Not known	?	Juman 2001
		Loss of visibility/ aesthetics for divers (varies seasonally)	About 20% visibility during rainy season	6	

Table RA5.2.2. Buccoo Reef/ Bon Accord Lagoon: DPSIR matrix characterizing major catchment based drivers/pressures and a qualitative ranking of related state changes impacting the coastal zone versus catchment size class. (in this case small basins: passive coast).
State change dimension: major; medium; minor; 0 = no impact; ? = insufficient information
Time scale: p = progressive (continuous); d = direct (spontaneous)

Driver	Pressures	State change (qualitative index)	Impact on the coastal system	Time scale
Agriculture	• Siltation • Pesticide contamination • Hypernutrification	**minor** **minor** **major**	Declining water quality Biodiversity loss Eutrophication	**p**
Urbanization (Point source Effluents)/ Resort Development	• Sewage and • heavy metal contamination	**major** **minor**	Eutrophication Declining water quality Biodiversity loss	**p**
Tourism	• Mechanical damage to reef through tourist related activities on site	**major**	Biodiversity loss	**p**

Table RA5.2.3. Buccoo Reef/ Bon Accord Lagoon: the link between coastal issues/impacts and land-based drivers – overview and qualitative ranking on local or catchment scale.
Impact category and relative class of importance:1 = low – 10 = high.

Coastal Impact/Issue	Drivers	Impact category	Trend expectations	References/ data sources
Declining water quality	• Agriculture • Urbanization • Tourism	8	⇑	IMA 1994, 1996
Eutrophication	• Agriculture • Urbanization	10	⇑	Laydoo *et al.* 1987; IMA 1996; Juman 2001
Biodiversity loss	• Agriculture • Tourism • Urbanization	6	⇑	CARICOMP data (IMA) Juman 2001

Table RA5.2.6. Buccoo Reef/ Bon Accord Lagoon: scientific and/or management response to coastal impact/issues on catchment, sub-regional and regional scale.

River catchment or island	Response catchment scale		Response Sub-regional/ Country scale		Response Regional scale	
	Scientific	Management	Scientific	Management	Scientific	Management
Buccoo Reef/ Bon Accord Lagoon	Various studies by THA, IMA, UWI	Only Marine Park in Trinidad and Tobago. Designation a marine protected areas since 1973 under the Marine Preservation and Enhancement Act of 1970. A Management Plan was formulated in 1994 by the IMA. Manage by the THA	Various studies by UWI, IMA, THA	Tobago House of Assembly National Wetlands Committee and Policy Specially Sensitive Areas Rules Effluent standards EMA	CARICOMP	UNEP-Regional Coordinating Unit

IMA Institute of Marine Affairs
UWI University of the West Indies, St Augustine
EMA Environmental Management Authority
THA- Tobago House of Assembly

5.3 Kingston Harbour, Jamaica

Trion Clarke and Dale Webber

Table Summary

Kingston Harbour, Jamaica has been contaminated by domestic, industrial and fluvial effluent for the better part of the last three centuries, with the worst deterioration occurring in the last fifty years. Contamination has resulted in increased eutrophication, sedimentation and chemical pollution, with resultant decreases in biodiversity and aesthetic appeal.

Land-based activities are mainly responsible for the contamination. These include poor agricultural practices and sewage disposal. Sewage outfall from treatment plants is the most important source of pollution to Kingston Harbour, though volumetric flow rates are lower than other sources such as the Rio Cobre and Duhaney rivers. Nutrient, sediment and chemical inputs from these two rivers are significant.

The critical thresholds for proper system functioning for most of the indices have been surpassed and negative impacts on the coastal area are expected to increase in intensity over the near and medium future.

Extensive scientific work has taken place in Kingston Harbour, but little has occurred in the drainage basins. Various management entities have been established with direct responsibility for the harbour, but very little in terms of actual management has occurred. Scientific and management efforts continue.

Because all the land-based impacts are concentrated into one harbour basin, there is no need to provide a detailed table of coastal issues versus drivers (i.e. Table 1).

Table RA5.3.2. Kingston Harbour: DPSIR matrix characterizing major catchment-based drivers/pressures on and a qualitative ranking of related state changes impacting the coastal zone versus catchment size class (area influenced by small catchments).

State change dimension: major; medium; minor; 0 = no impact; ? = insufficient information
Time scale: p = progressive (continuous); d = direct (spontaneous)

Driver	Pressures	State change (qualitative index)	Impact on the coastal system	Time scale
Agriculture	Nutrient, sediment and pesticide input	**major**	• Eutrophication • chemical contamination, smothering of seagrass beds • increased turbidity	**p**
Industries	Nutrient and chemical input	**medium**	• Eutrophication and • chemical contamination	**p**
Deforestation	Sediment input Habitat removal	**minor**	• Smothering of seagrass beds • increased turbidity • decreased biodiversity	**p**
Navigation	Nutrient and sediment resuspension Shoreline construction Chemical contaminant input	**medium**	• Eutrophication • Siltation • pollution of water • Loss of aesthetic appeal	**p**
Urbanization	Nutrient and sewage input	**major**	• Eutrophication and • bacterial contamination	**p**
Fisheries	Over-exploitation, destructive practices, food web attenuation	**medium**	• Lowered biodiversity • loss of species and • loss of habitat	**p**

Table RA5.3.3. Kingston Harbour: the link between coastal issues/impacts and land-based drivers – overview and qualitative ranking on local or catchment scale.
Impact category and relative class of importance:1 = low – 10 = high.

Coastal Impact/ Issues	Drivers	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ Data sources
		Locations around Kingston Harbour in detail	**Impact Category**		
Eutrophication	a. Urbanization	a. Sewage input along shoreline.	10	⇑	
	b. Agriculture	b. Rio Cobre basin	6	⇑	
	c. Industries	c. Inflow through gullies.	2	⇑	
	d. Navigation	d. Within harbour and along shoreline.	2	⇑	
Bacterial contamination	a. Urbanization	a. Sewage input along shoreline	10	⇑	
Siltation (smothering)	a. Agriculture	a. Rio Cobre basin	6	⇑	
Lowered biodiversity	a. Deforestation	a. Along shoreline	4	⇑	
	b. Fishing	b. Inside harbour	6	⇑	
Chemical contamination	a. Agriculture	a. Rio Cobre basin	2	⇑	
	b. Industry	b. Shoreline gullies	2	⇑	

Table RA5.3.6. Kingston Harbour: scientific and/or management response to coastal impact/issues on catchment, sub-regional and regional scale. (n a. = not applicable).

Response Catchment scale		**Response Sub regional/ Country scale**	
Scientific	Management	Scientific	Management
Sediment loading data. Nutrient loading data. Bacterial Analysis. Sewage loading data. Plankton studies. Circulation and bathymetric studies. Sediment biota studies. Chemical pollution data. Water discharge data. Water quality data.	Establishment of various management entities such as: Kingston Harbour Restoration Plan. Kingston Harbour Rehabilitation Programme.	General monitoring and assessment by academic and governmental and non-governmental bodies and institutions.	Natural Resource Conservation Authority Act (1992) and the establishment of the National Environment and Planning Agency (2001).

Wade (1976); SENTAR (1993); Simmonds (1997); Mansingh and Wilson (1995); CIMAB (1997); Williams (1997); Ranston (1998); Webber and Webber (1998); Wilson-Kelly (in press);

5.4 Parque Nacional Morrocoy, Venezuela

David Bone

Table Summary

Of Venezuela's approximately 2,875 km of continental coastline, 1,927 km (67%) are on the Caribbean Sea and 948 km (33%) on the Atlantic Ocean. The major shallow marine and coastal habitats are sandy beaches, rocky shores, seagrass beds, coral reefs, coastal lagoons and mangroves. Primary production is high, due to upwelling and additional nutrient supply by rivers and watersheds. Some of the ecosystems exist within a delicate dynamic equilibrium which is influenced by continental water masses, and interact by means of material and energy transfer. During recent decades, negative impacts from anthropogenic activities have reportedly affected coastal marine ecosystems.

A variety of economic activities take place, including fisheries, tourism and industrial output. Of special interest along this coast is the area of Golfo Triste, an extensive marine region located to the middle west of the country. This area is directly influenced by the discharges from the Aroa and Yaracuy river basins, which together have a catchment area of 4,720 km^2. Human settlement in the basin areas have increased, from less than 100,000 inhabitants in 1950 to more than 800,000 in 1998. This population increase is related to urbanization, changing from 38% in 1950 to 76% in 1990. Urban centers including the state capital have developed in the central region of the basins. The main economic activities are agriculture and cattle-raising, with 85% of the total area dedicated to this activity. Mining also takes place, with copper and iron as the main products. Three dams have been built on these rivers: two on the Aroa River and the largest one on the Yaracuy River. At present, the Aroa and Yaracuy basins provide water for agriculture, industrial and urban activities, energy generation and dam construction, and the main river courses are used for effluent discharge. In addition, the basins have been subjected to intense deforestation, which increases soil erosion and causes deterioration downstream, where the amount of river sediment, nutrients, organic matter and pollutants have increased, eventually impacting the marine areas. The Parque Nacional Morrocoy and its surrounding areas represent by far the most important and complex marine ecosystem of this continental shore, with extensive coral reef areas, mangrove forests and seagrass meadows, estuarine and hypersaline environments. During the last two decades, these marine communities have been affected by a variety of man-made disturbances, locally and on the mainland, whereby poor land management has created serious erosion problems and sediments have been carried into the park by runoff and by coastal currents.

Table RA5.4.1. Parque Nacional Morrocoy: major coastal impacts/issues and critical thresholds – overview and qualitative ranking.
Impact category and relative class of importance:1 = low – 10 = high.

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
Sediment/ siltation	Aroa-Yaracuy River	Live coral cover >35% Biodiversity, >80%	Currently down to 5% Currently reduced to 20% **No distance**	10	Bastidas *et al.* 1997
Pollution (heavy metals)	Aroa-Yaracuy River	ppb	Arising to ppm	7	Bastidas *et al.* 1997
Nutrients/ eutrophication	Aroa-Yaracuy River	High, but periodical	**No distance** (temporarily)	5	
Habitat alteration (reduction)	Aroa-Yaracuy River	High biodiversity	Overall 35% reduction	5	Losada 1998

Table RA5.4.2. Parque Nacional Morrocoy: DPSIR matrix characterizing major catchment based drivers/pressures and a qualitative ranking of related state changes impacting the coastal zone versus catchment size class (small basins on a tectonically passive coast).
State change dimension: major; medium; minor; 0 = no impact; ? = insufficient information
Time scale: p = progressive (continuous); d = direct (spontaneous)

Driver	Pressures	State change (qualitative index)	Impact on the coastal system	Time scale
		Small basins: passive coast		
Agriculture/ Cattle raising	Increased runoff Increased sediment input Increased organic and nutrient input	**medium**	Nutrification Eutrophication Water quality change Pollution TSS increase	**p**
Damming	Nutrients and sediments sequestration	**minor**	River flow reduction	**d**
Deforestation	Increased runoff Increased sediment Increase organic and nutrient inputs	**medium**	Habitat degradation, TSS increase	**p**
Tourism	Construction along shore-line. Increase sewage/solid waste input Extraction of commercial species Boating	**major**	Habitat reduction Habitat alteration Loss of biodiversity Litter contamination	**p**
Urbanization (Effluents)	Construction along shore-line Increased contaminants and sewage inputs	**major**	Habitat reduction Habitat alteration Loss of biodiversity Litter and solid contamination Sewage	**p**
Fishing	Over-exploitation of commercial resources	**medium**	Loss of biodiversity Loss of critical species Habitat alteration	**P**

Table RA5.4.3. Parque Nacional Morrocoy: the link between coastal issues/impacts and land-based drivers – overview and qualitative ranking on local or catchment scale.
Impact category and relative class of importance:1 = low – 10 = high.

Coastal Impact/Issues	Drivers	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ data sources
		River	Impact category		
Decline in water quality	Agriculture/cattle-raising Deforestation Industry Urbanization Damming	Aroa-Yaracuy River	8	⇑	Bone *et al.* 1993
Habitat alteration	Urbanization Agriculture/ cattle Tourism	Aroa-Yaracuy River	8	⇑	Bastidas *et al.* 1997 Losada 1998
Biodiversity loss	Urbanization Agriculture/cattle Tourism Natural drivers?	Aroa-Yaracuy River	10 ?	⇑	Losada 1998

Table RA5.4.6. Parque Nacional Morrocoy: 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
Aroa-Yaracuy rivers	Several studies by USB, UCV, MARNR	MARNR, Land use policies Basin use policies	Several studies by USB, UCV, MARNR	Declaring protected areas Land Use INPARQUE MARNR	CARICOMP	UNEP

5.5 Magdalena River, Colombia

Juan Dario Restrepo

Table Summary

The Magdalena River is 1,612 km long and drains a 257,438 km² basin that occupies a major portion of the Colombian Andes. It is the largest fluvial system in Colombia and its headwaters are in the Andean Cordillera at an elevation of 3,300 m. The river discharges into the western Caribbean and forms a 1,690 km² triangular delta. It has the highest sediment yield of any medium or large river along the Caribbean and Atlantic coasts.

Over the last fifty years the Magdalena River and associated coastal areas have been under increasing environmental stress. Economic development of Colombia between the 70s and 80s has increased demand for river control and utilization. Ongoing trends in the drainage basins have included:

(1) escalating population densities along the basin and at river mouth. The main cities of Colombia including Bogotá, Medellín, Cali, and Barranquilla are located in the basin;
(2) accelerating upland erosion rates due to poor agricultural practices and increasing deforestation; and
(3) partly a result of points 1 and 2, increasing levels of pollution within the water.

All of these trends and impacts have produced a severe distortion of natural hydrographs leading to the potential loss of critical habitat, biodiversity and altered material transport.

Water and sediment discharges of the Magdalena River have strongly impacted the adjacent coastal ecosystems. Since 1954, the government of Colombia has dredged the Canal del Dique, a 114 km man-made channel from the Magdalena River at Calamar to Cartagena Bay. Because of the increased sedimentation in the bay during the 1970's, new canals were constructed from El Dique to Barbacoas Bay, and since then the suspended sediment load into Barbacoas has reached and impacted the El Rosario Islands, the second largest coral reef ecosystem in the Caribbean Sea of Colombia, and is probably responsible for most of the observed coral mortality. Water diversion due to the construction of a highway in the Magdalena delta/lagoon complex, the Ciénaga Grande de Santa Marta, has resulted in hypersalinization of mangrove soils and consequent die-off of almost 270 km² of mangrove forests over a 39-year period. The changes in the hydrological regime have also caused water quality changes in the lagoons and associated channels. In addition, urban, agricultural, mining and industrial waste inputs from the Magdalena basin have aggravated the conditions of the lagoon and coastal ecosystems. Biodiversity has been reported to be considerably lower in the area affected by mangrove mortality and in the coastal zone. Declining fisheries in the delta, from 63,700 tons in 1978 to 7,850 tons in 1998, indicate decreasing environmental conditions and water quality.

The Magdalena River is a major river for which the historic database is shockingly small. It deserves international attention because it has such a significant sediment yield (the largest on South America's Atlantic and Caribbean seaboards). In addition, it has a close teleconnection with the ENSO (La Niña events trigger high discharges and flooding events) and it has the most significant freshwater source for the Caribbean Sea. Thus, the fluvial inputs of the Magdalena River have great environmental and economic impacts on the adjacent coastal ecosystems.

Table RA5.5.1. Magdalena River: major coastal impacts/issues and critical thresholds of fluxes – overview and qualitative ranking:
Impact category and relative class of importance:1 = low – 10 = high.

Coastal Impact/ Issue	Local site/region	Critical threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category	References/ Data source
Eutrophication Pollution	Magdalena River Delta/ Lagoon-delta complex/ Caribbean coast of Colombia	Biological communities near the delta show signs of mortality. Declining yield in fish resources, with total catches from more than 63700 t/yr in 1978 to 7850 t/yr 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 2000b.
Water discharge 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; INVEMAR 2000b; Restrepo and Kjerfve 2000
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; INVEMAR 2000b
Erosion (coastal sediment budget)	Magdalena River Delta	Observed coastal erosion of 17 m/yr 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 RA5.5.2. Magdalena River: DPSIR matrix characterizing major catchment-based drivers/pressures and a qualitative ranking of related state changes having impact on the coastal zone.

State change dimension: major; medium; minor; 0 = no impact; ? = insufficient information.
Time scale: p = progressive (continuous); d = direct.

Driver	Pressures	State change (qualitative index)	Impact on the coastal system	Time scale
Agriculture	Soil conservation Poor agricultural practices	**medium**	Lost of coastal ecosystems due to accelerating upland erosion rates and eutrophication	**p**
Deforestation	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 Jetty construction in the Magadalena delta mouth	**major** **?**	Discharge of suspended sediment load into coastal ecosystems Imbalance in the coastal sediment budget	**P** **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-major**	Contamination and eutrophication Fish, invertebrate and avian bio-diversity and biomass are much lower than 10 years ago	**p**

Table RA5.5.3. Magdalena River: the link between coastal issues/impacts and land-based drivers – overview and qualitative ranking on local or catchment scale.
Impact category and relative class of importance:1 = low – 10 = high.

Coastal Impact/ Issues	Drivers	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ data sources
		River or other	Category		
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-INGEOMINAS 1991; Cardona and Botero 1998.
Water discharge and sediment load diversion	Diversion	Magdalena River	10	⇒	Vernette 1985; Restrepo and Kjerfve 2000
Erosion (coastal sediment budget)	Navigation	Magdalena River delta	8	⇑	Correa 1996; Martínez 1993
Hyper-salinization of mangrove soils	Diversion	Magdalena lagoon-delta complex	9	⇒	Cardona and Botero 1998.

Table RA5.5.6. Magdalena River: scientific and/or management response to coastal impact/issues on catchment, sub-regional and regional scale.
n.a. = not applicable

Response Catchment scale		Response Sub-regional/ Country scale	
Scientific	Management	Scientific	Management
Water discharge data (1940-2000). Sediment load data (1972-2000) Source: IDEAM (Colombia) Heavy metals 1980-1990 Source: HIMAT-INGEOMINAS 1999; Bustos (1999).	Quality criteria for waste water in the tributary basins. Source: Ministry of the Environment. Colombia.	In general: Monitoring programmes through hydrological and geological institutes. Sources: IDEAM, HIMAT-INGEOMINAS National Program of Monitoring Marine Ecosystems (SINAM) (INVEMAR 2000b and Ministerio del Medio Ambiente, Colombia)	Major rehabilitation program of the Magdalena Delta / Lagoon Complex, Cienaga Grande de Santa Marta (Colombian Government, GTZ-Germany and IDBank)

5.6 La Estrella River/Cahuita Reef, Costa Rica

Ana Fonseca and Jorge Cortés

Table Summary

The main pressure to Cahuita Reef deterioration is siltation. Some eutrophication and pollution may be occurring, associated with the sediment. The main drivers of siltation are agriculture, cattle ranching and logging in the La Estrella river basin, and some coastal urbanization, so these seem to be the main sources of reef deterioration. Contamination comes basically from agriculture and coastal urbanization, and eutrophication from agriculture. Secondary pressures are harvesting, anchoring and reef-walking from fishing and tourism activities, all of which are increasing.. There is also a threat of marine oil exploitation in the future. There is some scientific response especially at the catchment and regional scale. There is no a strong national support for research yet. Management initiatives are in place at the country and regional scales; at the catchment scale specific actions to minimize impacts are very scarce. This means that the national and regional policies for conservation and management are not being implemented at the catchment scale.

Table RA5.6.1. La Estrella River/Cahuita Reef: major coastal impacts/issues and critical thresholds – overview and qualitative ranking.

Coastal Impact/ Issue	Critical threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category (Impact code and relative class of importance)	References/ Data source
Siltation	Coral mortality (live coral cover is 11%) Change in coral species composition Low water quality Loss of biodiversity General reef deterioration	No distance Survivors are resistant species	9	Cortes 1993
Eutrophication	Non-coralline macroalgae overgrowth Low live coral cover General reef deterioration	No distance Algae are out-competing corals	Not measured	Cortes 1993
Pollution	Heavy metals on sea cucumbers and corals Low water quality General reef deterioration	Not known	5?	Abarca & Ruepert 1992 Guzman & Jimenez 1992
Harvesting	Low commercial stock populations	Low impact There are 10 active fishermen in Cahuita using just line fishing	3	Mug 2000
Anchoring and reef walking	Destroyed reef structure	The problem is serious only locally in the shallow reef lagoon	2	Cortes 1993

Table RA5.6.2. La Estrella River/Cahuita Reef: DPSIR matrix characterizing major catchment based drivers/pressures and a qualitative ranking of related state changes impacting the coastal zone versus catchment size class (here a small basin in a tectonically active area).
State change dimension: major; medium; minor; 0 = no impact; ? = insufficient information
Time scale: p = progressive (continuous); d = direct (spontaneous)

Driver	Pressures	State change (qualitative index)	Impact on the coastal system	Time scale
				p
Agriculture	Siltation Pesticides contamination Eutrophication	**major**	Declining water quality Reef deterioration	**p**
Ranching	Siltation	**major**	Declining water quality Reef deterioration	**p**
Logging	Siltation	**major**	Declining water quality Reef deterioration	**p**
Fishing	Harvesting	**minor**	Reef deterioration	**p**
Urbanization (Point Source Effluents)	Siltation Bacterial contamination Waste solids contamination	**medium**	Declining water quality Reef deterioration	**p**
Tourism	Destruction Extraction	**minor**	Reef deterioration	**p**
Oil exploration	Further oil exploitation	**?**	Declining water quality Reef deterioration	**d**

Table RA5.4.3. La Estrella River/Cahuita Reef: the link between coastal issues/impacts and land based drivers – overview and qualitative ranking on local or catchment scale.
Impact category and relative class of importance:1 = low – 10 = high.

Coastal Impact/ Issues	Drivers	Impact category	Trend expectations	References/ data sources
Siltation	Agriculture Ranching Logging Urbanization	9 9 4 3	⇑ ⇑ ⇑ ?	ProAmbiente 1998
Eutrophication	Agriculture	9	⇑	ProAmbiente 1998
Pollution	Agriculture	9	⇑	ProAmbiente 1998
Harvesting	Fishing Tourism	3 2	⇑	Mug 2000
Anchoring and reef walking	Tourism	2	⇑	ProAmbiente 1998

Table RA5.6.6. La Estrella River/Cahuita Reef: scientific and/or management response to coastal impact/issues on catchment, sub regional and regional scale. n.a. = not applicable

Response Catchment scale		Response Sub-regional/ country scale		Response Regional scale	
Scientific	**Management**	**Scientific**	**Management**	**Scientific**	**Management**
Siltation and reef deterioration (1981-2000) Heavy metals in corals (1992) Heavy metals in sea cucumbers () River contamination (1992) Land use (1998) Fishing (2000) Tourist impact (2000)	Some soil conservation practices are being considered by banana companies to get the green certificate 1SO 14001 (vegetal cover of river borders and drainage channels, reduction of pesticides and fertilizers Quality criteria for wastewater One hotel in Cahuita has the green certificate (water treatment plant) Creation of Cahuita National Park (1975) and other protected areas at La Estrella river basin Fishing is regulated inside the park (line fishing only is permitted) Scuba diving is not allowed inside the park Creation of Commission for the Banano, Bananito and La Estrella River basin (1999) for watershed management Workshop on land use conservation with actors from La Estrella River basin and Cahuita Management Plan for Cahuita National Park	Research institutions for resources management and marine sciences	Forestry law (15 m along the rivers must be forest) Fishing law Green certificate for hotels (Costa Rican Institute of tourism-ICT) Country was divided in Conservation Areas for its management (ACLAC)	CARICOMP monitoring network (since 1999) AGRRA Coral reef evaluation (2000) CariBas (a component of LOICZ)-2002?	Green certificates for banana companies (ISO 14001) Biological Corridor Project CITES Red list of threaten species in Central America Central America Water Tribunal

5.7 Meso-American Barrier Reef System

Bruce Hatcher

Table Summary

The Meso-American Barrier Reef System (MBRS) is an ecologically-bounded, marine bio-geographical entity that transcends approximately 30 river catchments in four adjacent nation states: Mexico, Belize, Guatemala and Honduras. It represents an appropriate geo-political unit for integrated regional management of coastal and ocean space (Hatcher 2000). Spanning more than 1100 km of coast, with more than 360 km of near continuous barrier reef, it is the largest barrier reef system in the northern and western hemispheres (second only in size to the GBR system of Australia) and is recognized as a major part of the global natural heritage of mankind. The necessity and potential of regional governance structures and actions to preserve the marine biodiversity and conserve the marine resources of the MBRS has led the governments of the four nations to formally commit management resources and authority to the common goal (the Declaration of Tulum, 1997). This initiative is supported through an international agency (the Central American Commission for the Environment and Development – CCAD), which will implement a new, US$11 million GEF grant for the sustainable management of the MBRS.

Inputs to coral reef communities of nutrients, pollutants and contaminants in groundwater and rivers draining coastal catchments exposed to agricultural, urban and tourism development are identified as significant threats to the health of the MBRS (Sale *et al.* 1999; Dulan 2000). The health of coral reef ecosystems is generally assessed on the basis of their coral and fish community structures (e.g. Hughes 1994). Consequently, the largest component of the GEF grant is allocated to the establishment of a regionally coordinated environmental monitoring and information system that will identify and quantify anthropogenic change in the reef communities. A by-product of the initiative is a programme of bio-physical research aimed at measuring and modelling the ecological connections among coral reefs (ECONAR). The resulting models can be used to link land-based activities to change in coral reef ecosystems, and identify source-sink relationships at regional scales.

Importing this eco-regional approach to ecosystem-based management into the LOICZ Basins programme is logical and satisfying. The essential concept is to use a spatially coherent and socially valuable charismatic ecosystem (the MBRS) as a regional integrator of terrestrial biogeochemical inputs and anthropogenic stressors across an ecologically and politically defensible geopolitical management unit. The tables are arranged so as to reflect this perspective.

The stressors are all defined in terms of well-known negative changes in coral reef community structure and function. For illustration, only the impact issue of phase shifts in benthic coral reef community structure (i.e. from live hard coral to macroalgae) is considered here in detail, but this indicator of ecosystem health captures most of the documented responses and major stressors already established in other LOICZ Basins studies.

The regional basin is defined by the spatial domain of the MBRS. It is somewhat arbitrary (perhaps political) in the specification of its southern border, but the northern and eastern borders are well-delineated by the edges of reef structures. The western (landward) extent is defined by the upper edges of the groundwater tables and river catchments that border on the marine realm.

The sub-regional basins are defined physiographically and oceanographically as the NE coast of Honduras with its associated coastal fringing and shelf platform reefs; the Bay of Honduras with its shared catchments in northern Honduras, Guatemala and southern Belize and the southern extremity of the barrier reef; the barrier reef proper with its coastal lagoon bordering Belize and Mexico and its off-shelf atolls; and the Yucatan coast of Mexico with its associated fringing, shelf patch and atoll reefs. Current knowledge of the extent of river catchments, and ocean advection and transport in the region supports these sub-regional distinctions, but they will certainly change in response to new knowledge. The Gulf of Honduras, the barrier reef lagoon off Belize and southern Mexico, and the Yucatan groundwater system appear to be particularly robust sub-regional basin units.

The local basins consist of the individual river catchments in the three southern countries and are thus well-determined on the terrestrial side. Ignorance of the actual flow and transport data for these rivers is reflected in the tables, as is the current lack of clear management responsibilities. Much of these data may become available as the MBRS and ECONAR projects evolve. The appropriate partitioning of the individual groundwater basins within the eastern Yucatan is also far from obvious, and this is identified as a priority information gap.

The most problematic aspect of specification at the level of the individual basin is of course the coastal marine component. Here, the spatial scale of along- and cross-shelf advection exceeds and smears the outputs from individual catchments such that the delineation of the zone of influence is highly variable in space and time. This is where measurement and modeling the hydrodynamic environment is required to link source to sink, action to impact.

Finally, the ranking and prioritization of state changes and categories of impact and the identification of hot spots and trends in these tables reflects my own assessment. The values are not in general disagreement with the information presented in Sale *et al.* (1999) and Dulan (2000), but may differ from the better-informed views of scientists and managers with better local knowledge.

Table RA5.7.1. Meso-American Barrier Reef: major coastal impacts/issues and critical thresholds – overview and qualitative ranking:

Coastal Impact/ Issue	Local site/ region (contributing river basins)	Critical threshold (for system functioning)	Distance to critical threshold (qualitative or quantitative)	Impact category	Reference/ Data sources
Regime shifts in **coral reef communities** of the **MBRS**: macroalgae replace hard corals, reducing the quality and quantity of ecosystem goods & services. Thought to result from the synergistic effect of decreased herbivore abundance and increased loading of reefs with inorganic nutrients, organic material & inorganic sediments.	**Fringing reefs** adjacent to the groundwater aquifer of the E. Yucatan Peninsula, **Mexico**	Equivocal, but generally a **live hard coral cover** (**lhcc**) of <10%, a **coral disease** infection rate >10%, a **macroalgal cover** of >60%, and a **reef fish biomass** of <10gF.W.m^{-2} is cause for serious concern on typical reefs of the MBRS region. Attempts have been made to specify critical thresholds for **Nitrate** and **Phosphate** concentrations in coral reef waters of 1.0uM and 0.1uM (resp.), but these are of dubious value.	Current values of **lhcc** are typically 12%, **disease** rates are 3%, and **macroalgal** cover is 44% at monitored sites in **Mexico.**	Impact category: downstream synergistic, direct & indirect. Importance class: **8** Justification: The MBRS is the largest coral reef ecosystem in the western hemisphere, part of the global heritage, providing multiple goods & services to the peoples of the four bordering nations. Sedimenta-tion & nutrification due to watershed activities degrade the majority of reefs world-wide.	Lapointe 1997 suggests critical thresholds for nutrients. Sale *et al.* 1999. Kramer & Kramer 2000 and Wilkinson 2000 review the status of reefs in the region. Hatcher *et al.* 1989 review the threats to coral reefs.
	Lagoon patch reefs & barrier reefs off Chetumal Bay, and the catchment of the Rio Hondo, **Mexico and Belize**		No data N.B. spatial variance of % approximates the means.		
	Lagoon patch reefs & barrier reefs off the Belize, Stann & Monkey river catchments of **Belize**		Typically, **lhcc** is 28%, **disease** rates are 5.5%, and **macroalgal** cover is 44% in **Belize.**		
	Fringing & barrier reefs of the Sarstoon, El Porvenir & Motagüa river basins of **Guatemala**		No data		
	Fringing & patch reefs adjacent to the Bay Islands and off the Chamelecon, Ulua & Aguan river catchements of N. coast of **Honduras**.		Typically, **lhcc** is 21%, **disease** rates are 6%, and **macroalgal** cover is 53% in **Honduras**		

Table RA5.7.2. Meso-American Barrier Reef: 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 index: major; medium; minor; 0 = no impact; ? = insufficient information, n/a = not applicable.

Time scale: p = progressive (continuous); d = direct (spontaneous)

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	Focus on coral reef communities of the Mesoamerican Barrier Reef System (MBRS)	
Tourism development	Shoreline construction, altered circulation, sediment & sewage inputs, recreational impacts.	**n/a**	**minor**	**n/a**	**medium**	Habitat destruction & degradation. eutrophication, loss of biodiversity & aesthetics.	**d** **1-10 years**
		Localized & mostly independent of basin size & tectonic regime.					
Agriculture	Increased runoff, organic & nutrient inputs.	**n/a**	**major**	**n/a**	**medium**	Nutrification / eutrophication, coralgal phase shifts, loss of biodiversity, rare & keystone species.	**p** **10-100 years**
		Scales with off-shore distance		Passive coasts filter better			
De-forestation	Increased runoff, sediment & organic inputs. Increased CO_2 / decreased $CaCo_3$	**n/a**	**major**	**n/a**	**major**	Salinity & sediment stress, habitat degradation, loss of biodiversity & rare species.	**p** **10-100 years**
		Comments as for Agriculture					
Port operations & Maritime navigation	Shoreline construction, altered circulation, collisions with benthos, contaminant inputs.	**n/a**	**minor**	**n/a**	**minor**	Habitat destruction & degradation, eutrophication, loss of biodiversity, productivity & aesthetics.	**d** **1-10 years**
		Localized & often independent of basin size & tectonic regime.					
Urbanization & Industrial development (Point source effluents)	Shoreline & watershed construction, altered circulation, sediment, contaminant & sewage inputs.	**n/a**	**major**	**n/a**	**minor**	Habitat destruction & degradation, eutrophication, loss of biodiversity, product-ivity & aesthetics.	**p** **10-100 years**
		Transport to reefs more likely in large basins & active coasts					
Fishing	Over-exploitation, food web attenuation, destructive practices & gears.	**n/a**	**major**	**n/a**	**medium**	Loss of productivity, biodiversity & keystone species, coralgal phase shifts, destruction of critical habitat.	**p** **1-10 years**
		Widespread & largely independent of basin size, tectonic regime					
Aquaculture development	Shoreline & watershed construction, altered circulation, sediment & organic inputs, disease & species introductions.	**n/a**	**minor**	**n/a**	**major**	Habitat degradation & destruction, over-exploitation of feed species, loss of biodiversity, rare & keystone species.	**p** **1-10 years**
		Reefs off small watersheds more susceptible					

Table RA5.7.3. Meso-American Barrier Reef: The link between coastal issues/impacts and land based drivers – overview and qualitative ranking on local or catchment scale.

Impact category and relative class of importance:1 = low – 10 = high.

Coastal Impacts / Issues	Drivers	Local catchment (allowing within and between catchment comparison)		Trend expectations	References/ Data sources
		Catchment / River basin	Category		
Shoreline construction, altered circulation, sediment & sewage inputs, recreational impacts.	Tourism development	Cancun, Cozumel and Central east coast Yucatan, Mexico. Roatan, Honduras	10 7 5 6	↑ Rapid, patchy spread & intensification on certain coastlines and on offshore islands and cays.	Sale *et al.* 1999; Sealy & Bustamante 2000
Shoreline & watershed construction, altered circulation, collisions with benthos, sediment, contaminant & sewage inputs.	Urbanization, Industrial development, fort operations & Maritime navigation	Chetumal Bay, Mexico. Belize City. Bahia de Amatique & Manabique, Guatemala. Roatan, Honduras	8 6 4 7 6	↑ Steady, progressive spread & intensification along coastlines and up river catchments. Hot spots related to population density and economy.	Sale *et al.* 1999; Sealy & Bustamante 2000
Increased runoff, sediment & organic inputs. Increased CO_2 / decreased CaCo$_3$	Agriculture and deforestation	Belize, Sibun, Stann & Monkey basins, Belize. Sarstoon & Motogua basins, Guatemala. Chamelecon, Ulua & Aguan basins, Honduras.	5 3 6 8 8 5	↑ Steady, progressive spread up river catchments. Most severe developments in Guatemala & Honduras, where hurricane impacts are amplified.	Sale *et al.* 1999; Sealy & Bustamante 2000
Over-exploitation, Food-web attenuation, destructive practices & gears. Shoreline & watershed construction, altered circulation, sediment & organic inputs, disease & species introductions.	Fishing and aquaculture development	Chetumal Bay, Mexico. Corozol Bay, Big Creek, Punta Gorda, Belize. Bahia de Amatique & Manabique, Cerro san Gil Guatemala. Gulf of Honduras.	7 5 3 5 7 4 6	= Static artisanal & ↓ declining industrial fisheries are offset by sporadic and patchy ↑ expansion of coastal and aquatic aquaculture.	Sale *et al.* 1999; Sealy & Bustamante 2000

Table RA5.7.6. Meso-American Barrier Reef: scientific and/or management response to coastal impact/issues on catchment, sub regional and regional scale.

<table>
<tr><th>River catchment or Islands</th><th colspan="2">Response
Catchment scale</th><th colspan="2">Response
Sub-regional/ Country scale</th><th colspan="2">Response
Regional scale</th></tr>
<tr><th>River/Island</th><th>Scientific</th><th>Management</th><th>Scientific</th><th>Management</th><th>Scientific</th><th>Management</th></tr>
<tr><td>Cozumel, Mexico</td><td>Basic monitoring CNA</td><td>Single govt agency: SEMARNAP</td><td rowspan="3"><u>Yucatan</u>: Patchy monitor-ing by: CNA, INE, INP INEGI, CZMI, DOE-EWQMP DOF, LIC-CEDS</td><td rowspan="3"><u>Yucatan</u>: National Government authorities: SEMARNAP UCANP, PROFEPA, CZMA, DOF</td><td rowspan="10">MBRS:
Patchy monitoring of sea level & meteorology: CPACC.

Limited involvement in other international environ-mental monitoring programmes:
AGRAA C-GOOS
LOICZ,
WOCE
Etc.</td><td rowspan="10">MBRS:
World Bank – GEF – CEC Project: Conservation & sustainable use of the Meso-american barrier reef system (MBRS) in Mexico, Belize, Guatemala & Honduras (2001).

Components:
Regional monitoring & environ-mental information system;
Sustainable tourism;
Conservation of shared fish stocks;
Network of marine protected areas;
Harmonized legislation & regulation.</td></tr>
<tr><td>Cancun & N. Yucatan coast, Mexico</td><td>Detailed monitoring CNA</td><td>Multiple govt agencies & NGOs</td></tr>
<tr><td>S. Yucatan coast Mexico & Amergris Caye, Belize</td><td>Ditto + Research: CINVES-TAV, UNAM, CEA, UCB</td><td>Ditto plus: LADSK, CEA, CZMA, DOF, BAS</td></tr>
<tr><td>Chetumal Bay, Mexico</td><td>Basic monitoring CNA ECOSuR</td><td>Single govt agency: SEMARNAP</td><td rowspan="7"><u>N.Barrier Reef System</u>: Patchy monitor-ing by Govt. agencies: CNA, INE, INP CZMI, DOE-EWQMP DOF, LIC-CEDS, NMS, Universi-ties UCB ECOSuR
& NGOs BAS, WRIScS</td><td rowspan="7"><u>N.Barrier Reef System</u>:

No international management structure at this scale, but BBRC co-ordinates management in the Belize section.</td></tr>
<tr><td>Rio Hondo, Mexico</td><td>?</td><td>ditto</td></tr>
<tr><td>Corozal Bay, Belize</td><td>?</td><td>?</td></tr>
<tr><td>New River</td><td>?</td><td>?</td></tr>
<tr><td>N. coast lagoons, Belize</td><td>?</td><td>?</td></tr>
<tr><td>N. barrier reef lagoon, Belize</td><td>?</td><td>Multiple govt agencies & NGOs: CZMA, DOF, BAS</td></tr>
<tr><td>Belize River</td><td>Basic monitoring by DOE, NMS, WRIScS</td><td>Minimal: DOE</td></tr>
</table>

Table RA5.7.6 continued

River catchment or Islands	Response Catchment scale		Response Sub-regional/ Country scale		Response Regional scale	
River/Island	Scientific	Management	Scientific	Management	Scientific	Management
Offshore atolls, Mexico	Limited monitoring by INE, UNA	Single govt agency: SEMARNAP	Outer MBRS: Patchy monitoring & research by Gov't. agencies: INE, INP INEGI, CZMI, DOF, Universities: CINVE-STAV, ECOSuR UNAM, UCB, & NGOs: BAS, CCC, WRIScS	Outer MBRS: Management is nationalized across this sub-region. Unified in the case of Mexico through the SEMARNAP Fragmented in the Case of Belize. There is no unified management protocol for these offshore sections of the MBRS.	As above	As above
Offshore reefs, atolls & islands, Belize	Local monitoring & research CCC, DOF, STRI WCS	Multiple govt agencies, with co-ordination by CZMA & BBRC				
Barrier reefs & islands, Belize	ditto	ditto				
Sibun River	Flow NMS	?	Central MBRS Lagoon: Patchy monitor-ing by DOE-EWQMPNMS WRIScS	Central MBRS Lagoon: Multiple Gov't. agencies, with limited co-ordination by CZMA & BBRC	As above	As above
Central Coastal lagoons, Belize	?	?				
Mullins River, Belize	Flow NMS	?				
North Stann Creek	Total catchment monitored by WRIScS	?				
Stann Creek Basin		?				
Sittee River		?				
South Stann Creek		?				
Mango Creek	?	?				
Big Creek	Monitored by NMS, DOE-EWQMP & TIDE	Community-based management TIDE				
Monkey River, Belize						
Punta Ycacos Lagoon	?	?	Gulf of Honduras: Patchy monitoring by Gov't. agencies & NGOs coordinated by TRIGOH TNC	Gulf of Honduras: Fragmented management Authority contracted to local NGOs CONAMA & CONADES. Support from RECOSMO - PROARCA / Costas		
Deep River	Flow NMS	?				
Port Honduras	?	?				
Rio Grande	Flow NMS	?			As above	As above
Moho River	?	?				
Temash River, Belize	Flow NMS	?				

Table RA5.7.6 continued

River catchment or Islands	Response Catchment scale		Response Sub-regional/ Country scale		Response Regional scale	
River/Island	Scientific	Management	Scientific	Management	Scientific	Management
Rio Sarstun, Guatemala	Some monitoring by UNEPA, UdV, CEMA-USAC, FUND-AECO	Local NGOs: FUNDAECO Contracted by CONAMA / CONAP	As above	As above	As above	As above
Lago de Izabel y Golfete	As above	As above				
Punta de Manabique	As above	As above				
Bahia de Amatique	Fisheries monitoring by UNEPA, CEMA-USAC	As above				
Rio Mario Dary	Monitor-ing by FUND-ARY	Local NGOs: FUNDARY Contracted by CONAMA / CONAP				
Rio Motagua, Guatemala	?	?				
Rio Chamelecon	Patchy monitoring by UdV, USAC, PROLA-NSATE, WCS	Local NGO: PROLAN-SATE contracted by CONAMA / CONAP				
Rio Ulua,						
Punta Sal lagoon, Honduras						
Rio Izopo, Honduras						
Rio Salado	?	?	NW.Honduras: Patchy monitoring by Gov.t. agencies & NGOs. Some coordination by PROAR-CA / Costas	NW. Honduras: Management authority contracted to local NGOs from CONAMA & CONADES, with support from WWF, TNC, RECOSMO - PROARCA / Costas		
Rio Cangrejal	?	?				
Laguna de Guaimoreto	?	?				
Rio Aguan	?	?				
Islas de la Bahia, Honduras	Detailed monitoring by BICA, CCC, CRIPCACSSMMEMP BI, HCRF, RIMS	Competing Gov't. agencies & NGO's: DIGIPESCA, DAPVS, BICA, EMPBI				

Acronyms and abbreviations used in Table RA5.7.6

AFE	Administración Forestal del Estado: Honduras
AGRRA	Atlantic and Gulf Rapid Reef Assessment: monitoring protocol
ALIDES	Alianza Centroamericana Para el Desarrollo Sostenible (part of CCAD
ASOREMA	Alliance of NGOs responsible for managing protected areas in Guatemala
BICA	Bay Islands Conservation Association: Honduran NGO
BAS	Belize Audubon Society: manages several national parks
BBRC	Belize Barrier Reef Committee, N-STAC for MBRS project, Belize
CARICOMP	Caribbean Coastal Marine Productivity Program: monitoring protocol
CCAD	Comisión Centroamericana de Ambiente y Desarrollo: Guatemala
CCC	Coral Cay Conservation: United Kingdom NGO
CEA:	Centro Ecológico de Akumal: Mexican NGO
CECON	Centro de Estudios Conservacióniosta de la Universidad de San Carlos, Guatemala
CEDS	Conservation and Environmental Data System: Belize Ministry of Natural Resources and Environment, LIC
CEMA	Centro de Estudios del Mar y Acuicultura Conservacióniosta de la Universidad de San Carlos: Guatemala
CFRAMP	CARICOM Fisheries Resource Assessment and Management Program, Belize
CHAMP	Coral Health and Monitoring Program, NOAA
CICIMAR	El Centro Interdisciplinario de Ciencias Marinas, México
CINESTAV	Centro de Investigación y de Estudios Avanzados, México
COCCYTAC	Comite Consultor Científico y Tecnico de los Arrecifes Coralinos de México
COHDEFOR	Comisión Hondureña de Desarrollo Forestal: sub-unit of SERNA, Honduras
CONAB	Comisión Nacional de la Biodiversidad, Guatemala
CONADES	Consejo Nacional de Desarrollo Sostenible, Honduras
CONAMA	Comisión Nacional del Medio Ambiente, Guatemala
CONAP	Consejo Nacional de Areas Protegidas, Guatemala
CONCYT	Consejo Nacional de Ciencia y Tecnología: Guatemalan research funding agency
CNA	Comisión Nacional del Agua, México
CPACC	Caribbean: Planning for Adaptation to Climate Change: support organization funded by GEF/World Bank and executed by OAS
CRIP	Centro Regional de Investigación Pesquera: INP, México
CSSMM	Consorcio Safege-Sogreah-Moncada y Moncada: consortium of two large Honduran NGOs funded by the IDB
CZMA	Coastal Zone Management Authority, Belize
CZMI	Coastal Zone Management Institute, Belize
CZMU	Coastal Zone Management Unit, Belize
DAPVS	Deparmento de Areas Protegidas y Vide Silvestre, Honduras
DiBio	Dirección de Biodiversidad, SERNA, Honduras
DIGEPESCA	Dirección General de Pesca y Acuicultura, Honduras
DOE:	Department of Environment, Belize
DOF	Department of Fisheries, Belize
ECONAR	Ecological Connections Among Reefs: proposed component of MBRS project
ECOSUR	El Colegio de la Frontera Sur, México
EMPBI	Environmental Management Program of the Bay Islands, Honduras
EWQMP	Environmental Water Quality Monitoring Programme, DOE, Belize
FUNDAECO	Fundación para el Ecodesarrollo y la Conservación: Guatemalan NGO
FUNDARY	Fundación para la Conservación del Medio Ambiente y los Recursos Naturales, Mario Dary Rivera: Guatemalan NGO
GCRMN	Global Coral Reef Monitoring Network
GOOS	Global Ocean Observing System: global system for observations, modeling and analysis of marine and ocean variables coordinated by IOC, WMO, UNEP, and ICSU.
HCRF	Honduran Coral Reef Foundation: Honduran NGO
ICRI	International Coral Reef Initiative
ICSU	International Council for Science

IDB	Inter-American Development Bank
IGN	Instituto Geográphico Nacional, Guatemala
INE	Instituto Nacional de Ecología, SEMARNAP, México
INEGI	Instituto Nacional de Estadística, Geografia y Infomática, México
INGAUT	Instituto Guatemalteco de Turismo, Guatemala
INSIVUMEH	Instituto Nacional de Sismología Vulcanología Meteorología e Hidrología, Guatemala
INP	Instituto Nacional de Pesca, SEMARNAP, México
IOC	Intergovernmental Oceanographic Commission
LADSK	Los Amigos de Sian Ka'an A.C.: Mexican NGO
LIC	Land Information Centre, Belize Ministry of Natural Resources and Environment
LOICZ	Land-Ocean Interactions in the Coastal Zone
MAGA	Ministerio de Agricultura, Ganadería y Alimentación, Guatemala
MBC	Mesoamerican Biological Corridor: World Bank-GEF project
MBRS	Mesoamerican Barrier Reef System: World Bank-GEF project
NARMAP	Natural Resource Management and Protection Project: USAID, Belize
NGO	Non Governmental Organization
NMS	National Meteorological Service, Ministry of Energy, Science, Technology & Transportation, Belize
N-STAC	National Science and Technology Advisory Committee, Belize
OAS	Organization of American States
OCRET	Oficino de Reservas Territoriales, Guatemala
PRADEPESCA	Programa Regional de Apoyo al Desarrollo de la Pesca en el Istmo Centroamericano: European Union funded regional fisheries programme.
PROARCA/ Costas	Programa Ambiental Regional para Centroamerica Componente de Manejo de la Zona Costera: consortium of TNC, WWF, Univ. Of Rhode Island, and local NGOs, supported by USAID-G/CAP
PROFEPA	Procuraduría Federal de Protección al Ambiente, SEMARNAP, México
PROLANSATE	Fundación para la Protección de Lancetilla, Punta Sal, y Texigaut: Honduran NGO
RARE	RARE Center for Tropical Conservation: U.S. NGO
RECOSMO	Region de Conservación y Desarrollo Sostenible Sarstun-Motagua: an official government agency of CONAP, governed by a board of four members (UNDP, CONAP, CONAMA, MAGA), and managed by the UNDP
REHDES	Red Ecológista Hondureña Para el Desarrollo Sostenible, Honduran NGO
RIMS	Roatán Institute for Marine Science
SEMARNAP	Secretaría de Medio Ambiente, Recursos Naturales y Pesca, México
SERNA	Secretaría de Estado en el Despacho de Recursos Naturales y Ambiente, Honduras
STRI	Smithsonian Tropical Research Insitute, at Carrie Bow Cay, Belize.
TIDE	Toledo Institute for Development and Environment: Belize NGO
TNC	The Nature Conservancy: international environmental conservation agency based in U.S.
TRIGOH	Tri-national Alliance for the Gulf of Honduras: international consortium of NGOs, Belize, Guatemala and Honduras
UCANP	Unidad Coordinadora de Areas Naturales Protegidas, INE, México
UCB	University College of Belize
UdV	Universidad de Valle, Guatemala
UNAM	Universidad Nacional Autónoma de México
UNEPA	Unidad de Ejecución Pesquera y Acuicola, Fisheries Division of MAGA, Guatemala
USAC	Universidad de San Carlos de Guatemala
WCS	Wildlife Conservation Society, international wildlife conservation society based in New York
WOCE	World Ocean Circulation Experiment: international project studying ocean circulation
WMO	World Meteorological Organization, United Nations agency
WRIScS	Watershed-Reef Interconnectivity Scientific Study, conducted by Raleigh International, Ambios Environmental Consultants and University of Exeter
WWF	World Wildlife Fund: International wildlife conservation organization

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APPENDICES

Appendix I Human dimensions of land-based fluxes to the coastal zone: the LOICZ-Basins approach

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

The following appendix provides a general introduction in methodology of the regional assessment and synthesis of human dimensions of land-based fluxes to the coastal zone as performed in the LOICZ-Basins core project. In using a common methodology, harmonized assessment protocols and project designs for research on global scales, the LOICZ-Basins framework aims to assist in interregional exchange and acquisition of funding opportunities on local, sub-regional and regional scales.

Background

Coasts worldwide are subject to many pressures which are expected to continue or increase in the future. Natural flows of water, nutrients and sediments to the coast are largely and increasingly influenced by past and planned physical changes in rivers (e.g., damming). In addition, the increase in tourism, fisheries, urbanization and traffic will offer challenges for the coastal zone managers and regulators. The management issues and their solutions require an integrated approach of the natural and socio-economic sciences (Turner *et al.* 1998; Salomons *et al.* 1999). Numerous studies (often mono-disciplinary) have been conducted to deal directly with these issues but could benefit from more integrated assessment. This integration of the results of past studies requires a simple and harmonized framework for assessment and analysis. For the integration LOICZ-Basins uses the DPSIR framework:

LOICZ-Basins faces 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, particularly when local, regional, national, and multi-national governmental bodies with conflicting interests are involved.

The DPSIR framework

The Driver-Pressure-State-Impact-Response or DPSIR scheme (Turner *et al.* 1998; Turner and Bower 1999), provides a standardised frame for site assessment and evaluation. It ultimately enables the calculation and modelling of the impacts of change on the delivery and use of environmental goods and services expressed in scientific and monetary terms. The scheme sets up a platform for independent review and feedback evaluation of political and managerial response and options. The elements of this framework are:

Drivers: resulting from societal demands the sectoral activities with consequences for the coastal zone include:

- 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
- 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 on political and/or managemnet level:

- 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.

The pressures are manifold, so we narrow them down within the LOICZ context, which deals with changes in biogeochemical cycles as major indicators. The LOICZ-Basins project therefore deals with the impact of human society on the material transport such as water, sediments, nutrients, heavy metals and man-made chemicals to the coast. It assesses the loads and their coastal impact and tries to provide feasible management options together with an analysis of success and failure of past regulatory measures. Since changes in fluxes are mostly land or catchment-based (including whole islands as single catchments in some cases), the catchment–coastal sea system is treated as one unit – a water continuum. In applying this scale to loads and coastal change phenomena this means that beyond activities from agriculture, fisheries, urban development, industry, transport, tourism also morphological changes made to a catchment (e.g. damming) have to be taken into account.

In particular the following parameters will be assessed:

- material flow of water, sediments, nutrients and priority substances (past, current and future trends);
- socio-economic drivers which have changed or will change the material flows;
- indicators for impacts 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 being developed within the UN/ECE CLRTAP convention will develop this link. (The "United Nations Economic Commission for Europe's convention on Long-Range

Transboundary Air Pollution" has held several workshops and produced handbooks on the critical load concept for terrestrial and freshwater systems. In LOICZ-Basins these concepts are extended to the marine environment). In a systems approach it can be used (as has been done for atmospheric pollution abatement) 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 Observation System, C-GOOS, of UNESCO's IOC.

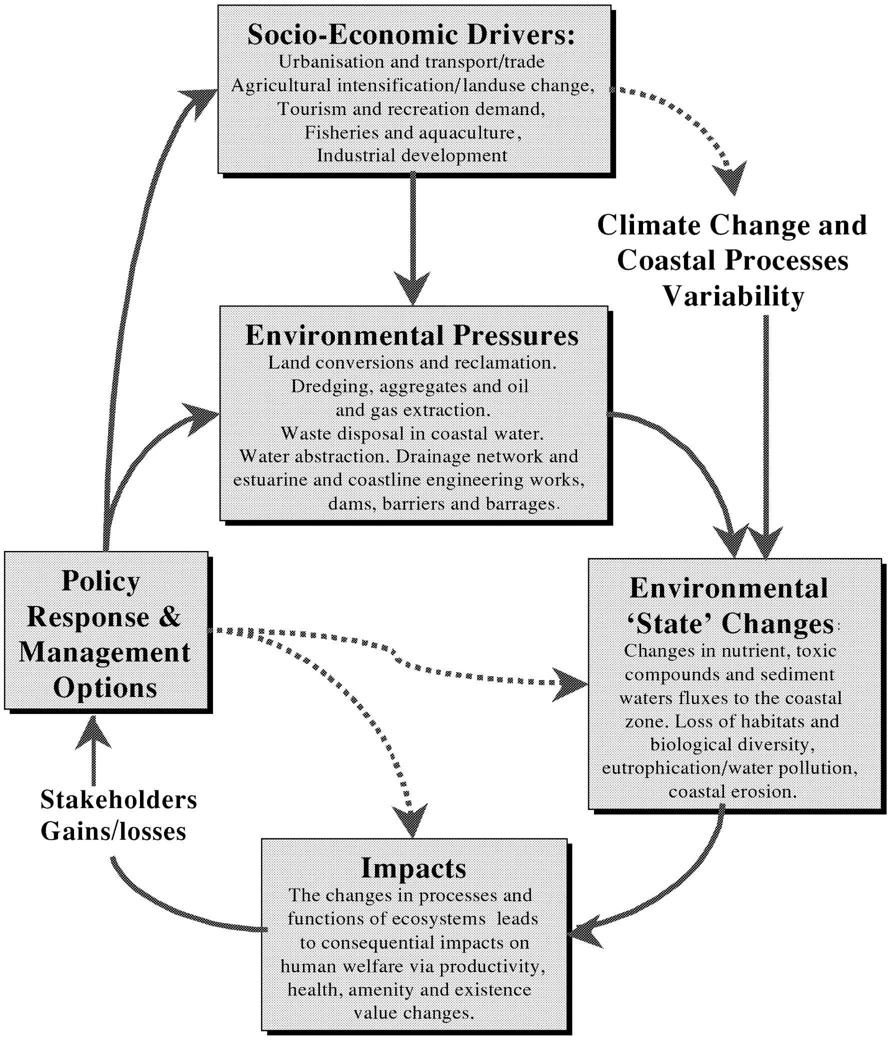

Figure A1.1. Description of the Driver-Pressure-State-Impact-Response (DPSIR) Framework.

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

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

The indicators and targets will be used to derive critical concentrations. Taking into account transformations and dispersion in the coastal environment, a critical load to the coastal zone can be calculated. This critical load, the **critical outflow** of the catchment/island, 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 carry out scenarios for cost-benefit analysis and trade-offs. This will require the integration of existing modelling tools from the natural and social sciences.

The DPSIR framework is applied to determine critical loads of selected substances, under different development scenarios, with diverse biophysical and socio-economic settings, triggering the discharge into the coastal seas. It aims to provide the interdisciplinary platform for participatory approaches jointly with natural, social and economic scientists, and to incorporate representatives of stakeholders including industry, agriculture, environmental organizations and citizens.

Large catchments seem to be obvious examples to be addressed within a global LOICZ synthesizing effort (e.g. Amazon, Nile, Yangtze, or in the Caribbean case the Magdalena and Orinoco Rivers). However, from the perspective of coastal change on regional and global scales, considerable if not major influence from land-based flows is generated in small to medium catchments with high levels of socio-economic activity. In island dominated regions surface run off of a whole island contribute to the coastal zone or in other words the whole land area is a coastal zone subject to influences generated by both anthropogenic drivers and global forcing. Changes in land cover and sectoral use need much shorter time-frames to translate into coastal change and usually exhibit more visible impacts than in large catchments where the "buffer capacity" against land-based change is higher simply as a function of catchment size. Thus, small and medium catchments are in principle of equal priority to the global LOICZ-Basins assessment.

The approach

Regional networks, assessment workshops/desk studies

Through two-stage regional workshops, LOICZ-Basins builds 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 first ranking order of current and predicted impacts with trend analysis, based on expert judgement and published scientific information. A second workshop finalises the first regional synthesis, improves the geographical and thematic coverage and assists in preparing research proposals for local and regional funding. Emphasis is given to close coupling of biogeochemical and physical sciences with human dimensions. Workshops have been held and networks established in Europe, South America, East Asia and Africa, while desk studies cover the Oceania Region and the Russian Arctic.

In February 2001 the European Catchments (EuroCat) project, funded by the European Union, started (http://www.iia-cnr.unical.it/ EUROCAT/project.htm) as a direct result 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 (in implementation with support from START as a pilot study phase 2002/03 – four catchments), and Latin America. In East Asia a similar development is foreseen for the near future.

A **LOICZ Basins** WWW page is now available at the GKSS Research Center, Geesthacht, Germany, (http://w3g.gkss.de/projects/loicz_basins/) and through the LOICZ web-site (www.nioz.nl/loicz/). It is updated continuously and provides copies of reports for downloading.

Proposals and projects that develop from regional LOICZ-Basins efforts contribute to the global LOICZ assessment. They also contribute to the Integrated Coastal Area Management initiative, ICAM, as well as to the Coastal GOOS "Global Ocean Observing System" of UNESCO/IOC. Links to the typology up-scaling effort considering global river run off and coastal biogeochemistry (a joint project of LOICZ and BAHC through the University of New Hampshire, are being pursued (http://www.kgs.ukans.edu/Hexacoral/Tools/tools.htm). Watching briefs exist with other global efforts such as GIWA, the WWAP and Millennium Assessment. Increasing the links with the Regional Seas initiatives under UNEP and the GPA is under consideration.

The framework for LOICZ Basins Synthesis and Project Development
Since LOICZ-Basins workshops have a regional focus, assessment and ranking follow a hierarchy of scales finally allowing a full regional picture to be generated – the scales increase from:

- local catchments via
- sub-regional or provincial scales up to
- regional scale which could also be a country (e.g., Continental China) or a sub-continent or continent.

To facilitate 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:

a) set up a **list of coastal change issues** of and **related Drivers** in the catchment (plenary-task).
b) characterize and provide a ranking order of the various issues of change based on either **qualitative information** (i.e., expert judgement - if there are no hard figures) or **hard data** coming from investigations or archived material; this includes identifying **critical load** and **threshold** information for system functioning.
c) derive a list of current or prospective **"hot spots"** representative of a type or class of catchment-coast system, from which to develop a **proposal** for future interdisciplinary work.

In other words 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 and follow a sequence of **regional assessment tables**, participants are asked to fill in prior to the workshops. A generic scheme is shown below. All major assessment tables closely follow this scheme, and allow inner and interregional comparison within the global LOICZ-Basins effort, although the entries to the tables can be different.

Up-scaling process

Drivers ranked for importance by expert judgement

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

* = see comments on this driver identification and ranking on the following pages.

Figure A1.2. Basic schema of assessment tables.

Ranking and classification
The OSPAR 2000 quality status report (http://www.ospar.com) lists human pressures on the coastal sea 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 A1.1 shows a few examples compiled along the OSPAR guidelines, adapted to fit the LOICZ-Basins concept. It focuses on issues, which link to land-based activities.

Table A1.1. Examples of impacts, pressures and driver/pressure settings in the LOICZ context.

Impact priority	Priority classes of human pressures	Driver/Pressure settings - 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, (wastewater, 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, 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

From these and other examples, adapted to the LOICZ needs and relying strongly on regional expert judgement and - if available - regional quality standard protocols and agreements, the LOICZ-Basins task group has developed a set of **Basins Regional Assessment tables** for global application.

LOICZ-Basins Regional Assessment Tables (RA 1- 7) and key questions for workshops, synthesis and project development

The tabulated DPSIR analysis has proven to be an appropriate descriptive framework for this purpose. The questions leading through the tables have usually been addressed in the first phase of the Basins worklshops. The tables ensure a standardize approach within the global LOICZ-Basins effort. They allow integration of the regional assessments and expert typologies into the global scales and help to fill gaps and harmonise the synthesis. Data included in the first workshop are reviewed and confirmed in light of new information delivered to the second workshop. Detailed source references for data or critical load information is included wherever possible (they can, however, also rely on expert knowledge to a considerable extend).

Table Input
Major data needed for the assessment are material flows and loads (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?) provide 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 comparable instruments.

The steps taken are outlined in the following tables.

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 (Island) 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 (Islands) XYZ				

Notes for use

This table is a first priority list of issues for the regional coast based on riverine (i.e. catchment and/or island - 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/islands 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 here refers to the categories in tables 1 and 3-5; however, it is less detailed here combining in category "minor" importance rank-order 1-3, "medium: importance rank-order 4-6, major importance rank-order 7-10.

State changes in coastal zones driven by a catchment/island – based process will vary according to catchment size, for example: Deforestation even on large scale if conducted in a huge catchment such as the Orinoco will cause a rather moderate if any coastal signal as compared to effects originating from pressures on small catchments or islands where even minor deforestation can dramatically influence the sediment budget in the coastal zone. So, deforestation in some large catchments could be scored 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 Pacific coast of Latin America for example are in a tectonically rather active area exhibiting high slopes but they also featuer high amplitiudes of seasonal runoff variation on a yearly time-scale while small rivers draining to other coastal areas and some of the islands are located in tectonically rather passive areas.

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/Island A	Category (1 low – 10 high)		
Erosion	Damming	• Area… • Volume… • Run off reduction… • …..	10	Increasing	XYZ, 2000
	Deforestation	• Area… • Residual 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/Island 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 (Island) 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… • Residual TSS production…	8	increasing	
	Diversion	• Little, area…; effect on water flow…	4	increasing	
Erosion (total in sub region A)	All drivers and rivers weighted	b 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., Central America, Gulf of Mexico, 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	ll 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/island scale		RESPONSE Sub-regional/ country scale		RESPONSE Regional scale	
	Scientific	Management	Scientific	Management	Scientific	Management
River (Island) A	e.g. monitoring programme 19--2001, Data: …; Source:	e.g. commission established; thresholds set; legislation in place… Source:	e.g. (combining catchments A-B-… Programs? Data? Source:	e.g.…	e.g. UNEP Regional Seas programme Source:	e.g. quality criteria for the regional waters? Source
River B						
River C						
River D						
River E						

Notes for users:

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

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

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

Key questions:

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

River catchment/ island	**"Hot spot" catchment/island scale**		**"Hot spot" sub regional/ country scale (e.g., a certain island group or the Meso-American Reef 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 (Island) A	…	• Biogeochemical studies • Residual calculation by economic sectors • Critical flux investigation • Stakeholder and scale analysis • ACTION • ….		e.g.…	…	…
River B						
River C						
River D						

Notes for use:

This table extracts from the regional assessment the potential demonstration sites, which can be included in a proposal for a future Regional Catchment/Coast Assessment Project - "…Cat". Ideally the sites should represent different settings which are typical for a special sub-region. This would allow up-scaling of the findings to comparable "classes" of catchment/coastal systems at a later stage. An accompanying note may be given informing about ongoing activities, link suggestions and key contact persons.

Emphasis should be on the human dimensions of catchment–coastal sea interaction considering the co-evolution of natural and societal systems (i.e. involving natural and socio-economic sciences).

Appendix II CariBas I and II Meeting Reports

Both the CariBas regional study and the Oceania Basins desk research were a direct follow-on from the 4th LOICZ Open Science Meeting, held in Bahia Blanca, Argentina, in November 1999. There, a global island regions working group recommended regional Basins assessments of island-dominated regions, to be included in the first LOICZ global synthesis planned for late 2002.

The Caribbean Basins (CariBas) assessment and synthesis was carried out in two phases. Based on a desk study commissioned to the University of South Carolina and key scientists of the CARICOMP network a first, general workshop (CariBas 1) was held in Trinidad, in December 2000. A second workshop, CariBas 2, held in Miami, Florida in June 2001, refined the earlier assessment and focussed on the human dimension. CariBas 2 also worked towards a sound scientific basis on which to develop project proposals addressing indicators for coastal monitoring as well as river/island-based and coastal management issues.

CariBas 1 - Institute of Marine Affairs, Chaguaramas, Trinidad, 7-9 December 2000

The regional assessment (CariBas 1) conducted in Trinidad, together with the preceding desk study, provided a comprehensive overview of the current understanding of catchment–coastal sea interaction in the Caribbean encompassing both island-based coastal issues such as in Trinidad and Jamaica and issues along the Caribbean mainland coasts, such as the Meso American Barrier Reef. Using geomorphologic and hydrologic characteristics, the working groups provided initial descriptions of the key drivers and their pressures on the catchment coast continuum. Impacts were analyzed and critical threshold information was identified. The DPSIR scheme (Turner *et al.* 1998) was evaluated and applied to standardize the descriptive approach and enable inter-regional comparison across various spatial and temporal scales.

The information compiled in this process was to be developed further to an "expert typology" of the regional systems and their change under various forcing in a second step. This should include a DPSIR-based ranking to derive form the further synthesis refined threshold information and a trend analysis. Issues addressed covered:

- Coastal geomorphology
- Coastal habitats/biodiversity
- Climate influence
- People relationships (demography and drivers)
- Catchment size and seasonal runoff features
- Land use and cover characteristics

The information obtained before and during the workshop was to be distilled using a set of LOICZ-Basins assessment tables, and made available for the second workshop in 2001.

CariBas 2 - Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Florida, USA, 28-30 June 2001

Following a welcome address provided by Dean Prof. Otis Brown and Assistant Prof Liana Talaue McManus, on behalf of the Rosenstiel School, an introduction to LOICZ by Dr Hartwig Kremer provided the background of the progress made since 1999 towards a new globally applied LOICZ-Basins assessment of catchment/island - coastal sea interaction and human dimension studies. Developments made in the methodology since CariBas 1 in 2000 were presented, in particular the standardised regional assessment tables developed for global application. 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.

Prof Bjorn Kjerfve summarised the key findings of the first meeting (see above) and Dr Kremer commented on 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. He pointed out that the overall regional engagement of LOICZ would be supported by the IOC and should therefore be seen also as a contribution to the activities of their IOCARIBE Sub-Commission. While initially supported also by the Inter American Institute for Global Change Research (IAI), CariBas results will also be communicated to the regional scientific agendas developed by the IAI for future global change research in the Americas. The results generated on regional levels and pilot studies to be addressed in future research under the aegis of LOICZ would prove valuable within IOC's and IAIs' networks. IOC will support further development of CariBas-related project proposals in South America.

A detailed introduction and subsequent discussion provided the background and scientific rationale of the key questions leading through the set of seven assessment tables. Dr Kremer explained the input expected for each of the tables and how to process available information for up-scaling from local to regional 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. Examples were shown (from earlier SAmBas assessments) and it was pointed out that a parallel study on the purely island or atoll dominated Oceania region was underway which may prove valuable for island-based studies in the Caribbean.

Presentations of catchment/island–coast biogeochemical critical threshold and socio-economic information was evaluated posing the key LOICZ questions:
- 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, regional synthesis and key driver evaluation were provided for river/island - coast systems in various sub-regions, including:

General Caribbean:
- Approaches and analytical tools for integrated assessments of Caribbean river basins

Island based issues
- Caroni River Basin, Trinidad
- Buccoo Reef and Bon Accord Lagoon, Tobago
- Kingston Harbor, Jamaica

Mainland Caribbean coast
- Parque Nacional Morrocoy, Venezuela
- Magdalena River and other Caribbean rivers of Colombia
- La Estrella River basin and soil erosion effects on the Cahuita Reef system, Costa Rica
- Caribbean economies with particular reference to the role of the tourism industry
- Meso-American Barrier Reef (Mexico, Guatemala, Belize, Honduras)

Driver evaluation
- Caribbean economies with particular reference to the role of the tourism industry

In breakout groups, draft versions of assessment tables produced prior to the meeting were revised and amended taking into consideration both the results of other LOICZ-Basins workshops and new information. Gaps from the first phase were the paucity of information on island systems and on socio-economic background data. Special attention was paid to indicators and critical loads and how to apply a system view to allow determinations between land-based (anthropogenic) and more globally driven (climate and sea-level change) pressures and impacts. While there is some information on fluxes and land-use patterns, in some cases covering reasonable time-frames of data-sampling, indicators reflecting human development and their influence on water and material transports are rather scarce. The issue of integrated indicators was highlighted since it was recognised that while the Caribbean is quite data-rich, the quality and scope of data is often inappropriate for integrated systems analyses.

Outcomes and Wrap-up

- Assessment tables including the latest information available to the participants (chapter 2 and 5) were produced, covering sites, sub-regional and regional scales. Trend information on future changes and the current status of response were included where possible. Critical load/threshold information was provided for some sites.
- The meeting agreed to produce its findings in the form of a multi-authored LOICZ R&S volume, providing first regional pictures designed using the DPSIR framework. Expansion of the extended executive summaries to full scientific publication for joint publication in the peer-reviewed journal "Regional Environmental Change" by Springer publishers was an option welcomed by the participants.
- The CariBas network has encouraged the development and design of regional proposals for holistic future work. This work (and optional task proposals, see Chapter 3) would 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 project "EuroCat" will provide a sound template for the draft of a "CariCat". Prof. Bacon agreed to coordinate this effort in the region in cooperation with Profs Kjerfve and Wiebe. The meeting agreed further to pursue formal and/or operational links with ongoing international efforts such as the ICAM (Integrated Coastal Area Management) and GOOS (Global Ocean Observation System) of UNESCO/IOC, and the IAI, providing for global application and use of the outcomes.

CariBas participants and the LOICZ IPO expressed their special thanks to Prof. Liana McManus and her team namely Marlen Solotongo for the excellent organization, support and hosting of this second CariBas workshop. Financial support from UNESCO/IOC and LOICZ was gratefully acknowledged.

Appendix III. CariBas I and II Workshop Agendas and Participants

CariBas I
Institute of Marine Affairs, Chaguaramas, Trinidad, 7-9 December 2000

Agenda

6 December 2000
Arrival of participants

7 December 2000

0900-0930	Welcome address by Ms. Hazel McShine, Director, Institute of Marine Affairs
0930-1000	Caribbean basins and coastal impacts: the LOICZ perspective - B. Kjerfve
1000-1030	Reception arranged by the Institute of Marine Affairs
1030-1130	Caroni Basin - Peter Bacon and Rahanna Juman
	Morrocoy - David Bone
	Kingston Harbour - Trion Clarke and Dale Webber
	Cahuita - Ana Fonseca and Jorge Cortés
1130-1200	Review of workshop objectives
1330-1530	Work Session at the IMA
1600-1730	Work sessions at the IMA

8 December 2000

0830-1000	Work session at the IMA
1030-1230	Work session at the IMA
1230-1830	Field trip through the Caroni basin and swamp to the coast
1900-2300	West Indian dinner surprise at the home of Rahanna Juman

9 December 2000

0830-1000	Work session at the IMA
1030-1200	Work session at the IMA
1330-1530	Work session at the IMA
1600-1730	Concluding session at the IMA

10 December 2000
Departure of participants

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Figure AIII.1. Participants from left to right: Peter Bacon, Trion Clarke, David Bone, Rahanna Juman, Eugene Ramcharan, Lloyd Gerald, William J. Wiebe, Ana Fonseca, Björn Kjerfve, Dennis Pantin.

CariBas II Workshop
Rosenstiel School of Marine and Atmospheric Sciences, University of Miami, Florida, USA,
28-30 June 2001

Agenda
27 June 2001
Travel to Miami, Florida, USA

28 June 2001

09:00-09:30	Workshop registration, RSMAS, University of Miami
09:30-10:00	Opening session Presentation by H. Kremer, LOICZ Welcome address by RSMAS Dean O. Brown Welcome address by local host L. T. McManus Address by CariBas Task Leader B. Kjerfve
1100-1230	Plenary Session on Coastal Issues, Drivers, Pressures and State/State-Changes in the Wider Caribbean – and overview of CariBas I results and gaps
1400-1730	Introduction to the LOICZ regional Basins Assessment Tables Issues/Impacts (critical thresholds, trends and ranking – building an expert typology) based on coastal change in the region of concern.

29 June 2001

09:00-12:30	Plenary and working group sessions (working on tables): Coastal Issues & land based forcing – catchment & bigger sub-regional and regional scales
14:00-17:30	Identification of "Hot spots" and key scientific questions for future work; Discussion of LOICZ/CariBas/CariCat proposal ideas

30 June 2001

09:00-11:30 Planning for LOICZ/CariBas proposal

- What, Why (Regional and Global Relevance), Where,
- How, (incl. structure),
- Who, (identify co-ordinators and get commitment to finish and submit proposal/s),
- Funding, Timelines.

11:30-12:30 Concluding Plenary

- Approval in plenary of products, proposal suggestions, commitments, timelines
- Strengthening the CariBAS Network
- Conclusion
- Outlook

1 July 2001
Departure of participants

CariBas II Workshop participants

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Figure AIII.2. CariBas II participants (left to right): Björn Kjerfve, Hartwig Kremer, Marlene Attzs, Ana Fonseca, David Bone, Rahanna Juman, Peter Bacon, Trion Clarke, Bill Wiebe, Juan Restrepo, Bruce Hatcher.

Appendix IV Terms of Reference

LOICZ Caribbean Basins (CariBas)

Concluding workshop (CariBas II) on horizontal material fluxes (river and island runoff) to the coastal zone and human dimensions of change
(Impacts of land-based activities on coastal seas of the Wider Caribbean)

Rosenstiel School of Oceanography, University of Miami, Florida, USA
28-30 June 2001

CariBas, the regional assessment and synthesis of land-based drivers and their coastal impact and related change, was conducted in a two-step approach (desktop study and first scoping workshop and concluding workshop). While the TOR given below apply in principle to the whole process, they guided in particular the last concluding workshop held in Miami. The results of the first meeting and desk research were reviewed and synthesised in this second meeting.

1. Introduction - the LOICZ-Basins background

The 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 reviewed as a systemic, i.e. receiving, part of the whole water continuum. This reflects in an increasing number of targeted programs and key actions such as the new European 5th Framework Program as well as among UNESCO, UNEP and GEF based/supported initiatives. The International Geosphere Biosphere Program, IGBP, responds through concentrating considerable effort on the human dimension of global change issues taking the whole water cascade as a scale. Some of these issues are addressed in the "water group" initiative of IGBP, to which LOICZ contributes on various levels such as the Sediment/Runoff Group (J. Syvitski) and the Basins core project (Wim Salomons, H. Kremer).

2. The LOICZ-Basins Strategy

The LOICZ-Basins core project is working *inter alia* to develop a global evaluation of the importance of coastal seas as receiving bodies of land-based and globally driven changes of horizontal material fluxes such as carbon, nitrogen and phosphorus as well as water and sediments. The scale applied to assess these pathways including groundwater is the river catchment scale (or whole islands, if appropriate). Beyond giving an overview on coastal zone functioning as sink or source for nutrients and carbon, priority attention is paid to the relative importance of these materials and their biogeochemical cycles as indicators. In other words, to what extent do they represent environmental functioning and sustainability of goods and services provision under the dynamic natural and anthropogenic forcing of change. Assessment and modelling therefore aim to focus on residual transports of materials (C, N, P, sediments, others) as key indicators. This is usually referred to as the human dimension of coastal change. Changing fluxes impacting the state of the environment and their feedback on the socio-economic system functioning are to be reviewed against the conceptual question of critical thresholds of loads reaching the coastal zone and their potential to force systems to flip.

One challenging aspect in this kind of assessment is to review coastal changes and issues from the perspective of catchment-based *drivers, pressures and state changes* (fluxes and material cycles). Another is to derive from those figures some information on *critical thresholds* for the coastal change issues of concern based on
a) political regulations,
b) environmental monitoring including historical information and
c) stakeholder perception and requirements for coastal use (land- and sea-based).

Beyond the regional studies, the LOICZ commitment to global assessment of coastal change requires a basis for interregional and global comparison and up-scaling. LOICZ-Basins therefore continues to identify classes or defined types of coastal sea/river systems and to describe interaction and change through qualitative or semi-quantitative ranking of drivers and pressures applied to a catchment (or island) scale. These can also be linked to classes or types of state changes observed in the coastal zone. The latter refers to biogeochemical but also biological state parameters and may also encompass changes in human use such as sediment increase affecting aquaculture business for example. The ranking into categories as done by the experts of the various regional networks is under parallel development within the South American, Asian, African and European Basins studies. It is intended that the information, the categorization and the ranking will eventually – after further refinement and quantification – be used as an entry into the LOICZ typology clustering tool, which is under continuous refinement. This effort is conducted in co-operation with parts of the IGBP BAHC (Biospheric Aspects of the Hydrological Cycle) programme (see www.nioz.nl/loicz/ or http://www.kgs.ukans.edu/Hexacoral/Tools/tools.htm).

As with other regional LOICZ-Basins efforts, Caribbean Basins will continue improving the level of standardization of approaches in addressing the coastal issues in a holistic way. For this purpose, the simple DPSIR: *Drivers*, *Pressures*, *State* (State Change), *Impact, Response* framework (OECD 1993 and LOICZ R&S No. 11, 1998) provides the underlying descriptive framework helping to sketch the various forcing functions and boundary conditions. In a mid-term perspective this approach is seen to enable assessment and modeling of coastal change on the delivery and use of environmental goods and services, their scientific and monetary equivalents and to review the political *response* and options. Caribbean Basins expands on earlier assessment efforts in the wider American region: South American Basins (SAmBas) held in late 1999 in Bahia Blanca and May 2001 in Fortaleza, Brazil (LOICZ R&S Report 21) and the CariBas desk study which commenced in 2000 and is in its final stage.

3. Links and Synergies

Within the broader context of the IGBP, LOICZ-Basins provides the scientific frame in which mid- and long-term collaboration with other core projects such as BAHC (Biospheric Aspects of the Hydrological Cycle – see typology), LUCC (Land Use and Cover Change) and PAGES (Past Global Changes) as well as with the IHDP and WCRP will be developed and strengthened. Implications and links with new global change programmes expected under the second phase of the IGBP (2003+) such as the Land and Ocean programmes will be investigated as appropriate.

With regard to science exploitation and application, the issue-driven and human dimensions-oriented character of LOICZ-Basins investigations on catchment or island scales and related coastal zones have an implication for coastal zone management. Engaging with users in policy advisory groups and with the private sector therefore is a necessity for the demonstration projects resulting form the current study. In Europe the operational example is (EuroCat: http://www.iia-cnr.unical.it/EUROCAT/project.htm). The approach and the results have good potential to serve the objectives of intergovernmental organizations and LOICZ-Basins therefore continues to build its working relations with UNESCO/IOC and its ICAM (Integrated Coastal Area Management) and C-GOOS (Coastal Global Oceans Observing System) programs. On sub regional scale this might find operational links with the IOCARIBE and IAI activities.

However, LOICZ-Basins results, particularly from the *Response* aspect (i.e. policy and management response to coastal change), may also fertilize discussion on more local management needs dealing with catchment/coast interaction issues or classes of those. Response investigations provide insight into how society acknowledges the *Pressure - State-change and Impact relation* and how this is reflected in either success or failure of sustainable coastal use/management, especially when the time between at least two investigations at the same location is considered. A global synthesising effort such as LOICZ can thus provide decision-makers with relevant scientific indicators and trend analysis to enable this judgement, while remaining a neutral platform for joint discussion and generation of joint ownership of issues among science and users. Examples in Europe are a Rotterdam – Rhine project dealing with forecasting of sediment quality, where LOICZ-Basins provides a scientific frame for trend analysis and interdisciplinary catchment scale approaches against concrete user needs (http://w3g.gkss.de/i_a/dredged_material/index.html).

4. Specific Workshop Objectives

1. Review, complete and/or develop further, the state of the art reports of river catchment – coastal sea interactions as developed in the Bahia Blanca 1999. Set up a first qualitative or semi-quantitative system to categorise key pressures and state change settings providing a ranking order as a data entry for up-scaling purposes on regional scale (see 2).
2. Scale up the information to broader regional and global synthesis using the ranking system provided (and adapted to regional conditions when necessary) by identifying and clustering areas of similar change features. This may benefit from the use of typology tools and the Drivers, Pressures, State, Impact, Response framework, DPSIR, for standardised site classification.

   Due to the large differences in coastal change, uses, management status and legislation among the different countries in the Caribbean region, up-scaling using a typology approach may not be a simple exercise. Finding the best proxy for observed coastal change and adapting and optimising to the regional reality should also constitute a major objective of the present workshop in close relation to the other LOICZ core projects, e.g., the regional biogeochemical budgeting effort (UNEP/GEF).
3. Provide the regional data and information base for an interregional/global LOICZ-Basins core project synthesis by the principal investigators, to summarize the available regional information to an overall *global LOICZ Basins synthesis* planned for publication in 2003.
4. Review, based on earlier and new information, the set of pilot areas discussed in Bahia Blanca and those expected to be part of the CariBas report as well as identify possible new ones. This is aimed to develop proposals for specific case studies integrating natural and socio-economic sciences and to elaborate on the "human dimensions" of global change along the catchment–seawater continuum.
5. strengthen a regional Caribbean or if appropriate Latin American Basins network to continue the science and synthesis, to strengthen existing and to seek new value-added links to other projects and organisations such as UNEP, GIWA, IOC-UNESCO (GOOS and ICAM), START and IHDP. This will be facilitated through the LOICZ platform; but will only be possible with the involvement of national scientific programs and agencies.

5. Focus of workshop

To achieve the objectives outlined the workshop aims to work along the framework of the DPSIR scheme. The process of *assessment, analysis, categorisation and indexing* will make us of a tabulated approach which is applied also in other regional Basins studies and is developed along a set of key questions. (see Basins approach and regional assessment tables in Appendix I).

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, tourism);
- Mining activities.

They cause **PRESSURES** on ecosystem and social system functioning, affecting the **STATE** and hence **changing** the **STATE** of the coastal environment due to natural and anthropogenic forcing. This follows the scientific guidelines of the LOICZ global synthesising experiment taking:

- Water, nutrient and sediment transportation throughout the catchments/islands 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 the catchment); as well as
- 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. They translate into the **COASTAL ISSUES** from which the assessment process embarks. And finally the

RESPONSE, reflecting action taken (coastal management) to either protect against change such as increased nutrient or contaminant input, secondary sea-level rise by means of reduced sediment loads etc, ameliorate adverse effects and ensure sustainable use of system's resources.

6. Products and Expectations

Successful Caribbean Basins assessment will lead the way to:

- Provision of the information needed for the LOICZ *regional synthesis* the backbone of which will be a LOICZ R&S series volume along the workshop focus addressing key issues of the following topics:

LOICZ R&S Volume – Caribbean Basins
LOICZ Global Change Assessment and Synthesis of River Catchment (Island) – Coastal Sea Interaction and Human Dimensions of Change

1. COASTAL IMPACT/ISSUES (environmental and socio economic focus)
    - 1.1 Providing an expert based ranking
    - 1.2 Categorise the relevance of Impacts
2. DRIVERS
3. PRESSURES
    - 2.1 Providing an expert based ranking
    - 2.2 Categorise the relevance of Pressures
4. STATES and STATE-CHANGES (Fluxes, Material 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 ranking of the various aspects (optional – subject to data availability);
7. TREND ANALYSIS
    - 7.1 Expert prediction of future trends of key parameters and developments of change;
8. GAPS
    - 8.1 Data and Information gaps;
    - 8.2 Efforts/Commitments needed to fill these gaps.

- drafting of a *follow-up proposal* (optional for the CariBas network) aimed at integrated cross-disciplinary, i.e. combining natural and social science, pilot studies complementing those under parallel development within the other regional Basins efforts.
  (As outlined earlier a key criterion for their selection is the potential for up-scaling i.e. to be representative for a certain type of catchment - coastal sea systems and driver interaction that is characteristic for a sub region)
- information flow into the first *global LOICZ-Basins synthesis* and provide the input for the respective LOICZ Synthesis Book Chapter.

7) Workplan (tentative)

- The workshop is to be held 28-30 June 2001, in Miami, USA;
- Background documents, (SAmBas I report (Meeting Report Vol. 37, 1999), LOICZ R&S report No 11 and first draft report CariBas (currently in the editing process); further information will either be delivered prior to the meeting or made available through the web R&S No. 11 on Integrated Modelling and the DPSIR can be downloaded as a pdf file from http://www.nioz.nl/loicz/

- Participants will be asked to start filling the LOICZ-Basins regional assessment tables against the key questions outlined prior to arrival to enable targeted working through those key questions during the first half of the meeting.
- Participants list will be circulated subject to expression of interest returned to the organizers.
- Products foreseen will be a LOICZ Reports & Studies volume (R&S) published jointly with the partner organisations the draft to be prepared during the meeting and finalised within four months after the workshop. Special publications in peer-reviewed journals are encouraged.
- The meeting will agree on timelines and approve the schedule for and contents of products to be delivered.
- Pilot areas will be identified at the meeting and drafting of the proposals will be a participant's task already in the meeting – subject to approval by the meeting.

8. Participants

The scientists who have been or will be approached for expression of interest are researchers from Latin America and elsewhere who are exposed through their field of research to the issues of relevance. The workshop is supposed to be highly product-oriented and attendance will therefore be limited to a maximum of 20 to 25 participants including LOICZ resource scientists and organisers and plus technical secretarial support (preferably asked from the local organiser). Invitation and support will be based on expression of interest and approval of this TOR – especially the workplan - expressed to the organisers.

9. Concluding Remark

Appropriate inclusion of socio-economic information in the analysis and development of pressure–state–response indices usually turns out to be the major challenge and to have the biggest gaps in appropriate networking and should therefore be a priority issue in the process of network formation and further development. The network is therefore encouraged to identify respective capacities in their surrounding and encourage the participation of the appropriate people.

In the process of verifying and approving demonstration sites for which to draft holistic project proposals, emphasis will be put on both the potential to up-scaling and management relevance and on the broader contribution to global and regional projects.

10. Further Working Documents

A draft program for the workshop will be circulated by email; further background information, the key questions and related LOICZ-Basins regional assessment tables will be provided with some examples and a set of empty forms for preparation work.

Appendix V List of acronyms and abbreviations used

AfriBasins	African Basins Programme (LOICZ)
BAHC	Biospheric Aspects of the Hydrological Cycle
CariBas	Caribbean Basins Programme (LOICZ)
CARICOMP	Caribbean Coastal Marine Productivity project
C-GOOS	Coastal Global Ocean Observing System
CONICET	National Scientific Investigation Research Council (Colombia)
DEFINITE	Decisions on a Finite Set of Alternatives, software for multi-criteria analysis
DPSIR	Driver-Pressure-State-Impact-Response Framework
EC$	Eastern Caribbean dollar
EuroCat	European Catchment Project/part of the "European Land Ocean Interaction Studies", ELOISE cluster, DG Research
GEF	Global Environmental Facility
GIWA	Global International Waters Assessment
GOOS	Global Ocean Observing System
IAI	Inter American Institute for Global Change
ICAM	Integrated Coastal Area Management
ICZM	Integrated Coastal Zone Management
IOCARIBE	Caribbean regional sub-commission of IOC
IDEAM	Institute of Hydrology, Meteorology and Environmental Studies of Colombia
IGBP	International Geosphere-Biosphere Programme; A Study of Global Change
IHDP	International Human Dimensions Programme on Global Change
ILTER	International Long-Term Ecological Research Network
IMF	International Monetray Fund
INGEOMINAS	National Institute of Mining and Geology, Colombia
IOC	Intergovernmental Oceanographic Commission (UNESCO, Paris)
INVEMAR	Institute of Marine Research, Punta Betin, Colombia
LOICZ	Land Ocean Interactions in the Coastal Zone
LTER	Long-Term Ecological Research
LUCC	Land Use and Cover Change
MONERIS	Modelling Nutrient Emission in River Systems
OSM	Open Science Meeting
PAB	Policy Advisory Board
SAmBas	South American Basins Programme (LOICZ)
SARCS	South Asia Committee for START
SeaWiFS	Sea Viewing Wide Field of view Sensor project
SINAM	National Program of Monitoring Marine Ecosystems, Colombia
START	Global change system for Analysis, Research and Training
SWOL	SARCS/WOTRO/LOICZ – South East Asian LOICZ core project 1996-99
UNDP	United Nations Development Program
UNEP	United Nations Environment Programme
UNESCO	United Nations Education and Cultural Organization
WCRP	World Climate Research Programme
WOTRO	The Netherlands Foundation for the Advancement of Tropical Research
WP	Work Package

II. Literature review and categorization (development of indices) of natural and anthropogenic material fluxes and their impact on environmental and socio-economic systems in the coastal zone of islands in the Oceania Region.

1. Introduction

In May 2001 LOICZ commissioned the Department of Geographical and Environmental Studies, Adelaide University, Australia to undertake a desk-top study to describe the significance, cycling and expected trends of water, sediment, nutrient, carbon and contaminant fluxes in the coastal zone of the Oceania Region (Figure 1). Details on the activities and output required can be found in the consultancy brief, which is appended to this report (Appendix II).

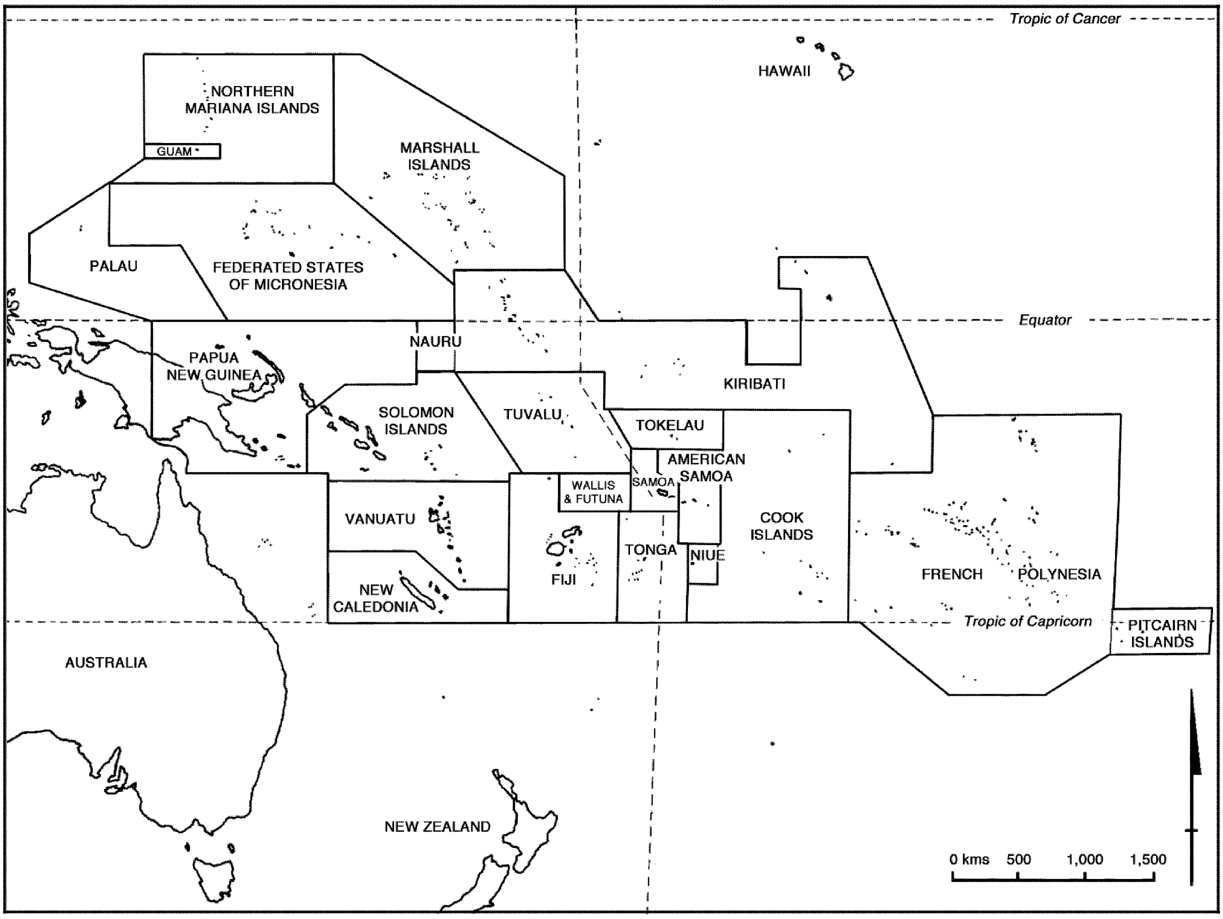

Figure 1. The Oceania region.

For the purposes of this study, the Oceania Region was defined as including the following nations, dependencies and territories (Table 1).

Oceania is served by the Secretariat of the Pacific Community (SPC) and the South Pacific Regional Environmental Program (SPREP). The SPC is a non-political organisation delivering technical development assistance, training and applied research to the region through advisory and consultative activities; and SPREP is a regional organisation established by the governments and administrations of the Pacific region to protect its environment. This is reflected in the Mission Statement of SPREP which calls on the organisation, 'to promote cooperation in the South Pacific region and to provide assistance in order to protect and improve its environment and to ensure sustainable development for present and future generations'. Although reference (in the literature) is often made to the study area as 'the South Pacific', Oceania is a more precise description, since Micronesia and other island groups extend well north of the equator.

Table 1. Nations, dependencies and territories in Oceania.

Nations	Dependencies and Territories
Fiji	American Samoa
Kiribati	Cook Islands
Marshall Islands	French Polynesia
Micronesia	Guam
Nauru	New Caledonia
Palau	Niue
Papua New Guinea	Northern Mariana Islands
Samoa	Pitcairn Islands
Solomon Islands	Tokelau
Tonga	Wallis and Futuna Islands
Tuvalu	
Vanuatu	

The popular view that Oceania is a vast tropical paradise is misleading, since much of the region has environmental problems such as widespread destruction of mangrove forests and coral reefs around population centres, runaway urbanization, overfishing, deforestation of upland and coastal forests, soil erosion, misuse of pesticides, pollution of rivers and drinking water supplies, improper disposal of industrial and municipal wastes, lack of sewage treatment facilities and biological impoverishment (Hinrichsen 1998). The environmental and human impact of nuclear fallout from British, American, French and Soviet bombs and radiation (leaking from nuclear dumpsites) may never be known (Danielsson 1984; Henningham 1995; Hinrichsen 1998).

Due to a paucity of published information on the cycling of water, sediment, nutrient, carbon and contaminant fluxes in the coastal zone of the Oceania region, the study focussed on and expected trends. The investigation of nutrient fluxes in the coastal zone of the Oceania region was excluded due to a lack of information, but a section on chemicals and hazardous waste was added.

2. Natural and anthropogenic fluxes

2.1 Water

Significance
Oceania has a chronic freshwater shortage (Dahl 1984; Hinrichsen 1998). In the Marshall Islands (an extreme example) the lack of fresh water is a serious problem for both rural and urban areas (Price and Maragos 2000), so that water rationing has been imposed and water is routinely supplied for only one hour every second day (Hinrichsen 1998). Urbanisation, domestic sewage and solid waste, agricultural wastes and industrial wastes all threaten the quality and supply of fresh water, in particular to low islands (Cocklin and Keen 2000; UNEP 2000).

Polluted rivers and drinking water supplies are common in Oceania. Fresh water is often polluted from untreated municipal waste, urban sewage, agricultural runoff (Dahl 1984; Brodie and Morrison 1984; Convard 1993; Hinrichsen 1998) and mining (Bains and Morrison 1990; Maun 1994; Henningham 1995; Hinrichsen 1998; Overton and Scheyvens 1999). In Papua New Guinea, the Fly River has been polluted by the BHP OK Tedi mine since 1984, with millions of tonnes of polluted tailings every year (Hinrichsen 1998; Harper and Israel 1999). During the years 1984-1989 the mining company was given virtually free rein on dumping waste into the Fly (Harper and Israel 1999) These wastes contained significant levels of copper, a toxic metal for aquatic ecosystems (Harper and Israel 1999).

Accidental spillages of cyanide into the Fly River (Viner 1984; Baines and Morrison 1990; Hinrichsen 1998; Harper and Israel 1999) have killed thousands of fish and crustaceans and scores of saltwater crocodiles. Contamination of aquatic life in the Fly River has caused losses of important food sources for the locals living along the river (Overton and Scheyvens 1999). The extensive environmental damage finally resulted in a multi-million dollar compensation court ruling in June 1996 in favour of the local communities (Hinrichsen 1998; Harper and Israel 1999); $320 million to be used for pollution control and $32 million to relocate whole villages (Hinrichsen 1998).

The effect of the Bougainville Copper Mine (ceased 1990) on the Jaba River (Papua New Guinea) is a similar tragedy (Baines and Morrison 1990; Henningham 1995; Hinrichsen 1998; Overton and Scheyvens 1999). The Jaba River was routinely polluted with sediments and heavy metals from mining operations (Hinrichsen 1998:137). An estimated 135,000-150,000 tonnes of contaminated tailings were dumped into the Jaba River every day (Hinrichsen 1998; Baines and Morrison 1990), and in 1988 alone approximately 48 million tonnes was disposed of into the Jaba River system in the form of tailings (Henningham 1995). In New Caledonia, rivers turned orange-red from soil from open-pit mines (Hinrichsen 1998); and in Guam high levels of heavy metals, in particular mercury, have been found in water supplies (Zucker 1984).

Coastal waters in the Oceania region are also polluted by industry (Brodie and Morrison 1984; Convard 1993; Hinrichsen 1998; Cocklin and Keen 2000; UNEP 2000). Industries such as fish canning, sugar milling, beer brewing and edible oils processing are significant regional pollutants of marine waters (Convard 1993 in UNEP 2000).

Quantitative information (where available) on industrial pollutant loadings reaching marine waters is available for each country and industry (UNEP 2000). Table 2 shows the industrial pollutant loadings for Papua New Guinea, as an example.

Table 2. Industrial pollutant loadings for Papua New Guinea. Data taken from UNEP (2000).

Country	Process	B.O.D. t/yr	S.S. t/yr	Oil T/yr	N t/yr	P t/yr	Other t/yr
Papua New Guinea	Edible oils	246,6	974,6	764,3			
	Brewing	48,9	8				
	Sugar milling	213,44	100,8				

Many hazardous and toxic wastes such as solvents and heavy metals associated with medium-scale industrial bases in Fiji and Papua New Guinea are not well-documented (UNEP 2000). Industrial waste loading in Oceania is increasing, as is the toxicity (Convard 1993).

Domestic activities are the major contributor to marine pollutant loads in Oceania (UNEP 2000). Suva Harbour, in Fiji, is toxic from untreated domestic and industrial effluent, organic chemicals, heavy metals and toxics (Hinrichsen 1998; UNEP 2000). Elsewhere discharge of sewage directly into lagoons or onto reefs, and toilets built directly over the sea on some atolls is common (Thistlewaite and Votaw (1992), cited in Cocklin and Keen (2000)).

Public health problems that arise from the degradation of fresh and marine water quality are serious issues in Oceania. Problems through water-related diseases (e.g., diarrhoea and gastrointestinal illness) and contamination of resources, plus the increased economic costs for treatment, result in significant socio-economic implications for the region (UNEP 2000). For example in Suva, 95% of mangrove shellfish collected at eight sites were found to exceed World Health Organization limits for human consumption" (Bryant-Tokalau (1995), cited in Cocklin and Keen (2000)).

Milliman *et al.* (1995) suggest that 3900 km^3 yr^{-1} of water is discharged from the islands of Oceania, but this figure includes the Philippines, New Zealand and Taiwan.

Expected trends

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

Pollution of fresh, coastal and marine waters is now recognized in Oceania, and the SPREP Action Plan may provide an effective way forward with respect to environmental concerns. In particular, the objectives from the Action Plan for Managing the Environment (SPREP 2000) suggest research programs to protect freshwater, coastal and marine ecosystems while ensuring ecologically sustainable utilisation of resources; and reducing land-based, freshwater and marine pollution. If the Action Plan (SPREP 2000) can be successfully implemented, Oceania waters (fresh, coastal and marine) may greatly improve.

In American Samoa, legislation is in place for water quality standards, land-use regulation, waste disposal and other environmental issues (Craig *et al.* 2000). In addition, the establishment of Marine Protected Areas in Vanuatu, New Caledonia, Tonga and the Samoa group is encouraging (Zann and Vuki 2000).

The potentially irreversible environmental destruction caused by mining in Oceania, and the economically damaging compensation ruling (e.g., Ok Tedi) may serve as a warning for other companies, perhaps making potential mining companies acutely aware of their environmental responsibilities. Currently mining is limited to a few countries in Oceania (i.e. Papua New Guinea, Fiji, Nauru and Solomon Islands). Phosphate, nickel, copper and gold are mined in Oceania. However, prospecting is occurring in a number of areas, so mining may spread to other countries (UNEP 2000).

2.2 Sediment

Significance
Sedimentation is a natural process in the marine environment, but low and/or high sediment loads can damage coastal habitats. Sediment yields relative to catchment size are high in Oceania, exceeding those of Africa by an order of magnitude (Appendix 1; Asquith *et al.* 1994; Bird *et al.* 1995). Sediment yield and mobility are linked to climate through rainfall and runoff. High erosion and sediment transport rates are understandable considering the geologic youth and massive rainfall of the region e.g., Viti Levu, Fiji receives 1400 mm/month.

Sediments can transport pollutants such as heavy metals, pesticides and other organic substances. Sediment supply can be increased by logging activities, rapid coastal development, mining, intensive agriculture and natural events (Convard 1993; Asquith *et al.* 1994). However, distinguishing natural volumes of sediment from human influences is extremely difficult, and little if any data exists for Oceania. One of the primary causes of increased sedimentation in Oceania is changes in land use such as logging, urbanisation, reclamation (Baines and Morrison 1990; Asquith *et al.* 1994; Convard 1993; UNEP 2000; Zann and Vuki 2000). Other modifications to the land include agricultural practices, construction activities, mining operations and coastal erosion (Nittrouer *et al.* 1995; UNEP 2000).

Pollution due to sedimentation is a major problem in Oceania, in particular for coral reefs and mangroves (Lal 1984; Asquith *et al.* 1994; Hinrichsen 1998; UNEP 2000). About 60% of islands in Oceania suffer soil degradation (Hinrichsen 1998). Coral reefs situated near Suva have been lost due to sediment from logging and upland farming, municipal and industrial pollution and dredging for sand (Hinrichsen 1998). Development-related problems in Fiji have also resulted in loads of sediments (by rivers and streams) smothering coral reefs and mangroves (Lal 1984).

In addition, the Gulf of Papua (GOP) receives sediment from the Fly and the Purari rivers, two of the world's top 20 rivers in terms of sediment discharge, with approximately 340×10^6 t yr^{-1} entering the marine environment (Bird *et al.* 1995). The Ok Tedi mining project has caused extensive environmental damage by discharging substantial quantities of sediment in river systems (Harper and Israel 1999). However, comparative data regarding natural and human influenced sources of sediment are not available.

Expected trends
With pressures from economic development and a rapidly expanding population, Oceania is likely to continue large-scale deforestation and more intensive agriculture, resulting in continued sediment inputs to rivers and coastal waters (Baines and Morrison 1990); land degradation also appears to be worsening (Hinrichsen 1998, Zann and Vuki 2000). However, the Action Plan for Managing the Environment (SPREP 2000) has as one objective the monitoring and assessment of the state of the environment in the region, including the impacts of human activities on the ecosystems, and intends to encourage development undertaken to be directed towards maintaining or enhancing environmental qualities. If this action plan is successfully implemented, it may have significant impact in improving pollution due to sedimentation.

2.3 Carbon

Significance
Extrapolating results from a study by Milliman and Syvitski (1992), Bird *et al.* (1995) calculate that the total flux of particulate organic carbon (POC) to the world's oceans from the islands of Oceania is ~90×10^6 t yr^{-1} or twice the flux of riverine POC from the major rivers of North America, South America and Africa combined. Oceania's rate of discharge is three times higher than the next highest, the Amazon (31×10^{12} g C yr^{-1}). The rivers of Oceania therefore represent a major but poorly documented source of sediment and organic carbon to the global ocean. However, Milliman and Syvitski include the Philippines, New Zealand and Taiwan in 'Oceania'. In addition, estimates of total organic carbon transported from land to the ocean via the worlds' rivers vary considerably (see Table 3).

Table 3. The quantity of organic carbon runoff from land via rivers. Data from Schlünz and Schneider (2000).

	Quantity of organic carbon
Degens *et al.* 1991	334.5×10^{12} g C yr^{-1}
Meybeck 1993	368×10^{12} g C yr^{-1}
Ludwig *et al.* 1996	380×10^{12} g C yr^{-1}

Chester (2000) ranks Oceania fourth in annual discharge of particulate organic carbon, but does not cite Bird *et al.* 1995 or Schlünz and Schneider (2000). However, data obtained by Schlünz and Schneider (2000) for Oceania from Nittrouer *et al.* 1995 is confusing, and varying definitions of Oceania in these papers is also problematic.

Expected trends
There is no reason to expect that rates of organic carbon discharge from Oceania will decrease; particularly with increasing economic development and a rapidly expanding population.

2.4 Chemicals and hazardous wastes

Significance
Oceania has a history of mismanaging chemical and hazardous wastes (Brodie and Morrison 1984; Convard 1993; Hinrichsen 1998; Burns *et al.* 2000). Large stockpiles of persistent organic pollutants (e.g., pesticides, polychlorinated biphenyls, industrial, medical and laboratory wastes, oil and bitumen) exist on islands in Oceania. Pesticides such as DDT are still commonly used (Hinrichsen 1998) and therefore pesticide spills into lagoons (e.g., Fiji: Tokelau; Truk) have caused significant environmental damage (Brodie and Morrison 1984).

The Australian Agency for International Development (AusAID) identified from a study of waste management issues that the greatest need (for Oceania) was for management of waste chemicals. As a result of this AusAID study, the Persistent Organic Pollutants in Pacific Island Countries (PoPs in PICs) project was established. All SPREP member countries except Papua New Guinea were assessed.

The objective of the PoPs in PICs project is to establish management of chemical and hazardous wastes. In Phase I, the assessment of stockpiles of waste and obsolete chemical and the identification of contaminated areas was undertaken. Over 100 potentially contaminated sites were identified, and 86 of these warranted extensive investigation (Burns *et al.* 2000). A summary of the total volume of unwanted chemicals and chemical contaminated sites (Table 4) and of the waste and obsolete chemicals and chemical contaminated sites (Table 5) demonstrates "significant examples of inadequate chemical management practices" in Oceania (Burns *et al.* 2000:13).

Table 4. Summary of total volume of unwanted chemicals and chemical contaminated sites. Data from Burns *et al.* 2000.
(PCB's = polychlorinated biphenyls)

Country	Agricultural chemicals (kg)	Oil + PCB's (L)	Laboratory chemicals (kg)	Waste oil (L)	Obsolete chemicals (kg)	Waste bitumen (L)	Timber chemicals (L)	DDT (kg)	Number of sites
Cook Islands	5,700	4,000	380	20,000					2
Federated States of Micronesia	7,430	55,000	36,400	126,000					18
Fiji	21,210	Nil	>800 L	>8,000	75				19
Kiribati#	700	5,500	2,270	7,000		200,000			6
Marshall Islands	60	800		800+		20,000			4
Niue	1500	1000		Nil		Nil			1
Palau*	100	18,000	7,300	10,000		5,200			2
Samoa^	200	9,000	400				10,000		8
Solomon Islands	11,000 excl. DDT	1,200	300 L	>4,000	750			9,000	8
Tonga	Nil	6,000		2,000					3
Tuvalu	Nil	8,000		1,500 +		60,000			4
Vanuatu	300 excl. DDT	13,000	> 100 L	>15,000			122,000 kg	900	4

Kiribati has 1000 L of copper/chromium/arsenic sludge.
* Palau has 300 m^3 of asbestos.
^ Samoa has 3,000 kg of buried agricultural chemicals

In addition, the management and disposal of laboratory chemicals and the management of infectious medical wastes was of great concern. Phases II and III should see the development of safe storage facilities in each country and disposal activities respectively (Burns *et al.* 2000). However, disposal operations are more urgently required than storage facilities.

Table 5. Waste and obsolete chemicals and chemical contaminated sites. Data from Annex: B1-List of sites in each Country (Burns *et al.* 2000).

Country	Total number of sites	Number of sites with surplus chemicals	Number of sites that were contaminated
Cook Islands	18	17	3
Fiji	19	16	11
Fed. States of Micronesia			
Chuuk	8	6	4
Kosrae	10	4	6
Pohnpei	14	9	8
Yap	19	8	6
Kiribati	22	13	12
Marshall Islands	6	4	4
Nauru	9	7	5
Niue	6	5	1
Palau	21	12	8
Samoa	17	12	10
Solomon Islands	15	9	10
Tonga	3	1	3
Tuvalu	9	7	4
Vanuatu	17	11	8
Totals	213	141	103

Expected trends

Chemical and hazardous waste management should continue to improve in Oceania, with the focus on long-term strategies. The move towards implementing the Basel, Waigani, Rotterdam and Persistent Organic Pollutants (POP's) conventions will be fundamental to the removal of toxic chemical and other hazardous wastes in Oceania. In particular, the Basel and Waigani conventions provide a legal framework (SPREP 2000).

3. Conclusions

There is a distinct lack of basic and ongoing research in Oceania. Data obtained from the scientific literature, specific texts and literature of the South Pacific Regional Environment Programme (SPREP) suggest that several major problems should be addressed by the Oceania region, as a whole:

- ◊ Pollution from untreated municipal waste and urban sewage
- ◊ Deforestation and the effect of sediment transport
- ◊ Mining and its environmental impacts
- ◊ Chemical and hazardous waste management
- ◊ Effects of urbanization

Most of these problems are highlighted by the Action Plan for Managing the Environment (SPREP 2000). The success of this Management Plan may be critical for long-term environmental improvement in Oceania. Specific impacts and issues affecting Oceania are tabulated in the standardised assessment tables (Tables 6-9). Basin-level analysis for Oceania is problematic, since many of the island groups in Oceania have no established drainage networks in which sediment can be mobilised and transported (Asquith *et al.* 1994).

4. Recommendations for pilot studies:

- ◊ Examine the cycling of water sediment, nutrient, carbon and contaminant fluxes in the coastal zone of the Oceania region
- ◊ Examine nutrient fluxes in the coastal zone of the Oceania region

◊ Commitment to community education programs on the impact of pollution on the river, coastal and marine environment
◊ Examine the social implications of water rationing
◊ Examine potential water (fresh) saving approaches
◊ Look at the impact of fresh water discharge from Islands in Oceania
◊ Examine the potential to establish water quality monitoring of rivers and lagoons
◊ Examine the use and management of pesticides
◊ Identify the proportion of sediments that occur naturally from those that are not
◊ Examine logging and the effect on increased sediment load
◊ Assess the effects of sediments carrying pollutants such as heavy metals and pesticides
◊ Examine the effect of intensive agriculture and how it is contributing to sediment loads in rivers and the marine environment
◊ Examine the impact of runoff on the coastal and marine environment
◊ Investigate the possibility of using sediment loads as a pollutant indicator.

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Table 6. Major coastal impacts/issues and critical thresholds in South Pacific Coastal Zones – Overview and qualitative ranking.

Impact code and relative class of importance e.g. 1- 10

Coastal Impact/ Issue	Local site/Region (contributing river basins)	Distance to critical threshold	Impact category	References/ Datasource
Erosion (Coastal geomorphology)	Tarawa Atoll, Kiribati.	Betio-Bairiki causeway and channel infilling.	8	Nunn 1994
Eutrophication	Fly, Ok Tedi and Jaba Rivers, PNG.	Contaminated sediment loads have changed the rivers ecosystem.	10	Hinrichsen 1998, Bains and Morrison 1990
Pollution	a. Fly, Ok, Tedi,and Jaba Rivers. b. Rivers in Southern New Caledonia. c. Coastal waters around Suva. d. Coral reefs in French Polynesia. e. Nubukulou Creek, Suva. f. Coastal waters around the Coo Islands. g. Lagoon and oceans in Tonga. h. Coral reefs in the Solomon Islands.	a. Cyanide (past), copper, heavy metals, cadmium, sediment. b. Laterite clay. c. Logging and farming upland, municipal and industrial waste, sand dredging. d. Raw sewage, industrial waste, dredging and sand mining. e. Effluents from electricity plant and septic tanks. f. Dieldrin used for fishing, washing of spray equipment in streams. g. Refuse and urban sewerage. Siltation due to logging.	10	Viner 1984, Asquith *et al* 1994, Baker *et al* 1990, Bains and Morrison 1990 Hinrichsen 1998, Lal 1984,Dahl 1984, Overton and Scheyvens 1999, Henningham 1995, UNEP 2000
Biodiversity loss and/or decreasing biological productivity	a. Fly River, PNG. b. Jaba River, PNG. c. Rivers in Southern New Caledonia. d. Coastal waters around Suva.	a. Fish stock reduced by up to 80%. b. Biologically dead. c. Mangrove loss, reef death and estuaries filled. Tree cover stripped away Fish population decline and coral reefs lost.	10	Asquith *et al* 1994, Bains and Morrison 1990, Nunn 1994, Hinrichsen 1998, Lal 1984, UNEP 2000
Sedimentation	a. Fly and Jaba Rivers, PNG. b. Coastal waters around Suva, from rivers c. Rivers in New Caledonia.	a. Before 1990, Jaba River 135,000 metric tons of mine tailing/day. b. Coral reef loss from logging upland and poorly planned developments.	10	a. Lal 1984, Hinrichsen 1998, Bains & Morrison 1990, Harper & Israel 1999 b. Hinrichsen 1998, Bains & Morrison 1990, Lal 1984. c. Labrosse *et al.* 2000
Contamination	a. Marshall atolls: Bikini and Eniwetok. b. Guam coastal waters. c. Tuamotu Group, French Polynesia	a. Nuclear testing (not current). b. Radioactivity in marine food chain increased to 100 times ambient levels. c. Radioactive waste, treat to human health	10	Branch 1984, Henningham 1995, Hinrichsen 1998.

Table 7. DPSIR matrix characterizing major catchment based drivers/pressures and a qualitative ranking of related state changes impacting the coastal zone

State change dimension: 3 = major; 2 = medium; 1 = minor; 0 = no impact; ? = insufficient information.

Time scale: p = progressive (continuous); d = direct (spontaneous)

Driver	Pressures	State change	Impact on the coastal system	Time scale
		Large-medium basins		
Climate (rainfall)	• Increased sediment transport	3	Siltation Erosion	**p**
Agriculture	• Fertilizer (nutrient) effluent • Land clearing and reclamation • Water extraction increase • Increased sediment transport • Changes to water balance and runoff regime • Intensive agriculture along coastal areas	1 3 3 3 3 3	Eutrophication Pollution (heavy metals) Siltation Biodiversity loss Erosion of stream banks and increased sedimentation	**p**
Deforestation	• Increased sediment loads • Alteration to water balance • Changes to runoff regime • Siltation • Ecological damage	3 2 3 3 3	Siltation of coral reefs and mangroves Sediment accretion Erosion Biodiversity loss	**p**
Mining	• Increased sediment loads • Changes to hydrological cycle	3 3	Pollution (heavy metals) Siltation Eutrophication Sediment accretion Erosion Contamination Biodiversity loss	**p**
Urbanization (point source effluents)	• Pollution discharge • Population growth • Increased sediment runoff • Water extraction	3 3 3 2	Pollution Eutrophication Contamination Biodiversity loss	**p**
Nuclear Tests	• Radioactive residues	3	Pollution Contamination Biodiversity loss	**d**

Table 8. The link between coastal issues/impacts and land based drivers in South Pacific Coastal Zones – 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	Rewa River, Fiji.	7	Increase	Bains & Morrison 1990
	Deforestation	Rivers of Fiji.	7	Increase	Asquith *et al.* 1994
	Urbanization	Rivers of Fiji.	8	Increase	Asquith *et al.* 1994
	Mining	Fly, Ok Tedi and Jaba Rivers, PNG.	10	?	Hinrichsen 1998, Bains & Morrison 1990, Hettler and Lehmann 1995
Erosion	Agriculture	Streams in Fiji (pesticides).	7	Increase	Brodie and Morrison 1984
	Deforestation	Streams in Fiji, New Caledonia and Solomon Is.	7	Increase	Brodie and Morrison 1984
	Urbanization	Tarawa Atoll, Kiribati.	6	Stable	Nunn 1994
	Mining	a. Jaba River, PNG. b. Rivers in New Caledonia.	10	?	a. Nunn 1994, b. Nunn 1994, Hettler & Lehmann 1995
Pollution	Agriculture	Rewa River, Fiji.	8	Decreasing	Bains & Morrison 1990
	Deforestation	Rivers in southern New Caledonia.	10	Increase	Hinrichsen 1998
	Urbanization	a. Rewa River, Fiji (sewage), Tarawa Lagoon, Kiribati (sewage). b. Vatuwaga River, Fiji (sewage). c. Nubukulou Creek (electricity and septic tanks). d. Suva Harbour, Fiji (sewage).	8	Stable	a. Brodie & Morrison 1984 b. Lal 1984 c. Hinrichsen 1998 d. Hinrichsen 1998
	Mining	a. Fly, Ok Tedi and Jaba Rivers, PNG. b. Rivers in southern New Caledonia.	10	?	a. Bains & Morrison 1990, Asquith *et al.* 1994, Nunn 1994, Hettler & Lehmann 1995, Hinrichsen 1998, Harper & Israel 1999 b. Nunn 1994, Hinrichsen 1998
Sedimentation	Agriculture	a. Rewa River, Fiji. b. Waimanu River, Fiji.	5	Increase	a. Bains & Morrison 1990 b. Vuki *at al.* 2000
	Deforestation	Streams in Fiji, New Caledonia and Solomon Is.	10	Increase	Brodie and Morrison 1984
	Urbanization	Qaraniqio River, Fiji.	8	Increase	Lal 1984
	Mining	a. Fly, Ok Tedi and Jaba Rivers, PNG. b. Rivers in New Caledonia.	10	?	a. Asquith *et al.* 1994, Bains & Morrison 1990, Hettler & Lehmann 1995, Hinrichsen 1998 b. Labrosse *et al.* 2000

Table 9. The link between coastal issues/impacts and land-based drivers in South Pacific coastal zones – overview and qualitative ranking on local, sub regional or country scale.
Category: (1 low – 10 high)

Coastal Impact/Issues	Drivers	Sub-regional (i.e. by country or considering open versus enclosed seas)		Trend-expectation	References/ Data sources
		Sub-region A	Category		
Eutrophication	Agriculture	Rewa River, Fiji.	7	Increase	Bains & Morrison 1990
	Deforestation	Rivers in Fiji.	7	Increase	Asquith *et al.* 1994
	Urbanization	Rivers in Fiji.	8	Increase	Asquith *et al.* 1994
	Mining	Fly, Ok Tedi and Jaba Rivers, PNG.	10	?	Hinrichsen 1998, Bains & Morrison 1990
Erosion	Agriculture	Streams in Fiji.	7	Increase	Bains & Morrison 1990
	Deforestation	Streams in Fiji, New Caledonia and Solomon Is.	7	Increase	Brodie & Morrison 1984
	Urbanization	Tarawa Atoll, Kiribati.	6	Stable	Nunn 1994
	Mining	Jaba River, PNG; Rivers in New Caledonia.	10	?	Nunn 1994
Pollution	Agriculture	Streams in Fiji (pesticides).	8	Decreasing	Brodie & Morrison 1984
	Deforestation	Rivers in southern New Caledonia.	10	Increase	Hinrichsen 1998
	Urbanisation	a. Rewa River, Fiji (sewage), Tarawa lagoon, Kiribati (sewage). b. Vatuwaga River, Fiji (sewage). c. Nubukulou Creek (Electricity and septic tanks). d. Suva Harbor, Fiji (sewage).	8	Stable	a. Brodie & Morrison 1984 b. Lal 1984 c. Hinrichsen 1998 d. Hinrichsen 1998
	Mining	e. Fly, Ok Tedi and Jaba rivers, PNG. f. Rivers in southern New Caledonia.	10	?	a. Bains & Morrison 1990, Asquith *et al.* 1994, Nunn 1994, Hettler & Lehmann 1995, Hinrichsen 1998 b. Nunn 1994, Hinrichsen 1998
Sedimentation	Agriculture	a. Rewa River, Fiji. b. Waimanu River, Fiji.	5	Increase	a. Bains and Morrison 1990 b. Vuki *et al.* 2000
	Deforestation	Streams in Fiji, New Caledonia and Solomon Is.	10	Increase	Brodie & Morrison 1984
	Urbanisation	Qaraniqio River, Fiji.	8	Increase	Lal 1984
	Mining	a. Fly, Ok Tedi and Jaba rivers, PNG. b. Rivers in New Caledonia.	10	?	a. Asquith *et al.* 1994, Bains and Morrison 1990, Hettler and Lehmann 1995, Hinrichsen 1998 b. Labrosse *et al.* 2000

Appendices

Appendix 1. Regional sediment yield calculations for Oceania, using the Fournier (1960) method. (Data from Asquith *et al.* 1994).

Islands and island groups	**Drainage area, km²**	**Calculated sediment yield**				
		Volume m^3 km^{-2} x 1000	Minimum T km^{-2} yr^{-1} x 1000	Maximum T km^{-2} yr^{-1} x 1000	Total Min. t yr^{-1} x 1000	Total Max. t yr^{-1} x 1000
American Samoa						
Tutuila	145	1.74	3.66	4.43	530.27	656.60
Ofu	0					
Olosenga	0					
Tau	0					
Cook Islands						
Atiu	0					
Mangaia	0					
Rarotonga	67	1.43	2.99	3.71	201.10	248.97
Federated States of Micronesia						
Kosrae	108	2.95	6.20	7.67	669.28	828.58
Pohnpei	334	2.33	4.89	6.06	1634.43	2023.37
Chuk	61	1.17	2.45	3.93	149.39	184.93
Yap	98	2.11	4.44	5.49	436.66	540.63
Fiji						
Viti Levu	10389	3.43	7.21	8.93	74915.08	92758.17
Vanua Levu	5538	2.73	5.73	7.10	31754.89	39314.26
Taveuni	435	2.27	4.76	5.90	2072.30	2565.60
Ovalau	125	1.95	4.10	5.08	410.30	507.90
Koro	108	1.95	4.10	5.08	443.12	548.53
Gau	100	1.95	4.10	5.08	512.88	634.88
Kadavu	408	1.83	3.85	3.77	1571.21	1945.44
French Polynesia						
Tahiti and Moore	1052	3.06	6.42	7.95	6750.68	8358.14
Tahaa	88	1.38	2.89	3.58	254.23	314.78
Raiatea	194	1.38	2.89	3.58	560.47	694.05
Rurutu	28					
Nukuhiva and Uapou	435	5.08	1.07	1.32	446.58	575.07
Hivaoa and Tauhata	370	9.54	2.00	2.48	741.11	917.60
Marshall Is.	0					
Nauru	0					
New Caledonia	171	1.70	3.56	4.40	61274.01	75440.52
Niue	0					
Northern Marianas						
Saipan	5	2.43	5.09	6.31	25.47	31.54
Palau						
Babelthuap	396	2.27	4.76	5.90	1886.07	2337.20
Papua New Guinea (mainland provinces)						
Oro	22800	2.56	5.37	6.65	122390.40	151551.60
Milne Bay	14000	1.90	3.99	4.95	55916.00	69230.00
Central and N. Capital	29740	1.80	3.78	4.68	112506.42	139302.16
Morobe	34500	1.20	2.51	3.11	68829.50	107260.50
E. Sepic and	79100	1.30	2.73	3.35	215784.80	267152.34

Sanduan						
Mandang	29000	2.44	5.10	6.34	147958.00	183831.00
W. Highlands and Enga	21300	1.51	3.17	3.92	67414.50	83474.70
S. Highlands	23800	1.47	3.09	3.83	73565.80	91082.60
E. Highlands and Simbu	17380	1.54	3.24	4.00	56259.06	6924.28
Gulf	34500		1.73		59581.50	
Western	99300		1.06		105124.46	
Island provinces						
New Britain	39807	6.06	12.72	15.74	506146.01	626681.60
New Ireland	9974	2.30	4.84	5.99	48264.19	59754.23
Bouganville	9300	1.90	3.99	4.94	37088.40	45923.40
Lorengau/ Manus	01943	1.65	3.47	4.30	6748.04	8354.90
Pitcairn	0					
Solomon Islands						
Choisel	2590	1.32	2.78	3.44	7200.20	8914.78
Santa Isabel	4122	2.45	5.15	6.38	21228.30	26281.87
Malaita and Marimasike	4900	3.49	7.33	9.07	35902.30	44447.90
San Cristobal	3125	2.27	4.76	5.90	14887.50	18431.25
Guadal-canal	6400	2.48	5.20	6.44	33292.80	41241.60
New Georgia Group	4250	2.71	5.69	7.05	24186.75	29945.50
Tokelau	0					
Tonga						
Eua	15	1.06	2.23	2.76	33.44	41.40
Tofua	28	2.00	4.11	5.08	114.97	142.35
Kao	1	2.00	1.41	5.08	4.11	5.08
Tuvalu	0					
Vanuatu						
Espirito Santo	3680	1.64	3.44	4.26	12655.52	15669.44
Malekula	2023	2.11	4.43	5.49	8967.96	11102.22
Tanna	549	1.95	4.10	5.09	2252.55	2791.67
Aneityum	65	2.37	4.98	6.17	323.90	401.16
Ambrym	665	3.11	6.53	8.08	4339.79	5373.73
Epi	444	1.53	3.22	3.99	1429.24	1763.41
Erromanga	975	1.95	4.10	5.08	3998.77	4950.08
Efate	915	2.43	5.09	6.31	461.01	5770.91
Pentecost	438	3.70	7.77	9.62	3402.62	4212.77
Aoba	339	3.04	6.38	7.90	2163.71	2678.88
Maewo	269	2.50	5.26	6.51	1414.62	1751.43
Vanua Lava	308	2.11	4.43	5.49	1365.36	1690.30
Western Samoa						
Saval'l	503	2.61	5.48	6.79	2756.44	3412.86
Upolu	708	2.90	6.09	7.54	4309.60	5335.49
Regional Mean		2.33	4.63	5.76		
Regional Total					2015673.05	2486186.63

Appendix II. Consultancy Brief

Land Ocean Interactions in the Coastal Zone (LOICZ) International Project Office

Consultancy

Literature review and categorization (development of indices) of natural and anthropogenic material fluxes and their impact on environmental and socio-economic systems in the coastal zone of islands in the Oceania Region.

LOICZ is working *inter alia* to develop a global evaluation of the importance of coastal seas as receiving bodies of land based changes of horizontal material fluxes such as carbon, nitrogen and phosphorus as well as water and sediments. The scale of transport pathways applied is the river catchments (including horizontal island runoff) and groundwater fluxes and their natural and anthropogenic drivers.

Beyond providing an overview on whether the coastal zones function as sinks or sources for nutrients and carbon, the goal is to elaborate on the relative importance of these materials and their biogeochemical cycles under the dynamic natural and anthropogenic changing forcing functions. Changing fluxes impacting the state of the environment and their feedback on the socio-economic system functioning are to be reviewed against the conceptual question of critical loads reaching the coastal zone and forcing systems to flip.

Current efforts in LOICZ are making advances in addressing these issues in a standardized way by applying the simple **DPSIR**: Drivers, Pressures, State (State Change), Impact Response scheme (OECD 1993 and LOICZ R&S No. 11, 1998) as a descriptive framework in which to sketch the various forcing functions and boundary conditions. The mid-term goal is to involve the calculation and modelling of effects on the delivery and use of environmental goods and services, their scientific and monetary expressions and to review the political response and options.

While earlier LOICZ BASINS efforts have concentrated on river catchments throughout Europe, South America and Africa, to date, LOICZ has not attempted to properly evaluate the significance of the flux changes, their drivers and critical loads to coastal zones of island dominated areas. Following the recommendations of the Global Island Working Group of the 4th Open Science Meeting, Bahia Blanca, Nov. 1999, LOICZ now seeks to commission an expert literature review to address these issues for the Oceania region.

Activities

Prepare a literature review and a qualitative/semi quantitative index system describing the significance, cycling and expected trends of water, sediment, nutrient, carbon and contaminant fluxes in the coastal zone of the Oceania Region, including:

- Establishing the relevance of island coastal areas for natural and anthropogenic forcing of flux changes through river catchments (or depending on size the whole island), groundwater and other land based inputs;
- Identify impacts on ecosystems in reach of these fluxes, and as far as possible the critical loads with respect to expected change of functions and goods and services and regulatory response (legislation, private sector needs); and
- Provide recommendations for representative pilot studies for higher order integrated modelling with their potential to regional upscaling

Output

1. A report describing the source, significance and magnitude of water, sediment, carbon, nutrient and contaminant fluxes, their pathways and commentary on classification and significance of their major drivers and expected trends. This to be provided with a system of indices of drivers and pressures applied to a catchment (island) scale showing their links to state change and critical loads observed in the coastal zone providing the interface to up-scaling in the LOICZ typology.
2. An electronic copy of the report suitable for web-site listing.
3. A scientific article for peer-reviewed publishing.