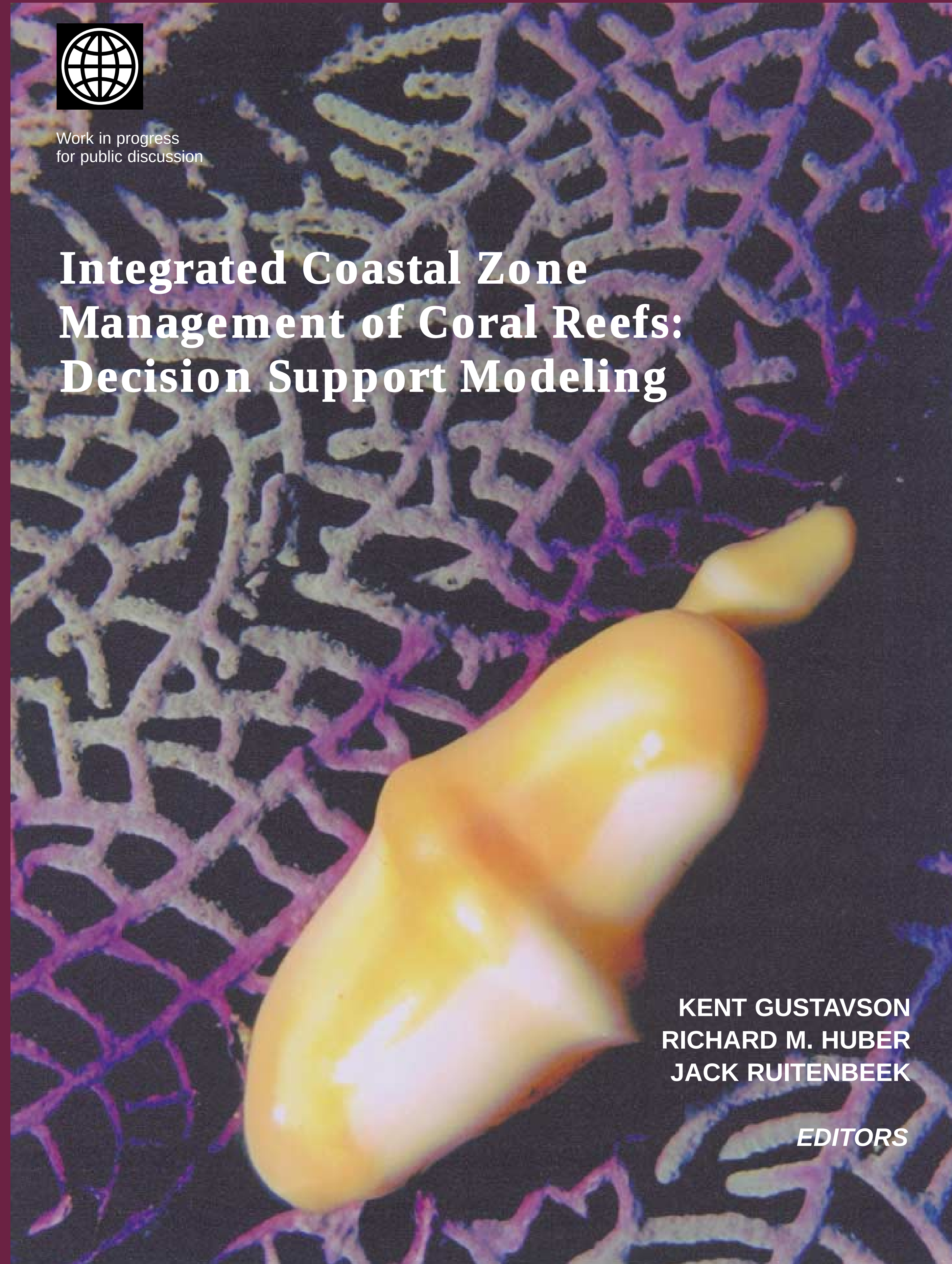

Work in progress
for public discussion

Integrated Coastal Zone Management of Coral Reefs: Decision Support Modeling

KENT GUSTAVSON
RICHARD M. HUBER
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EDITORS

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Integrated Coastal Zone Management of Coral Reefs
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WORK IN PROGRESS
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Integrated Coastal Zone Management of Coral Reefs: Decision Support Modeling

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Foreword

Everything should be as simple as possible, but not simpler.

– Albert Einstein

Coral reefs are sometimes referred to as "canaries of the sea" because of their early warning ability to show near-shore oceanic stress. Because of their biological diversity, they are also called "rainforests of the sea". Coral reefs are vital to the well-being of millions of people.

1997 and 1998 were devastating years for many of the world's coral reefs. Elevated sea surface temperatures in many tropical regions triggered the most geographically widespread bleaching and the heaviest mortality of corals ever documented in such a short period. "Managers and scientists from around the globe are particularly concerned about this past year's unprecedented, global bleaching episode," said D. James Baker, NOAA administrator. "The bleaching and mortality rate may even worsen in the years ahead. This serves as a wake-up call for more research and monitoring to help protect these valuable coral reef ecosystems." According to the Global Coral Reef Monitoring Network's status report for 1998 (Wilkinson 1998), some reefs had up to 95% coral mortality in shallow waters. These unprecedented events have elevated concern about coral reef degradation worldwide. Coral reef ecosystems have been identified as one of the highest priority areas for conservation (Hatziolos, Hooten, and Fodor, 1998).

Coral reef managers and government officials trying to save their valuable national resources need management-related information on coral reefs. The research results presented in the following chapters merit much attention because it is useful for decision support and training in integrated coastal zone management (ICZM). The work on *cost-effectiveness analysis* has developed integrated economic and ecological models, relying extensively on fuzzy logic procedures to model impacts and effects of interventions within the reef environment (Chapters 3, 4 and 8). The *marine system valuation* work provides economic valuations of coral reefs, demonstrating the use of different modeling methods and treating key policy issues within this context (Chapters 5, 6, 7 and 12).

This research focused on three case study sites: Montego Bay, Jamaica, the south coast of Curacao, and The Maldives, with primary attention being paid to the Montego Bay site. Montego Bay Marine Park (the Park) is a bold experiment that was initiated in 1992. The Montego Bay Marine Park Trust, a non-government organization (NGO), was given responsibility by the Government of Jamaica to manage the Park under the authority of the Natural Resources Conservation Authority.

Over a period of several years, the people of Montego Bay have endured the repercussions of poor planning (Chapters 2 and 11):

- Increasing pollution of the inshore, coastal and ocean environment;
- Damage to productive coastal ecosystems, which increases losses of life and property from coastal hazards and disasters; and,
- Conflicts of interests among user groups.

They have also begun to share a common vision:

- A desire to increase the economic benefits flowing from the use of coastal resources; and,
- Perceived economic opportunities associated with new forms of development in the coastal zone.

Potential solutions include:

- Participatory approaches to planning, involving NGOs and community based groups;
- Strong institutions with accepted mechanisms for cross-sectoral cooperation;
- Enforcement of and compliance with integrated policies through the use of positive reinforcement, encouragement, and incentives;
- Establishment of recognized boundaries with the rights and rules accepted by the user groups with provisions for sanctions; and,
- A seamless flow of information through different mediums.

A new Montego Bay Marine Park management plan is being implemented that includes: i) a new park zoning plan (with mooring and demarcation buoy programs); ii) a watershed management program; iii) alternative income and retraining programs for fishers; iv) merchandise, user fee and ecotourism programs for revenue generation; v) education programs for school children, church groups, and the community; vi) volunteer and public relations programs; vii) enhanced enforcement to protect fisheries resources from poaching; and, viii) research and monitoring programs to evaluate the recovery of the ecosystem and track the success of park programs (Chapter 2).

Montego Bay was an ideal case study site, because it realizes its revenues equivalently from manufacturing, services, and tourism; making it a more complex economy than the usual sun, sand and sea destination. Most important, the Trust Board, managers, and park rangers of the Montego Bay Marine Park took great interest in the research and organized each of the 5 national level workshops and dozens of local level workshops held there over the last 5 years. Additionally, the Trust helped to develop the methodology, field test the decision-support model, and complete the pre-test and 1000 sample CV survey.

What is clear about decision support tools is that they assist in decision making, but are still an imperfect art. A critical next step will be to continue to refine the model in Montego Bay (or one of the other sites), and monitor the results over time to see whether the predicted changes in ecosystems quality occurred with the introduction of certain management interventions. This implies a long-term commitment by the Trust, but it will need to be done at some point to test the validity and ultimately the utility of the approaches presented here.

The process of consultation with the user groups was extensive at levels from the fisherfolk to senior decision makers and the private sector. The Greater Montego Bay Redevelopment Company, representing trade groups and the private sector, was involved throughout. They took ownership of the processes, as they saw the outputs answering real life management questions. Having a clearer understanding of the different tools and how they fit together was very pertinent to them (e.g., economic valuation techniques to determine the inherent value of the coral reef resource under threat, and then using the model to identify the relative costs and benefits of a range of options that then helps to determine a logical sequence of mitigation measures). It then became clear that safeguarding the structure and function of the coral reefs would result in an increased flow of benefits from greater protection.

This applied research tries to shed light on two main questions. First, "If acres of healthy coral reef at a future time is the objective, where do we get the biggest bang for the buck?" Conventional economic procedures for modeling cost-effectiveness can, unfortunately, result in suboptimal policy choices when applied to complex systems such as coral reefs. In Montego Bay, up to a 20% increase in coral abundance may be achievable through using appropriate policy measures having a present value cost of US$153 million over 25 years (Chapter 8). Second, "What is a coral reef worth?" When a cruiseship hit a reef in the Gulf of Aqaba some years ago, Egypt sought US$10,000/m2 of damaged reef. This suggests that reefs are among the most valuable real estate in the world. What would it cost to rehabilitate reefs that have become degraded? How much should we invest in reef rehabilitation? Who should pay? The least cost and valuation (benefits) exercises, utilized together, suggested an "optimal" improvement of coral reef abundance of 13% in Montego Bay, requiring net expenditures of US$27 million, primarily through installation of a sediment trap, waste aeration, installation of a sewage outfall, implementation of improved household solid waste collection, and implementation of economic incentives to improve waste management by the hotel industry (Chapter 9).

The Montego Bay work also polled more than 1,000 tourists and local people through a contingent valuation survey (Chapter 6). The objective was to answer a key question: "How much would you be willing to pay to protect the coral reef?" This and other valuation techniques indicated that the total benefit attributable to the reef in its current condition is approximately US$470 million, and that every 1% change in abundance is likely to generate a marginal benefit of approximately US$10 million (Chapter 9). Most of the value is attributable to direct tourism revenues dependent on healthy coral reefs (Chapter 5). Coastal protection and non-use benefits are next in terms of planning importance.

In the social arena, the Montego Bay work highlights several major insights regarding the importance of: i) user group awareness and concern; ii) opportunities to market the Park and to provide incentives; iii) user group involvement in management; iv) management of the Park as a community resource; and, v) intersectoral coordination among user groups (Chapter 11). The synergy of this information will assist Montego Bay Marine Park to maximize the socio-economic benefits of reef use through effective management.

Given the diversity of the stakeholders, the objectives of the Montego Bay Marine Park are to allow multiple, sustainable levels of activities, including fishing. Some misunderstandings are bound to occur, with some of the fishers, hoteliers, and water sports operators lacking trust in the equity of Park management's solutions. In the earlier years of the Park, misunderstandings produced low levels of compliance with regulations and management directives. The result was waning support. With the population of Montego Bay projected to double in the next 20 years, demand will press on marine resources, augmenting rival behavior of the users, animosity and conflict.

The applied research indicates that, to improve awareness, park education programs should be targeted specifically to the user groups primarily through outreach programs. Further, the Park's management programs should be highlighted, particularly the beneficial, tangible products and services (benefits) the Park provides to each user group (e.g., training for fishers, mooring systems for water sports operators). The closer the tie between reef conditions and business earnings, the greater the users' support for reef conservation.

The research highlighted economic and social benefits, and thereby helped create among user groups an awareness of Park benefits that may not have been immediately apparent to them.

For example, the tourism business in the area depends to a large extent on Montego Bay maintaining an image of a near pristine marine environment with a biologically diverse and healthy coral reef environment. However, although the economic health of the accommodations sector directly depends on tourism, the direct link between the marine environmental conditions and business activity is not necessarily perceived by owners and managers. Consequently, business and management decisions rarely consider the potential impacts of decisions on the reefs.

The coral reefs of Montego Bay are a common pool of resources managed under a regime of open access. The restrictions that have been put in place with the intent of preventing or curtailing the use by some groups have been ineffectively enforced (e.g., the ban on spear fishing), while there are no restrictions on use by other groups (e.g., diving and snorkeling). The user groups are generally aware of the severe decline in the reef conditions, yet under the current management environment, it is unrealistic to expect the users to curtail or alter their use patterns. To do so would cause an associated loss in short-term benefits or additional incurred costs, and would be seen as a sacrifice for the benefit of others.

The challenge is to shift from an open access regime to a management regime. The objective is to provide sustainable benefits perceived as fair to all users. Assigning individual rights, thereby restricting access and creating incentives is being explored with the hope of establishing and enforcing fishery priority areas and diving priority areas. Zoning is also pertinent in the area of genetic resources. Processed marine biological products (chemicals, enzymes and genes) are prized by the pharmaceutical industry because of their complex structures and novel biological activities (Chapter 12).

An example of bioprospecting in action is in Oman, where in November 1999 an international team of scientists in conjunction with a local university undertook a study of a coral reef off the coast of Oman to look for new molecules with possible antibiotic and cancer treatment uses. Since cancer does not occur in fish, scientists look for anti-tumoral agents in marine organisms, and are researching chemical defense systems in sponges. Between 1963 and 1995, 63 marine substances with anti-tumoral properties were patented worldwide. On previous expeditions Ardoukoba scientists have found sponges with anti-bacterial and anti-fungal properties. A mission to Mozambique produced substances which turned out to be effective in fighting herpes and HIV, the virus causing AIDS (Source Greenwire, November 27, 1999). Jamaican organizations offering these types of material would give Jamaica a clear competitive advantage over other countries.

Overall, we call for greater emphasis on the following:

- *Socio-economic concerns and clarification of property rights*, involving the promotion of practical local management regimes that involve affected stakeholders in the resource base;
- *Institutional strengthening to participate in potential bioprospecting benefits*; and,
- *Ecosystem analysis*, focusing on functional linkages and relationships and protection of critical ecosystems.

The research is relevant to ongoing and, particularly, future World Bank operations. To date in the World Bank, there has been little lending specifically for integrated coastal zone and coral reef management. Two notable exceptions are the Coral Reef Rehabilitation and Management Project (COREMAP) in Indonesia, which establishes viable, operational, and institutionalized coral reef management areas in priority reef sites, and the Meso-American Coral Reef Initiative, which is encouraging dialogue on better reef management between Mexico and Central American countries. The World Bank's role in these projects is expected to increase in the future, and it is currently assisting several countries in designing coastal zone related projects. Also, the Global Environment Facility (GEF), for which the World Bank is an implementing agency, is interested in developing projects to manage and protect biodiversity, such as that found in coral reefs. We conclude that better integration of ICZM requires:

- Building consensus on national coastal management priorities;
- Supporting innovative local initiatives such as the Montego Bay Marine Park;
- Developing quantifiable indicators of change in the coastal zone; and,
- Strengthening institutional capacity and partnerships in the form of international maritime agreements.

The research has been supported by the World Bank Research Committee, Knowledge Management (KM), and Dutch and Canada trust funds, and may be found on the BIONODE and Water Resources websites. Work will continue in the form of a dissemination strategy that has four facets (Chapter 13):

- Launch a road show to disseminate this publication that includes a CD-ROM of the Coral-Curaçao, Coral-Maldives, COCOMO (COastal COnservation in MOntego Bay) decision support models (Chapter 10);
- Continue workshops supported by Knowledge Management, of which dozens have been held at the national and local level;
- Create interactive programs on the World Bank Knowledge Management web sites (BIONODE and Water Resources) and other websites; and,
- Assist the Montego Bay Marine Park Trust in the preparation of a regional replicable project entitled ReefFix (Chapter 2).

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Many individuals made important contributions to the work as presented in the individual chapters and to research in earlier phases of projects. Creating the models required a true team effort. For the Montego Bay study site, Kirk Taylor and Jill Williams of the Montego Bay Marine Park Trust helped coordinate the efforts. In the Republic of the Maldives, Mohammed Kahleel, Simad Saeed and Azima Shakoor of the Ministry of Population, Human Resources and Environment acted as government contacts and provided coordination. In Curaçao, the Ministry of Public Health and Environment of the Netherlands Antilles served this function. Jeffrey Sybesma (VOMIL), Leon Pors (Curaçao Underwater Park) and Imma Curiel (University of the Netherlands Antilles) were also exceptionally helpful.

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Any opinions or conclusions expressed herein are those of the authors and do not necessarily reflect the position of the World Bank or its affiliated agencies.

Publication Production and Photographs

Typesetting and technical services were provided by Diane Braithwaite and Ken Josephson of Technical Services, Department of Geography, University of Victoria in Victoria, British Columbia, Canada. All of the photographs that appear in this publication, with the exception of the aerial photographs of Chapter 1, were selected from an exhibition of more than 120 photographs held at the Montego Bay Marine Park Resource Centre during the summer of 1999. The photographs appear here with the permission of the photographers and the Montego Bay Marine Park Trust. The photographers include Hannie and Theo Smit, Terry Silsbury, and Janos Bayer. In addition, Dean Salmon and Salmon's Photo Studios in Montego Bay provided necessary processing of the images. The use of these photographs would not be possible without the contributions made by all of these individuals.

Hannie and Theo Smit are long-term residents of Montego Bay, dive-masters, and owners of Poseidon Divers in Montego Bay. They are renown as the diving experts of Jamaica and recently authored *The Diving Guide to Jamaica* published by Lonely Planet. Theo Smit is a founding director and still active on the board of the Montego Bay Marine Park Trust. His early writings and lobbying efforts in the 1980s were largely responsible for the creation of the Montego Bay Marine Park in 1992.

Terry Silsbury, a native of Toronto, Canada, has been diving in Montego Bay twice yearly for over 20 years and has seen many changes for the worse and the better in that time. His keen observations and spectacular photographs have been a source of encouragement for park management in recent years as improvements have begun to be noticed.

Janos Bayer is a long-term resident of Jamaica. He is an architect, town planner and environmental engineer, but his poignant impressions of life in Jamaica have been exhibited worldwide and won numerous awards.

Key to Photographs

Cover:	Flamingo tongued snail and common Caribbean sea fan, photographed by Theo Smit.
Page iii:	Fishing boats on beach at White House, photographed by Janos Bayer.
Page viii, top:	Canterbury housing settlement, photographed by Janos Bayer.
Page viii, bottom:	Fire coral, photographed by Theo Smit.
Page xiv, top:	Fishing boat in mangroves at White House, photographed by Janos Bayer.
Page xiv, bottom:	Soft coral, sponges and other corals, photographed by Theo Smit.
Page 46, top:	Yellow tailed jacks, photographed by Terry Silsbury.
Page 46, bottom:	Fishing boats on River Bay fishing beach, photographed by Janos Bayer.
Page 156, top:	Brain coral and Christams tree tube worms, photographed by Theo Smit.
Page 156, bottom:	Fishing boat at Flankers canal, photographed by Janos Bayer.
Page 205, top:	The North Gully, photographed by Janos Bayer.
Page 205, bottom:	Anemone and shrimp, photographed by Hannie Smit.

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I: The Need for Decision Support Models

Chapter 1

Integrated Coastal Zone Management in the Tropical Americas and the Role of Decision Support Models

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Coral reef ecosystems are under increasing pressure, the threats being primarily from human activities. In some cases, natural disturbances further compound the effects of anthropogenic stress. The declining state of coral reef ecosystems has sparked concern by scientists, managers and government officials. The 1991 National Science Foundation, Environmental Protection Agency and National Oceanic and Atmospheric Administration sponsored workshop on coral bleaching, coral reef ecosystems and global climate change (D'Elia *et al*. 1991), the Seventh International Coral Reef Symposium in 1992 (Richmond 1993), and the meeting of experts on "Global Aspects of Coral Reefs: Health, Hazards and History" held at the Rosentiel School of Marine and Atmospheric Science in Miami (Ginsburg 1994) all stressed these concerns. The IUCN (1993) estimated that about 10% of tropical coral reefs have already been degraded beyond recovery and another 30% are likely to decline significantly within the next 20 years. An International Coral Reef Initiative report (Jameson *et al*. 1995) stressed that unless effective integrated coastal zone management is implemented, more than two-thirds of the world's coral reefs may become seriously depleted of corals and associated biota within two generations.

The coral reef ecosystems at greatest risk are in South and Southeast Asia, East Africa, and the Caribbean; however, people have damaged or destroyed reefs in more than 93 countries (Jameson *et al*. 1995). Rapid population growth and migration to coastal areas, where coral reef ecosystems occur, exacerbate the problem. The resulting coastal congestion leads to increased coastal pollution and problems related to coastal construction. Increasing competition for limited marine resources results in the adoption of destructive fishing methods. Technologies allow humans to exploit the reef with mechanical dredges, hydraulic suction, dynamiting, and poisoning. Some of the major causes of localized coral reef ecosystem decline include:

- The overexploitation of reef resources (fish stocks have declined significantly in many reef areas, especially near centers of human population);
- Excessive domestic and agricultural pollution; and,
- Poor land use practices that increase the amount of sediment entering the coastal environment.

Results of the 1997 and 1998 Global Coral Reef Monitoring Network/Reef Check surveys showed that most of the world's reef-building "corals" are in good to excellent condition, because they are either remote from human populations, or they are under good management, such as the Great Barrier Reef (Wilkenson 1998). Reef Check 1997 surveys, from over 300 reefs in 31 countries, found that the mean percentage of living coral cover on reefs was 31% world-wide; the Caribbean had the lowest percentage at 22%, "possibly reflecting losses due to bleaching and disease" (Reef Check 1997). However, 1997 Reef Check surveys indicated that few "coral reefs" were unaffected by human activities, even in very remote sites, because overfishing has reduced high-value indicator organisms such as lobster, sharks and grouper to low levels at most reefs, including some with marine protected areas (Hodgson 1998). Surveys also showed that management in most marine parks is failing to stop the loss of high-value, edible species, and that greater attention is needed to improve management. The ecological balance in many of the world's best reefs has been altered by the removal of high-value organisms (Wilkenson 1998). In 1998, over 40 countries participated in the second annual Reef Check survey, and results showed that extensive bleaching and mortality of corals has occurred in parallel with the massive 1997/1998 El Niño event. Mortality on a scale never previously reported is occurring, including some corals that have previously survived for centuries (Hodgson 1998).

A recent estimate by the World Resources Institute, using map-based indicators, suggested that as many as 58% of the world's reefs are threatened by human activity (Bryant *et al.* 1998). Approximately 10% of the world's reefs have been severely damaged or destroyed by being mined for sand and rock, reclaimed for development (particularly for airports), or buried under sediment washing into the sea from inappropriate land use (Wilkenson 1998).

Based on current global climate change and population trends, Kleypas *et al.* (1999) and Buddemeier (1999) predict that, on a large scale within the next few decades, coral reefs will continue to die because of rising human population levels, rising temperatures, rising atmospheric/surface ocean CO_2 levels, and other local aspects of global climate change.

Benefits of Coral Reefs

Millions of people depend on reefs for a source of food and livelihood. Reefs also create sheltered lagoons and protect coastlines and mangroves against wave damage. Mangroves in turn protect reefs from sedimentation and eutrophication. Mangroves and seagrasses also play an important role in coastal protection and provide spawning and nursery areas for reef and offshore fishes. The economies of many atoll nations are primarily based on marine resources. In the Pacific, over 2.5 million people live on islands built by, or surrounded by, coral reef ecosystems. In Hawaii, coral reefs are central to a US$700 million marine recreation industry. Reef fish, lobsters, and bottom fish generate approximately US$20 million in landings annually and are an important source of food for local people and for restaurant consumption (Grigg 1997). Diving brings US$148.6 million annually to Guam (Birkeland 1997). Over 300,000 people live on coral islands in the Indian Ocean and many more in the Caribbean. Coral reefs provide 10% to 12% of the harvest of finfish and shellfish in tropical countries and 20% to 25% of the fish catch of developing countries. As much as 90% of the animal protein consumed on many Pacific islands comes from marine sources (IUCN 1993).

The potential sustainable yield of fishes, crustaceans and molluscs from coral reefs could be some 9,000,000t (12% of the world fisheries catch; IUCN 1993). At the present time, only a fraction of this potential yield is realized. More important than the actual monetary values associated with the fisheries, people more widely benefit from reef use as a major source of income and employment in regions where often few employment alternatives exist. Tourism and the recreational use of reefs on a large-scale are recent developments.

Numerous figures are available describing tourist revenue derived from coral reefs, but few are clearly defined or comparable. The coral reefs of Florida alone have been estimated to generate US$1.6 billion annually from recreation uses (USDOC 1994). Figures for developing countries are better expressed in other ways. For many Caribbean countries, tourism is now the key economic sector, often providing over 50% of GNP, and growing quickly (Jameson *et al.* 1995). In 1990, Caribbean tourism earned US$8.9 billion and employed over 350,000 people (Holder 1991). Divers and other special interest tourists may account for one-fifth or more of this total. A 1981 Island Resources Foundation cost-benefit study of the Virgin Islands National Park found that the benefits associated with reef use (US$23.3 million, of which US$20.0 million was indirect) were more than ten times larger than the costs (US$2.1 million), clearly showing the economic benefits of a marine protected area (Dixon 1993). In Thailand, some 5,000 small boat and dive shop operations are dependent on reef tourism (Spencer Davies and Brown 1992).

Collecting aquarium fishes and live corals for European and North American markets has developed into another lucrative, but sometimes destructive, industry. Harvesting methods often kill organisms not intended for collection and many of the fish collected may die before reaching markets. Tourism can be an environmentally friendly way of generating income from coral reef ecosystems, but only when resort development and operations are carefully controlled. Unlimited collecting, sport fishing, and accidental damage by waders, swimmers and boat anchors can all degrade the reefs that earn tourist dollars. Allowing sewage and other wastes from tourist facilities to pollute reefs, or siting resorts such that beach erosion increases, can be even more degrading to the health of the reefs than the direct damage caused by individuals. Degradation of coral reef ecosystems would have significant negative impacts on world food sources, long-term negative economic impacts on fishery and tourist industries, and devastating social and economic impacts on millions of people around the world for whom coral reefs represent the primary source of livelihood.

The North Coast of Jamaica Perspective

In the most frequently cited work on the status of Jamaica north coast coral reefs, Hughes (1994) attributes the decline in coral cover (from more than 50% in the late 1970s to less than 5% in 1993) and the increase in macroalgal cover (representing a "phase shift" in the community) to the combined effects of overfishing, hurricane damage, and disease. He further states that "there is no evidence that the nation-wide algal bloom in Jamaica was caused by increased nutrients, because it occurred throughout the Caribbean immediately following *Diadema antillarum* [sea urchin] die-off, usually far from sources of pollution", and that there is "an urgent need to control overfishing" (Hughes 1994). However, there is considerable evidence that eutrophication, by itself, can lead to a reduction in reef fish populations (Johannes 1975). Thus, it is unlikely that simply controlling fishing practices will restore Jamaica's reefs, or other coral reefs being impacted by severe eutrophication. More importantly, the reality of large-scale coastal eutrophication needs to be vigorously confronted by scientists and managers alike, both in Jamaica and world-wide.

Discovery Bay

LaPointe *et al*. (1997), using 1987 data (i.e., nutrient enrichment bioassays, alkaline phosphatase assays, water-column nutrient determinations, indicator species, biotic cover and tissue nitrogen levels) from when reef communities were undergoing a phase shift from coral to macroalgal dominance, challenged Hughes' (1994) assumptions concerning the role of nutrient enrichment by showing that it was, in fact, an important synergistic factor responsible for the increased growth rates and standing crop of macroalgae on reefs at Discovery Bay. This finding offers an additional dimension of complexity and robustness towards fully understanding the phase shift.

LaPointe *et al*. (1997) affirms the need to adopt broad theoretical approaches to testing management related hypotheses regarding the degradation of coral reefs. He warns that scientists should guard against preconceived concepts, research designed to verify rather than falsify hypotheses, and narrow approaches that do not test multiple hypotheses, which can all lead to the acceptance of oversimplified hypotheses. While this is unhealthy for science in general, it can be especially devastating for coral reef conservation, especially in light of bureaucrats and resource managers often looking for a politically expedient "quick fix". Hughes' (1994) conclusion that a ban on fish traps is needed to save Jamaican reefs is extremely important, but unfortunately implies to managers that the effects of eutrophication are relatively minor.

Other points made by LaPointe *et al*. (1997) that have important management implications for other reef locations on the north coast of Jamaica, and throughout the world, include the following:

- The dissolved inorganic nitrogen (DIN) and soluble reactive phosphorus (SRP) concentrations at Discovery Bay measured during this study rank among the highest concentrations reported for coral reefs anywhere in the world and explain why such impressive macroalgal biomass now dominates this eutrophic reef system.
- The potential eutrophication at Discovery Bay was documented by widespread groundwater inputs of nitrate (NO_3^-) in conjunction with predictions of increased SRP enrichment associated with exponential human population growth and sewage pollution.
- NO_3^- and SRP concentrations reported by D'Elia *et al*. (1981) for back-reef habitats already exceeded critical nutrient thresholds for eutrophication, explaining why macroalgal blooms began expanding in the early 1980s throughout back-reef communities prior to the die-off of *Diadema antillarum* in 1983.
- Near-shore groundwater data from Lapointe *et al*. (1997) and D'Elia *et al*. (1981) suggest that nutrient concentrations increased in the back-reef during the 1980s and spatially spread offshore, elevating DIN and SRP levels on the fore-reef above critical thresholds.
- The significant NO_3^- levels and concomitant salinity stratification throughout the study area at Discovery Bay shows that nutrients derived from submarine groundwater discharges and springs along the shore are transported offshore as buoyant plumes.
- In addition to offshore nitrogen dispersion via buoyant surface plumes, low salinity, high NO_3^- pore waters have been found (Pigott and Land 1986) in fore-reef sediments at Discovery Bay, suggesting that NO_3^--rich groundwater is seeping through the fore-reef itself and clearly showing that extensive areas of the Discovery Bay fringing reefs to depths of at least 24m are being affected by groundwater DIN enrichment.
- DIN and SRP concentrations throughout the back-reef had been above critical thresholds for over a decade before Hurricane Allen struck in 1980, causing severe damage to the reef and the luxuriant stands of elkhorn coral. The reduction of upright corals to rubble, at a time when nutrient concentrations were above critical thresholds, allowed the faster developing macroalgae to physically out-compete the corals and turf algae. Eutrophication not only increases the biomass of macroalgae, but also reduces the reproductive capacity of hermatypic reef corals and inhibits coral larval settlement and survival.

All of these factors, driven by eutrophication processes, provide a more robust explanation for the replacement of corals by macroalgae on reefs at Discovery Bay.

- Other evidence moderating the "top-down" interpretation of Hughes (1994) includes the fact that fish populations on the deep fore-reef (below 15m) were overfished through intensive use of fish traps in the 1960s (Munro 1983), long before the widespread and massive blooms of *Sargassum polyceratium* developed on the reefs in the late 1980s. Furthermore, the mass mortality of *Diadema antillarum* occurred in 1983, years prior to the expansion of *Chaetomorphia linum* and *Sargassum polyceratium* from restricted areas around grottos in the back-reef onto the fore-reef. Hence, there is inconsistency in the timeline between reduced herbivory from overfishing and massive macroalgal overgrowth in both shallow and deep habitats. These observations further reinforce the conclusion that reduced herbivory could not have been the only factor causing the massive macroalgal blooms that developed on reefs at Discovery Bay.
- The locations of most of the macroalgal dominated habitats cited by Hughes (1994) suggest large-scale non-point-source nutrient loading associated with deforestation, sewage, and agricultural and industrial development. All of these sources increased in prominence along Jamaica's coast over the past decades and, hypothetically, contributed to nutrient over-enrichment, giving rise to the macroalgal blooms that now dominate these degraded coral reefs.

Montego Bay

Sullivan and Chiappone (1994), in their rapid ecological assessment of Montego Bay, consider nutrient loading and eutrophication, water quality and circulation changes, and mechanical damage as the three most serious threats to the coral reef ecosystem within the Montego Bay Marine Park. Jameson (1997), Hitchman (1997) and USAID (1996) also show nutrient levels above threshold values for coral reef ecosystems. Box 1.1 describes an environmental monitoring program conducted for Montego Bay that was funded by the patron of the new sewage treatment plant.

Williams and Polunin (1999) discovered that Jamaica (Montego Bay and Negril sites) had the lowest abundance of herbivorous fishes, the highest coverage of macroalgae (70.5% for Montego Bay and 66.15% for Negril) and the lowest coverage of grazed substratum (turf, bare and crustose coralline surfaces) of 19 reefs surveyed throughout the Caribbean. Except for Jamaica, the abundance of herbivorous fishes was broadly similar on most of the other 19 reefs. There was a six-fold difference (2.7g/m^2 vs. 17.1g/m^2) in the concentration of herbivorous fishes between Jamaica and Barbados (the highest abundance in the study). Pooled data from all sites sampled in Montego Bay by Sullivan and Chiappone (1994) and Williams and Polunin (1999) shows that, from 1992 to 1997, algae cover (all types) increased from 36% to 84%.

The big challenge for Montego Bay Marine Park will be to reverse the aforementioned phase shift. Effectively dealing with the nutrient rich secondary treated effluent that will be discharged into the Park by the new sewage treatment plant is top priority (unfortunately, only human health concerns, not coral reef health, were considered when the new facility was designed). A deep ocean outfall taking the effluent nutrients away from the coral reefs or artificial wetlands that remove the nutrients before discharge into the bay are viable options. Identifying and mitigating other land-based sources of pollution will also be of the utmost importance. Restoring the herbivorous fish population and the critically important macroalgae grazing sea urchin population (Woodley 1999; Woodley et al. 1999) will also be a vital part of the restoration process required to bring this valuable ecosystem back into balance (see Chapter 2).

Negril

Recent water quality research off Negril (LaPointe 1999), using radioisotope techniques, shows that the reefs are, on average, above the nitrogen threshold for macroalgal blooms. The nitrogen was high year round on both deep and shallow reefs, whereas phosphorus concentrations significantly increased in rivers, streams and groundwaters within the watershed and throughout the entire Negril Marine Park. The nitrogen concentration is always high in the Park because it is consistently being transported and discharged through groundwater into the marine environment. Salinity data from Sands Club showed that fresh water from groundwater discharges is affecting reefs several kilometres from shore. Video surveys show that macroalgal blooms on deep and shallow reefs had distinct compositions. *Halimeda*, a calcareous algae, dominated deep reefs off Green Island and Little Bay, compared to shallow reefs that were dominated by fleshy macroalgae, such as *Sargassum, Dictyota, Cladophora,* and *Chaetomorphia*. Rainfall and nutrient data indicated that the massive blooms of *Chaetomorpha* on the shallow reefs of Orange Bay were initiated by phosphorus enrichment, apparently linked to "soak aways" (cesspits) on the adjacent watershed, as well as possibly other sources such as fertilizers. The radioisotope monitoring data revealed that the nitrogen ratio in macroalgae at Davis Cove, North Negril, Long Bay and Little Bay were linked to sugarcane fertilizers, in comparison to macroalgae in South Negril and to a lesser extent Ironshore, where they were found to be associated with sewage nitrogen. The watershed monitoring data illustrated how different land uses enrich the rivers and streams in the area. In the low salinity areas where there are fresh water inputs, there were higher levels of nitrogen and phosphorus. All data consistently showed that salinity was inversely correlated with nitrogen and phosphorus, showing the importance of enrichment to nutrient delivery on downstream reefs. Both phosphorus and nitrogen concentrations on the Davis Cove sub-watershed were significantly higher around canefields, showing the nutrient enrichment associated with fertilizers on canefields in the Davis River that flows out to the reef. In the South Negril River sub-watershed, the high phosphorus concentrations in the estuarine portion of this study area are linked to the considerable sewage inputs from "soak away" pits, squatter communities without sanitary conveniences, inadequately treated sewage outfalls, and livestock on the river bank.

The Monitoring of Coral Reefs

Information for accurately evaluating the condition of the world's reefs is critical for effective management. In many cases, however, this knowledge is lacking. Many countries with coral reef ecosystems need training and capacity building to apply scientific management principles. Non-governmental organizations (NGOs) have played and will continue to play a significant role in coral reef ecosystem conservation. As most countries have not incorporated integrated coastal zone management (ICZM), economic and environmental decision-making has not been fully integrated for the protection and sustainable use of coral reef ecosystems. However, global and regional coral reef programs have developed (Table 1.1).

A project which is specifically designed to provide centralized access to information from these and other coral reef programs is ReefBase: the International Database on Coral Reefs (McManus and Ablan 1997). This project of the International Center for Living Aquatic Resources Management (ICLARM) seeks to gather a broad range of information about the status of the world's reefs from papers, reports and inputs from monitoring projects. The project includes an activity of the World Conservation Monitoring Center (WCMC) to digitize maps of coral reefs and to make them available through the database. The ReefBase project serves as a medium of information exchange for scientists, particularly those in developing countries with limited library facilities, and as a conduit of useful information to coastal planners and managers.

The Land-Ocean Interactions in the Coastal Zone (LOICZ) project of the International Geosphere-Biosphere Programme (IGBP) is looking at the role of coastal processes in global climate change. The crucial role of CO_2 and other gases in the calcification process of reef-building corals is of critical importance with the increasing CO_2 levels associated with global warming. They stress the need to better understand coral reef systems, with various scales and perspectives, especially with respect to survival, adaptation and acclimatization (Buddemeier 1999). They also stress the need to better understand human impacts on reef functions, the responses of reefs to changes in sea level, and the interactions between coral reefs and other ecosystems. In particular, more needs to be known about interactions with adjacent land masses, such as through the hydrological cycle. LOICZ is also concerned that rising sea levels would have very serious consequences for many nations situated on low coral reef archipelagos, such as the Republic of the Maldives.

Table 1.1. Relevant partnerships involved with global or regional coral reef programs (source: derived from a database maintained by Anthony J. Hooten of the World Bank)

Partnership or activity	*Region or country*	*Specific activities*	*Resources (million US$)*	*Status*
Coral Bleaching and Mortality in the Central and Western Indian Ocean	India, Kenya, Madagascar, Maldives, Mozambique, Seychelles, Sri Lanka, and Tanzania	Program will focus on the ecological and socio-economic effects of coral mortality in coastal areas of eight participating countries	1.1 over three years (Sida/ SAREC)	Approved (first meeting January 1999)
Coral Bleaching and Mortality in the Central and Western Indian Ocean	Same as above	Same as above	0.35 (World Bank/ Netherlands)	Approved (first meeting January 1999)

Table 1.1 continued overleaf

Table 1.1. continued

Partnership or activity	*Region or country*	*Specific activities*	*Resources (million US$)*	*Status*
World Bank/ GEF Indian Ocean Commission/ France - WIO Coral Reef Monitoring	Comoros, Madagascar, Mauritius, Reunion, and Seychelles	Establishment of a long-term coral reef monitoring program for the IOC countries	1.0 for medium-sized GEF project	Under preparation (endorsement letter from all countries)
Meso-American Barrier Reef Initiative (MBRI)	Belize, Guatemala, Honduras, and Mexico	Regional program to jointly manage and protect the world's second largest barrier reef	16.25	Under preparation (began 1998)
International Coral Reef Initiative (ICRI)/ Global Coral Reef Monitoring Network (GCRMN)	World-wide, based upon six regional nodes and the ICRI Secretariat	A global effort to increase capacity of regions and countries to monitor and manage coral reefs and associated ecosystems through ICZM and other vehicles, with over 80 participating countries	Unknown (some support from US State Department, Australia, and France)	Secretariat transferred to France for 1998 to 2000; five of six regional nodes identified for the GCRMN
International Coral Reef Action Network (ICRAN)	World-wide (total of eight regions)	A global effort to reverse the trend of coral reef degradation by initiating priority protective action in constituent countries, including model protected areas and coral reef management systems	1.15 start-up (United Nations Fund; four year action phase TBD)	Anticipated early 1999, pending proposal acceptance before the United Nations Fund
COREMAP Indonesia (supported by the World Bank, ADB, and USAID)	Indonesia	Establishment of management structures in Indonesia, including improved monitoring efforts	33.1 phase one; total of 263.1 over 15 years	Supported by the World Bank, ADB, USAID, and Indonesia
Information related to the Caribbean Program for Adaptation to Climate Change (CPACC) - World Bank/ OAS	Caribbean basin (three pilot countries - Bahamas, Belize, and Jamaica)	Pilot to establish a Caribbean monitoring program to measure effects of climate change and anthropogenic impacts	0.406	Underway (workshop held in 1998; monitoring to be established in 1999)
Reefs At Risk - World Resources Institute (in collaboration with ICLARM, WCMC, and UNEP)	World-wide	Map-based indicator of threats to the world's coral reefs	Unknown (supported by WRI and ICLARM)	Global phase completed; beginning regional assessments, starting with the Philippines
ReefBase	World-wide	Serves as a global database for coral reef related information, including the GCRMN	Unknown (supported by ICLARM)	Active
Edited Monograph on Coral Reef Economics	World-wide	Text of coral reef economics with global case histories	Unknown (supported by Sida/ SAREC)	Under development (estimated completion late 1999)

Diagnostic Biological Monitoring— Essential to Manage Coral Reef Ecosystems

Coral reef monitoring programs have become ubiquitous over the course of the past two decades (Eakin *et al*. 1997; Risk 1992), ranging from monitoring by individual research scientists to that conducted by large institutions like the Australian Institute of Marine Science, the CARICOMP (Caribbean Coastal Marine Productivity) network or world-wide efforts such as the Global Coral Reef Monitoring Network. The scope of reef monitoring has recently expanded even further with the introduction of monitoring programs specifically designed for volunteer sport divers, such as the ReefBase Aquanaut and Reef Check programs (Hodgson 1997; McManus *et al*. 1997). While these "state of the art" efforts have been very successful at what they were designed to do (i.e., document change in coral reef ecosystems), they are, for the most part, not capable of predicting what is causing the changes.

Because of the non-diagnostic nature of most coral reef monitoring programs, policy-makers and government officials are not well equipped to communicate to the public or politicians the causes of coral reef resource decline or the appropriate solution for remediation. To protect coral reef resources, we should track the biological condition of these ecosystems in a manner similar to the way we track local and national economies or diagnose personal health—using calibrated indicators. Indicators that integrate the influence of all forms of degradation caused by human actions can thus guide diagnostic, curative, restorative and preventive management actions.

Importance of Bioindicators in Coral Reef Ecosystem Assessment

Indicator organisms have a long history of use for detecting qualities about an environment that are otherwise difficult to perceive, from the well-known "canary in the coal mine" to the highly successful "Musselwatch" program in North American bays (Soule 1988). Freshwater and marine organisms have been used extensively as bioindicators since the 1970s (Phillips 1980).

The use of bioindicators has been justified in marine pollution monitoring programs for at least three reasons (Maher and Norris 1990):

1. They assess only those pollutants which are bioavailable, ostensibly those which are most important;
2. They can reveal biological effects at contaminant levels below current chemical analytical detection limits (either due to chronic, low level pollution or short-term pulses); and,
3. They can help assess synergistic or additive antagonistic relationships among pollutants, an important consideration given the typical multiple pollution impacts impinging on most reefs in the developing world (Ginsburg 1994).

The aim of any coral reef ecosystem assessment program is to distinguish relevant biological signals from noise caused by natural spatial and temporal variations. In choosing biological indicators, one should focus on attributes that are sensitive to the underlying condition of interest (e.g., human influences) but insensitive to extraneous conditions. Faced with the dizzying number of variables, disturbances, endpoints, and processes, marine managers and researchers have periodically failed to choose those attributes that give the clearest signals of human impact. The world's coral reef ecosystems have declined as a result.

Status of Coral Reef Ecosystem Bioindicators

Jameson *et al*. (1998) review the status of coral reef ecosystem bioindicators. With few notable exceptions, the majority of these bioassays have not yet been fully developed into usable monitoring protocols. In these respects, coral reef bioindicators lag far behind freshwater and temperate marine biomonitoring programs, many of which have undergone extensive calibration and have been developed into multi-metric indices of "biotic integrity" with well-defined interpretative frameworks (e.g., Davis and Simon 1995; Karr 1991; Karr and Chu 1999; Karr *et al*. 1986; Kerans and Karr 1994; Lang *et al*. 1989; Lenat 1988; Rosenberg and Resh 1993; Wilson and Jeffrey 1994). Many of these indices result in the calculation of a simple numerical "score" for a particular site, which can then be compared over time or with other sites. Such rankings have an intuitive appeal to resource managers and users, and can be an effective means of galvanizing political willpower towards pollution prevention and conservation activities.

Developing Biological Criteria for Coral Reef Ecosystem Assessment

Biological criteria are narrative expressions or numerical values that describe the "biological integrity" of aquatic communities inhabitating waters of a given designated aquatic life use (USEPA 1990a). Biological integrity is the condition of the aquatic community inhabiting unimpaired or minimally impaired water bodies of a specified habitat as measured by community structure and function (USEPA 1990b).

The first step towards effective biological monitoring and assessment is to realize that the goal is to measure and evaluate the consequences of human actions on biological systems. The relevant measurement endpoint for biological monitoring is biological condition. Detecting change in that endpoint, comparing the change with a minimally disturbed baseline condition, identifying the causes of the change, and communicating these findings to policymakers and citizens are the tasks of biological monitoring programs. Understanding and communicating those consequences to all members of the human community is perhaps the greatest challenge of modern ecology (Karr and Chu 1999).

The use of multiple measures, or metrics, to develop biocriteria is a systematic process involving discrete steps (Jameson *et al*. 1998). The United States Environmental Protection Agency recognizes the need and benefits of a biological criteria program for coral reef ecosystem assessment and is in the process of exploring the feasibility of developing a program for coral reef ecosystems under United States jurisdiction (Jameson *et al*. 1998, 1999).

The Need for Integrated Coastal Zone Management

As stated in the introduction to this chapter, many marine ecosystems in the tropics are deteriorating under heavy pressure from human and economic activities. About 10% of the world's reefs have already been degraded beyond recognition, while another 60% are likely to disappear in the next 10 to 40 years; the 30% that do not appear to be undergoing negative effects are those in remote areas, essentially removed from the influences of man. Lack of harmonized legislation between the tropical islands (such as regional sand mining legislation), lack of appropriate policies (such as existing subsidies for gasoline to artisanal fishers), lack of adequate protection mechanisms (such as designated marine protected areas), lack of appropriate zoning (such as designated fishery priority areas), and lack of infrastructure to support tourism (such as sewage and solid waste management) have all caused marine resource deterioration, threatening the natural and cultural fabric of these vulnerable small island developing states.

International tourism has been an important economic element in the post-war period to the Caribbean. These countries primarily draw on outstanding marine ecosystems attracting the "sun-sea-sand" clientele and the ecotourist, who is also attracted by cultural/ethno-historical phenomena such as pre-Colombian archaeological sites, colonial architecture, and contemporary handicraft industries. Both types of tourists require distinct packages and infrastructure, and both types have led to resource and cultural deterioration, coining the phrase "tourism destroys tourism".

Rehabilitation and management of conservation areas, revitalization of the tourism industry, and empowerment of local governments and communities to manage and benefit from the sustainable use of natural resources, are now high priorities for the Caribbean countries as demonstrated by important policy and institutional reforms already completed or underway. Montego Bay, Jamaica, provides an excellent example. Responsibility for management of the marine park has recently been transferred from the Jamaican government to an NGO—the Montego Bay Marine Park Trust (the Trust). The Trust has an explicit policy of promoting community participation in management and the sharing of the benefits.

Over a period of several years, the people of Montego Bay have felt the repercussions of poor planning:

- Serious resource depletion problems increasing pollution of the inshore, coastal and ocean environment;
- Loss or damage to productive coastal ecosystems, increasing losses of life and property from coastal hazards and disasters; and,
- Conflicts of interests among user groups.

They began to share a common vision, including a desire to increase the economic benefits flowing from the use of coastal zone resources and the exploration of economic opportunities associated with new forms of development in the coastal zone. Solutions included implementing a more participatory approach to planning involving NGOs and community-based groups, developing institutional mechanisms for cross-sectoral cooperation, and the enforcement of and compliance with integrated policies, including the use of positive reinforcement and incentives (see Chapters 2 and 11). There are examples to which the Trust can turn that demonstrate the elements of a successful ICZM strategy. Box 1.2 describes a case study that provided rapid results in the United States.

The World Bank and Integrated Coastal Zone Management

There is a growing interest, particularly among private sector hotel associations and environmental NGOs, in adopting ICZM as a means of maintaining a balance between economic growth and the protection of valuable ecosystems. ICZM guides jointly the activities of two or more sectors in the planning, development and implementation of projects, instead of treating individual sectors separately (e.g., sewage pollution and industrial waste management). The World Bank has recently issued guidelines for the use of ICZM (World Bank 1993a, 1996; guidelines have also been developed for integrated water resources management for the environmental impact assessment of projects that might affect coastal ecosystems).

The definition of the coastal zone used for small islands usually includes the island as a whole—that is, including all watersheds that drain into the coastal zone. Also, from an ecological perspective, the zone in which freshwater and saltwater mix (i.e., estuaries, mangroves or lagoons) is usually very valuable. These gradient zones often have a very high level of biodiversity and productivity. There are also many physical linkages between coastal and freshwater resources:

- Watershed management influences run-off and erosion, which affects water quality in the coastal zone (e.g., non-point source pollution);
- Groundwater exploitation in alluvial coastal plains that lowers the groundwater table often increases saline seepage and infiltration;
- Wastewater management (e.g., treatment plants, ocean outfalls) directly influences water quality in the coastal zone;
- Coastal wetlands, such as mangroves and lagoons, are dependant on both the water resources and coastal zone management; and,
- For coastal tourism, the management of the coastal zone and the water resources are often intricately linked.

Immediate government priority must be placed on the development and implementation of ICZM strategies to effectively manage the coral reef ecosystems of the world. These strategies should address human activities in the coastal watershed and marine environment and involve combinations of:

- Public education (including education in the use of traditional forms of reef tenure and management, education on sustainable use practices, and education to stabilize population growth);
- Community development;
- Economic incentives;
- Legal and institutional restructuring;
- Well managed marine protected areas;
- Regulation and enforcement of reef resource exploitation;
- Management of tourism and recreational activities (e.g., education programs, installation of mooring buoys);
- Management of land-based activities and coastal development (e.g., using environmental impact assessments, wise siting of facilities); and,
- Coral reef ecosystem monitoring, mapping, and database creation and restoration.

Combining these management techniques is critical for success. If used alone, these techniques tend to be ineffective over the long-term. They must be strongly supported at scales ranging from the village to the nation, and often at the regional scale as well. They must be oriented towards the long-term sustainability of reef resources, and designed to be adaptive to different cultures and governments, as well as changing situations, without compromising effectiveness.

A world-wide system of marine protected areas should be established to encompass at least 20% of all reefs (Jameson *et al*. 1995; PDT 1990). This should include widely dispersed small reserves involving up to a few tens of square kilometres, and several strategically located large reserves at the scale of hundreds or thousands of square kilometres. Ideally, these protected areas should form part of wider coastal zone planning initiatives encompassing the reef systems of entire countries and integrating the needs of local peoples, commercial fisheries, tourism, terrestrial construction and agriculture development, and nature conservation.

Capacity Building

A concerted effort must be made to enhance the capacities of countries, particularly developing countries with coral reefs, to conduct scientific research and to design and implement informed, effective integrated management systems. This implies not only the transfer of information, but more importantly, the exchange of experiential learning among developing countries.

Improved Scientific Understanding of Coral Reef Ecosystems

Efforts must be enhanced to survey the coral reefs of the world to provide information on their ecological and management status. Scientific management information is needed for:

- Understanding the relationship of natural to anthropogenic impacts;
- Conducting damage assessments;
- Understanding coral recruitment, and the maintenance and renewal of reefs;
- Understanding current patterns to determine the distribution of reefs and the fate of pollutants; and,
- Developing an improved scientific concept of what constitutes a healthy reef so it will be possible to gage changes on impacted ecosystems.

So that the health of coral reef ecosystems can be monitored in a systematic manner, the Intergovernmental Oceanographic Commission (IOC) Global Coral Reef Monitoring Network, which will provide valuable data to the larger Global Ocean Observing System, should be maintained and improved (Jameson *et al*. 1995). In addition, new efforts to develop diagnostic coral reef monitoring techniques (Jameson *et al*. 1998, 1999) should be supported. This information will not only help local authorities monitor the health of their coral reef ecosystems and improve management capabilities, it will also provide a perspective on the conditions of coral reef ecosystems and the effects of climate change world-wide.

The coral reef ecosystems of the world represent an important resource, both in terms of global biological diversity and with respect to the well-being of the people who live near and depend upon them. Many coral reefs are at risk and better management is required. The future actions of managers, scientists, national bodies, local communities and international programs will be critical in determining whether or not these natural treasures are saved.

The Role of Decision Support Models

The Need For Modeling—Integrated Coastal Zone Management Decision Support

Throughout the world, both in developed and developing nations, we face complex coastal zone management challenges associated with our attempt to achieve economic growth without destroying the ecological systems that support human existence. As previously outlined, coral reef ecosystems are valuable for many reasons. They provide thousands of people with food, tourism revenue, coastal protection, and potential new medications for the treatment of diseases—despite being among the least monitored and protected natural habitats in the world.

Coastal zone management decisions often require the integration of numerous parameters, frequently more than the human mind can handle effectively. In the management of tropical coral reef ecosystems, some of these parameters include the location of industrial and tourist facilities, water quality issues such as nutrient concentrations and sedimentation, fishing pressure, and socio-economic concerns.

To assist the three small island developing states of the Maldives, Curaçao and Jamaica (i.e., Montego Bay) in effective coral reef management, the World Bank recently created models using multivariate statistical procedures that show the result of ICZM decisions when a variety of parameters interact together (see subsequent chapters). Costs are incorporated into the models to help decision-makers choose least-cost solutions, without making costly mistakes that are, in many cases, irrevocable.

Capacity Building with the Models—Helping Stakeholders

The integrated socio-economic and ecological model, framed with a user-friendly computer interface will benefit stakeholders by:

- Assisting the communication between the various stakeholder groups;
- Facilitating the planning process required for successful ICZM;
- Providing a powerful tool to managers and stakeholders for demonstrating the need for coastal zone management and the impacts of status quo management on valuable coral reef resources and the local economy; and,
- Identifying appropriate policy and institutional reforms for improving the capture of resource values associated with coral reefs in developing countries, and clarifying the potential operational role of the World Bank and other development assistance agencies in helping to effect these reforms.

The Dissemination Strategy

The dissemination strategy for this work focuses on in-country workshops and seminars for user groups and stakeholders, government agencies, and private and non-governmental organizations involved in ICZM. In addition, it includes activities to foster cooperation among countries on coordinated environmental policies, strategies, and action plans in the coastal zone, and provides a consultation mechanism for formulating, strengthening, harmonizing, and enforcing environmental laws and regulations.

Ten Commandments for ICZM

In order to further guide the effective and successful implementation of an ICZM strategy, the following “ten commandments” are suggested:

1. *Identify problems and causes*. It is tempting to blame what is visible for all the problems (e.g., garbage and eroded beaches) and difficult to identify the actual causes of serious problems, which are usually multiple in number and difficult to uncover. The identification of the root causes of problems and solutions is required to ultimately prevent or reduce problems. A cleanup alone is not sufficient to prevent re-occurrence. Controlling problems at the source is the most efficient and effective means to reduce cost and improve quality (Scanlan 1988).

2. *Strive for continuous improvement*. However, know that the environmental quality improvement journey is not without setbacks. Stay focused on the goal with continuous effort and eliminate the sources of the problems that affect the reaching of your goal. A fast repair strategy is required to achieve minimum performance standards, and a root cause prevention strategy is required to achieve excellence. Continuous improvement requires continuous discovery, continuous development, and continuous maintenance. Measures of results (samples) are required to provide data for control and improvement. Invent awards with criteria that can be used to check progress, provide feedback for improvement, and recognize excellence (Scanlan 1988).

3. *Gradualism and realism*. National or regional policies can be implemented gradually by pilot projects or experimental programs. The establishment of plausible and enforceable norms, standards, and guidelines is an important starting point. Start modest. Do not try to implement policies and instruments beyond the institutional means available.

4. *Institutional integration*. Intragovernmental and intergovernmental integration must be pursued to overcome barriers and to merge institutional strengths. Government economic agencies must be included, as well as parliamentary representation.

5. *Leadership*. The environmental management sector must lead the decision-making process by identifying stakeholders, barriers, and channels to consensus building.

6. *Participation*. Public participation is a key issue. Participation by stakeholders must be planned and based on information building and sharing. Avoid stalemate issues that might paralyze the process. Equity issues must be properly identified, evaluated and addressed.

7. *Market reliance*. The growing reliance on markets must be incorporated into environmental policy and incentive structures to influence behavioral changes. Avoid high transaction and collection costs. Do not outpace implementation and acceptance of market adjustments.

8. *Seek out business partners and recognize them*. Work with the decision-makers first as those controlling the resources must be informed and supportive of ICZM efforts. Tackle the more simple jobs first—a visible improvement will build constituencies.

9. *Recognize, motivate, and promote excellence and good behavior*. This is more effective than handing out fines, and more constructive. More people working on a solution results in more solutions (Scanlan 1988).

10. *Minimize government, and maximize voluntary management and partnerships*. Governments rely too heavily on laws, regulations and punishment. Citizens must be involved to help set goals for excellence for our society. They are the customers for government services. The governance process, as well as key operational processes, in business or government, has to be continuously improved to meet changing marketplace situations and new stakeholder requirements. Government does not regulate itself well and is often the worst offender. Government should not require subsidies for things citizens do not want and should fund things that support our objectives (Scanlan 1988).

Box 1.1. Environmental monitoring data as a basis for management decisions: The Montego Bay case study.

Bernward Hay

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Among the goals of any integrated coastal zone management program is to protect coastal resources, or improve them if degraded, while at the same time balance the various uses of the stakeholders of the coastal zone. A key element towards achieving this goal is a solid understanding of the environmental conditions of the coastal resources within the management district and factors that affect the state of these resources now and in the future. Some of the most significant resources are the biological ecosystem and water quality. Factors that affect the state of these resources include contaminated water sources entering the coastal zone (i.e., rivers, stormwater, sewage pipes and outfalls, groundwater seepage), circulation patterns, land use, urban growth, and many others.

The specific biological resources and the factors influencing their state vary for each coastal management district. Prior to the development of every integrated management plan, existing environmental information needs to be collected and synthesized. Data gaps should be identified and an approach should be developed to fill these gaps. In many cases, the appropriate approach may consist of an environmental monitoring plan. Monitoring essentially provides for the collection of data at regular time intervals, but should also allow for the collection of data during extreme events. Regular data collection intervals are important as coastal systems may vary daily, monthly, seasonally, or annually. Extreme events such as hurricanes, major rainstorms, or drought periods may be crucial as well, as certain coastal resources are only impacted during such events.

The Montego Bay Environmental Monitoring Program (USAID 1996) is an example of an environmental baseline study that has already benefited coastal zone management decision-making. At the same time, lessons learned in Montego Bay apply to many other places in the developing tropics.

Overview of the Montego Bay Coastal Environment

Montego Bay is the second largest city of Jamaica and the largest port city for cruise ships in Jamaica (Figure 1.1). Tourism is a vital industry for the economy of the country (see Chapter 5). The city has grown rapidly in the last 30 years when much of the now developed urban areas still consisted of sugarcane fields (Figure 1.2). In addition, a large part of the valuable mangrove forest has since been filled and converted to mainly industrial and commercial property.

The coastal environment of Montego Bay includes two main waterbodies—Montego Bay, which consists of a deep natural harbor and engineered port basin, and the Bogue Lagoon, a shallow lagoon with a fringing coral reef and mangrove forest. Both waterbodies are part of the Montego Bay Marine Park.

The major river entering into Montego Bay is the Montego River, draining a comparatively large watershed. Land use in the watershed consists of urban and rural developments, agriculture (mainly sugarcane and plantations), and woodlands. The discharge in the river varies greatly between dry and rainstorm conditions, an important factor to be considered for monitoring and the development of management plans. For example, the suspended sediment load in the bay three days after hurricane Gilbert in 1989 (Figure 1.3) was significantly larger than the load from runoff after a regular rainfall (Figure 1.1). River runoff affecting coastal resources in the bay consists largely of eroded soil from the watershed and stormwater runoff from urban areas. Some of the suspended sediment is deposited on the reefs along the outer fringes of the bay, resulting in the smothering of reef organisms. In addition, release of nutrients during decomposition of organic matter contained in the sediment may be utilized by macroalgae, resulting in overgrown reefs.

In addition to the river, the bay receives domestic wastewater effluent from an old treatment plant, as well as from non-point source discharges into gullies and small channels that drain into the bay. These discharges have been a large source of bacteria and nutrients entering into the bay.

In contrast, discharges to Bogue Lagoon consist only of stormwater runoff from the immediate area of the lagoon and inflow from a groundwater spring.

Project Components

Currently, the wastewater treatment system of the city is being greatly expanded to meet the needs of the growing population and tourism industry. The main components of the new system are nine waste stabilization ponds constructed adjacent to the upland side of the mangrove forest surrounding Bogue Lagoon (Figure 1.4). As part of the final design phase for the new treatment system, Louis Berger International Inc. was hired by the U.S. Agency for International Development (USAID) to monitor the existing conditions in the coastal zone and to assess the impacts of the new treatment system on the coastal environment.

The five-year program included regular water quality sampling of coastal waters, rivers and gullies, and groundwater (Figure 1.4), biological surveys of the mangrove system, waste source determinations, and hydrodynamic surveys. Present and future water quality conditions and contaminant loads were modeled. In addition, a circulation model was developed to simulate the movement of contaminants in the coastal zone. The monitoring program was part of a larger infrastructure improvement program in Jamaica (Northern Jamaica Development Project), carried out for the Planning Institute of Jamaica and the National Water Commission (USAID 1996).

Bogue Lagoon

In the original design, the wastewater effluent from the new treatment system was to be discharged into Bogue Lagoon. However, the monitoring results clearly demonstrated that the lagoon is already experiencing some environmental stress at the present time due to slow circulation and, thus, a slow water exchange rate with the ocean. Slow circulation is caused by the shallow reef that spans the entire entrance to the lagoon. The lagoon is nutrient enriched, in part because nutrients in the sediment are recycled back into the water column several times before they are transported out to sea. On the other hand, the concentrations of fecal bacteria in the lagoon waters are very low, making the lagoon suitable for water contact recreation.

Discharging effluent from the new wastewater treatment ponds into the lagoon would have increased the nutrient concentrations in the lagoon by 200% to 1,300% by the year 2015, greatly reducing the diversity and abundance of aquatic species. Possible adverse effects could also have been floating macroalgal mats, occasional fish kills, and odor development. Further, increased bacteria loading from the effluent would have rendered the lagoon unsuitable for water contact recreation. Aside from serious ecological impacts, the tourism industry would have suffered.

Montego Bay

In the bay of Montego Bay, the water exchange rate with the open ocean is roughly an order of magnitude more rapid than in Bogue Lagoon. Thus, nutrients and bacteria from land sources are transported comparatively rapidly to the open ocean rather than staying in the bay. Further, the main coastal resources are limited to the outer bay, including fringing reefs and three beaches on the northern side.

Environmental monitoring and modeling indicated that the nutrient loads in the bay would increase from the new wastewater treatment system by only 5% to 15% by the year 2015. Bacteria concentrations would sharply decrease, possibly to levels that would allow contact recreation in the outer bay during dry weather. However, the data also showed that during rainstorms, the runoff from the Montego River watershed would continue to discharge elevated concentrations of bacteria and nutrients into the bay. Management of the coastal resources in Montego Bay needs to take source reduction in this watershed into consideration for future management activities.

Main Project Recommendations

Given the existing conditions in the coastal zone of Montego Bay, our monitoring team recommended changing the targeted effluent receiving body from the lagoon to the bay. In addition, we recommended lining the wastewater treatment ponds with an impermeable layer to prevent seepage of nutrient-rich wastewater through the ground into the lagoon. These recommendations prevented serious environmental problems for the coastal waters in Bogue Lagoon, and averted negative economic consequences for the tourism industry. For example, a multi-million dollar condominium development along a small part of the lagoon is currently under construction. The lagoon has further potential for ecotourism activities, thus providing income for sustaining local businesses and potentially for financing the marine park. Also, the cruise ship port is immediately adjacent to the lagoon. Property values would have been considerably lower, ecotourism would not be possible, and the first impression of Jamaica by tourists arriving in the cruise ship port would have suffered if the lagoon was overgrown with algal mats and experiencing occasional massive fish kills and odors.

At the same time, the impacts to Montego Bay are considered minor given the limited natural resources in the bay, the circulation pattern in the bay which tends to transport land runoff straight out to sea, and the fact that there are other, in part natural, factors that will limit the development of pristine coral reefs within the bay proper, such as large stormwater discharge events that carry large amounts of silt, nutrients and bacteria from the Montego River watershed.

The recommendations from our study were adopted by the National Water Commission of Jamaica prior to construction of the new wastewater treatment system. Construction is expected to be completed by the summer of 1999.

Long-Term Benefits

Long-term, the extensive environmental database generated for the coastal waters in the area will serve as the basis for other coastal zone management decisions in the future. Such decisions will include, for example, issues related to the rapid growth of the city, the expansion of the industrial zone and associated handling of discharges, stormwater management, coastal zoning for appropriate uses, and the management of the marine park.

The project in Montego Bay demonstrated that understanding of the environment and its response to human induced changes of influencing factors should be one of the first steps in the process towards balanced coastal zone management decisions. Such understanding is frequently also important for the "ground-truthing" of economic benefit models and necessary in the development of integrated ecological economic models.

Figure 1.1. Photograph of the coastal zone of Montego Bay, looking to the northeast. Bogue Lagoon is in the foreground. Montego Bay (the waterbody) is in the centre of the photograph. The waste stabilization pond system is currently under construction to the right of Bogue Lagoon adjacent to the mangrove forest. The straight brown plume entering Montego Bay via Montego River consists of suspended sediment derived from soil erosion after earlier rainfall. The City of Montego Bay is in the background. The peninsula in the middle of the photograph is Montego Freeport (photograph taken by J.S. Tyndale-Biscoe on September 9, 1990).

Figure 1.2. Bogue Lagoon 35 years ago, looking to the west. Montego Freeport at that time consisted of several mangrove islands that were later filled and connected. Most of the land use in the area was sugarcane cultivation. The mouth of Montego River was located in the southern corner of Montego Bay. The mouth was later moved east during straightening of the river (photograph taken by J.S. Tyndale-Biscoe on October 24, 1960).

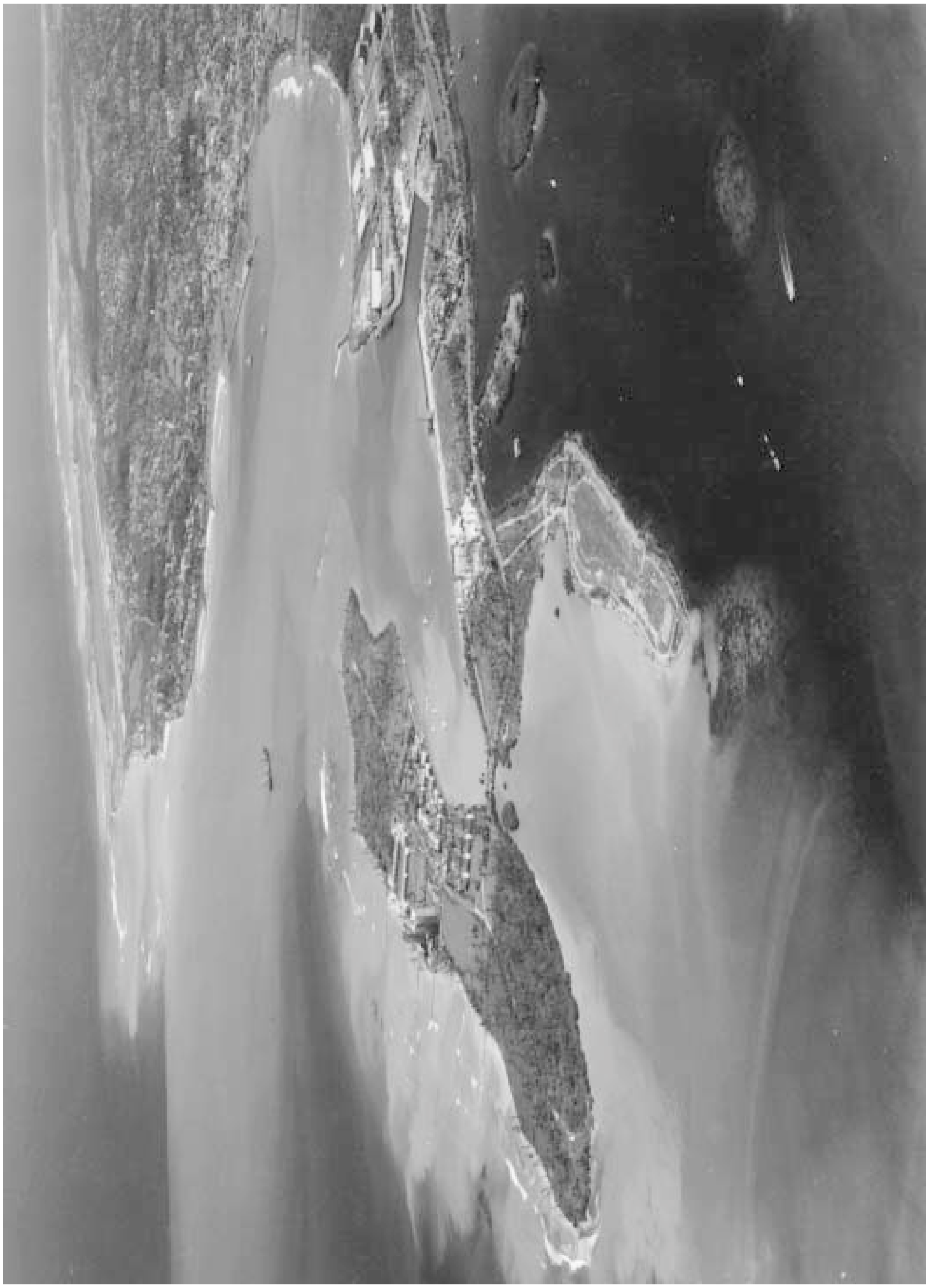

Figure 1.3. Project area three days after hurricane Gilbert, looking to the northeast. The hurricane resulted in a large inflow of suspended sediments into Montego Bay. The basin of the port does not appear to be affected strongly by the Montego River plume. Sediment was also resuspended from Montego Freeport and the outer Bogue Lagoon. The inner lagoon showed little effects (photograph taken by J.S. Tyndale-Biscoe on September 15, 1988).

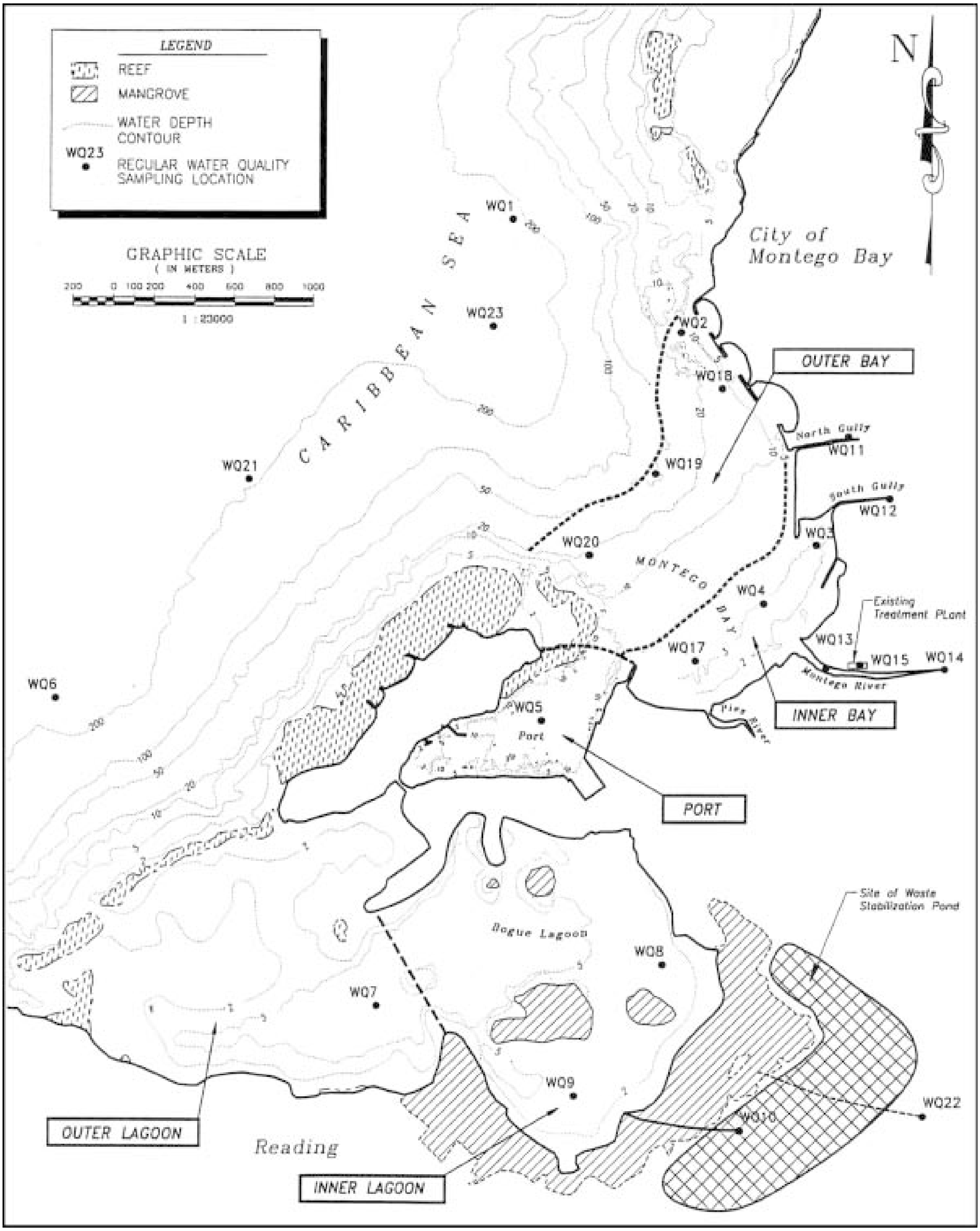

Figure 1.4. Bathymetry of the coastal zone and overview map of the station locations of the environmental monitoring program (USAID 1996). Shown also is the location of the new waste stabilization pond system adjacent to the mangrove forest of Bogue Lagoon. The thicker dashed lines within Montego Bay and Bogue Lagoon represent the boundaries of subareas in these waterbodies that were used for water quality modeling (i.e., inner bay, outer bay, port, inner lagoon, and outer lagoon).

Box 1.2. A successful ICZM case study achieving rapid results.

The Dolphins Are Back: A Successful Quality Model for Healing the Environment (Scanlan 1988)

By the end of the 1980s, the once beautiful and treasured New Jersey shoreline had become one of the most polluted coasts in the United States. Communities felt the frustration of a record high number of beach closures and disappearing wildlife. In one dramatic example, over 1,000 bottlenose dolphins washed ashore along the Atlantic coast from Florida to New Jersey. As the situation worsened, the challenging job of finding a solution was eventually taken up by an innovative partnership representing business, government and private citizens.

At the direction of Phillip Scanlan, who brought along his talent and Baldrige Award-winning experience as quality vice-president at AT&T, the group borrowed a successful tactic businesses had been using for years—they applied a total quality approach to clean up the shore and achieved a culture of continuous improvement.

Scanlan (1988) outlines two compelling stories simultaneously—his experience implementing the industry-renowned quality methodology at AT&T, as well as the struggles and ultimate success of applying this same quality approach to cleaning up the New Jersey shore. The book highlights the importance of recognizing the potential strength in relationships among business, government, and citizens. In a quality environment, these partnerships have the ability to tackle any seemingly complex and impossible task.

Chapter 2

Local Needs and Interventions for Management of Coral Reefs in the Developing Tropical Americas—The Montego Bay Marine Park Case Study

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The coral reefs, mangroves, seagrass beds, and other ecosystems of coastal zones in the developing tropical Americas are a source of diverse, unique, and useful economic and ecological goods and services. These ecosystems serve as the backbone of local and regional economies, providing services such as filtering organic waste and mitigating coastal erosion, potentially yielding medicines and compounds for biomedical research, and forming an irreplaceable source of biodiversity, educational and scientific knowledge, and aesthetic pleasure.

Montego Bay (Figure 2.1) is one of the Caribbean's leading tourist centers (Taylor 1993) and, largely as a result of this, has one of the most threatened near-shore coral reef ecosystems in the region (Hughs 1994, Jameson *et al*. 1995). Natural and anthropogenic forces over many years have combined to inflict a deadly blow (Figure 2.2). Water pollution, in the form of nutrient enrichment from municipal raw sewage discharges, household waste, associated leaching, and sedimentation, has been especially devastating to the near-shore coral reef ecosystem (Hitchman 1997; Jameson 1997; LaPointe *et al*. 1997; see also Chapter 1). Oil pollution and runoff of agricultural fertilizers and pesticides continually add to the problems. Once luxuriant near-shore coral reefs are now smothered by macrophytic algae and struggling for survival (Sullivan and Chiappone 1994; Williams and Polunin 1999).

In Montego Bay, significant changes in land use and hydrology have been occurring for the past 500 years. Several events in the coastal ecosystem most likely had the largest impacts on marine communities:

- The development of the Freeport and Seawind Island resort area by the filling in of mangrove forests and islands in 1967 and the reclamation of the entire waterfront area in the 1970s;
- The change in drainage patterns and nutrient loading of coastal rivers and estuaries associated with a growing human population and inadequate infrastructure;
- The bulkheading of coastlines, loss of coastal vegetation, and changes in the quality of storm-water runoff; and,
- Natural impacts such as Hurricane Allen in 1980, Hurricane Gilbert in 1988 and the sea urchin *Diadema antillarum* die-off in 1983-84.

The high relief spur and groove area of the fore-reef illustrates the dramatic nature of these impacts. Here, once luxuriant coral communities are now dominated by frondose brown algae—algae cover is over 70% of the reef surface, coral cover is less than 15% of the reef surface, coral rubble is abundant and colonized by algae, sponges consist of boring and encrusting species, and octocorals are rare or absent (Sullivan and Chiappone 1994).

Montego Bay Marine Park (the Park; Figure 2.3) is a mosaic of marine communities that includes seagrass beds, mangrove islands, beaches, and some of Jamaica's best coral reefs. The land is joined to the ocean through rivers, wetlands, and coastal watersheds. Jamaicans have benefited in the past from this ecosystem through the provision of fishes, conch and lobster. Montego Bay can be recalled as a scenic coastline with beautiful beaches, near-shore reefs, freshwater wetlands, and mangrove islands. The Park is the focal point of the economic and social health of Montego Bay and its environs.

Two watersheds drain into the Park—the Great River and the Montego River. These carry the inland pollutants to the Park waters. Coastal mangroves, other wetland areas, and seagrass beds that provide breeding, feeding and nursery grounds for fish and shrimp, are being destroyed. Harbors and near-shore water bodies are becoming more

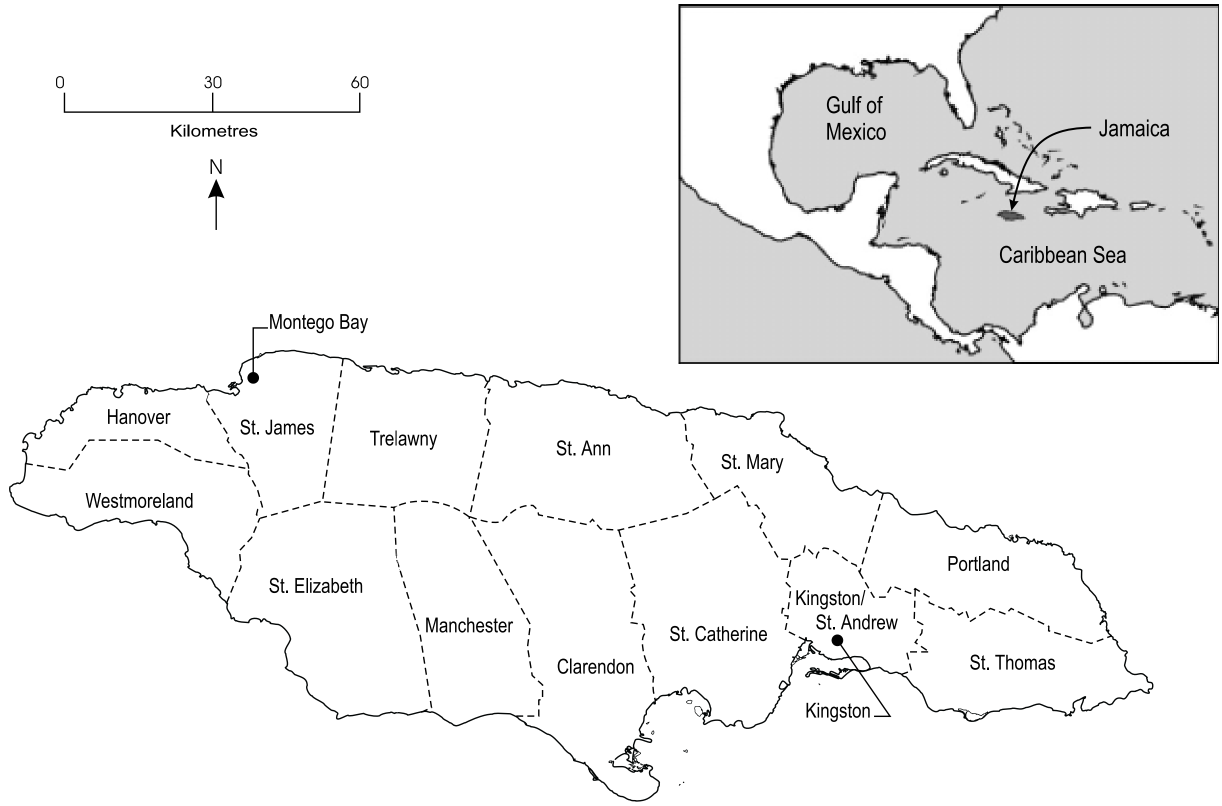


Figure 2.1. Jamaica, showing parishes and the locations of the urban centers of Kingston and Montego Bay (adapted from Gustavson 1999).

polluted from raw sewage discharges. Coral smothering algal cover has increased from about 36% in 1992 to about 84% in l997, confirming eutrophication (Sullivan and Chiappone 1994; Williams and Polunin 1999). Impacts from wind blown dust and illegal sand removal are causing loss of aesthetic value and failure in the rehabilitation of coastal areas. The Montego Bay Marine Park Trust, charged with conserving this valuable national resource, is now faced with a long-term and expensive restoration project.

Originally under government jurisdiction, a bold experiment was undertaken when the Park was transferred to non-government organization (NGO) management (private) in 1996. A group of concerned citizens who had earlier formed the Montego Bay Marine Park Trust in 1992, obtained responsibility from the Government of Jamaica (public) to manage the Park under the authority of the Natural Resources Conservation Authority (NRCA).

In the early 1970s, local dive shop operators noticed the deterioration in the coastal marine environment and started lobbying the Ministry of Tourism for establishment of a marine protected area. In July, 1974, a 59ha

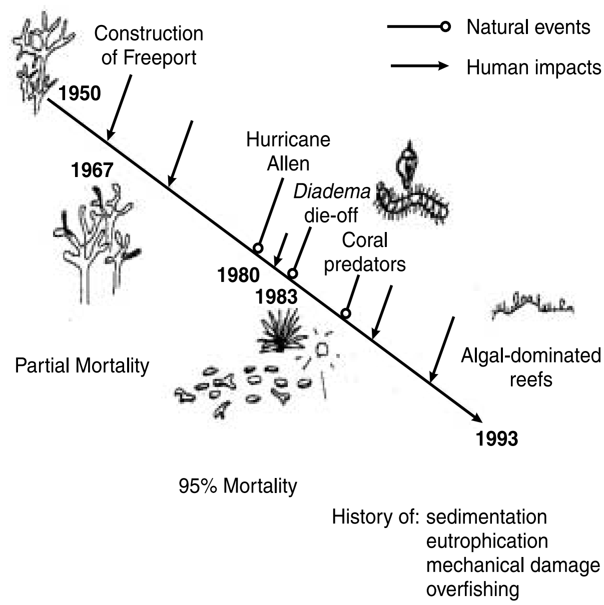


Figure 2.2. Natural and anthropogenic impacts to the coral reef ecosystem in Montego Bay, Jamaica (adapted from Sullivan and Chiappone 1994).

protected area off Cornwall Beach was created by the Government of Jamaica under the Beach Control Act and the management responsibility given to the Jamaica Tourist Board. The area was called the Cornwall Beach Marine Park. The boundaries were never marked, although the marker buoys had been purchased, and the regulations were never enforced although five wardens had been appointed. Similar to the Ocho Rios Marine Park that was created in 1966, the Cornwall Beach Marine Park was only a "paper park".

In 1986, the Minister of Tourism formed the Marine Park Action Committee to act as a catalyst for the development of marine parks in Jamaica. The committee initiated the preparation of a project proposal for the development of the Montego Bay Marine Park. The study was incorporated by the Government of Jamaica and the United States Agency for International Development (USAID) into the proposal for the establishment of a Jamaica National Parks System, which was implemented as the Protected Areas Resource Conservation (PARC) project in August 1989, with funding from the Government of Jamaica and USAID, and technical assistance from The Nature Conservancy (TNC) and the Jamaica Conservation and Development Trust.

In August, 1989, the Montego Bay Marine Park became a reality. The steering committee evolved into the Local Advisory Committee (LAC), which was responsible for the hiring of the first members of staff and offices being established at Cornwall Beach. Further legislation was put in place under the Natural Resources Conservation Authority Act, Natural Resources (Montego Bay Marine Park) Order, 1991, for the governance of the Park. Initially, the Project Management Unit (PMU) for the PARC project was based at the Natural Resources Conservation Authority (NRCA) before moving to the Planning Institute of Jamaica. Under an agreement between the United States and the Government of Jamaica, a "debt for nature swap" created the capital for the Jamaica National Park Trust Fund to provide perpetual funding for the two national parks, the Montego Bay Marine Park

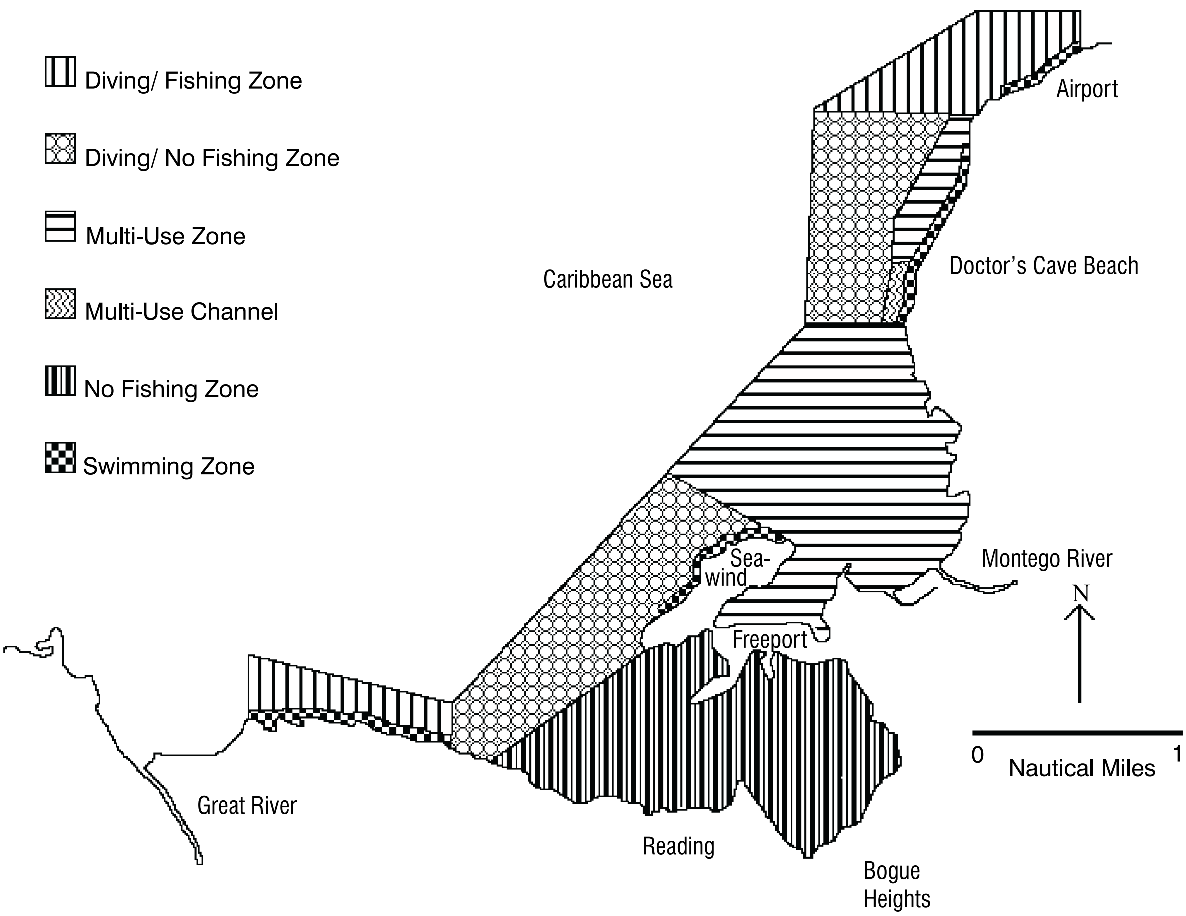


Figure 2.3. The Montego Bay Marine Park and the new zoning plan.

and the terrestrial Blue and John Crow Mountain National Park. Park staff reported to the government and the manager met regularly with the LAC. A group of members of the LAC went on to incorporate the Montego Bay Marine Park Trust as a membership organization for Friends of the Park in 1992.

The PMU managed the park until April, 1996, when funding under the PARC project came to an end and responsibility for the Marine Park reverted to the NRCA. On September 20, 1996, the NRCA delegated management for the Park to the Montego Bay Marine Park Trust (MBMPT) under an innovative co-management policy adopted for Jamaica's National Parks and Protected Area System.

The Montego Bay Marine Park's purpose is embodied in its mission statement: "To conserve, restore and manage marine coastal resources in Montego Bay for the maximum sustainable benefit of traditional users, the community, the nation, and the enjoyment of all mankind, by providing effective programs for public education, technical support, monitoring and interpretive enforcement". The MBMPT embarked on a management program for increased effectiveness. A five year management plan for the expansion of the ongoing science, education and enforcement program and a business plan which outlined costs for equipment and personnel requirements were prepared. This nation-wide experiment in public-private management of national marine and terrestrial parks is starting to show signs of fruit in Montego Bay.

The purpose of this chapter is to:

1. Characterize local needs for coral reef ecosystem management in the developing tropical Americas by using the Montego Bay Marine Park as a case study example. Local needs for management are identified and addressed through ReefFix, a specially designed watershed management and coral reef restoration program designed to implement the International Coral Reef Initiative (ICRI) Framework for Action in the Tropical Americas. ReefFix is also the implementation phase of the COral reef COasts in MOntego Bay (COCOMO) integrated coastal zone management decision support modeling program (Huber and Jameson 1999; Chapter 10).
2. Outline ongoing Park interventions to address local needs for management, as well as interventions involving public-private partnerships to prevent and manage water pollution in this valuable coral reef ecosystem.
3. Elucidate some of the social and poverty related issues that make coral reef ecosystem management and water quality improvement extremely challenging in Montego Bay.

Local Needs for Management Using ReefFix to Implement ICRI and COCOMO

Jamaica is a key player in the International Coral Reef Initiative (ICRI). They were one of the original eight founding countries of ICRI and Montego Bay hosted the ICRI Tropical Americas Regional Workshop where management, capacity building, and research and monitoring priorities were outlined for implementing ICRI in the region (Woodley 1995).

Continuing their leadership role, Jamaica—via the Montego Bay Marine Park—is setting the example for ICRI implementation in the tropical Americas through the new ICZM coral reef restoration, watershed management and capacity building demonstration project called ReefFix. ReefFix is also the implementation phase of the World Bank coral reef ecosystem decision support modeling project for Montego Bay, the results of which are reported elsewhere in this publication (specifically, see Chapters 9 and 10).

Rationale

The International Coral Reef Initiative *State of the Reefs* report (Jameson *et al.* 1995) concludes that the coral reef ecosystems at greatest risk around the world are in South and Southeast Asia, East Africa, and the tropical Americas (see Chapter 1). The Caribbean Sea contains some of the world's most productive and biologically rich marine environments, including the world's second largest barrier reef—the Belize Barrier Reef. Unfortunately, reefs and other coastal environments throughout the region are under increasing assault. Pollution from sewage wastes and fertilizers, coastal erosion, overfishing, and unmanaged coastal development are contributing to coastal decline. Recognizing the magnitude of these threats and the need for counter measures, the International Maritime Organization declared the Caribbean a "particularly sensitive area" (Jameson *et al*. 1995).

The goal of ReefFix is to design and implement a least cost ICZM coral reef ecosystem restoration and watershed management project and then transfer the information and technology to 20 other tropical American countries facing similar challenges. At present, no country (or any of the over 100 marine protected areas) in the tropical Americas is taking an integrated model-driven approach to watershed management for coral reef protection and management.

Unlike most marine projects that strive to do research in areas with good environmental conditions, ReefFix will take a more management related approach. It will work in an area that suffers from many, if not all, of the watershed and marine ailments of Tropical American countries —an area that desperately needs ICZM and restoration— Montego Bay, Jamaica.

Major Components

The two integrated components of ReefFix promote the restoration, conservation and sustainable use of biodiversity in the region and promote the sustainable use of coral reefs, watersheds and international waters. Specifically, these include:

1. An ICZM Coral Reef Restoration and Watershed Management Demonstration component that will restore a coral reef ecosystem and manage a watershed at Montego Bay, Jamaica.
2. An ICZM Capacity Building component that will transfer the information and technology from the demonstration component to 20 countries (as identified in an ICRI report; see Woodley 1995) throughout the tropical Americas with coral reef eutrophication and sedimentation problems. These countries potentially include the Bahamas, Barbados, Brazil, Cayman Islands, Colombia, Costa Rica, Cuba, Curaçao, Dominica, Dominican Republic, Ecuador, Grenada, Guadeloupe, Haiti, Martinique, Nicaragua, Panama, St. Lucia, Trinidad and Tobago, and Venezuela.

The ICZM Coral Reef Restoration and Watershed Management Demonstration component is the operational aspect of ReefFix. In this component, ReefFix will use and develop cost-effective techniques that can be replicated throughout the tropical Americas. These include:

- Marine protected area management;
- Management of land-based activities and coastal development;
- Resource assessment, monitoring, restoration, and database creation;
- Environmental impact assessment;
- Community development;
- Tourism and recreation management;
- Economic incentives;
- Regulation and enforcement;
- Legal and institutional restructuring; and,
- Public education and outreach.

Combining these management approaches is critical for success. If used alone, these approaches tend to be ineffective over the long-term. They must be strongly supported at scales ranging from the village to nation, and often at the regional scale as well. They must be oriented towards long-term sustainability of coastal resources and designed to be adaptive to different cultures and governments, as well as changing situations, without compromising effectiveness.

The ICZM Capacity Building component will focus on regional capacity building and will draw on the successes of the Montego Bay Marine Park Coral Reef Restoration and Watershed Management Demonstration project. Capacity building includes establishing and strengthening human resource and institutional capabilities for integrated coastal resources management, science, training and education. A concerted effort must be made to enhance the capacities of countries responsible for valuable coastal resources to conduct science-based research and to design and implement informed, effective integrated management systems. This implies not only the transfer of information, but more importantly, the exchange of experiential learning among countries of the region. ReefFix will design and implement a program to build expertise in coral reef management and integrated coastal resources management. Presently, the shortage of trained personnel on many islands in the region requires the sharing of limited expertise through networking. The project will draw on the talents and experience of other regional institutions and facilities in the design and implementation of its capacity building program.

ReefFix will also encourage the private sector's role in ICZM by seriously engaging them in the management of coral reefs and related coastal ecosystems by demonstrating to them, via workshops, educational material, media products and technical assistance, the benefits of:

- Using appropriate technologies;
- Developing a trained and educated workforce; and,
- Using innovative approaches to improve environmental operating standards.

Objectives and Outcomes

ReefFix will meet its goals by accomplishing the following objectives:

1. Develop a generic least cost ICZM decision support model template that can be custom tailored for any coral reef ecosystem in the tropical Americas;
2. Develop a least cost ICZM coral reef decision support model for the Montego Bay Marine Park (COCOMO; Chapter 10);
3. Develop and implement a Montego Bay Watershed Management Action Plan that will, over time, improve water quality for the coral reef ecosystem (reduce eutrophication and sedimentation), improve water quality for human users (reduce fecal coliform), and increase coral cover and decrease algal cover on the Park's reefs;

4. Develop and implement a Montego Bay Marine Park Fisheries Management Action Plan, including eco-tourism alternative income programs for retrained fishers in Montego Bay that will, over time, increase fish abundance, improve economic conditions for fishers, and help make Montego Bay Marine Park financially self-sustaining; and,
5. Implement a Tropical Americas Demonstration Action Plan that will improve ICZM capacity for restoring coral reef ecosystems in 20 tropical American countries as a result of the demonstration program that includes a ReefFix coral reef watershed restoration handbook, a video, and workshop materials.

Links to National Priorities

On the national level, ReefFix is directly linked to priority programs of Jamaica's Natural Resources Conservation Authority (NRCA) to manage watersheds and to establish and restore marine protected areas under the management of local NGOs. As outlined above, the NRCA delegated authority to manage the Montego Bay Marine Park to the Montego Bay Marine Park Trust. ReefFix also meets many of the objectives outlined in the Montego Bay Marine Park Management Plan (Tables 2.1 to 2.6).

On the regional level, ReefFix is linked to the Regional International Coral Reef Initiative (ICRI), the UNEP Global Program of Action for the Protection of the Marine Environment from Land-Based Activities, and the IOC Global Coral Reef Monitoring Network (see Chapter 1). ReefFix addresses the specific needs identified in a survey of the 25 tropical American countries participating in the 1995 ICRI Regional Workshop (Woodley 1995). These include a need for ICZM planning approaches (i.e., restoration, mitigation of specific impacts, and determination of carrying capacities), capacity building in coastal and marine resource management, and increased research and monitoring capabilities. Workshop participants also identified a series of initial steps required to provide a basis for increased regional collaboration, including initiatives to strengthen management capabilities in special area management planning, education and environmental awareness programs, and increased capacity at regional marine institutions.

Stakeholders Involved

In the ReefFix demonstration phase, stakeholders include Montego Bay businesses, community groups, NGOs, residents, educational institutions, and national and local government agencies (i.e., Montego Bay Marine Park, Natural Resources Conservation Authority, Water Resources Authority, National Water Commission, Montego Bay Sewage Treatment Plant, Ministry of Agriculture's Fisheries Division, Jamaica Tourist Board, Montego Bay Resort Board, Tourism Product Development Company, Jamaica Hotel and Tourism Association, Greater Montego Bay Redevelopment Company, St. James Parish Council, and United States Agency for International Development). In the capacity building phase, stakeholders include the 20 countries where workshops are held, and will be similar to those listed for the demonstration phase but with a local and national focus specific to the country involved.

Interventions

To address local needs for management, the Montego Bay Marine Park Trust is implementing a variety of low cost and effective programs that can be called "soft interventions". These soft interventions focus primarily on education, enforcement, public relations activities, research and monitoring, and volunteer programs (Tables 2.1 to 2.5). In addition, the Park, in partnership with various public entities, is implementing a variety of programs to mitigate water pollution impacts to the coral reef ecosystem (Table 2.6).

Education Strategies and Activities

One of the primary mandates of the Montego Bay Marine Park is to provide the public with information about environmental issues that surround and affect the Park. The diverse habitats and resources and the setting of the Park offer unique educational opportunities for the interpretation of tropical marine environments for Jamaicans and visitors alike. Educational strategies fall into two distinct categories—community participation and product development (Table 2.1). The community participation program encompasses all projects that involve direct interaction with the public by Park officials, including training workshops, exhibit production, special events, environment watch clubs, and fishing trap mesh exchange programs. The product development strategies include production of displays, signs, and printed materials, as well as media programs.

Montego Bay Marine Park Education Goals and Objectives

The Montego Bay Marine Park, as an integral part of the Jamaican National Park System, reflects a unique and important aspect of Jamaica's natural heritage. Hence,

Table 2.1. Education interventions for the Montego Bay Marine Park—agencies, organizations, and staff identified for implementing strategies and activities (EWO = Environmental Watch Organization; NEST = National Environmental Societies Trust; JCDT = Jamaica Conservation Development Trust; NRCA = Natural Resources Conservation Authority of Jamaica; MBMP = Montego Bay Marine Park; JTB = Jamaica Tourist Board; EE = environmental education).

	Agencies and organizations							*MBMP staff*				
Interventions	EWO	NEST	JCDT	NRCA	Hotels	Water sports	Media	Education coordinator	Enforcement coordinator	Volunteer coordinator	Research and monitoring	Director coordinator
COMMUNITY INVOLVEMENT												
Training, workshops, and schools												
EE in schools	●	○	●			○	○	●		○		○
Sponsor and support adult EE	●	○		○		○	○	●		○		○
Establish a certification program	○				●	○	○	●		○	○	○
Regular educational tours					●	●		●	○	○		○
Public forums												
Lecture series	○	○		○	○		○	●		○		○
Poster and photo contest	○						○	●		○		○
Special events												
Maintain exposition booths		○		○				●		○		○
Organize environmental expositions	●	○		○	○			●		○		○
Earth Day and other events	●	○	○	○	○		○	●		○		○
Summer youth program	○							●	○	○		○
PRODUCT DEVELOPMENT												
Printed material												
Reproduce brochure								●				○
Produce a quarterly newsletter		○						●				○
Maintain a internet web page								●				○
Shipping to businesses	○							●		○	○	○
Provide information to user groups	○	○						●		○	○	○
Periodicals and publications							●	●				○
Produce a fact-sheet for JTB		○						●		○		○
Provide information to service industry		○	○					●			○	○
Audio-visual materials												
Audio-visual library								●		○		○
Theme oriented slide presentations								●				○
Displays												
Develop mobile displays								●		○		○
Public service announcements												
Develop a program of announcements	○						●	●		○		○
Staffing levels												
Hire staff												●

● lead
○ assist

Table 2.2. Enforcement interventions for the Montego Bay Marine Park—agencies, organizations, and staff identified for implementing strategies and activities (JDFCG = Jamaica Defence Forces-Coast Guard; NRCA = Natural Resources Conservation Authority of Jamaica; MBMP = Montego Bay Marine Park; JCF = Jamaica Constabulary Force; JMI = Jamaica Maritime Institute; MBFD = Montego Bay Fire Department; HAZMAT = hazardous materials).

	Agencies and organizations										*MBMP staff*		
Interventions	Resort Patrol	JDFCG	Marine Police	NRCA	MBMP	JCF	JMI	MBFD	Education coordinator	Volunteer coordinator	Secretary	Rangers	Enforcement coordinator
OPERATIONAL STRATEGIES													
Comprehensive enforcement program													
Spot check of vessels												○	●
Simplify regulation and pamphlet issuing												●	○
Document warnings											●	○	
Improve land support	○											●	
Develop special operations	○	○	○	○								○	●
Develop joint operations	○	○	○	○								○	●
STAFFING STRATEGIES													
Staffing levels													
Establish volunteer ranger program									○	○			●
Hire park rangers					●								○
EQUIPMENT STRATEGIES													
Upgrade equipment													
Purchase equipment					●								○
Preventative maintenance													
Bi-monthly enforcement equipment programs												○	●
Weekly enforcement equipment programs												○	●
Develop office equipment program												○	●
Acquire preventative maintenance material					●								○
COMMUNICATION STRATEGIES													
Communication system													
Hand-held radio acquisition					●								○
Acquire beeper					●								○
Upgrade mobile station					●								○
Improve radio linkages				○									●

Table 2.2. continued

	Agencies and organizations								MBMP staff				
Interventions	Resort Patrol	JDFCG	Marine Police	NRCA	MBMP	JCF	JMI	MBFD	Education coordinator	Volunteer coordinator	Secretary	Rangers	Enforcement coordinator
Enforcement action code													
Construct code A				○								○	●
Construct code B				○								○	●
Implement use of codes				○								○	●
Deter breaches of codes				○								○	●
Develop code designation	○	○	○	○								○	●
TRAINING STRATEGIES													
Enforcement training													
Implement HAZMAT training		○		○	○							○	●
Acquire oil spill training				○	○								●
Acquire conflict resolution training		○		○	○								●
Acquire weapon handling training						○							●
Develop self-defense capabilities												○	●
Improve outboard motor repair training		○			○							○	●
Improve marine fire fighting capabilities							○	○				○	●
REGULATION STRATEGIES													
Regulation amendments													
Increase fines				●									○
Acquire seizure and confiscation powers				●								○	
Hire legal advisor				●								○	
ZONING STRATEGIES													
New zoning plan													
Obtain approval of plan				○	●								
Install and maintain demarcation buoys												○	●
Install and maintain mooring buoys												○	●

● lead
○ assist

Table 2.3. Public relations interventions for the Montego Bay Marine Park—agencies, organizations, and staff identified for implementing strategies and activities (MBMP = Montego Bay Marine Park).

	Agencies and organizations		*MBMP staff*					
Interventions	MBMP	Media	Administration coordinator	Education coordinator	Volunteer coordinator	Research & monitoring coordinator	Enforcement coordinator	Director
Park identity								
New park logo	●							○
New uniforms	●			●	●	●	●	○
Membership								
Begin membership	○		●	●	○	○	○	○
Newsletter								
Produce quarterly newsletter (see Table 2.1)								
Mailing list database			●	●	●			○
Media								
Newspaper articles (see Table 2.1)								
Press releases		●		●	○	○	○	○
Radio program		●		●				○
Television program		●		●				○
Staff levels								
Hire staff								○
Public service announcements (see Table 2.1)								

● lead
○ assist

it is of the utmost importance to educate the public concerning the natural treasures at risk to ensure that this heritage is preserved for future generations. These goals respond to the specific environmental education needs of the Montego Bay community and include:

- Promoting the awareness of and support for the Montego Bay Marine Park;
- Encouraging and promoting a sense of stewardship regarding the marine environment;
- Facilitating environmental education opportunities for all segments of society;
- Promoting a clear awareness of the economic, biological, recreational, educational, and cultural values of the marine ecosystem, as well as the interdependence of these factors upon one another; and,
- Providing income generating training opportunities for individuals displaced by the enforcement of Park regulations.

To achieve the goals defined above, the following objectives should be met:

- Increase community cooperation and participation in the management of the Park;
- Increase understanding of and voluntary compliance with regulatory requirements of the Park (e.g., zoning regulations);
- Develop, support, and maintain cooperative educational programs with the community (e.g., turtle watches with hotels; tours with boat operators);
- Provide the public with information gained through research within and about the Park and relevant resources;
- Increase public awareness about the cumulative environmental impacts degrading the Park and provide relevant solutions to the problems addressed;
- Provide opportunities for individuals to become "stewards of the environment";

Table 2.4a. Research and monitoring interventions for the Montego Bay Marine Park—agencies and organizations identified for implementing strategies and activities (MBMP = Montego Bay Marine Park; NRCA = Natural Resource Conservation Authority; FD = Fisheries Division; NWC = National Water Commission; UWA = Underground Water Authority; NEST = National Environmental Societies Trust; TPDCo = Tourist Product Development Corporation; PIOJ = Planning Institute of Jamaica; PCD = Parish Council Public Works Department; CDC = Conservation Data Centre; UWI = University of the West Indies; GMRC = Greater Montego Bay Redevelopment Company; JTB = Jamaica Tourist Board; RB = Resort Board; QA/QC = quality assurance/quality control).

	Agencies and organizations													
Interventions	MBMP	NRCA	FD	NWC	UWA	NEST	TPDCo	PIOJ	PCD	CDC	UWI	GMRC	JTB	RB
RESEARCH MANAGEMENT														
Park database														
Assess user needs	●	○	○				○						○	○
Implementation plan	●	○	○	○										
Disseminate findings														
Information exchange	●					○								
Sponsor conferences	●					○								
Journal publication	●													
Advisory committee														
Establish committee	●													
MONITORING STRATEGIES														
Water quality monitoring														
Historical assessment	●			○	○									
Circulation studies	●	○		○										
Water quality standards	○	●												
Inter-park laboratory	●	○		○										
Runoff practices	○	○						●	○					
Monitoring implementation plan	●	○		○										
Select organization	●	○		○										
QA/QC authority and protocols	●	○		○										
Implement monitoring	○	○		●										
Indicators														
Develop and evaluate indicators	●	○		○										
Ecological monitoring														
Hire coordinator	●													
Ecological information system	○	●								○				
Status and trends assessment	●	○	○											
Fisheries ecological monitoring	●	○	○											
Sampling protocol	●	○	○											
QA/QC protocol	●	○	○											

Table 2.4a. continued

	Agencies and organizations													
Interventions	MBMP	NRCA	FD	NWC	UWA	NEST	TPDCo	PIOJ	PCD	CDC	UWI	GMRC	JTB	RB
Index of park health	●	○	○											
Volunteer program	●													
Socio-economic monitoring														
Fishing gear survey	○		●											
License program	○	○	●										○	
Control area monitoring														
Develop baseline data	●	○	○											
Monitor control area	●	○	○											
FISHERIES IMPACTS														
Aquaculture alternatives														
Assess, develop, and promote alternatives	●	○	○											
Artificial reefs														
Assess impacts	●	○												
ENVIRONMENTAL ASSESSMENT														
Habitat restoration														
Program of restoration research	●	○												
Carrying capacity														
Assess impacts	●	○	○											
Leachate transport														
Research on leachate transport	○	○			●									
Global change														
Research on global change	○	○									●			
PREDICTIVE STRATEGIES														
Predictive models														
Predictive modeling workshop	●	○									○	○		
Water quality impact research														
Water quality impact research	○	○		●										
STAFFING STRATEGIES														
Staffing levels														
Hire staff														

● lead
○ assist

Table 2.4b. Research and monitoring interventions for the Montego Bay Marine Park – staff identified for implementing strategies and activities (MBMP = Montego Bay Marine Park; QA/QC = quality assurance/quality control).

	MBMP staff				
Interventions	Education coordinator	Research and monitoring coordinator	Volunteer coordinator	Secretary	Director
RESEARCH MANAGEMENT					
Park database					
Assess user needs		●			○
Implementation plan		●			○
Disseminate findings					
Information exchange	○	●			○
Sponsor conferences	○	●		○	○
Journal publication	○	●			○
Advisory committee					
Establish committee		●		○	○
MONITORING STRATEGIES					
Water quality monitoring					
Historical assessment		●			○
Circulation studies		●			○
Water quality standards		●			○
Inter-park laboratory		●			○
Runoff practices	○	●			○
Monitoring implementation plan		●			○
Select organization		●			○
QA/QC authority and protocols		●			○
Implement monitoring		●			○
Indicators					
Develop and evaluate indicators		●			○
Ecological monitoring					
Hire coordinator					●
Ecological information system		●			○
Status and trends assessment		●			○
Fisheries ecological monitoring		●			○
Sampling protocol		●			○
QA/QC protocol		●			○
Index of park health		●			○
Volunteer program		●	○		○
Socio-economic monitoring					
Fishing gear survey		●			○
License program		●			○
Control area monitoring					
Develop baseline data		●			○
Monitor control area		●			○
FISHERIES IMPACTS					
Aquaculture alternatives					
Assess, develop, and promote alternatives		●			○
Artificial reefs					
Assess impacts		●			○

Table 2.4b. continued

	MBMP staff				
Interventions	Education coordinator	Research and monitoring coordinator	Volunteer coordinator	Secretary	Director
ENVIRONMENTAL ASSESSMENT					
Habitat restoration					
Program of restoration research		●			○
Carrying capacity					
Assess impacts		●			○
Leachate transport					
Research on leachate transport		●			○
Global change					
Research on global change		●			○
PREDICTIVE STRATEGIES					
Predictive models					
Predictive modeling workshop		●			○
Water quality impact research					
Water quality impact research		●			○
STAFFING STRATEGIES					
Staffing levels					
Hire staff		○			●

● lead
○ assist

- Provide and support multi-disciplinary environmental education experiences;
- Provide information at high profile locations;
- Provide and support training opportunities for resource users (e.g., training programs to retrain displaced fishers);
- Provide informative educational programs to school systems;
- Provide sequential exposure to environmental education, allowing for the construction and understanding of an ecosystem approach over time (e.g., weekly media articles);
- Provide educational information at technical and scientific meetings; and,
- Provide environmental education opportunities for adults and those not attending school.

Existing Education Programs

The following programs are currently being operated by the Montego Bay Marine Park:

- *Promoting and supporting environmental education in schools.* The Park currently works closely with five area high schools and conducts trips and presentations for other schools whenever possible, including the University of the West Indies at Mona. Past programs have dealt with rural schools and teacher training. The Education Coordinator also facilitates the organization of poster contests in Montego Bay schools during special events such as Earth Day.
- *Presenting information to user groups and community members.* The Education Coordinator currently gives presentations on request to various community and school groups. The Park also organizes boat trips and writes weekly articles and press releases for local newspapers (i.e., the *Western Mirror* and the *Jamaica Observer*) and other periodicals.
- *Conducting educational tours.* Currently, the Education Coordinator provides at least one tour per month to schools or other groups. Tours include site visits and descriptions of coral reef ecology and mangrove ecology. A tour guide is currently being trained so that four trips per month can be arranged.
- *Maintaining displays at local and national events.* The Park currently maintains a presence at most regional and some national events.

Table 2.5. Volunteer interventions for the Montego Bay Marine Park.

Strategy	*Activity*	*Description*
Boating	Boat access	Assist in public access survey
	Habitat restoration	Serve as "buddy divers" and underwater assistants
	Derelict vessels	Assist in a survey of abandoned and derelict vessels
	Mooring buoy and reef marking	Assist with mooring buoy and reef marking projects
	Visitor registration	Serve as registrars for the Park
	Damage assessment	Assist the damage assessment team
Fishing	Artificial reefs	Assist in reef construction, data collection and monitoring
	Gear removal	Assist in gear removal, particularly "ghost traps" (abandoned or lost fish traps)
	Gear and method impacts	Assist with research on low-impact fishing gear
Recreation	Recreation survey	Assist in implementing the recreation survey
Research and monitoring	Water quality monitoring	Provide monitoring assistance
	Ecological monitoring	Assist in the monitoring program
Education and outreach	Printed materials	Assist Park staff in developing and distributing printed materials
	Audio-visual materials	Assist in developing the audio-video library and audio and video products
	Signs, displays, and exhibits	Assist in developing and installing Park signs, displays, and exhibits
	Training, workshops, and school programs	Assist in training, workshops, and school programs
	Public service announcements	Assist in developing public service announcements, particularly local press releases
	Promotional	Assist in developing promotional materials
	Public forum	Assist in preparing for public meetings, volunteer speakers bureau, and bay watch hotline
	Special events	Assist at trade shows and special events
General support	Office support Computer support Marine and dock maintenance Fund-raising Inter-organizational volunteer coordination Group leaders Boat captains Special project	

- *Organizing environmental events.* The Education Coordinator currently organizes activities and displays for events, including park related expositions, mangrove replanting projects and beach clean-ups.
- *Summer children's programs.* The Park staff has traditionally organized a summer camp for kindergarten and primary school age children. The program has primarily focused on making crafts from reused materials. The traditional camp did not take place in 1997, but swimming and snorkel lessons were provided to members of environment watch clubs.
- *Quarterly newsletter.* The Education Coordinator is currently producing a quarterly newsletter and seeking funding for production.
- *Internet website.* A webpage is currently on-line and is updated periodically. The newsletter is in the process of being posted on the site.
- *Writing articles for publication in newspapers and magazines.* The Education Coordinator currently publishes weekly articles in local and national papers. Specific user groups are also being targeted, as articles are also being sent to international scuba magazines such as *Skin Diver.*

Enforcement Strategies and Activities

The enforcement program of the Park is an essential component of resource protection (Table 2.2). Adequate

Table 2.6. Public-private partnerships in water pollution prevention and management in Montego Bay, Jamaica (MBMP = Montego Bay Marine Park; NWC = National Water Commission; NRCA = Natural Resources Conservation Authority; JDFCG = Jamaica Defence Forces-Coast Guard; UWA = Underground Water Authority; SJPC = St. James Parish Council).

Public-private partnership	*Pesticides and oil*	*Sediments*	*Nutrient enrichment*	*Program status*
CORAL modeling (World Bank/MBMP)		Provides least cost solutions	Provides least cost solutions	Model operational early 1999
ReefFix restoration program (World Bank/MBMP)	Watershed management component	Watershed management component	Watershed management component	ReefFix proposal submitted for GEF approval
Sewage treatment and effluent disposal (NWC/MBMP)			Ideas for design of new plant and disposal methods submitted	Periodic interactions during new plant construction
Artificial wetlands program (NRCA/MBMP)		Critical for removing sediments from sewage effluent	Critical for removing sediments from sewage effluent	Under consideration by NWC and NRCA
Water quality enforcement (NRCA/NWC/ JDFCG/MBMP)	Oil spills (park rangers, coast guard and marine police operations)		Ships and hotels (park rangers, coast guard and marine police operations)	Ongoing
Mangrove reseeding program (NRCA/MBMP)		River bank and shore stabilization/ sediment filtration	Aids in removal of nutrients from polluted runoff	Ongoing, with school participation
Green certification (NRCA/Hotels/ MBMP)			Hotels must meet sewage treatment and disposal standards	Under development
Hydrology assessment (NRCA/ NWC/MBMP)		Examines effects of structural modifications	Clarifies role of inflows from land-based sources	Historical hydrological assessment requires funding
Circulation studies (NRCA/NWC/MBMP)	Estimates long-term and episodic transport	Estimates long-term and episodic transport	Estimates long-term and episodic transport	Requires funding
Water quality standards (NRCA/MBMP)	Pesticide and oil standards created	Sediment loading standards created	Nitrogen and phosphorous standards and biocriteria created	Under development
Inter-park laboratory (NRCA/NWC/MBMP)	Processes monitoring samples	Processes monitoring samples	Processes monitoring samples	Requires funding
Storm water runoff practices (UWA/ SJPC/MBMP)	Collection locations and education programs	Street sweeping and litter control programs	Ordinances aimed at controlling application on public and private landscapes	Ongoing (requires funding to expand reach and intensity)
Water quality monitoring program (NRCA/NWC/MBMP)	Relevant parameters monitored	Relevant parameters monitored	Relevant parameters monitored	Plan requires development and funds required for implementation
Indicator species program (NRCA/ NWC/MBMP)	Indicators require calibration and statistical framework	Indicators require calibration and statistical framework	Indicators require calibration and statistical framework	Requires funding; indicators incorporated into biocriteria program

financial support, effective supervision and a supportive judicial system, combined with proper ranger recruitment, training and equipment, form the basis of a professional enforcement operation. The goal of Park enforcement is to prevent negative resource impacts through full compliance with the Natural Resources (Marine Parks) Regulations, 1992, under the Natural Resources Conservation Authority Act, as well as relevant sections of regulations under other government acts (i.e., the Fisheries Act, the Tourist Board Act, the Wildlife Protection Act). A new zoning plan for the Park also helps achieve enforcement goals and objectives (Figure 2.3).

Successful enforcement relies on frequent land and water patrols, along with routine vessel inspections. Park rangers ensure that users are familiar with regulations. An interpretive style of enforcement seeks voluntary compliance, primarily through education (e.g., rangers speak with users and distribute brochures in the field). This allows rangers to make direct, informative contact with the Park users while conducting routine enforcement activities. In addition, rangers are called upon to give presentations both on site and within the community.

In Montego Bay, the success of enforcement efforts also depends on how well the enforcement bodies are coordinated. Because of limited resources, current enforcement assets must be targeted and used in an efficient and directed effort to be effective. Agreements among NGOs and government organizations in the Park service, Coast Guard, Fisheries Division, and Wildlife Division are being established to ensure a cooperative and integrated enforcement operation. In addition, local residents and frequent Park users are assisting by detecting and reporting violations.

Montego Bay Marine Park
Enforcement Goal and Objectives

The goal of enforcement in the Park is to protect the resources by achieving full compliance with all applicable laws. Effective enforcement of these laws, which seek protection of the natural, cultural, and historical resources within the Park, is required. The principal objectives associated with Park enforcement include:

- Increasing the public's understanding of why it is important to comply with Park regulations;
- Achieving voluntary compliance with applicable laws; and,
- Promoting public stewardship of the marine resources through interpretive enforcement efforts.

The mechanisms for accomplishing these goals include the following.

1. *Inter-agency agreements and cooperative strategies to:*

- Strengthen the existing enforcement efforts with other agencies;
- Develop partnerships with other enforcement agencies in order to provide a strong enforcement presence in the Park;
- Maintain an active relationship internally among Park staff members and with other enforcement agencies to identify areas of mutual concern and develop cooperative responses to enforcement issues;
- Explore cooperative relationships with foreign governments;
- Enter, if necessary, into memoranda of understanding (MOUs), cooperative enforcement agreements, and joint operation plans with other enforcement agencies as appropriate;
- Facilitate communication among agencies to avoid duplication of efforts;
- Promote cooperation, standardization of gear, and coordination of limited resources such as vessels, radios, radio frequencies and training; and,
- Promote training and deputation among enforcement agencies.

2. *Community involvement strategies to:*

- Encourage public involvement through site specific interpretive patrols by volunteer groups;
- Involve Jamaican Defence Forces-Coast Guard, Marine Police, resort patrols, charter boats, Fisheries Division, fishing organizations and game wardens in promoting compliance with Park regulations;
- Maintain an active relationship with citizen groups interested in compliance with Park regulations;
- Conduct community outreach programs to encourage compliance with Park regulation and citizen involvement in reporting violations; and,
- Establish a volunteer ranger program and train and engage the volunteer services in enforcement.

3. *Education strategies to:*

- Emphasize education as a tool to achieve compliance with legislation;
- Promote voluntary compliance and stewardship by the general public through specific outreach programs regarding enforcement of Park regulations;
- Train user groups about regulations and procedures for reporting violations (e.g., witness statements forms); and,
- Identify major user groups and develop and disseminate educational material through semi-annual meetings and workshops.

4. *Operational strategies to:*

- Maintain an investigative capability to ensure quick response to purposeful unlawful acts;
- Develop and maintain the capability to effectively respond to violations of the Park regulations and to emergencies;
- Establish an enforcement advisory committee consisting of relevant law enforcement organizations; and,
- Develop enforcement operation plans that identify specific enforcement strategies and priorities, and outline the best means of achieving them.

Public Relations Strategies and Activities

Community involvement and support are the centerpiece of the Montego Bay Marine Park's success. Historically, the Park has had tremendous support from certain aspects of the Montego Bay community. The Public Relations Action Plan seeks to strengthen support in traditional sectors and expand into sectors where Park support has traditionally been weak. The Public Relations Action Plan will focus on Park identity issues, membership strategies, newsletter distribution and media campaigns (Table 2.3).

Montego Bay Marine Park Public Relations Goals and Objectives

The Montego Bay Marine Park seeks to maximize community support for the Park and other areas of valuable natural heritage by sensitizing the community to various aspects of efforts to preserve the environment. The goals are designed to maximize awareness of the Park and its regulations and community involvement in the Park. Goals include:

- Creating a strong identity for the Park and its staff;
- Establishing a membership program; and,
- Increasing community participation, awareness, and support for Park programs.

The Park will meet the above goals by accomplishing the following objectives:

- Providing the staff with uniforms;
- Creating a new Park logo;
- Establishing a passive membership;
- Maintaining a quarterly newsletter; and,
- Establishing media campaigns.

Existing Public Relations Programs

The following programs are currently being operated by the Montego Bay Marine Park:

- *New staff uniforms.* Marine Park staff was recently outfitted with new uniforms designed to enhance the image of and respect for the Park.
- *Membership.* A passive membership campaign has been organized and will begin with the distribution of the first newsletter.
- *Newspaper articles and press releases.* Currently, the Education Coordinator submits weekly newspaper articles and press releases to regional and national newspapers.

Research and Monitoring Strategies and Activities

Research and monitoring are critical to achieving the Park's primary goal of resource protection. The Park's ecosystem is diverse and complex, and many of its processes and their interrelationships are not well known. Also, while many resource impacts are obvious and severe, they are often not documented or quantified. The causes of impacts may be even less clear or completely unknown. The purpose of research and monitoring is to establish a baseline of information on the resource and the various components of the ecosystem and how they interact. In this way, research and monitoring can ensure the effective implementation of management strategies using the best available scientific information.

Research and monitoring activities must focus on fundamental processes and specific management driven topics (Tables 2.4a and 2.4b). Information generated from such activities will be used to:

- Provide a means to evaluate the effectiveness of the Park;
- Provide a means to distinguish between the effects of human activities and natural variability;
- Develop hypotheses concerning causal relationships which can then be investigated;
- Evaluate management actions; and,
- Verify and validate quantitative predictive models used to evaluate and select management actions.

Research and monitoring efforts in the Park must be focused on priority issues, and various symposia and reports (i.e., coral reef modeling workshops and rapid ecological assessments; see Sullivan and Chiappone 1994; Chapter 13) have helped to define those issues. Park management will work to improve and enhance the funding, focus and quality of research and monitoring, as well as the free exchange and discussion of research and monitoring information. It will influence research and monitoring by establishing priorities, encouraging open communications among researchers and managers, and allowing Park staff to work closely with researchers to accomplish mutual goals.

Both research and monitoring activities are included in this discussion of local needs for management because they employ similar methods, are often conducted by the same people and agencies, and must be linked to one another. Research is goal orientated with well-defined, testable hypotheses, and is of finite duration. Monitoring involves systematic long-term data collection and analysis to measure the state of the resource and detect changes over time. Detecting such changes can prompt management decisions, can be used to evaluate the success of management strategies, or to focus research on determining the reason for the change.

Montego Bay Marine Park
Research and Monitoring Goals and Objectives

The primary goal of a research and monitoring program is to provide the knowledge necessary to make informed decisions to protect the biological diversity and natural ecosystem processes within the Park. Park goals include:

- Identification of priority areas for research;
- Establishment of an ecological monitoring program;
- Development of standards based on biological monitoring or assessment to ensure the protection and restoration of water quality, coral reefs and other marine resources;
- Establishment of a comprehensive water quality monitoring program to determine the sources of pollution and evaluate the results of pollution reduction efforts;
- Evaluation of progress in achieving water quality standards and protecting and restoring the Park's coral reefs and living marine resources;
- Establishment of strong communication and cooperation between the scientific community and resource managers;
- Coordination of research efforts to achieve the most beneficial results; and,
- Promotion of public awareness and resource stewardship.

To achieve these goals, the following objectives must be accomplished:

- The Park program's role in research and monitoring efforts must be well-defined;
- The Park and regional ecosystem must be understood and managed in a holistic manner;
- Managers, educators, and researchers must communicate effectively regarding issues and the results of studies;
- Data and other information should be shared among researchers and managers and should be easily accessible;
- Multi-agency research efforts should be coordinated for the greatest efficiency, including the definition of common priorities;
- Research funding should be sufficient, predictable and competitive;
- Research permitting should be coordinated among agencies;
- Management goals and objectives should be based on sound science; and,
- Sites protected from disturbance must be designed for sustained ecological research.

Existing Research and Monitoring Programs

Much research has been done in the Montego Bay Marine Park. Research is conducted by many groups, including local and federal agencies, public and private universities, private research foundations, environmental organizations, and independent researchers. While productive, research efforts are driven by diverse goals, vary in available resources and quality, and do not effectively share results. Leading research groups include The Nature Conservancy (rapid ecological assessment; Sullivan and Chiappone 1994), the United Kingdom Department for International Development (benthic and fish survey; Williams and Polunin 1999), the NRCA in conjunction with the Park (assessment of the Park's impacts on local fishers; Nicholson 1994), Harvard and Radcliff College (benthic survey and water nutrient analysis; Hitchman 1997), and the World Bank, along with various consulting firms, universities, and government organizations (see other contributions to this publication).

A number of monitoring activities are occurring in or near the Park. Specifically, these include Montego Bay water quality monitoring (National Water Commission and Louis Berger International Inc.), fisheries catch and effort data collection (Fisheries Division), and visual surveys of fish populations (Montego Bay Marine Park).

Volunteer Strategies and Activities

Volunteer activities and programs are decisive to the success of the Montego Bay Marine Park (Table 2.5). Available to implement a variety of strategy components, volunteers are seen as a valuable human resource. In addition to supporting management activities in the Park, the volunteer program will also coordinate assistance in other Park operations, mainly in the areas of enforcement, education and research.

The volunteer program is the focal point for determining the timing, source, type and degree of volunteer assistance provided for each Park strategy. The program is used to develop an organized method for providing volunteer assistance to the various public and private institutions involved in implementing strategies within the Park. Accordingly, volunteer efforts are planned and deliberate actions designed to accomplish specific management objectives. Each volunteer receives a handbook that provides information regarding his or her role while assisting the Park. The handbook includes all relevant documentation for monitoring the volunteer program's impact on attaining the Park's overall management plan objectives.

The success of the volunteer program is dependent on the involvement of the local and national community and the diversity of that involvement. Volunteers are recruited for the program and encouraged to participate in continuing recruiting efforts. Diversity among volunteers will be encouraged and emphasized in the recruiting efforts. This is to ensure that volunteers will be available to assist in the various programs where special technical skills are required. For example, volunteers that are certified divers may be asked to be "buddy divers", boat owners may be asked to help implement certain on-water activities, and volunteers with a science background may be asked to assist with the research and monitoring programs.

Montego Bay Marine Park
Volunteer Program Goals and Objectives

The Park's volunteer program goal is to provide a mechanism for involving the community in a variety of Park activities. Specific objectives include:

- Support efforts to improve public education and awareness about the Park;
- Provide information to Park managers to allow them to make more informed decisions; and,
- Develop a strategy to target the recruitment of volunteers.

The Park volunteer program strategy to target the recruitment of volunteers proposes approaches to generate interest in the program; explore sources to recruit from community groups, churches, neighborhood associations, and other volunteer groups and government agencies; encourage schools to start nature clubs from which volunteers may be recruited; and explore ways to appeal to potential volunteers with a diversity of interests and skills. The strategy will provide the new volunteers training, incentives and recognition. In doing so, the Park hopes to help keep volunteers involved and interested by providing them with a sense of stewardship and responsibility.

Existing Volunteer Programs

The Park has a history of using volunteers to assist with activities ranging from beach clean-ups and mangrove tree planting sessions, to maintenance tasks and public education programs. Volunteers currently help with office support, vessel and vehicle maintenance, underwater clean-up efforts, data entry and data base development, festival and special booth interpretive activities, mooring buoy installation and maintenance, and a variety of other Park projects. In addition, they act as visiting group leaders, boat captains and on-water interpreters. Based on the success of these existing programs, it is expected that volunteers will be an integral part of the Montego Bay Marine Park success.

The Park's volunteer coordinator is currently working with Park management to establish a framework for implementing education and outreach, research and monitoring, and other management strategies with a volunteer component. Volunteers are also visiting business and other sites in Montego Bay to determine their interest in displaying Park materials, interviewing businesses about their knowledge of the Park program, and developing a list of questions commonly asked about the Park. Existing volunteer programs that contribute to Park management but are not specific Park programs include boat and marina surveys and the monitoring of corals, rocky intertidal areas, sponges, algae, mangroves and water quality.

In addition to these activities, the volunteer program is currently being developed further. It is a cooperative effort between the Park and the local dive community using their expertise to develop a more comprehensive training program that will lead to improvements in environmental monitoring techniques. Programs currently being considered would focus on fish identification, artificial reef monitoring and reef clean-ups.

Public-Private Partnerships for
Water Pollution Prevention and Management

The Montego Bay Marine Park Trust, in partnership with various public entities, is in the process of implementing a variety of low cost and effective programs ("soft interventions") to mitigate water pollution impacts to the coral reef ecosystem (Table 2.6). These interventions form the basis of a comprehensive water quality management program for the Park.

Caught in the Poverty Cycle

Implementing the necessary management measures to ensure a healthy coral reef ecosystem will not be quick or easy. In about five years, 60% of the population in Jamaica will reside in urban areas, such as Montego Bay, and a third will be located in squatter communities not served by adequate household waste disposal (Huber and

Jameson 1998c). Only 25% of the country's households are connected to sewer systems, and even where such connections exist, wastewater treatment is inadequate (Huber and Jameson 1998c). The lack of a comprehensive waste management policy and clear lines of government responsibility delay implementation of effective waste management.

Taking all factors together, tourism is the largest economic engine in Jamaica today. In 1992, Jamaica received US$1,009.1 million in foreign exchange earnings (Johnson 1998). Government direct revenues from tourism for 1992 were US$89.87 million against expenditures of US$58.57 million. Tourism depends on the quality of the natural environment and, at the same time, can support protection of the environment. However, in Montego Bay, tourism impacts itself, local residents and water quality (Taylor 1993). The tourism industry makes many demands on the marine environment such as pressure on the beaches, use of precious resources for craft items, use of wetlands and outfalls in the sea for waste disposal, removal of seagrass for swimming beaches and blocking of visual and public access to the coast. Other negative environmental externalities, which have all been slowly working together to reduce the charm and quality of Montego Bay as a tourist destination, include upland sources of pollutants and soils washing down into coastal ecosystems from squatter settlements originating from increased tourist-based employment; overpumping and contamination of aquifers and aquifer recharge areas; disappearing beaches due to encroachment of structures and groynes; foreclosed public access and recreational opportunities in the coastal zone; threatened artisanal and small scale commercial fisheries from over harvesting; and degraded marine ecosystems. The result is reduced water quality, beach erosion, flooding and coral reef die back that threaten the sustainability of the tourist industry—an industry which is the most important foreign exchange earner in Jamaica.

While Montego Bay has the potential to create vast wealth and has had a measurable degree of success to date, little of this wealth has filtered down to the residents. All-inclusive hotels generate the largest amount of revenue but their impact on the economy is smaller per dollar of revenue than other accommodation subsectors (OAS 1994). For 1997 in Jamaica, Johnson (1998) estimates that the all-inclusive hotels attracted about 40% of all stopover visitors and captured about 60% of the total accommodation revenues. Unfortunately, only about 23% of this revenue stays in Jamaica (Johnson 1998). The trend towards the all-inclusive concept is increasing. Guests are discouraged from leaving the all-inclusive hotel property because of harassment and crime. Over recent years, this has led to poor earnings by local restaurants, sidewalk vendors and shops. The non-all-inclusive accommodations import less and employ more people per dollar of revenue than the all-inclusives (OAS 1994). For the entire tourism industry in 1997, the percentage of revenue remaining in Jamaica is about 43% (Johnson 1998).

The hotel industry should be a sector where linkages between economic development and environmental protection can enhance the well-being of the local community and maintain options for present and future generations. Unfortunately this is not the case and living conditions in Montego Bay are eroding. Over one third of Jamaicans live below the poverty line and many survive on remittances from 4.8 million Jamaicans living abroad. Women's unemployment rate was more than twice as high as men's but this has changed. Female unemployment is still higher but decreasing faster, and more young men are unemployed. People flock to the tourist centers for jobs. However, upon arrival, they find there is no affordable housing provided at these locations and, therefore, squatter communities are expanding. Visitor harassment is increasing as more people move without jobs from the countryside to tourism centers. The adult and juvenile crime rate is high and illegal spear fishing (mainly for subsistence) has helped to remove all breeding size fish from snorkel depth waters in the Park. Funding from the Government of Jamaica is totally inadequate to restore marine life. Gustavson (1998; Chapter 5) estimates that the net present value of local uses of the marine Park is US$489 (US$420 million for tourism, US$4.75 million for fisheries, and US$65 million for waterfront land storm protection) but government only contributed US$52,000 in 1997 (and less in 1998) to the marine Park budget. Government funds are scarce when 56% of GNP goes to pay off IMF and other foreign debts incurred as a consequence of the 1973 OPEC crisis. Therefore, unless the tourism sector becomes more proactive and puts money into the environment, the Montego Bay Marine Park Trust will have to go overseas or directly to the 1.2 million annual visitors for assistance. Population growth, without providing adequate housing and water, waste management, roads, schools and other services, is resulting in a vicious cycle of poverty related environmental degradation. It is likely that human impacts will continue to prolong the recovery period of coral reef communities.

In recent months, the economic environment has worsened. Inflation is down and interest rates are falling but bankruptcies and emigration are rising. Banks are repossessing small hotels and other businesses. Two of the five independent dive shops closed recently.

Breaking the Cycle

Early Park management was by central government and the style was classical based on the following model: science knows best, science informs regulations, regulations will be imposed, education will teach the children. In a society with low levels of education, high unemployment and little discipline, the result has been low awareness, low compliance, and public ignorance, apathy and criticism. The Park was seen as a discrete scientific and/or regulatory body that people did not understand and to which people did not pay much attention, with the exception that they expected the marine park to stop fishing activities and clean up others' wastes. Staff were becoming demoralized and defensive. In terms of economics, what rent was being captured was going to the private sector or the public purse and, while everyone claimed to be supportive, the support was moral rather than financial. The Park depended on government for funds but the environment was always low on the list of national priorities that had more pressing needs such as education, poverty, unemployment and child welfare.

The Montego Bay Marine Park Trust had been delegated management responsibility just over a year before the timing of the rapid socio-economic assessment of primary user groups (Bunce and Gustavson 1998a; Chapter 11), which was most helpful in informing a new management plan, guiding policy and shifting management style. The Park recognized the limitations of this assessment but, although "rapid" and subject to debate and further validation, provided useful feedback from users. What we learned from this study fell into two main categories—how the user groups felt about the Park, and the value of the Park to them.

Awareness among some user groups was lower than the Park had previously recognized and reflected a need for more information, not just in the formal school system, but also to user groups and the general public. Opinions varied along a spectrum ranging from unaware to apathetic to confrontational. The fishers were defensive towards Park enforcement personnel. The Park responded by becoming less authoritarian and listening more to their problems and concerns about being singled out as the main problem when land-based pollutants are not being addressed. Park management is now offering practical assistance in addressing their particular issues and needs and assisting them with advocacy. Water sports operators were supportive of Park objectives but critical of enforcement efforts. They wanted to become more involved in monitoring and wanted mooring buoys installed. Tourism players were generally supportive but critical of enforcement efforts to date. They also wanted more information for staff and guests who were largely ignorant of Park regulations.

Five guiding principles emerged (Bunce and Gustavson 1998a; Bunce *et al*. 1999; Chapter 11) which were implemented effectively in the following ways.

1. *Increasing user awareness:*

- Expanding "education" to "community relations";
- Holding workshop with fishers to discuss issues;
- Appointing fishers liaison officers;
- Attending fishers' meetings;
- Developing assistance for fishing improvement and alternatives;
- Maintaining hotel representation on management board;
- Presenting to hoteliers, staff and guests;
- Involving water sports operators in mooring buoy installation and maintenance;
- Holding a photo exhibition and competition;
- Turning the Park office into a resource centre, making it more interesting, inviting and entertaining;
- Revamping web page to be more entertaining;
- Involving divers in reef monitoring and fish counts; and,
- Training user groups to educate tourists.

2. *Promotion of conservation benefits:*

- Starting an aggressive outreach program;
- Developing public relations literature to promote benefits from the Park;
- Using economic values in presentations;
- Promoting operators of approved uses;
- Starting annual awards program;
- Advocating responsible fishing methods;
- Identifying opportunities for eco-tourism;
- Promoting financial savings from changing behavior; and,
- Using computer program to demonstrate cause-effect of coral conservation in Montego Bay (COCOMO; see Chapter 10).

3. *Increasing user involvement:*

- Listening to user issues to get support;
- Holding discussions and regular meetings with user groups;
- Increasing involvement with clean-ups and other projects; and,
- Changing "enforcement" to "compliance".

4. *Promotion of the "community resource" concept:*

- Changing language in materials (e.g., be a sea fan; national treasure and community resource; Mo Bay, My Bay; Wet, Wild and Wonderful);
- Creating brochures, bumper stickers and posters;
- Encouraging civic pride and sense of ownership;

- Forging linkages (e.g., farmers and fishers; hotels and schools);
- Involving the Chamber of Commerce and other groups in projects; and,
- Participating in more community events.

5. *Improving inter-sectoral coordination:*

- Starting network with enforcement agencies;
- Sitting on local government committees;
- Becoming agents for the Fisheries Division;
- Bringing different groups together;
- Influencing government ministers;
- Getting hotels to assist fishers;
- Bringing fishers into water sports and tourism;
- Holding regular meetings with tourism and development agencies to address land-based issues; and,
- Bringing private and public sectors together.

The data from the economic assessment (Gustavson 1998; Chapter 5) gave management a good picture of the financial value of the Park to the primary user groups, which was useful in designing implementation of a user fee system to be promulgated by government. The impressive figures added drama to public presentations in showing the importance of the Park. These figures are also useful to justify budget requirements to government, which made an impression even though national budget constraints prohibited adequate assistance. The data also suggested areas with potential for generating revenue through the other user groups as opposed to fees on direct use, such as hotels, beach fees and mooring buoy fees.

Attitude Adjustment

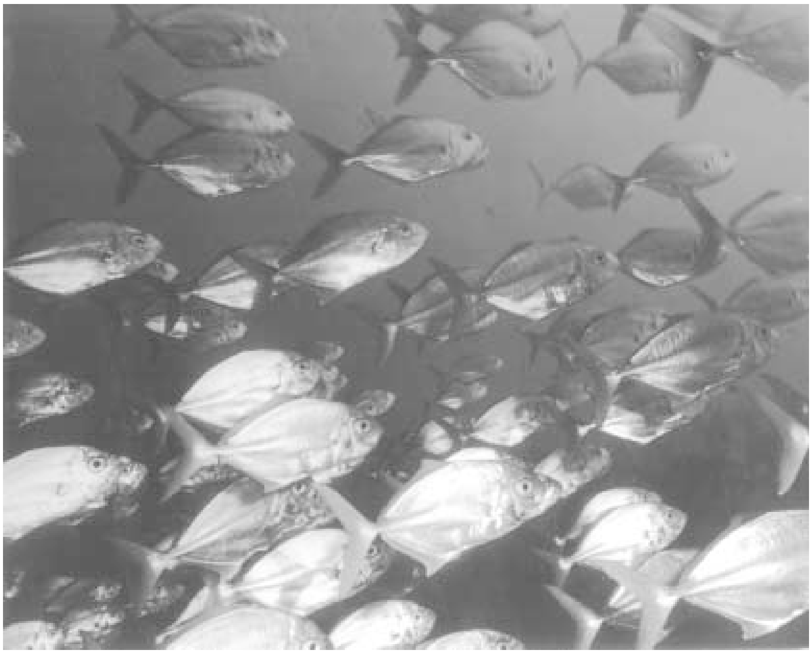
Management realized that a major attitude adjustment was necessary. If problems are human made, solutions must be as well. If solutions require change in behavior, then the motivations that govern behavior must be understood. Behavior is basically driven by the two opposing forces of reward and punishment. Traditionally, punishment has been used with less and less success. It is time to try incentives. Maslow defined an ascending hierarchy of universal needs that drive the human spirit, but one must start at the bottom and work up. So while universal, people (whether as individuals or in groups as nations) will be at different stages depending on their education and economic situation. Therefore, it is necessary to observe, assess and listen to what makes user groups "tick" before making recommendations, as well as to consider the conflicting perceptions and needs of different groups. Advocacy and negotiation between groups becomes important to success. The attitude adjustment had to start on the part of management itself.

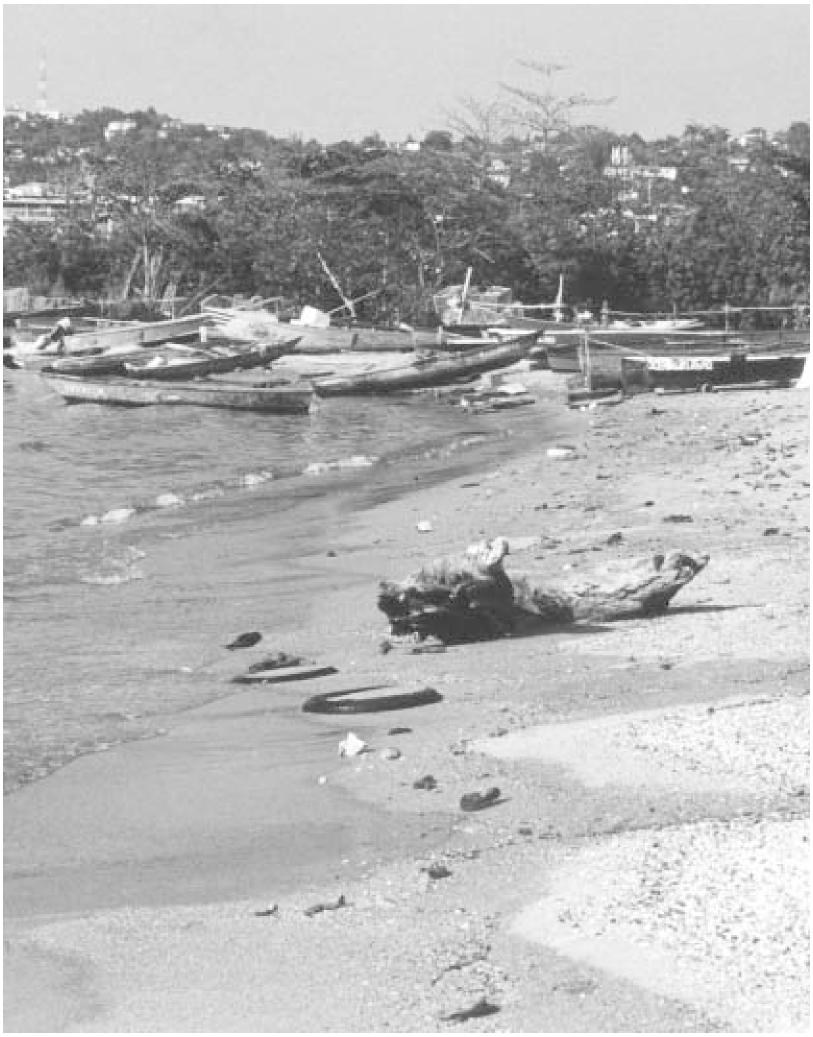
Management style is now based on a multi-disciplinary team approach. Science recommends management interventions and monitors results. Regulations must be justifiable and promoted to all concerned to achieve compliance rather than enforcement. Education goes "on the road" and takes the message to the primary user groups, community at large and the general public. Regular interaction with user groups was strengthened on issues such as the system of permits, to collect fees and data to inform carrying capacity assessment. Outreach efforts show the Park as a repository of useful information for the community, act as a conduit for information from abroad, central government and local government agencies, and provide feedback from the community. The Park must promote the importance of a healthy environment using all available tools such as the internet, mass media and community associations to improve public awareness and change behavior. In terms of economics, we can now demonstrate that the marine environment supports the economy with figures to "prove it". We can show that the Park is of primary importance to the economic health and welfare of the entire community, and can change the perception that Park management is a hindrance to development and oppressive to fishers. Now we can begin the real work to involve all sectors in understanding, taking ownership responsibility and moving away from the "tragedy of the commons" towards equitable use of resources. Only then will we have sustainable resource management and begin to attack the cycle of poverty.

We're All on the Same Team

The local communities are the principle force behind the need for reef conservation, standing to benefit considerably by protection, but also being the principle cause of reef loss. Notwithstanding these threats, the natural areas in Montego Bay remain in sufficient condition that, if properly managed and rehabilitated, they will provide substantial opportunities for economic growth, poverty alleviation and the maintenance of globally important biodiversity.

However, given the economic trade-offs and local awareness of environmental issues, coral reef ecosystem preservation and associated water quality is presently seen as a luxury. Until public relations and education efforts take root and *informed government policies and programs* dealing with pollution and poverty issues are enacted, coral reef managers will continue to be caught in a downward spiral of poverty that will defeat them. In any case, resource managers must demonstrate short-term economic benefits from conservation. Long-term payoffs mean nothing in an economy where subsistence is of primary concern.





II: Creating Decision Support Models

Chapter 3

Cost-Effectiveness Analysis of Coral Reef Management and Protection: A Case Study of Curaçao

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Curaçao lies in the southern part of the Caribbean Sea (Figure 3.1). It is one of the five islands making up the Netherlands Antilles, the others being Bonaire, St. Eustatius, St. Maarten and Saba. The total island area is 444km^2, with a length of 70km and a width varying from 5km to 14km. The capital of the island, Willemstad, is positioned in the center of the island around the Schottegat (Figure 3.1). This forms one of the largest natural harbors in the Caribbean Sea and is the center of the industrial zone of Curaçao. The main developments, both for housing and resorts, are currently along the central southern coastline. Oostpunt is the largest privately owned section of land on Curaçao and, as a result, is currently undeveloped. Westpunt has been gradually developing since the construction of a road that improved its accessibility; however, it still remains relatively undeveloped. The exposed north shore is also relatively undeveloped; this is the site of the Brievengat industrial zone and the airport, located at Hato.

Most of the coral reefs of Curaçao are in very good condition compared to many of the reefs in the Caribbean, although a stretch around the capital, Willemstad, has been seriously impacted by human activities. While Curaçao is still mostly dependent on its oil refinery, tourism is growing rapidly as a source of income. There are many planned tourism development projects, and the potential for the sector appears good, at least if the current quality of the coral reefs can be maintained. How can reef deterioration, which has occurred in many other places around the Caribbean, be prevented? Should certain areas be set aside? What will it take to rehabilitate the reefs in the Willemstad area, if that is at all possible? In 1995-96, a research project was carried out to develop an approach to answer these and similar questions.

Reef Research and Management

The Curaçao reefs have been well studied over the last 25 years in projects organized by or through the CARMABI Foundation in Curaçao (e.g., Bak and Nieuwland 1995). Most of the research that has taken place has been very specialized. It has focused on many aspects of marine biology, but rarely on the functioning of the reef as a whole. This is not as surprising as it may seem because coral reefs are extremely complex systems made up of hundreds of species of marine life that interact with each other in numerous ways. Where many biologists have worked for long periods to understand single species fisheries such as salmon, herring or anchovies without having completely succeeded, it is not that strange that coral reef biologists do not yet even have a generally accepted definition of coral reef health. Coral reef research often focuses on the response of a single species to a well defined disturbance under relatively carefully controlled conditions (e.g., Meesters *et al*. 1992; Veghel 1994).

From a perspective of coastal zone management, however, the relevant questions relate to the response of the reef system as a whole to a complex set of disturbances. Will the planned tourist developments and the associated wastewater discharges and artificial beaches have a significant impact on the coral reef? A coral reef biologist might answer this question by saying that the reefs are already under stress and that no new development should take place. A developer might answer this question by saying that the reefs of Curaçao are still in relatively good condition and that the economy of Curaçao needs the employment generated by tourism. In fact, the opposite argument is also used—because the reef is already

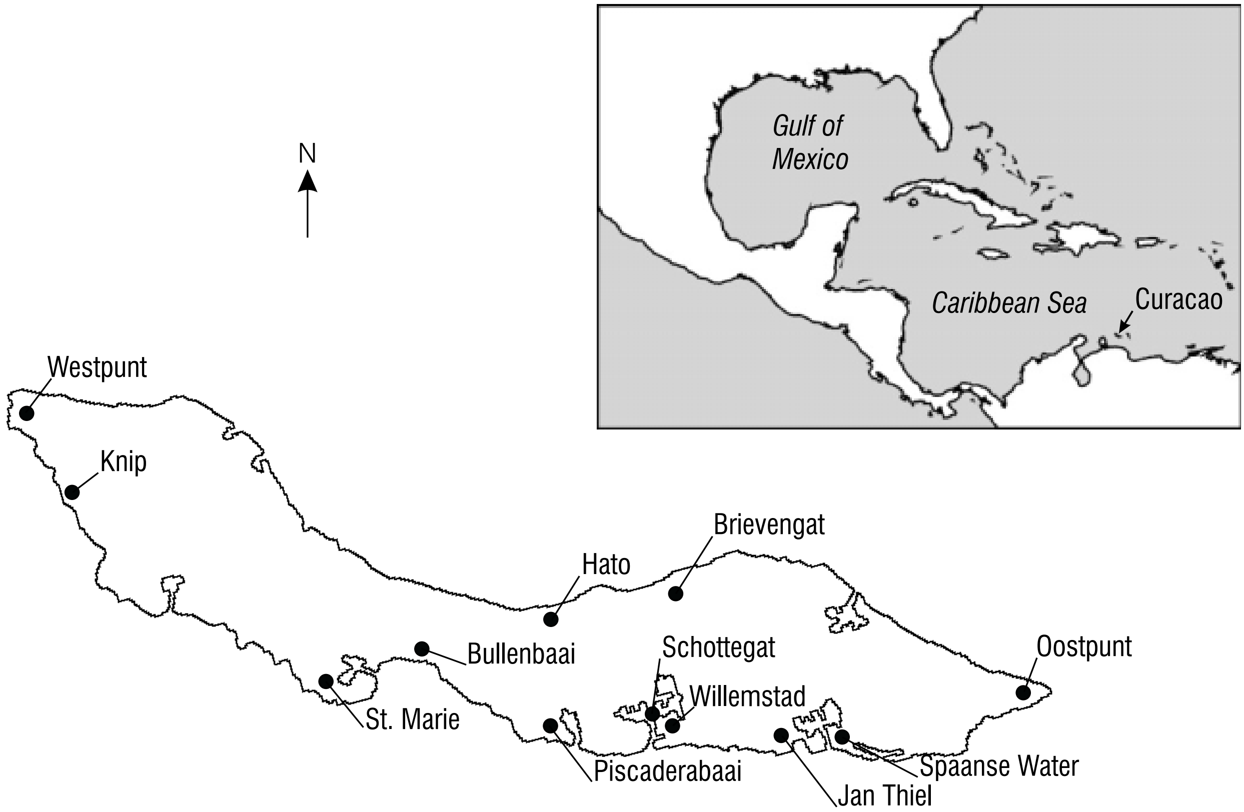

Figure 3.1. Curaçao, showing its location within the Caribbean.

degraded in certain locations, how can more development in those locations possibly harm the reef significantly? Both sides are likely to be partly right, but the more subtle answer to the question of how much development is sustainable requires: i) much more insight into the functioning of the reef as a whole; and, ii) a consensus among people involved concerning the quality of the reef that is desired or, in other words, the impacts to the reef that are socially acceptable.

Objective and Approach

The objective of the research project reported here is to develop an approach that will do two things, namely:

- Bring together the available knowledge in marine biology, economics and engineering to determine whether human use of the coastal zone will significantly affect the health of the coral reef system and what the most cost-effective manner is to prevent impacts on coral reef health; and,
- Provide a means to engage the various stakeholders in a discussion to determine what sustainable development of the coastal zone means for them and, therefore, what levels of reef health are socially desirable.

The Coral-Curaçao Decision Support System

The approach chosen to achieve these objectives has been to develop a computer-based decision support system, referred to as Coral-Curaçao (see also Chapter 4 and the companion CD-ROM). The two main innovative elements in the approach are: i) the interactive, computer-based approach to decision support for integrated coastal zone management (ICZM); and, ii) the ecological response model for coral reef health based on fuzzy logic.

The decision support system aspect of Coral-Curaçao has the following characteristics:

- It utilizes a graphics-based user interface that makes it easy for decision-makers or stakeholders to use;
- It utilizes a case study-based (i.e., location specific) approach, which has the advantage of demonstration through realistic examples rather than abstract theory;
- It guides users through a generic approach to ICZM that structures the development, analysis and evaluation of coastal zone management strategies;
- It is interactive (i.e., it allows user input with respect to setting of objectives and criteria, definition of scenarios, selection of measures and strategies, and evaluation of impact); and,

- It demonstrates inter-sectoral linkages and facilitates communication among stakeholder groups.

The fuzzy logic based response model for coral reef health has the following characteristics:

- The model is an expert system, based on fuzzy logic, that does not attempt to describe the behavior of the system deterministically (i.e., through equations that describe the behavior of the reef as a function of a set of driving variables and parameters), but simply uses a "black box" approach to describe reef behavior;
- The model encapsulates and synthesizes expert knowledge into a large number of decision rules that are subsequently used to "predict" reef behavior;
- The model brings together a large amount of varied experience and expertise, gained from many different sources, and applies it to the problem at hand; and,
- The response model for Curaçao links the concentrations of nutrients (i.e., nitrogen and phosphorus) and sediment over the reef to future values for coral reef health (defined by coral cover and relative species diversity) under various reef conditions (i.e., current reef health, available substrate and maximum colony size).

The development of the fuzzy logic model was originally based on the parallel model developed for Jamaica (Ridgley and Dollar 1996; Chapter 8). Subsequent revisions of both models show differences in the development due to the different local situations. The case study for the Maldives takes a more focused look at physical damage (Meesters and Westmacott 1996; Chapter 4).

Development of Scenarios and Environmental Strategies

The first use of Coral-Curaçao is to analyze the impact of alternative development scenarios for Curaçao on coral reef health, as well as on a number of other economic, environmental and social criteria. The second use is to determine the cost-effectiveness of alternative environmental and institutional measures to prevent impacts on coral reef health.

The development scenarios can be defined by the user through a combination of overall island-wide assumptions regarding expected economic growth, population growth, growth in expected tourist arrivals in Curaçao (the demand for tourism), and the discount rate (to determine the present value of future costs and benefits). In addition, the user can provide detailed assumptions on the preferred location of newly constructed or expanded hotels, apartments and residential developments, and new harbor developments.

Three example development scenarios are reported in this chapter. They illustrate the types of analyses that can be carried out with this model. Actual use of the model will require the identification of the scenarios and strategies in cooperation with the various coastal zone managers in Curaçao. The first scenario (the reference scenario) focuses on the current situation with little new investment, population growth as in the past, and a stagnating economy. Development is centered near Willemstad. The second scenario (the growth scenario) assumes 3% annual growth in the economy, particularly through the tourism sector. Two variations are made in this scenario: i) "growth-west", where a significant portion of residential and tourism development has been planned west of Willemstad and the east has been left largely undeveloped; and, ii) "growth-east", where growth concentrates more on the area east of Willemstad with at least one major hotel in Oostpunt. For each of these three scenarios, the impacts on the reefs have been analyzed and example environmental strategies have been developed to see how impacts could be prevented and at what cost.

It is intended that through further development and training with the model, it can be used in the development of coastal zone management plans. This will involve the coastal zone decision-makers to identify potential scenarios and formulate the environmental strategies. It will also involve a degree of cooperation and interaction between the different stakeholder groups, leading to the eventual formulation of alternative coastal zone management plans. Further information regarding the development of the Coral-Curaçao model can be found in Meesters (1995), Meesters *et al*. (1996a), Rijsberman *et al*. (1995a), Westmacott *et al*. (1995), and Rijsberman and Westmacott (1996).

Description of Coral-Curaçao

The approach adopted in the Coral-Curaçao model is based on cost-effectiveness analysis of coral reef health in an ICZM framework. The main components of the decision support system are a user interface, economic activity model, water quality model, and ecological response model (Figure 3.2). The user provides inputs concerning economic development scenarios and environmental management strategies through the user interface. The economic activity model translates these assumptions and choices into pollutant loadings along the coast and keeps track of a number of economic parameters (i.e., GDP per capita, employment, and environmental costs and investments). The base year for Coral-Curaçao is 1995 and projections are made over 10 years to 2005.

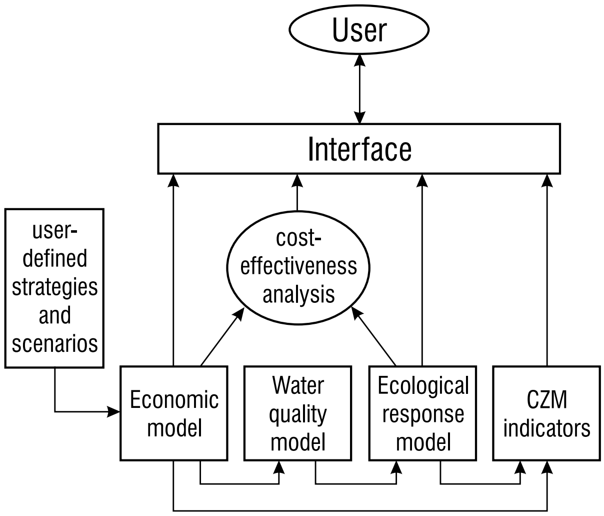

Figure 3.2. Structure of the Coral-Curaçao decision support system.

The water quality model determines the water quality that corresponds with the pollutant loadings for six sections along the southern coast of Curaçao (Figure 3.3). Water quality is defined in terms of concentrations of *E. coli* and in terms of nutrient (i.e., nitrogen and phosphorus) concentrations. Sediment impacts on the reefs are based on the locations and material of the artificial beaches, as well as the suspended material discharged by the land-based activities. The ecological response model then determines the resulting reef health (i.e., cover and diversity) for the six coastal sections. The outputs of the economic activity, water quality and ecological response models are shown to the user through tables and graphs in the user interface, along with several criteria that the user is asked to evaluate through user input (i.e., social acceptability and financial feasibility of the scenarios and strategies).

Cost-Effectiveness Analysis

In theory, if all benefits provided by coral reefs could be determined quantitatively and if all costs of protecting coral reefs from pollution or overuse could be enumerated, then one could determine the "optimal" level of investment in coral reef protection and management. Determination of the social and economic benefits provided by coral reef ecosystems is the subject of subsequent chapters. Although significant progress has been made in benefit valuation, it remains notoriously difficult, particularly for complex systems such as coral reefs.

The next best alternative would be to determine what level of coral reef health is socially desirable (a procedure similar to determining water quality standards, for instance) and then to analyze what the least expensive, or most cost-effective, manner is to provide the desired level of reef health. This is referred to as cost-effectiveness analysis.

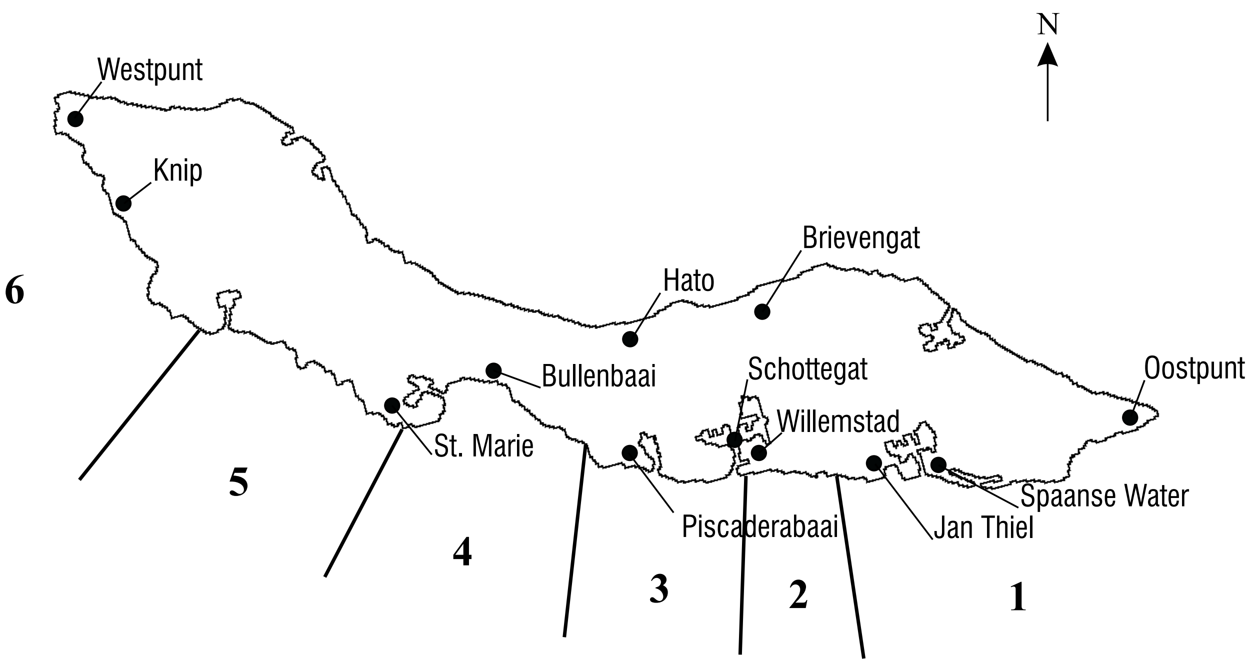

Figure 3.3. Coastal section divisions of Curaçao utilized in the model.

In the version of Coral-Curaçao presented here, no attempts are made to quantify the benefits of having a healthy reef. The basis for decision-making with Coral-Curaçao is, therefore, a form of cost-effectiveness analysis. An associated problem is then how to determine the level of socially desirable reef health. The socially desirable level of reef health has to be decided by the stakeholders. However, a model such as Coral-Curaçao can facilitate the discussion among stakeholders concerning these issues. For reference purposes, what is required to maintain the current level of reef health can be analyzed. Whether this is either necessary, or sufficient, remains a question that has to be answered by, in this case, the people of Curaçao.

The ICZM Framework for Analysis

The main structure of the coastal zone management analysis in Coral-Curaçao follows the structure of a generic framework for analysis that has been developed over the last 10 to 15 years (Bower *et al*. 1994; Resource Analysis and Delft Hydraulics 1993; Rijsberman and Koudstaal 1989; Westmacott 1995). Practical applications of this approach to coastal zone management issues are given by, for instance, Baarse and Rijsberman (1986, 1987) and Ridgley and Rijsberman (1992). Following this framework, the main steps in an ICZM analysis within Coral-Curaçao are as follows:

- Problem identification;
- Definition of objectives and criteria as yardsticks to measure fulfillment of objectives;
- Definition of scenarios for uncertain, exogenous developments;
- Definition of management strategies in terms of their component measures;
- Analysis of the impacts of the strategies in terms of the criteria; and,
- Evaluation and selection of the most desirable strategy.

The Decision Support System User Interface

The decision support system developed for Curaçao has a user interface of the type developed in 1993 for the coastal zone management training tools COSMO and CORONA (Resource Analysis and CZM Centre 1994; Rijsberman *et al*. 1995b). It has been shown in a series of workshops and seminars that this type of interface is easily accessible for specialists from various disciplines as well as policy-makers, including those with minimal or no computer experience or scientific background. The interface attempts to bridge the communication gap between policy-makers and coastal zone specialists. The interface is based mostly on graphic information to provide users with a quick overview with minimal text. The structure of the interface's main menu guides the user through the steps of the ICZM framework for analysis, as outlined above, and thereby structures the user's thinking about the problems at hand.

A major characteristic of the interface is that it is truly interactive. Many recent multimedia tools are called interactive but allow the user no more interaction than the order in which the screens are observed. Coral-Curaçao allows the user, as do similar decision support system tools in the "COSMO family", to input his or her own assumptions or preferences about scenarios and strategies, and examine the consequences. The development scenarios input screens in Coral-Curaçao provide the user with the opportunity to define a likely, or desirable, development path for the economy, with particular focus on development of the coastal zone. The user can provide detailed definitions of hotel, apartment, residential, artificial beach and harbor development projects in pre-defined locations along the coast.

The Economic Activity Model

The main purpose of the economic activity model is to determine the pollutant loadings resulting from assumptions about economic development combined with environmental strategies, as well as the costs of the environmental measures taken to reduce those pollutant loadings. The economic activities distinguished in Coral-Curaçao are tourism, harbors and shipping, manufacturing, fisheries, services and "other" (i.e., the rest of GDP), the oil refinery, and residences. Tourism, harbors and shipping, and fisheries are considered to be the coastal zone related activities, in the sense that they depend directly on the coastal zone. Manufacturing, the oil refinery, and residences are considered separately from the rest of the economy because of their potential impact on the coastal zone through discharges of pollutants. There is no agriculture to speak of in Curaçao with significant influences on the coastal zone.

Pollutant loadings are based on sectoral outputs multiplied by an emission factor per unit of output (in monetary terms) for all sectors except the oil refinery, residences and tourism. The base loadings produced by the economic activities can be reduced through end-of-pipe treatment. This yields the final loadings that are discharged. For residences, the loadings are based on emission factors per capita. For tourism, the loadings are based on the number of tourist nights. For the oil refinery, the loadings are based on emission factors multiplied by output in cubic metres of oil produced. The steps in the economic activity model are described in the following sections.

Step 1—Activity Levels

The total GDP in 2005 (in constant 1995 dollars), except for the tourism sector, is determined by an overall assumption of the annual economic growth (scenario variable). The sectoral output of tourism is determined by the lowest of: i) projected tourism demand (scenario variable); and, ii) hotel capacity, as influenced by hotel construction projects. The size of the population in 2005 is based on an assumption for annual population growth (scenario variable).

Step 2—Sectoral Shares and Spatial Distribution

The sectoral share of the GDP (except tourism) can be modified by the user through assuming that several investment projects (in harbors and manufacturing) take place. The overall growth rate is not affected by these investments; it is in fact assumed that the investments are shifts within an overall investment portfolio. The additional increase in the sectoral GDP due to the investment project is calculated as an assumed return on investment. The GDP of the other sectors (harbors, manufacturing, services and "other") are reduced by the same total amount, distributed proportional to their 1995 share of GDP. The investment projects, therefore, do not affect overall output, GDP or GDP per capita, but they can affect pollutant loadings because of the difference in emission coefficients per sector. Construction of housing and hotels is specified by the user and spatially distributed over six sections along the coast. The location of other sectoral activities (harbors, refinery, manufacturing, services and "other"), and consequent location of the discharges, is fixed in the model based on their current location. In short, the overall GDP and sectoral shares are determined by assumptions on overall economic growth and tourism demand together with assumptions on investment projects in harbors, manufacturing, hotel construction, residence construction, and artificial beach construction. Through the spatial distribution of, particularly, housing and hotels, the user specifies land use scenarios for the island. Such scenarios can determine development and conservation areas on the island (e.g., following ideas as presented in an approved island-wide development plan). The impact of such development choices on the reef is shown with the help of Coral-Curaçao.

The Coral-Curaçao user can actually define construction projects (houses, hotels, apartments, artificial beaches) in more detail than the six sections used for the water quality and coral reef computations. In the interface, the actual sites and locations (approximately 20 in total) along the coast are based on projects proposed by developers. This has the advantage of providing a better fit to the land use planning discussions and the public debate about projects that focus on specific hotel projects on specific beach or bay sites. This is intended to increase the acceptance and use of the decision support system for Curaçao.

Step 3—Base Pollutant Loadings

The activity levels (sectoral GDP shares and number of houses in 2005) multiplied by the emission factors generate base pollutant loadings. For each of the sectors, emission coefficients have been defined for nitrates (N), phosphates (P) and sediment (total suspended solids or TSS; see Rijsberman and Westmacott 1996).

Step 4—Final Pollutant Loadings (Wastewater Treatment)

In Coral-Curaçao, the user specifies wastewater treatment options for residential and tourism sector discharges. The following options are available:

- *No treatment*. The base load is discharged directly into the near-shore (septic tanks are assumed to play a marginal role).
- *On-site treatment for hotels and apartments*. The treated final load is discharged into the near-shore (if there is an outfall to move the discharge off the beach, it is assumed not to take the discharge beyond the reef area).
- *Sewage system connected to an ocean outfall*. This is assumed to bring the discharge beyond the reef area.
- *Sewage system connected to a sewage treatment plant*. There is subsequent discharge on the near-shore (no outfall or a short, near-shore outfall).
- *Sewage system connected to a sewage treatment plant with outfall*. There is subsequent discharge through an ocean outfall beyond the reef.
- *Sewage system for transport to a neighboring section*. Wastewater is removed completely from this section and subsequent discharge depends on treatment level and outfall construction in the neighboring section.

For the refinery, manufacturing, harbors and shipping, and services and "other" sectors, the user specifies base load reduction percentages directly. It is left undefined whether these reductions are the result of improved processes (i.e., reduced discharge coefficients) or end-of-pipe treatment. Only rough estimates of costs are available for these measures (see Step 6 below). Pollutant loadings (sediment discharge) from artificial beaches can be reduced by the use of coarser, more expensive types of calcareous sand. Sediment from artificial beaches is dealt with directly in the water quality model.

Step 5—Other Environmental Management Measures

The model also keeps track of assumptions on several other environmental management options (i.e., environmental awareness raising programs, establishment of a marine park, and increased inter-sectoral coordination). These are not assumed to modify loadings directly, but to increase the social acceptability and financial feasibility of the other environmental investments.

Step 6—Environmental Costs

The model calculates the cost of environmental management strategies. The major component of this is wastewater treatment. The costs of treatment consist of the investment costs of:

- On-site treatment systems for hotels and apartments;
- Construction of sewage systems;
- Construction of treatment plants; and,
- Construction of outfalls.

All investment costs are assumed to occur in year one and are not discounted. Annual costs of maintenance and operation are discounted (with a user-specified discount rate) to year one and added to the investment costs to obtain total costs. Other costs taken into account are:

- Additional cost of using calcareous sand for artificial beaches (3,500 NAF m^{-1} yr^{-1} additional investment costs and 500 NAF m^{-1} yr^{-1} additional maintenance costs);
- Cost of establishment and operation of a marine park (user defined);
- Cost of environmental awareness programs (user defined);
- Cost of reducing discharges from manufacturing (estimate); and,
- Cost of reducing discharges from the refinery (estimate).

The costs of the environmental management strategies are used for the analysis of cost-effectiveness of coral reef protection measures, where the effectiveness of a strategy is measured as the difference in reef health (either cover or diversity) as determined by the ecological response model.

Step 7—Other Indicators

The model also tracks several other parameters that are not used for the cost-effectiveness analysis. These do, however, provide the user with information about the economy under the given assumptions for economic growth, sectoral investments, and environmental management strategies. These parameters relate mainly to GDP, GDP per capita, GDP of coastal activities, total employment, and employment in coastal activities, as well as the financial and political feasibility of strategies (the latter two being user defined).

The Water Quality Model

A simple water quality model has been formulated to determine water quality (i.e., concentrations of nitrates and phosphates) in six sections along the coast (Figure 3.3). The model is driven by the average east to west current parallel to the coastline and takes into account the effects of tidal mixing (diffusion) perpendicular to the coastline, as well as decay of the pollutant materials within each of the six sections. This type of simple model is a relatively good approximation for a straight coastline with high lateral velocities compared to the tidal velocities. As this is the case for Curaçao, this type of model was used to provide approximate indications of water quality under average conditions in the six sections. Precise water quality determination for specified times and locations are not possible with this type of model, but, bearing in mind the level of accuracy of the ecological response model, this is not considered to be a major drawback.

For accurate estimates of water quality along beaches, the model that has been used is not very appropriate and could be improved. Estimates of sediment concentrations (in terms of low, medium and high, as required by the ecological response model) have been based on the location and composition (in terms of grain size) of artificial beaches. The water quality model is valid for the areas of reef flat. This is the part of the reef that is taken into account in the Coral-Curaçao model (see next section). If the model were to consider the reef slope then other aspects, such as the influence of mixing with ocean currents, would need to be considered.

The Coral Reef Ecological Response Model

An important component of the Coral-Curaçao modeling framework is an ecological response model to predict the impact of economic development on reef health. Reef health, defined as coral cover and relative species diversity, is used as the main indicator of the status of the marine ecosystem (i.e., the model outputs). The ecological response model has been designed to predict the impacts of the most significant pollutants on the reef flat. The reef flat has been selected because the majority of research and available information is based on this zone of the reef. This may result in a different level of impact than if the reef slope was also considered. The reef flat may be the first area to be affected from land-based pollution and storms, for example. The reef slope is the area most visited by recreational divers and potentially providing shelter and food for fish. However, on the grounds of data and knowledge availability, only the reef flat is included in this model.

The most significant pollutants in Curaçao have been identified as nutrient enrichment from the discharge of wastewater of land-based activities (i.e., sewage and industrial wastewater, and increased sediment concentrations that result from artificial beaches). There are other influences on reef health (e.g., consequences of anchoring, fishing or direct diver related impacts), but these have been evaluated to be relatively small in the current Curaçao context compared to the influence of nutrients and sediment. The main reef characteristics that influence how the inputs of nutrients and sediment affect reef health that have been accounted for in the model are: i) available substratum; ii) maximum colony size; iii) coral cover; and, iv) diversity. The methodology for the ecological response model has been developed by Ridgley and Dollar (1996) and has been modified and tested for Curaçao conditions. The Curaçao ecological response model has been developed as part of this project and is described in detail in Meesters (1995) and Meesters *et al.* (1996a, 1998).

The Curaçao reef response model determines coral cover and diversity for an imaginary situation 10 years after the impact levels have changed. The inputs are suspended particulate matter, soluble reactive phosphorus, dissolved inorganic nitrogen, maximum colony surface area, available substratum and, again, coral cover and diversity (species number). Each variable was divided into three triangular fuzzy sets reflecting low, medium and high values. Boundary values for the sets were based on fieldwork carried out for the project and on the literature (Meesters 1995). For each of the 2,187 possible input combinations, decision rules were formulated. Information on current reef conditions in Curaçao is provided in Table 3.1.

Case Studies for Curaçao

We now examine how the Coral-Curaçao decision support system can be used in the analysis of alternatives for coral reef management under different economic development scenarios. As stated previously, formulation of scenarios and strategies for both the economic development and the environmental protection measures should eventually be done in conjunction with the stakeholders in the region. Cooperation with the stakeholders on the island will enable a number of constraints and criteria to be identified that are likely to enter into decisions on reef management. The cases formulated in this chapter should be seen as examples of the how the Coral-Curaçao decision support system can potentially be used. The reader is encouraged to explore the model through use of the CD-ROM included with this publication.

Development Scenarios

As previously described, the following example economic development scenarios have been pre-defined in Coral-Curaçao: i) a reference scenario; and, ii) two growth scenarios, growth-west and growth-east. These scenarios are summarized in Table 3.2. These development scenarios are examples to demonstrate the use of Coral-Curaçao; they are not necessarily balanced development proposals for Curaçao.

Reference Scenario

In the reference scenario, no major investments are assumed to take place and most trends are, in essence, continued as observed in recent years. This means that the overall economic growth rate is near zero. There is some growth in the tourism sector (3% growth in demand per year) but this is balanced by some decline in other sectors.

Table 3.1. Curaçao reef conditions in 1995. The range of values shown is the values occurring in the sub-sections within the six main sections.

Section	*Cover* (%)	*Diversity* (% of species present)	*Available substratum* (%)	*Maximum colony size* (10^{-2} m^2)
1 (Oostpunt to Cornelisbaai)	14 to 23	33 to 61	40 to 50	77 to 316
2 (Cornelisbaai to Punda)	8 to 20	14 to 26	10 to 50	42 to 69
3 (Schottegat to St. Michael)	1 to 16	1 to 55	1 to 40	8 to 75
4 (Bullenbaai)	11 to 14	41 to 65	20 to 30	53 to 89
5 (Rif St. Marie to St. Martha)	12 to 16	26 to 100	20 to 40	89 to 143
6 (Jeremi to Playa Kalki)	15 to 23	17 to 98	40	275 to 455

Table 3.2. Development scenarios pre-defined in Coral-Curaçao.

Variables	*Units*	*Reference scenario*	*Growth-west*	*Growth-east*
Economic growth	%/yr	0	3	3
Population growth	%/yr	1.2	1	1
Growth in tourism demand	%/yr	3	8	8
Discount rate	%/yr	6	6	6
Residential development	# of houses	current pattern	600 from Westpunt to St. Martha Bay	600 in Spaanse Water and Jan Thiel
Hotels and apartments	# of rooms	600 in Piscadera and Cornelisbay	2,000 from Westpunt to Rif St. Marie	2,000 from Oostpunt to Marie Pompoen
Artificial beaches		none	Rif St. Marie Marie Pompoen	Oostpunt Cornelisbay Marie Pompoen Elyse Hotel
Harbor projects		none	Caracas Bay and Schottegat	none
Refinery output growth	%/yr	-1	-2	0
Manufacturing growth	%/yr	0	0	2

Population growth continues at about 1.2%/yr and, therefore, per capita income declines somewhat. Construction of new houses is assumed to continue in the present pattern without major shifts. The new tourist development projects (some 600 rooms) are assumed to be located around Piscadera Bay and the area just west of Seaquarium (referred to as Cornelisbay in Coral-Curaçao). No new artificial beaches would be constructed. There are no new harbor improvement or development projects.

Growth-West Scenario

In the growth-west scenario, an overall economic growth of 3%/yr is assumed to take place, with vigorous growth in the tourism sector (8% growth in demand per year). Population growth declines to 1%/yr. The scenario places emphasis on development of the western part of the island for tourism and residences, and expansion and improvement of harbor facilities in Caracas Bay and Schottegat. The refinery output is assumed to decline somewhat, while manufacturing stabilizes. Emphasis in development of the western part of the island to relieve congestion around Willemstad, as well as develop its tourism potential, implies that some 600 new houses are assumed to be constructed (following existing development plans) in the area from Westpunt to St. Martha Bay. Some 1,200 tourist rooms would be developed in the same area, from Westpunt to Rif St. Marie. The existing beaches would be supplemented by one artificial beach at Rif St. Marie. A second artificial beach would be constructed at Marie Pompoen. The harbor project consists of the proposed reception facilities in Caracas Bay. Oostpunt would, in essence, be preserved as a natural area in this scenario.

Growth-East Scenario

Growth east of Willemstad, with the same overall growth characteristics of the economy as for the growth-west scenario, places more emphasis on the eastern, rather than the western, part of the island. Residential development would be assumed to take place in the Spaanse Water and Jan Thiel areas. Tourist developments would emphasize at least one major hotel in the Oostpunt area (200 rooms) and other proposed projects between Oostpunt and Punda. In this scenario, four artificial beaches have been proposed for construction at Oostpunt, Cornelisbay, Marie Pompoen, and the Elysee Hotel. There would be no harbor development projects, relatively stable refinery output, and some growth in manufacturing.

Environmental and Other Impacts

The impacts of the development scenarios on both the economy and on the reefs are summarized in Table 3.3.

Table 3.3. Impacts of development scenarios without environmental strategies (GDP=gross domestic product; N=nitrogen; P=phosphorus; SPM=suspended particulate matter).

Criteria	*Units*	*Reference scenario*	*Growth-west*	*Growth-east*
GDP per capita	NAF/yr	13,000	17,300	17,300
Employment	number of jobs	58,000	77,000	78,000
GDP share of coastal activities	%	21	22	21
GDP tourism	million NAF	324	450	450
GDP fisheries	million NAF	10	13	13
GDP harbor and shipping	million NAF	115	176	154
Total N load	kg/day	2,100	2,200	2,200
Total P load	kg/day	790	840	870
Total SPM load	kg/day	17,800	17,700	18,900
Average coral reef diversity	%	32	32	32
Average coral reef cover	%	9	9	9
Problem beaches (bad water quality)	number	13	14	0

In essence, even though the development locations of the hotels, apartments and houses are quite drastically different, the overall impact of the three development scenarios on reef health is similar. There are differences within each of the coastal sections, but these are not drastic. The characterization of the situation remains that the eastern and western sections are relatively pristine and that the middle sections are heavily impacted. This impact reflects the effect of the industrial zone around the Schottegat. There is a significant difference in the water quality along the beaches. The western part of the island has a series of attractive beaches. The growth-east scenario maintains relatively good water quality conditions in the western part, at least at the first order accuracy of the simple water quality model used here. When there is some development in the western part, all these beaches become potential problem areas if there are no sanitation measures taken. The overall loadings of pollutants are determined more by the population growth rate than by tourism development (at least at the relatively modest tourism growth rates investigated here).

Environmental Strategies

A series of environmental measures are now investigated and subsequently combined into strategies to explore the potential improvement in coral reef health (i.e., cover and diversity) and the costs involved. These strategies are analyzed under each of the economic scenarios described previously.

The environmental protection options available to the user have been described above. The user can define these options for different locations, corresponding to the various settlements along the southern coast. The user is able to define any combination of measures and save these for the analysis. In addition, measures can be defined for the industrial area surrounding Schottegat Harbor.

To begin the analysis, the measures have been investigated on an individual basis. These are then combined into strategies or groups of measures all aiming to be complimentary in the achievement of an improved reef condition. Analyzing the individual measures allows the user to make an assessment as to the individual effectiveness. This will help in the formulation of effective combinations, rather than random combinations. Like the economic development options, the measures defined here are to be used to illustrate how the model works and explore its limits. They are not carefully formulated environmental management plans that have been decided upon by a group of decision-makers. Table 3.4 describes the environmental protection strategies that have been defined and used in the analysis. Three combinations of municipal waste disposal, industrial pollution control, and beach maintenance have been combined together to explore the effect of integrating measures and to examine the cumulative effect that these have on reef health.

Table 3.4. Descriptions of the environmental protection measures and strategies.

Code	*Description*
10H	100% treatment of hotel waste through onsite treatment.
10W6	100% connection of houses and hotels to sewage system; treatment with 60% reduction through five wastewater treatment plants.
10W9	100% connection of houses and hotels to sewage system; treatment with 90% reduction through five wastewater treatment plants.
10W9/10H	100% connection of houses to sewage system; treatment with 90% reduction through five wastewater treatment plants; 100% treatment of hotel waste through onsite treatment.
5W9	50% connection of houses and hotels to sewage system; treatment with 90% reduction through five wastewater treatment plants.
5W9/5H	50% connection of houses and hotels to sewage system; treatment with 90% reduction through five wastewater treatment plants; remaining 50% hotel waste treated through onsite treatment.
B	Maintenance of the artificial beaches with heavier calcarious sand reducing the transport from the shore onto the reef flat.
M9	90% reduction of manufacturing waste through onsite treatment.
O4	100% houses and hotels connected to the sewage system where disposal is through four outfalls.
O9	100% houses and hotels connected to the sewage system where disposal is through nine outfalls.
R	Reduction of refinery effluent.
R/S4/M9	Maximum reduction of industrial pollution through reduction of refinery effluent; 40% reduction of pollution from ships through improved reception facilities and 90% reduction in manufacturing waste through onsite treatment.
S4	40% reduction of waste from ships through improved reception facilities.
Strat1	50% connection of houses and hotels to sewage system; treatment with 90% reduction through five wastewater treatment plants; remaining 50% hotel waste treated through onsite treatment; reduction of refinery effluent; 40% reduction of pollution from ships through improved reception facilities and connection of manufacturing waste to sewage system.
Strat2	100% connection of houses to sewage system; treatment with 90% reduction through five wastewater treatment plants; 100% treatment of hotel waste through onsite treatment; reduction of refinery effluent; 90% reduction in manufacturing waste through onsite treatment.
Strat3	100% connection of houses, hotels and manufacturing waste to the sewage system and disposal through four outfalls; reduction of refinery effluent; 40% reduction of pollution from ships through improved reception facilities and beach maintenance.

Analysis of the Results

Tables 3.5 to 3.7 show the results of the environmental protection measures and strategies under the three economic development scenarios. The main indicators of the effectiveness of these measures and strategies are costs (investment, operation and maintenance) and the resulting coral cover and diversity. In addition, the number of problem beaches is also examined. This is an indication of the number of beaches likely to be threatened by fecal pollution.

The current reef health was found to decline in all of scenarios in a similar manner. The average for coral cover drops from 15% in the current situation (1995) to 9%, while the average for diversity drops from 55% to 32%. The major impact zone begins at the population center of Punda and moves westwards across the Schottegat entrance, extending up to Santa Marta Baai. This pattern is similar for both coral cover and diversity. The growth-east and growth-west scenarios follow similar patterns. This is due to the relatively small growth of population centers in the east and west. Compared to the pollution produced from the industrial zone and Willemstad, this appears to have a relatively small influence.

The eastern end of the island remains impact free in the reference situation and, for coral cover, the current situation is seen to improve by approximately 5%. This follows a pattern of steady coral growth without competition from algae and other competitors for space. However, the coral diversity declines slightly. This shows that the current diversity is not sustainable with the other reef conditions and eventually the reef will head towards an equilibrium with a lower diversity. This would represent a more developed reef than seen at present. The zone of greatest impact appears to spread along the coast from close to Schottegat westwards. This represents the effect of the westward current carrying pollutants from the industrial and heavily populated zone. This effect does not appear to reach Westpunt itself, having been sufficiently diluted along the coast.

These strongly declining conditions can be altered by the environmental protection measures and strategies implemented and shown in Tables 3.5 to 3.7. Each of these measures and strategies has a different reduction on the land-based loadings and, therefore, on reef health. The costs of the measures and strategies vary quite considerably. The major investments are linked to wastewater treatment and disposal that involves the construction of a complete sewage system. Septic tanks are not included in the model and these have, in the past, been widely used in Curaçao. In the more developed areas, they become increasingly less suitable; however, in the more sparsely populated areas, they may remain a feasible option. The model may need to take into account the seepage of the effluent into the groundwater table and, eventually, also into the near-shore waters. It is possible that seepage may be partly responsible for changes in the nutrient levels over the reefs. However, there has been limited research into this as yet.

The largest improvements in reef health can be obtained by a combination of measures addressing the various sources of pollutants. Disposing of sewage through four outfalls along the coast effectively removes the impact of sewage pollution from the reef. The average coral cover resulting from this measure is 11% and the resulting diversity is 38%. This does show an improvement from the reference conditions, with the major areas of improvement being the western sections. Coral cover does improve around Punda by 8% and in the far western sections by 7% to 12%. Diversity gradually improves from Bullenbaai to the west, where increases are seen between 5% and as much as 40%. Little change is seen around the Willemstad area. This is likely due to the remaining influence of the industrial pollution.

Table 3.5. Environmental protection options under the reference scenario.

Strategy code	*Investment cost (million NAF)*	*Operation and management (million NAF)*	*Coral cover (%)*	*Coral diversity (% of maximum)*	*Number of problem beaches*
10H	2.4	0.1	9	32	13
10W6	240	2.2	10	37	0
10W9	270	2.3	11	38	0
10W9/10H	270	2.4	11	38	0
5W9	130	1.1	10	36	0
5W9/5H	130	1.2	10	36	0
B	0	0.12	9	32	13
M9	0.41	0.01	9	32	13
O4	220	2.1	11	38	0
O9	220	2.5	11	38	0
R	47	3.4	10	36	13
R/S4/M9	52	3.8	10	36	13
S4	5.3	0.43	9	32	13
Strat1	190	5	14	47	0
Strat2	310	5.8	14	50	0
Strat3	270	6	15	51	0

Table 3.6. Environmental protection options under the growth-east scenario.

Strategy code	*Investment cost (million NAF)*	*Operation and management (million NAF)*	*Coral cover (%)*	*Coral diversity (% of maximum)*	*Number of problem beaches*
10H	3.4	0.15	9	32	0
10W6	240	2.2	9	34	0
10W9	270	2.3	10	37	0
10W9/10H	270	2.4	10	37	0
5W9	130	1.2	9	34	0
5W9/5H	140	1.2	9	34	0
B	3.0	0.16	9	34	0
M9	0.54	0.01	9	32	0
O4	220	2.0	11	37	0
O9	220	2.5	11	37	0
R	47	3.7	10	35	0
R/S4/M9	53	4.3	10	35	0
S4	5.3	0.58	9	32	0
Strat1	190	5.6	13	44	0
Strat2	320	6.2	14	49	0
Strat3	270	6.5	14	50	0

Table 3.7. Environmental protection options under the growth-west scenario.

Strategy code	*Investment cost (million NAF)*	*Operation and management (million NAF)*	*Coral cover (%)*	*Coral diversity (% of maximum)*	*Number of problem beaches*
10H	3.1	0.13	9	32	14
10W6	240	2.3	10	35	0
10W9	270	2.4	11	37	0
10W9/10H	260	2.5	11	37	0
5W9	130	1.3	9	35	0
5W9/5H	130	1.3	10	35	0
B	1.6	0.14	9	32	14
M9	0.54	0.01	9	32	14
O4	210	1.9	11	38	0
O9	220	2.5	11	38	0
R	47	3.0	10	35	14
R/S4/M9	53	3.6	10	36	14
S4	5.3	0.58	9	32	14
Strat1	190	5	13	45	0
Strat2	310	5.5	14	50	0
Strat3	270	5.6	15	51	0

As with the implementation of sewage disposal through outfalls, the reef improves in the western sections after a reduction in pollution from the refinery by 70%. Increase in coral cover ranges from 7% to 10% and increases in diversity range from 8% to 24%. Little improvement is actually seen around Schottegat. This is due to the continuing influence of sewage pollution around those sections.

These results clearly show the impact different environmental protection measures potentially have on the reef system and show that, with careful management and planning, development of the island does not need to lead to the gradual decline in the coral reef conditions as has been seen over the past 20 years (Bak and Nieuwland 1995). However, implementing the maximum environmental protection strategy may not be a feasible option in financial terms. The following sections examine the costs of the measures and their associated cost-effectiveness.

Cost-Effectiveness Analysis

A core feature of the Coral-Curaçao decision support system is the cost-effectiveness analysis, which allows for the comparison of sets of environmental protection measures and strategies in terms of the cost per unit gain in reef health. The unit of reef health is either the percent change in coral cover or diversity. Each comparison of environmental measures is carried out under the same economic scenario so that the different measures are directly comparable. As a result, a separate analysis should be carried out for each scenario defined. Figure 3.4 shows the cost-effectiveness of individual measures under the reference scenario using coral cover as the indicator of reef health. Figure 3.5 uses the same reference situation but analyzes the cost-effectiveness of strategies (i.e., combinations of measures).

Beach maintenance, the reduction of sewage pollution through on-site treatment of hotel waste, and the reduction of waste from manufacturing have no significant effect on the health status of the reef averaged for the south coast as a whole. They have, therefore, been left out of the cost-effectiveness analysis as their cost per unit of reef health will be infinite. On a local scale, these measures may have a significant effect, making the relatively small investments cost-effective. Reducing the waste from the refinery appears to be one of the more cost-effective measures. However, the cost data for the refinery should be treated as preliminary as there was

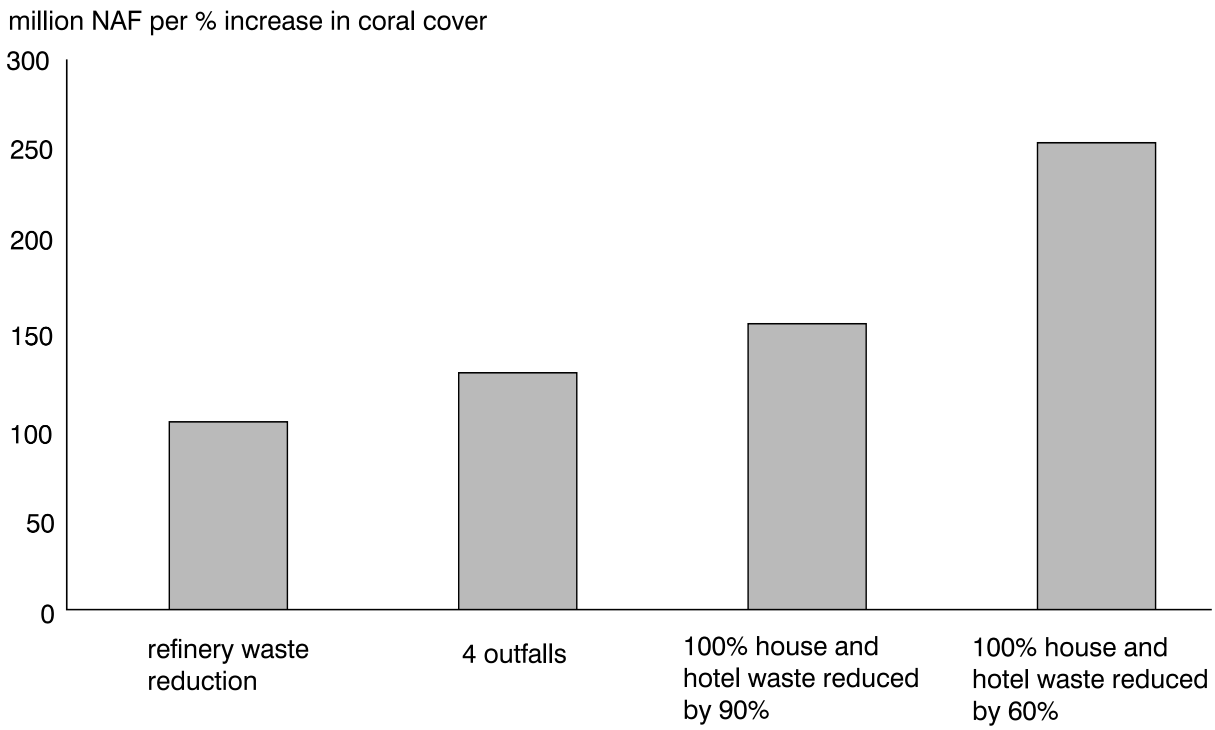

Figure 3.4. Cost-effectiveness of individual measures under the reference scenario using coral cover as the indicator of coral reef health.

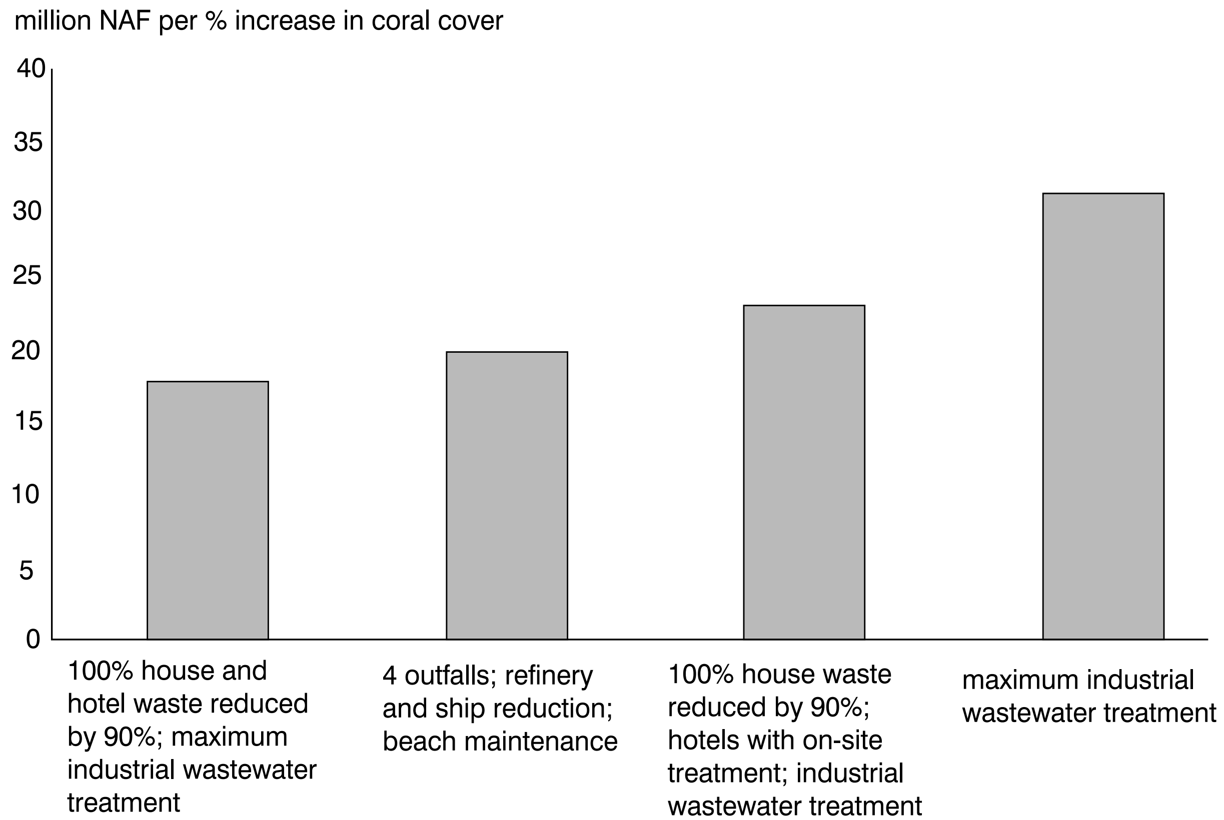

Figure 3.5. Cost-effectiveness of strategies or combinations of measures under the reference scenario using coral cover as the indicator of coral reef health.

very little data available. The least cost-effective measures are the implementation of sewage systems and wastewater treatment plants. These are expensive; however, they are important for public health reasons as well as reef health.

Combining the measures into strategies creates more cost-effective options. All the combinations shown create a cost-effectiveness of 15 million NAF/% change in reef health (for both cover and diversity) compared to 30 to 60 for coral diversity and 100 to 250 for coral cover. This illustrates the need to address more than one source of pollution simultaneously.

A similar analysis is carried out for the both the growth-east and growth-west scenarios. Figure 3.6 shows the cost-effectiveness of individual measures for the growth-east scenario using coral cover as the indicator of reef health. Further results are reported in Rijsberman and Westmacott (1996). Again, the improved beach maintenance, reduction of waste from ships, and manufacturing has little effect at the scale of the southern coastline and are, therefore, not included in the analysis. The patterns seen in the cost-effectiveness of individual measures are similar to those seen under the reference scenario, with the construction of sewage systems and wastewater treatment plants being the least cost-effective options.

There are no real significant differences between the scenarios, partly due to the similarity in the change seen to reef health and the general nature of the cost model—specifically, the fact that the model averages over the coastline will mask significant local changes. Further developments of the model may want to focus on smaller sections of the coast. An interesting feature is the increase in the cost-effectiveness of all the strategies. The cost-effectiveness of individual measures rarely falls below 100 million NAF/% increase in coral cover, whereas the strategies are generally considerably more cost-effective. This shows that the improvement of the reef is limited by more than one pollutant and undertaking one measure alone may be restricted in its effectiveness if other impacts remain in place. Significant improvements to cost-effectiveness come through addressing combinations of measures.

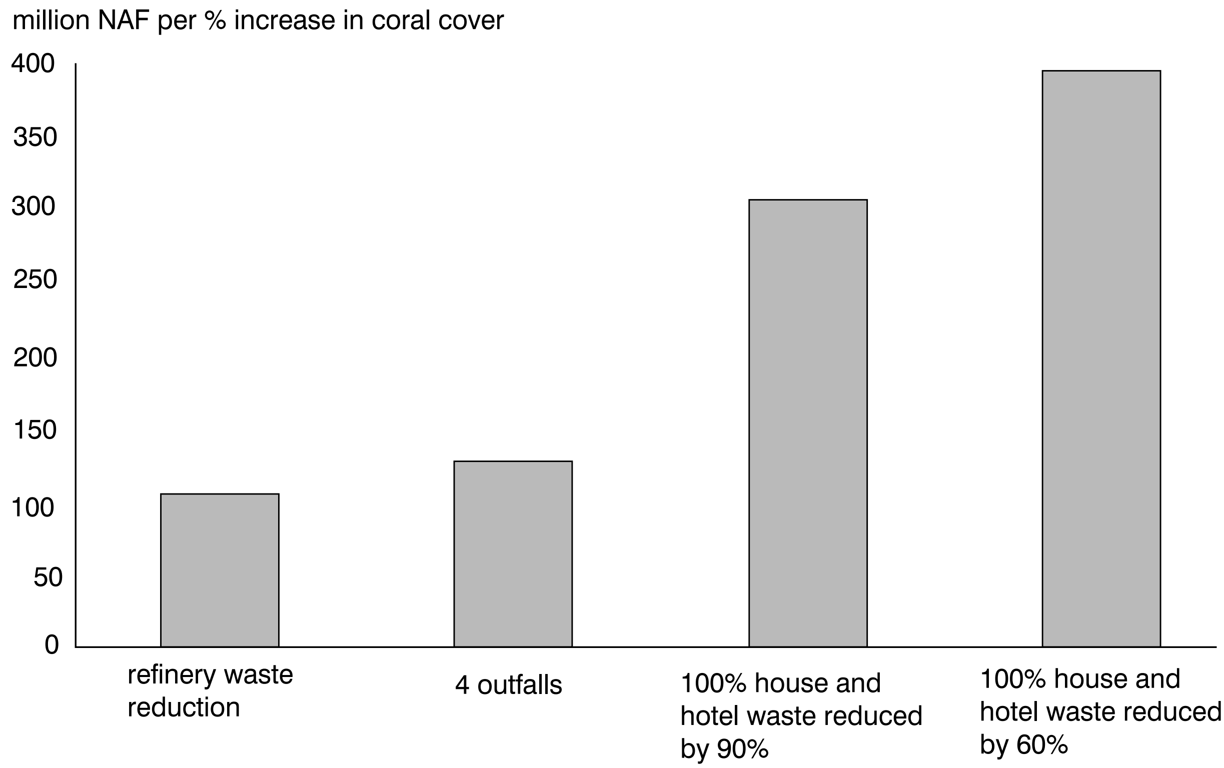

Figure 3.6. Cost-effectiveness of individual measures under the growth-east scenario using coral cover as the indicator of coral reef health.

Conclusions

A decision support tool has been developed that can be used for:

- Communication among stakeholder groups concerning desirable development directions and environmental strategies for the coastal zone in Curaçao;
- Analysis of the impacts, through the discharge of wastewater and sediment, of planned developments in the coastal zone on coral reef health, thereby integrating sectoral land use, tourism and nature conservation planning in one framework; and,
- Analysis of the cost-effectiveness of environmental measures and strategies in maintaining coral reef health.

The main innovations of Coral-Curaçao are its user-friendly but structured interface and its coral reef response model. The developers are of the opinion that the tool has shown to have potential for use, but that the real proof of whether this is an appropriate tool for management of coral reefs and the coastal zone of Curaçao will have to be demonstrated through an application. The tool has been developed in cooperation with government representatives, environmental non-government organizations (NGOs), representatives of the tourism and diving industries, and the management of the Curaçao Underwater Park. Most of these stakeholders have indicated a keen interest in the possibilities of using the tool in a "real life" management application.

Model Results

The model shows through the three scenarios developed that there is likely to be a very significant coral reef decline over the next 10 years. This is in line with the trend seen during the past 20 years reported by Bak and Nieuwland (1995). The model also shows that, with the implementation of environmental protection strategies, this trend can be halted and, in some cases, reversed with recovery to a state of coral reef health better than the current.

Improving the status of the reefs of Curaçao can be done through combinations of comprehensive sewage treatment and disposal methods, as well as reductions in refinery pollution. Measures such as environmentally friendly beach maintenance and the reduction of waste from manufacturing and shipping are not effective at the scale examined. The model can, however, be used to identify the areas where the reef conditions are poorest. Implementation of these measures on a smaller scale could well be effective.

The cost-effectiveness analysis allows a ranking of the measures, assisting the user in the formulation and reformulation of strategies. The costs of the strategies are, however, high. To reach an average coral cover of 14% and diversity of 50%, the initial investment is 310 million NAF and the yearly operation and maintenance costs are 6 million NAF. With a total GDP for Curaçao of 1,620 million NAF in 2005 under this scenario, the investment would amount to 20% of GDP. Since a careful optimization of environmental strategies has not taken place, these estimates may be on the high side.

The fact that a tool is now available with which a quantitative assessment can be made of the impact of development scenarios on coral reef health is a significant step forward. Experience in Curaçao showed clearly, however, that for the tool to be accepted as a reliable indication of sustainability, time and effort will be required to introduce its use. Users need to become both familiar with the possibilities and the limitations of the model and gain an understanding into the formulation of the model. As well, they need to become familiar with the multi-criteria approach used in the model.

Limitations of the Model

Although the issues included in the model have been selected through interviews and meetings with the various stakeholders in the regions, there are certain issues that could not be taken into account. Solid waste disposal, for example, is currently an issue. This will be an important factor, for aesthetic reasons as well as environmental reasons, when considering coastal zone management plans. Sediment and nutrients were considered the major pollutants and impacts on the reef in the current model.

The impact of implementing a marine park is difficult to assess in terms of the reduction of pollutants. It may be that the user would like to set standards of water quality that the marine park would monitor and enforce. By altering the focus of the model, it could be possible to calculate the cost of achieving these levels.

Fishing pressure and the effect on the reef that the extraction of certain fish species (e.g., algae grazers) may have is also not included. This is an issue that has been successfully included in the revised model for Jamaica (Ridgley and Dollar 1996; Chapter 8). The inclusion of oil pollution should also be considered.

It will be necessary to improve the database for the simulation results, as well as the detail with which both the economic development scenarios and the environmental strategies are defined. The data used in the model has been collected from a series of project reports. Little of the data was collected through fieldwork and, as a result, may have had to be adapted. In some areas, data was not available or hard to obtain. Subsequent updates of the model should attempt to improve this aspect. Once the model begins to be used by the various groups and departments as is intended, more data may be identified and produced that can be directly inserted into the model.

Further Model Developments

The modeling results reported in this chapter were completed in 1996. Since that time, Coral-Curaçao has been expanded, revised and used. A valuation study of benefits due to changes in reef health was incorporated. The model has also been demonstrated to the different stakeholder groups. For example, it was used as the basis for a university evening course for professionals, in which most of the relevant Curaçao coastal managers participated. Subsequently, the model was installed at the offices of most of the coastal managers. Various talks were also given at schools and for environmental NGOs to explain the project and the tool. The most recent version of Coral-Curaçao is described in Chapter 10 and a companion CD-ROM is included with this publication.

The overall conclusion to be drawn from the experience to date is that the model is quite helpful as a teaching, training and awareness raising tool, but too complicated and cumbersome to be used for quick reference during the day-to-day work of the coastal managers. As stated previously, the model was developed with sufficient realism to represent "real life" problems, but the day-to-day questions of the coastal managers appear to be slight variations, requiring changes to be made in the model.