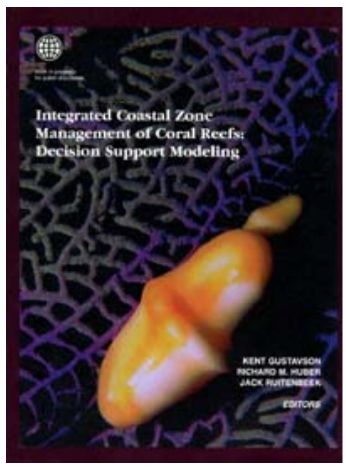
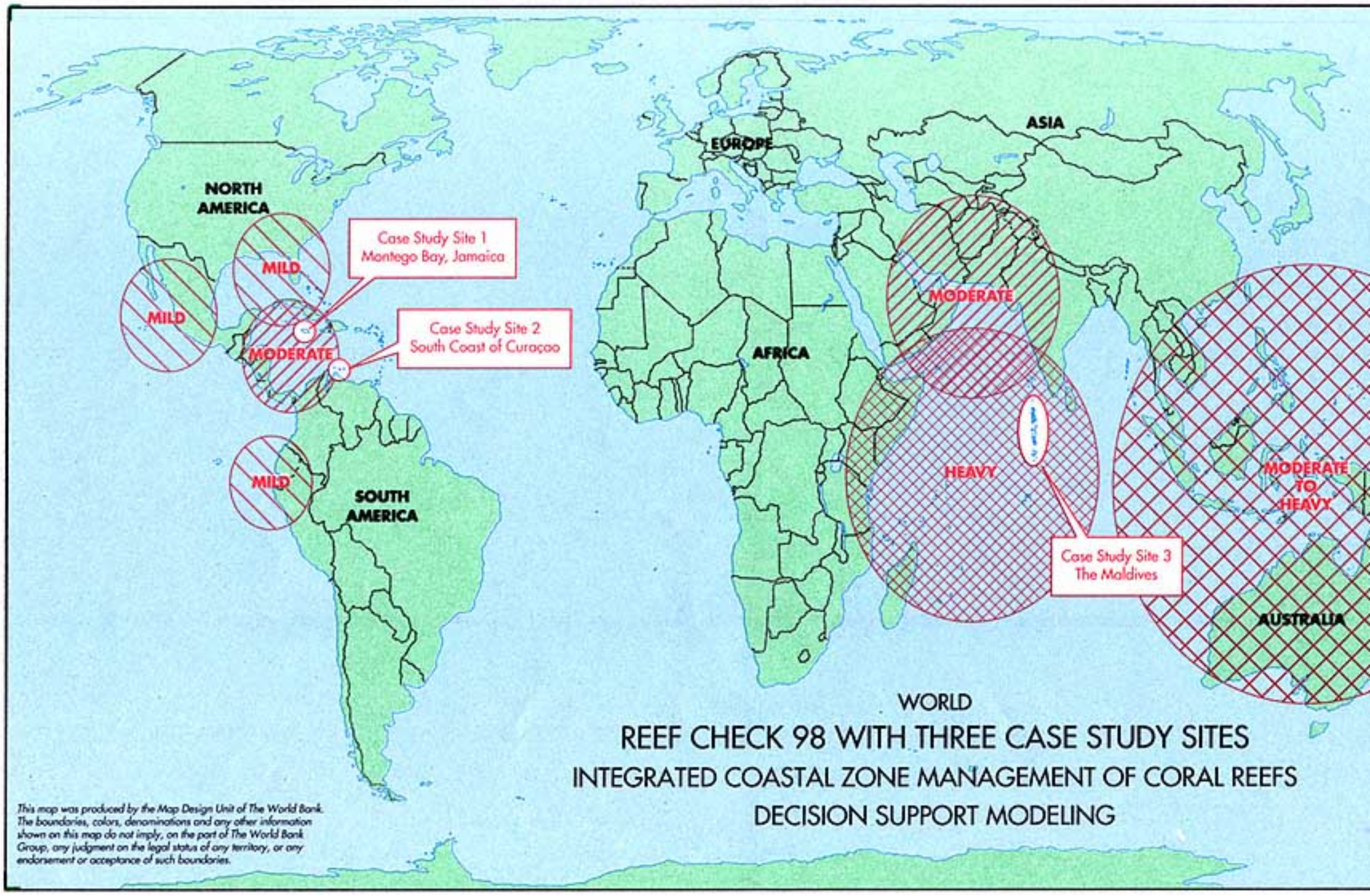


ated Coastal Zone Management of Coral Reefs: Decision Support

Integrated Coastal Zone Management of Coral Reefs: Decision Support Modeling



Integrated Coastal Zone Management of Coral Reefs: Decision Support Modeling

Kent Gustavson
Richard M. Huber
Jack Ruitenbeek
Editors

Disclaimer:
This netLibrary eBook does not include the ancillary media that was packaged with the original printed version of the book.

The International Bank for Reconstruction and Development/THE WORLD BANK
1818 H Street, N.W.
Washington, D.C. 20433, U.S.A.

Manufactured in the United States of America
irst printing February 2000

ISBN: 0821346288

Kent Gustavson is proprietor of Gustavson Ecological Resource Consulting and works in association with the Centre for Coastal Health Society in Gabriola, British Columbia, Canada. Richard M. Huber is an environmental specialist in the Latin American and Caribbean Environmentally and Socially Sustainable Development Sector Management Unit of the World Bank. Jack Ruitenbeek is president of H.J. Ruitenbeek Resource Consulting Limited in Gabriola, British Columbia, Canada.

Library of Congress Cataloging−in−Publication Data has been applied for .break

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 nearshore 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,continue

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 sub−optimal 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.break

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.break

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):

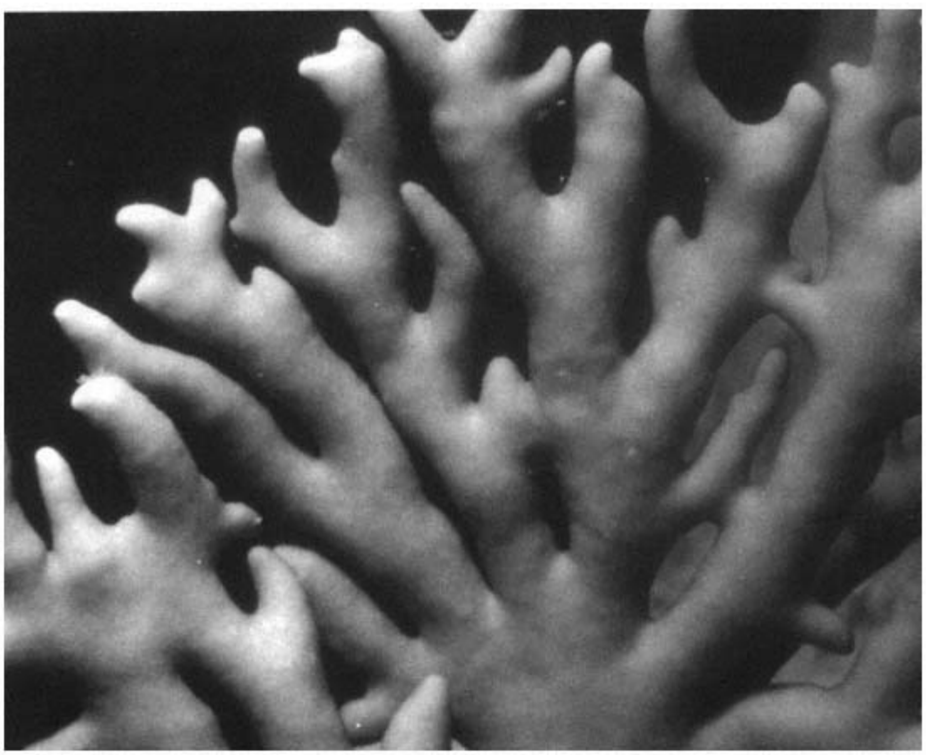
Launch a road show to disseminate this publication that includes a CD−ROM of the Coral−Curaçao, Coral−Maldives, COCOMO (COastal COnservation in MOntego Bay) decision support models (Chapter 10);

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).break

RICHARD M. HUBER
THE WORLD BANK, ENVIRONMENTALLY AND SOCIALLY SUSTAINABLE DEVELOPMENT SECTOR MANAGEMENT UNIT, LATIN AMERICA AND THE CARIBBEAN REGION (LCSES)



ACKNOWLEDGMENTS

Preparation of the report relied extensively on a series of background and related papers initiated in early 1995, as well as on helpful consultations and insights that were received from a series of workshops in the three case study sites (Montego Bay, Jamaica; Curacao; the Republic of the Maldives) involving World Bank staff, government officials and representatives from the private and academic sector and non−government organizations (NGOs). The research was supported by the World Bank Research Committee and Sweden, Canada and Netherlands Trust

Funds. Project management was provided by Richard M Huber of the World Bank, Environmentally and Socially Sustainable Development Sector Department (ESSD), Latin America and the Caribbean Region (LCSES). Marea Hatziolos, Jan Post, Carl Lundin and Herman Cesar of the World Bank provided peer review of the publication. The World Bank ESSD acting Director is John Redwood.

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.

Many others assisted in working through the methodological and analytical issues that arose during the development of the models or provided review and comment on selected components of project work: Neil Adger (Centre for Social and Economic Research on the Global Environment); Mahfuzuddin Ahmed (International Center for Living Aquatic Resources Management); Anthony Artuso (Food and Resource Economics, Cook College, Rutgers University); Marlin Atkinson (Hawaii Institute of Marine Biology); Rolf Bak (Department of Marine Ecology, Netherlands Institute of Sea Research); Barbara Brown (Department of Marine Sciences and Coastal Management, University of Newcastle upon Tyne); Robert Buddemeier (Kansas Geological Survey, University of Kansas); John Bythell (Department of Marine Sciences and Coastal Management, University of Newcastle upon Tyne); Susan Clark (Department of Marine Sciences and Coastal Management, University of Newcastle upon Tyne); Evelyn Cox (Hawaii Institute of Marine Biology); Sally Driml (Australia Great Barrier Reef Marine Park Authority); Alastair Edwards (Department of Marine Sciences and Coastal Management, University of Newcastle upon Tyne); Richard Grigg (Department of Oceanography, University of Hawaii), Tor Hundloe (Australia Great Barrier Reef Marine Park Authority); Donald Kinsey (Australian Institute of Marine Biology, ret.); James Maragos (US Fish and Wildlife Service, Pacific Islands Ecoregion); Subodh Mathur (consultant); Erik Meesters (Department of Marine Ecology, Netherlands Institute of Sea Research); Mike Nullet (Department of Geography, University of Hawaii at Manoa); Stephen V Smith (Department of Oceanography, University of Hawaii); Tim Swanson (Department of Economics, University College London); Gordon Tribble (US Geological Survey). Within Resource Analysis, Christiane Klöditz, Diederik Waardenburg and Saskia Werners provided key assistance. Within the World Bank, the following are noted for their contributions: Herman Cesar; John Dixon; Maria Donoso Clark; Clara Else; Surajit Goswami; Marea Hatziolos; Norman Hicks; Andy Hooten; Orsalia Kalantzopoulos; Maritta RVB Koch−Weser; Andres Liebenthal; Carl Lundin; Dennis Mahar; Jan Post; John Redwood; Carlo Rietveld; Robert Watson; Samuel Wedderburn; Anthony Whitten; and Tom Wiens.

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 Hanniecontinue

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.break

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.

CONTENTS

I—
THE NEED FOR DECISION SUPPORT MODELS

Chapter 1—
Integrated Coastal Zone Management in the Tropical Americas and the Role of Decision Support Models

Richard M Huber
Environmentally and Socially Sustainable Development Sector Management Unit, Latin American and Caribbean Region (LCSES), The World Bank, Washington, DC, USA

Stephen C Jameson
Coral Seas Inc. Integrated Coastal Zone Management, The Plains, VA, USA

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 over−fishing 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 improvecontinue

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 CO2 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 worldcontinue

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 macro−algal 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 (NO3) in conjunction with predictions of increased SRP enrichment associated with exponential human population growth and sewage pollution.

NO3 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 NO3 levels and concomitant salinity stratification throughout the study area at Discovery Bay shows that nutrients derived from submarine ground−water 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 NO3 pore waters have been found (Pigott and Land 1986) in fore−reef sediments at Discovery Bay, suggesting that NO3 −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.break

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 macro−algal 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/m2 vs. 17.1g/m2) 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 werecontinue

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 cane−fields, 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 CO2 and other gases in the calcification process of reef−building corals is of critical importance with the increasing CO2 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.break

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	Unknown (supported by ICLARM)	Active

		GCRMN		
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 forcontinue

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 policy−makers 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 watercontinue

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 tocontinue

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 reoccurrence. Controlling problems at the source is the most efficient and effective means to reduce cost and improve quality (Scanlan 1988).break

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).break

Box 1.1— Environmental Monitoring Data As a Basis for Management Decisions: The Montego Bay Case Study

Bernward Hay

Louis Berger International Inc., Needham, MA, USA

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.

(text box continued on next page)

(text box continued from previous page)

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 ground−water (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

(text box continued on next page)

(text box continued from previous page)

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.

(text box continued on next page)

(text box continued from previous page)

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).

(text box continued on next page)

(text box continued from previous page)

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).

(text box continued on next page)

(text box continued from previous page)

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).

(text box continued on next page)

(text box continued from previous page)

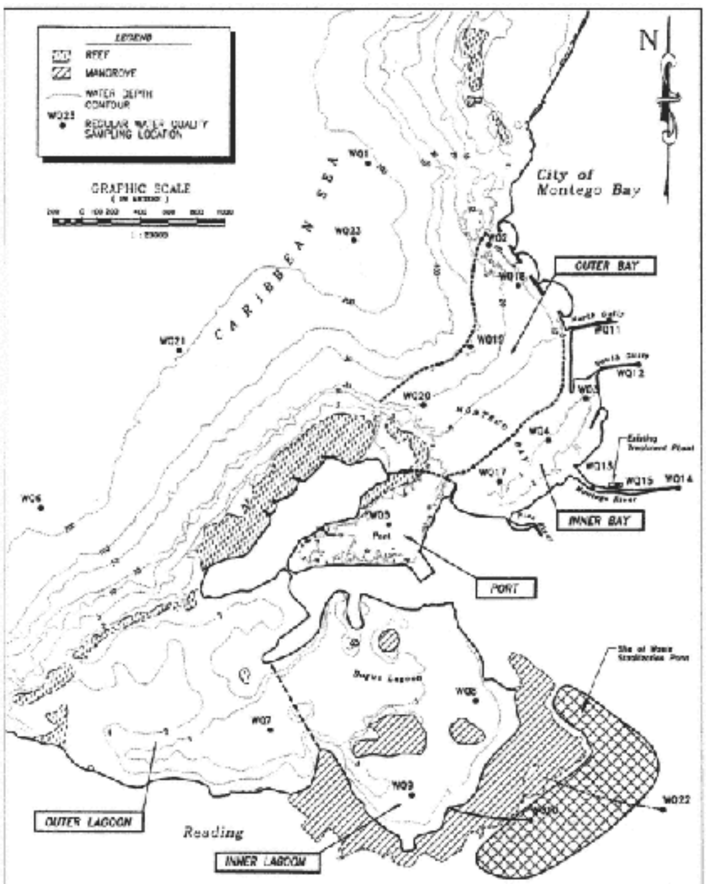


Figure 1.4.
Bathymetry of the coastal zone and overview map of the station locations of the environmental monitoring program (USAID 1996). Shown also is the location of the new waste stabilization pond system adjacent to the mangrove forest of Bogue Lagoon. The thicker dashed lineswithin Montego Bay and Bogue Lagoon represent the boundaries of subareas in thesewaterbodies 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 Heading 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

Stephen C Jameson
Coral Seas Inc. Integrated Coastal Zone Management, The Plains, VA, USA

Jill Williams
Montego Bay Marine Park Trust, Montego Bay, Jamaica

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 water−front 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 198384.

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 octo−corals 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 morecontinue

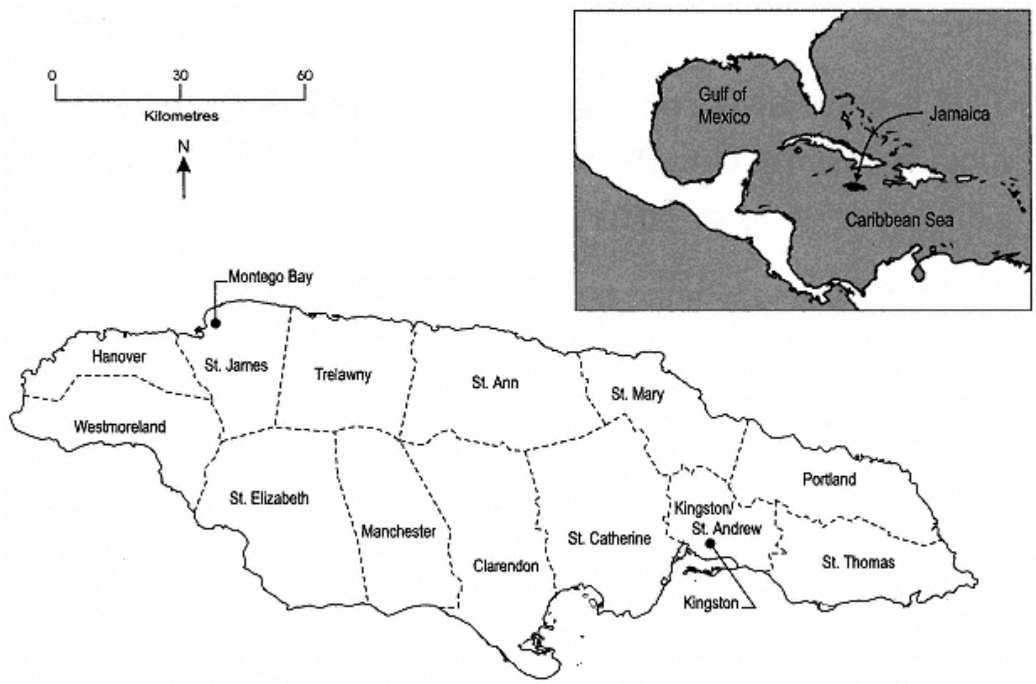


Figure 2.1.
Jamaica, showing parishes and the locations of the urban centers of Kingston and Montego Bay (adapted from Gustavson 1999).

polluted from raw sewage discharges. Coral smothering algal cover has increased from about 36% in 1992 to about 84% in 1997, 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 59hacontinue

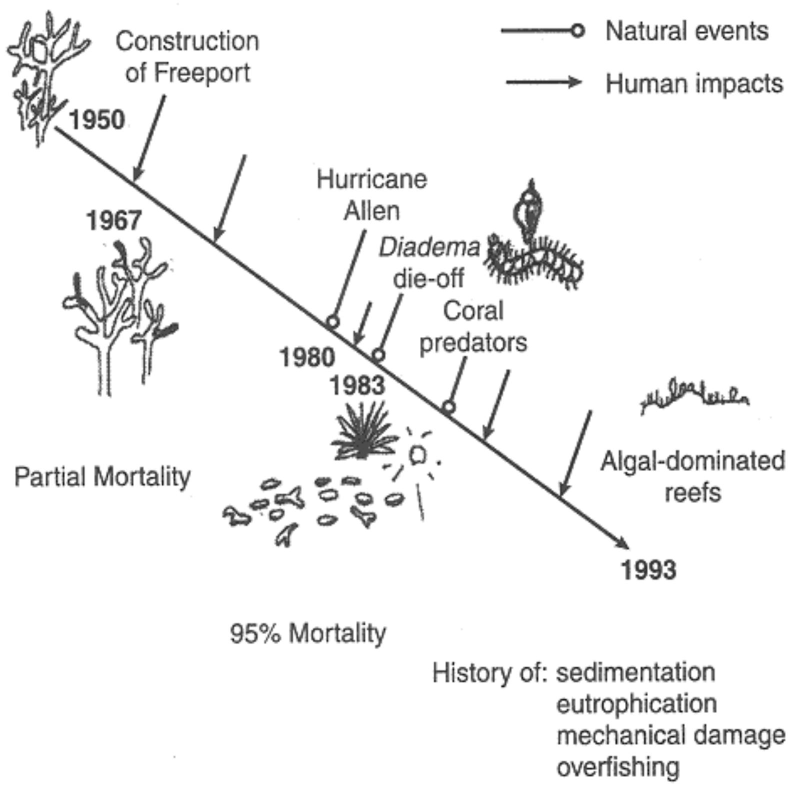


Figure 2.2.
Natural and anthropogenic impacts to the coral reef ecosystem in Montego Bay, Jamaica
(adapted from Sullivan and Chiappone 1994).

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 Parkcontinue

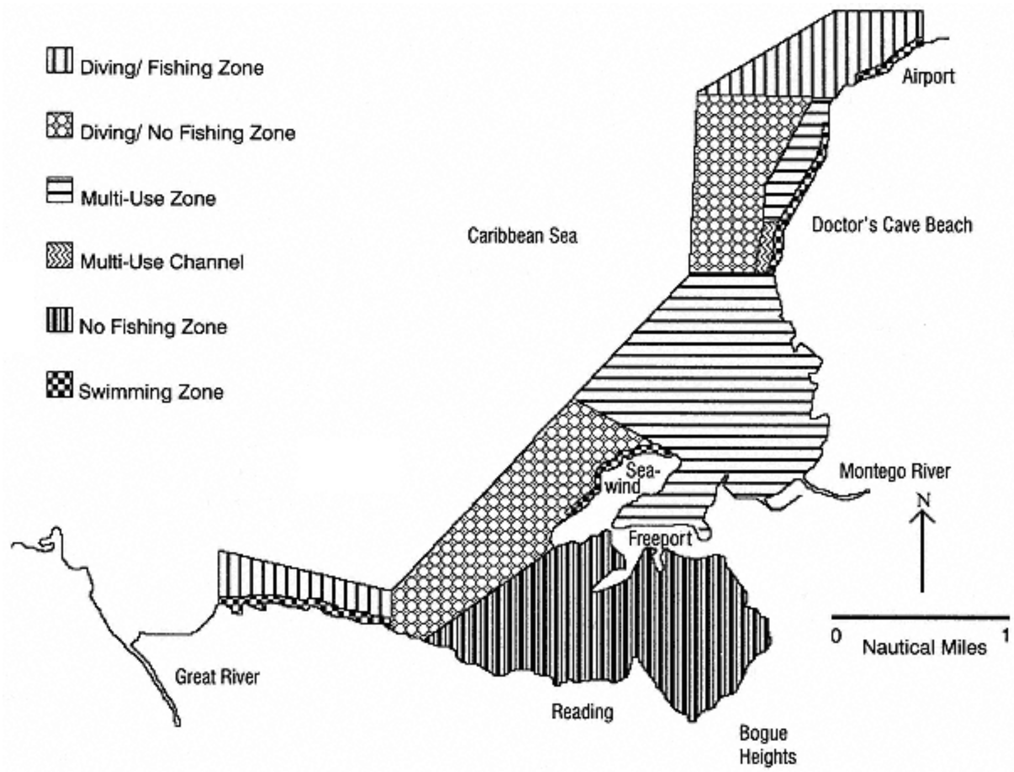


Figure 2.3.
The Montego Bay Marine Park and the new zoning plan.

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 workcontinue

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;break

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,continue

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

	Agencies and organizations							*MBMP staff*				
Interventions	EWO	NEST	JCDT	NRCA	Hotels	Water sports	Media	Education coordinator	Enforcement coordinator	Volunteer coordinator	Research and monitoring	Director coordinat
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 strateg and activities (JDFCG = Jamaica Defence Forces-Coast Guard; NRCA = Natural Resources Conservation Authority of Jamaica; MBMP = Montego Bay Mar 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	Enforceme coordinat
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 continued on next page)

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	Enforcem coordinat
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";break

Table 2.4a. Research and monitoring interventions for the Montego Bay Marine Park—agencies and organizations identified for implementi strategies and activities (MBMP = Montego Bay Marine Park; NRCA = Natural Resource Conservation Authority; FD = Fisheries Division; NWC = Natic Water Commission; UWA = Underground Water Authority; NEST = National Environmental Societies Trust; TPDCo = Tourist Product Development Corporati PIOJ = Planning Institute of Jamaica; PCD = Parish Council Public Works Department; CDC = Conservation Data Centre; UWI = University of the West Ind 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 continued on next page)

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.break

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). Adequatecontinue

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	Periodic interactions during new plant

			methods submitted	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	Relevant parameters	Relevant parameters monitored	Relevant parameters	Plan requires development and

(NRCA/NWC/MBMP)	monitored		monitored	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.break

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 becausecontinue

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).

Volunter 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 andcontinue

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 andcontinue

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 stop−over 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.break

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;break

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

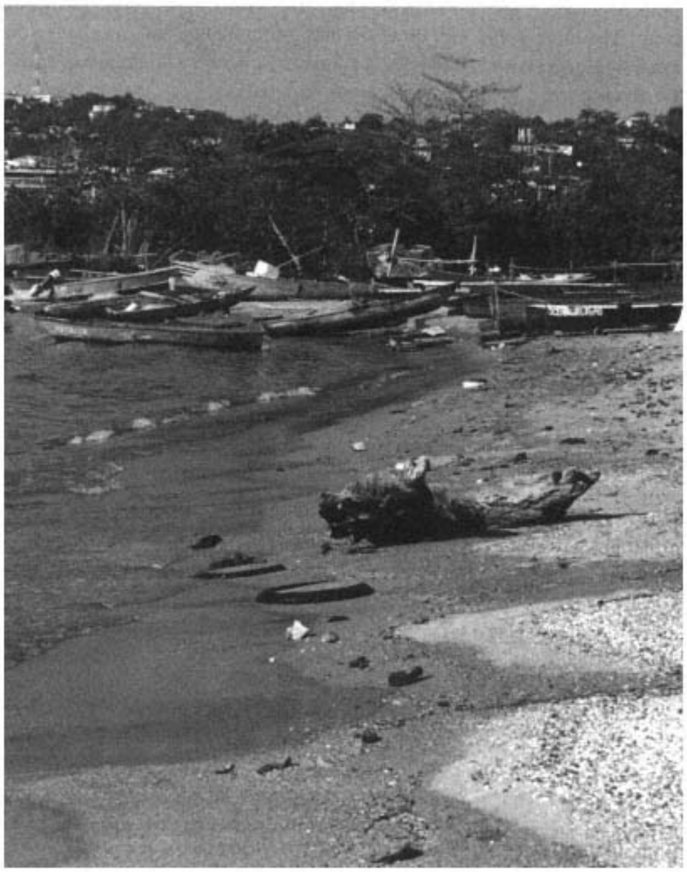
Management realized that a major attitude adjustment was necessary. If problems are human made, solutions must be as well. If solutions require change in behavior, then the motivations that govern behavior must be understood. Behavior is basically driven by the two opposing forces of reward and punishment. 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 concernbreak



II—
CREATING DECISION SUPPORT MODELS

Chapter 3— Cost−Effectiveness Analysis of Coral Reef Management and Protection: A Case Study of Curaçao

Frank Rijsberman and Susie Westmacott
Resource Analysis, Delft, The Netherlands

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 444km2 , 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 199596, 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 alreadycontinue

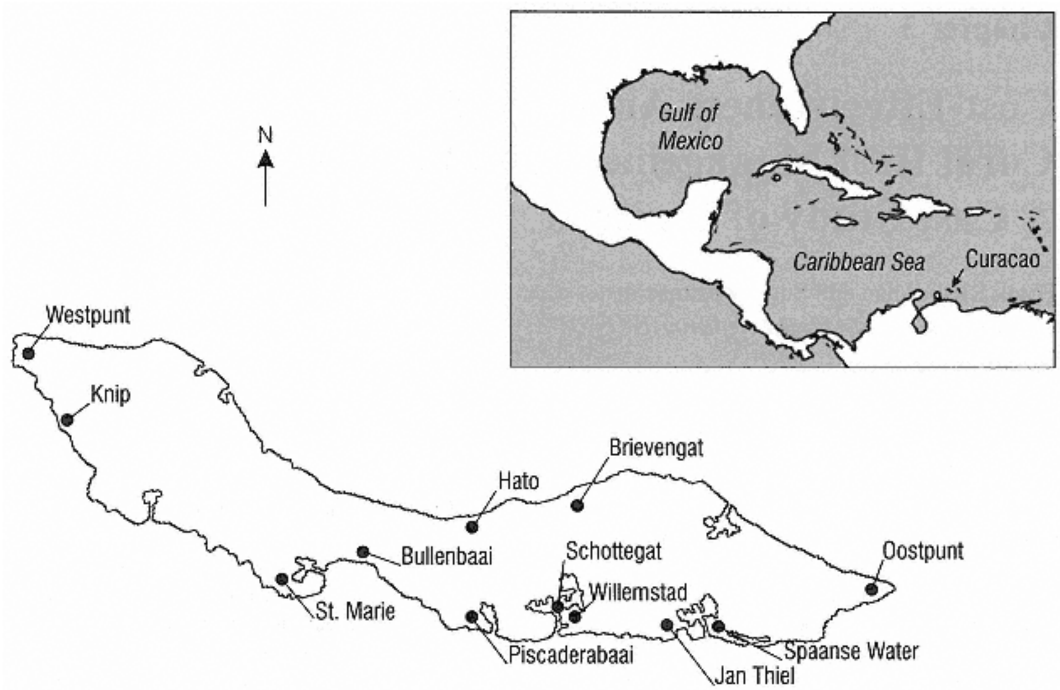


Figure 3.1.
Curaçao, showing its location within the Caribbean.

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,continue

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. break

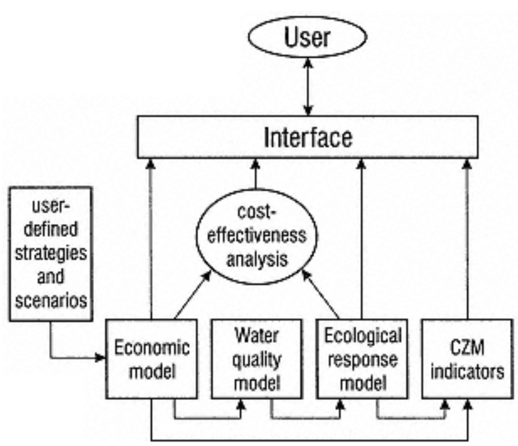


Figure 3.2.
Structure of the Coral−Curaçao decision support system.

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.break

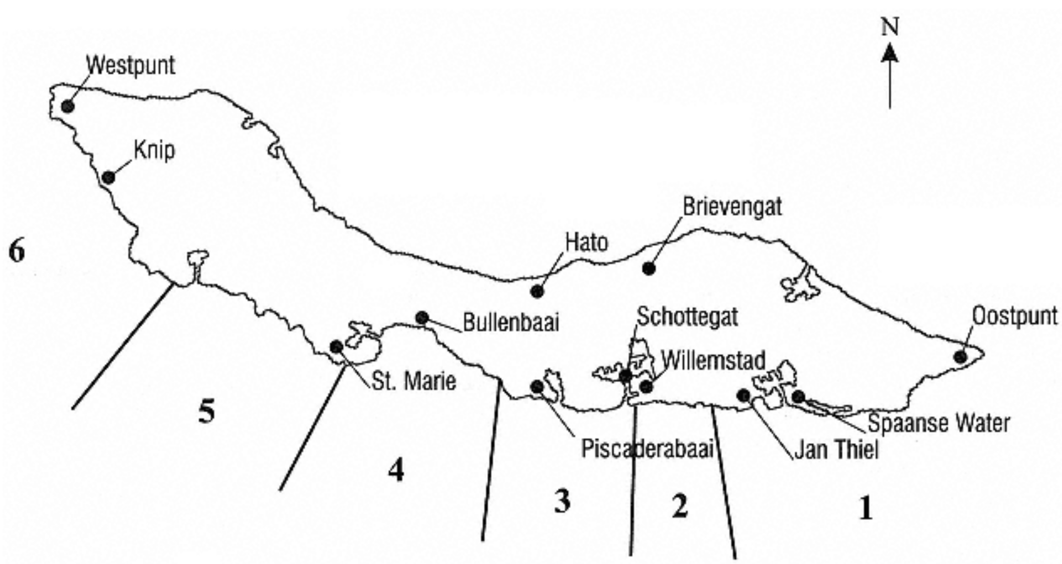


Figure 3.3.
Coastal section divisions of Curaçao utilized in the model.

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 metrescontinue

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.break

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 waste−water 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 m1 yr1 additional investment costs and 500 NAF m1 yr1 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 providingcontinue

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 field−work 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.break

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* (102 m2)
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.break

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.break

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.
Strat 1	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.
Strat 2	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.

Strat 3	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 pollutioncontinue

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.break

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 wascontinue

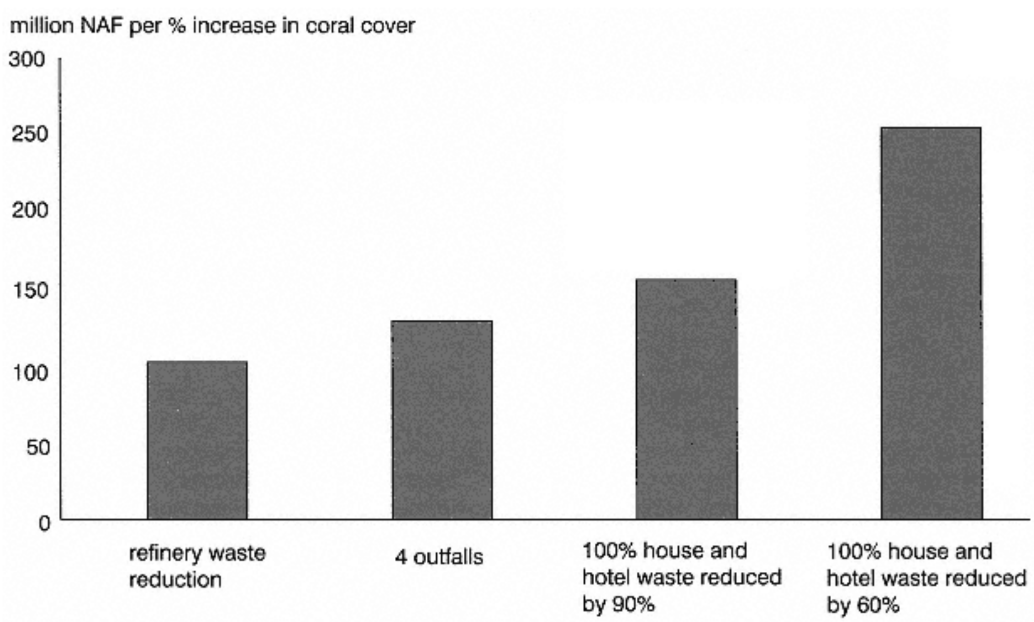


Figure 3.4.
Cost−effectiveness of individual measures under the reference scenario using coral cover as the indicator of coral reef health.

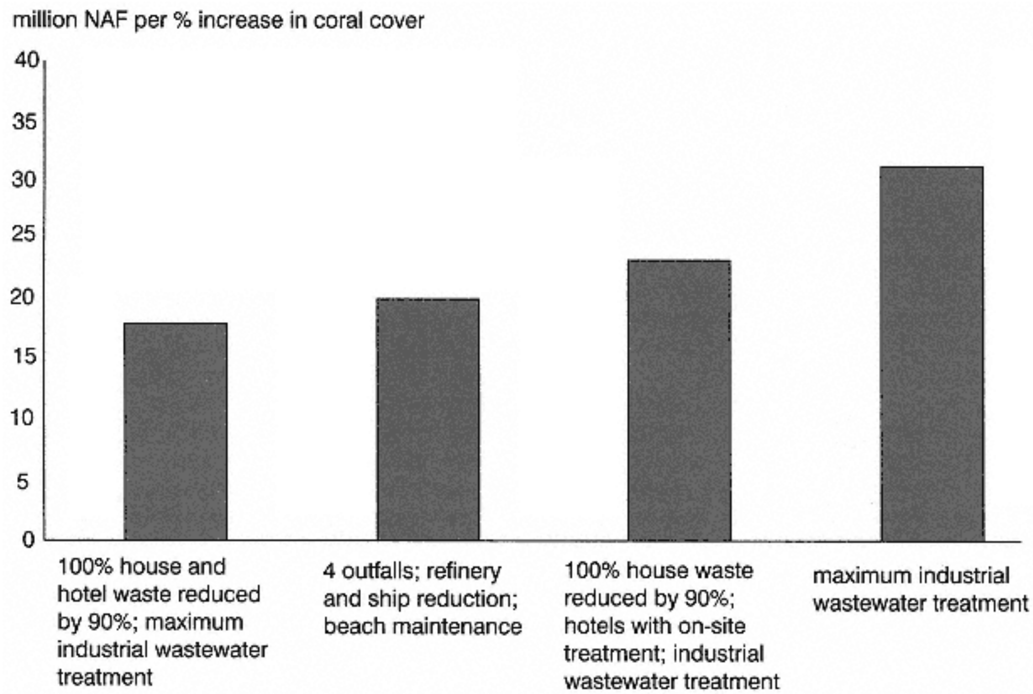


Figure 3.5.
Cost−effectiveness of strategies or combinations of measures under the reference scenario using coral cover as the indicator of coral reef health.

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.break

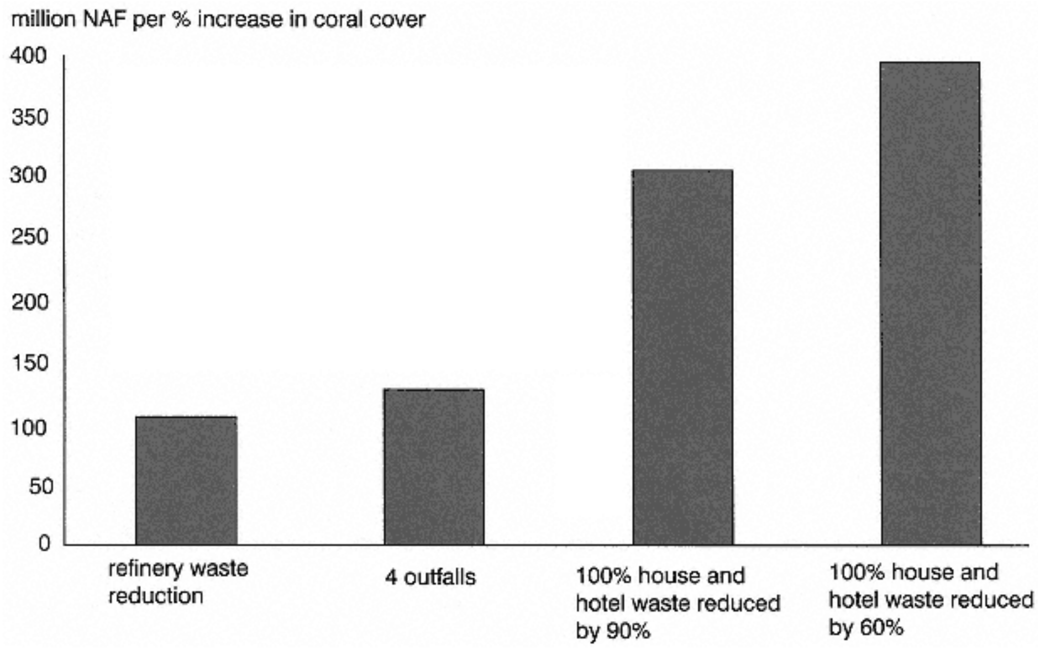


Figure 3.6.
Cost−effectiveness of individual measures under the growth−east scenario using coral cover as the indicator of coral reef health.

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 waste−water 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 tocontinue

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.break

Chapter 4— Cost−Effectiveness Analysis of Coral Reef Management and Protection: A Case Study of the Republic of the Maldives

Susie Westmacott and Frank Rijsberman
Resource Analysis, Delft, The Netherlands

The specific objective of the research is to develop a quantitative ecological economic model of coastal zones in the developing tropics, designed to assist in the formulation, evaluation and ranking of various cost−effective coastal zone management plans. The Republic of the Maldives, where the coral reefs are in many areas still relatively undisturbed but where development is rapidly changing these coral reef systems, was utilized as a case study site. The condition of the coastal zone is represented by an indicator of coral reef health that is measured in terms of coral cover and rugosity (an indicator of the structural development of the reef). In order to cope with the difficulties of assessing the benefits of improved coastal zone management, the research has been limited to assessing the costs of management using a framework that focuses on four main steps: i) the specification of economic sector interventions; ii) the modeling of the changes of these interventions on production and consumption; iii) the quantification of the physical response of these in terms of the wastes and physical damage generated; and, iv) the modeling of the impact of the wastes and physical damage on reef health. The final cost of each intervention is then computed, taking into account potential negative costs (e.g., from production changes). This enables interventions to be formulated in such a way as to incur the minimum costs while retaining a certain quality of reef.

The two objectives of the Maldives case study are:

1. To test and validate the cost−effectiveness analysis model of coral reef protection and management developed for Jamaica (Chapter 8) and Curaçao (Chapter 3); and,

2. To investigate whether the cost−effectiveness analysis model can be a useful tool for decision support for coastal zone management for the Republic of the Maldives.

The second objective required the establishment of a wider framework of multi−criteria decision−making in integrated coastal zone management (ICZM). This involved cooperating closely with local decision−makers and experts in order to shape the final product into a useful tool. The involvement of local decision−makers and experts was achieved through a series of workshops and consultations. The project was divided into four main phases:

1. *Project preparation* . The site was identified, contacts established and a detailed work plan was developed (Rijsberman 1995).

2. *Fieldwork* . The fieldwork involved problem formulation and data collection (Westmacott 1996).

3. *Model development* . This required the development of the socio−economic model (Westmacott and Rijsberman 1997) and the ecological response model (Meesters and Westmacott 1996). The cost−effectiveness methodology is incorporated in the linking of these two models. The computer user interface was also developed in this phase.

4. *Testing and validation* . This involved presentations of the model to those involved in its development and lead to the final revisions.

Research began during the fall of 1995. This chapter presents the results of the final report, which was completed early in 1997. Further detail can be found in Westmacott and Rijsberman (1997) and within the companion CD−ROM.

The area defined in the model is that of North and South Male within the Republic of the Maldives. This specific study site was selected as it is the most developed and contains some of the most densely populated islands. For modeling, the two atolls have been divided into 10 sections based on physical location (i.e., inner atoll islands or outer/surrounding islands and reefs, subsequently dividing east to west and north to south; Figure 4.1).break

Description of the Coral−Maldives Model

Coral−Maldives is a coastal zone management decision support system that incorporates a cost−effectiveness analysis for coral reef management. The decision support system is structured in such a way that different users are able to explore a series of different coastal zone management options under varying assumptions for exogenous variables (e.g., population growth rates). The analysis allows the users to focus on the most cost−effective options for coral reef management and protection for the various economic development options. The impacts can be seen in terms of economic, social and environmental indicators that are selected at the outset of the analysis. In addition to the selected indicators, the user is able to explore more detailed information relating to the economy, reef health and coastal erosion. The final step of the analysis shows a scorecard of all the selected indicators. The user can also use the cost−effectiveness analysis to rank the coastal zone management strategies in terms of cost per unit gain in reef health.

The user is able to structure analysis through the user definitions of indicators, scenarios and strategies and the final formulation of cases. First, users can choose which indicators to select in the analysis. This means they are able to include specific aspects of interest to themselves as well as more general coastal zone management aspects. In the case where the model does not adequately cover all

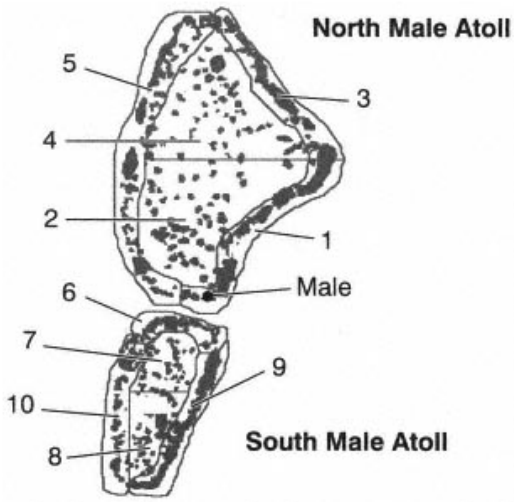


Figure 4.1.
Sections of North and South Male utilized in the model.

the interests of the user and where more research has been undertaken, additional indicators can be added to the analysis. Second, the user is able to define the scenarios. The scenarios represent a series of overall growth rates or policy decisions. The economic development and environmental protection options have been selected through discussions with various government agencies involved in coastal zone management within the Republic of the Maldives. The user is again free to define different combinations of these developments and protection measures. Once the definition of scenarios and formulation of strategies has been carried out, the user is able to select combinations of these (cases) for the analysis. The decision support system allows the user to delete less favorable cases so as to keep the analysis tractable.

Structure of the Decision Support System and the Coral−Maldives Model

The Coral−Maldives decision support system consists of the following:

A user interface;

The computational model in a spreadsheet;

The database of model parameters in the spreadsheet; and,

The database of information contained in interactive text and graphic files available to the user.

The steps involved in the analysis can be seen in Figure 4.2. The interface helps the user to assess the problems and issues found in the coastal zone and define the objectives of the analysis and the criteria or indicators with which to measure the success of each plan. The user definitions include scenarios, economic development and environmental protection options. The user can work through different options, saving each with a name and a description. These are then combined into cases in the analysis and analyzed on an individual basis and in a comparisons of all cases.

The user definitions (scenarios, economic development and environmental protection options) drive the socio−economic model, which results in a set of impacts distributed over the area. The impacts are measured by sediment loadings and levels of physical damage. These are then used as input into the ecological response model, which estimates changes in reef health over the impact areas. These changes will, in turn, affect the health of the reef fisheries, which has a feedback effect on commercial fisheries production. The costs of the environmental protection options and the changes in the reef health are considered in the cost−effectiveness analysis, which allowscontinue

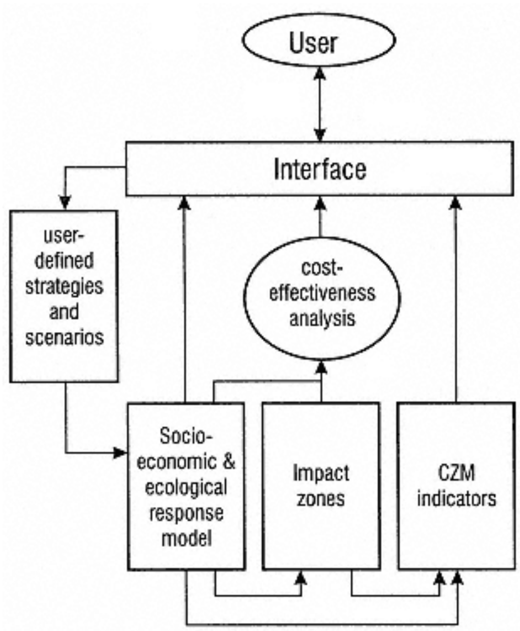


Figure 4.2.
Structure of the Coral−Maldives decision support system.

a ranking in terms of total cost per unit change in reef health. Two indicators of reef health are used—coral cover and rugosity. The user defines scenarios and strategies. The scenarios are exogenous developments, such as overall economic growth and population growth, which are used to drive the socio−economic model. The strategies are combinations of economic developments and environmental protection measures.

User Definitions

The model is driven by user−defined scenarios relating to external growth factors and policies. Growth is distributed throughout the islands through the definition of economic development options. Furthermore, the user can define various environmental protection measures and can examine the impacts of these under different scenarios. During the analysis, the user selects a growth scenario, an economic development scenario and a set of environmental protection measures that form a case. This is then compared to a reference case, which is defined as the projected situation in the year 2005 if no additional environmental protection measures are taken. This allows the analysis of only the environmental protection measures or of the coastal zone management strategies (i.e., economic and environmental options) or analysis of strategies under different scenarios.

The available user definitions are assumed to represent the major issues currently of concern in the coastal zone within the Republic of the Maldives:

1. Growth scenarios, defined for the study site and at the national level, including overall economic growth; population growth rates; investment in boats; an increase in number of tourists; an increase in price of foreign aggregate (alternative construction material); and the discount rate.

2. Economic development options, defined at the island level, including an increase in the number of houses; an increase in the number of resort rooms; an increase in the capacity for boats through development and/or

expansion of harbors and jetties; and protection of islands against coastal erosion and flooding through construction of seawalls or groynes.

3. Environmental protection options, defined for the study area, including reduction of pollution through treatment of wastewater by means of sewage treatment plants, septic tanks and outfalls; a setback policy for resorts; protected areas/marine parks; reduction of the areas available to mining through land use regulations; limitations to the use of coral in construction; reduction of sedimentation from construction through the use of sheet piling; construction of open jetties to minimize erosion; and education and awareness campaigns.

Population Growth and Migration Patterns

Population growth and the migration to Male is one of the major issues of concern at present in the Maldives. The model addresses this through user−defined scenarios. The user has several options. The first step is to define the natural growth rates for Male and the outer islands. These have been seen to differ and are, therefore, specified separately by the user. In addition to these growth rates, the user has the option to specify an out−migration rate. This represents potential decentralization policies, providing housing and services out of the Male area. Once the growth rates are established, the user can specify houses to be developed on each island. This defines the spatial distribution of population, based on current population densities and housing patterns, and assumes that people will remain on an island outside of Male if housing is provided. If housing is not provided, based on current migration patterns, it is assumed that people will migrate to Male. In the case of new land being created, the user specifies a number of houses for the reclaimed land and the model calculates the land area required based on an assumed area required per house.break

Economic Growth

The model contains a simple sector economic module. The fishery and tourism sectors are modeled, with the remaining sectors being aggregated. The total GDP figure used by the model takes into account that for North and South Male only and not that for the whole of the Republic. This division is based on fisheries production data and the tourism capacity of the atolls. The overall GDP is based on 1993 data.

The economy grows according to a growth rate specified by the user. The growth in the fisheries is based on two limiting factors. The first is the fishing capacity. This can be expanded through an investment in boats, specified by the user in terms of total number of boats. The second limiting factor is the available fish stocks. The model takes into account the state of the reef and, therefore, the potential density of reef fish based on a study by Brown *et al* . (1990) showing a relationship between reef fish density and the rugosity of the reef. As a result, this also affects the tuna fisheries through the availability of baitfish, which is dependent on the reef condition.

Tourism is limited by the demand from the international market or the capacity of the resorts based on the number of beds. The exogenous character of the growth of the international tourism market means it is dealt with as a scenario variable defined by the user. The capacity of the area to accept this demand is again user defined. Decisions can be made to expand existing resorts or create new resorts. Development can also be limited through setback policies.

The remaining economic sectors, which are combined, are modeled from the overall growth rate specified in the scenarios and fisheries and tourism GDP. The scenario provides a new overall GDP for the year selected. This GDP is then re−distributed in the economy through changes seen in the fisheries and tourism sectors, the remaining GDP belonging to the aggregated sectors. Although this simple model allows a clear and transparent modeling of the economy, it does omit several important side effects of changing the sector balance. For example, growth in tourism may increase GDP in the transportation sector, which in turn has an effect on the boat building industry and, perhaps, also provides employment for coral miners, currently working in a declining industry. This version of the model does not model these links between the sectors.

Economic Development Options

The economic development options spread the economic activity and the population spatially through the islands. These activities produce impacts on the reefs through sediment loadings and physical damage. Impact zones are used as input into the ecological response model. To minimize the impacts, the user is able to undertake a series of environmental protection measures.

Housing Development and Tourism Development

Housing and tourism activities increase the number of people on an island. Insufficient housing development for the growth in population will result in the excess population migrating to Male. An island can be developed as either a tourist island or a local island. The population on the tourist islands is related to the number of rooms, the quality of the resort, and the occupancy rate. The presence of people produces wastewater that is discharged off the reef. Any construction will place a demand on construction materials that is assumed to be coral rock unless otherwise specified. Any land reclamation depends on the additional houses constructed, expansion of the resorts or harbors developed. An estimation of the area that a house or resort room occupies is taken as the basis of the calculation. There is also an estimation made as to the current availability of land for each island.

Development of the Island's Accessibility

The user can define an investment in the number of boats in the specification of the scenarios. These are then distributed over the islands in the development options as expansion or construction of existing or new structures in the form of harbors or jetties. The size of the harbor or jetty is defined by the size of the boats with which it must be able to cope. Jetties and harbors do, however, create sediment loading, which can be minimized through sheet piling. They also create potential erosion that can, in the case of the jetties, be minimized through the design of the jetty on piles. In some cases, access channels are also required, which add to the localized erosion problems. Land reclamation will occur in the areas where harbors are developed. This assumes that the dredged material is dumped on the edge of the island to create new land areas. Again, this has a sediment loading effect.

Coastal Protection

Island development may lead to a certain level of instability through land reclamation and other activities such as the construction of jetties. This will lead to erosion of the island. There is also a certain level of natural erosion seen; however, this is not accounted for in the model as the islands are relatively dynamic and the seasonal changes, in many cases, transport the sediment from one part of the island to another, reversing direction at the change of season.break

Environmental Protection Measures

Environmental options are available to the user to minimize the impacts of economic development on the reef. Taking each measure separately, the user can define, for example, different levels of treatment or the number of protected areas. These can then be formulated into strategies (i.e., combinations of individual measures). These strategies should be formulated with the objectives of the plan in mind. This will also aid the user in the first stages of the analysis to selectively delete those less successful or unfeasible strategies. Strategies may be unfeasible for financial or social reasons. Each measure or combination of measures has an associated reduction in the loading modeled in terms of the sediment produced or the level or physical damage seen. In addition, each measure has an associated cost. This varies depending on the measure and the scale in which the measure is implemented.

Sewage Treatment and Disposal

Sewage from the islands can be treated in several ways. These are through construction of septic tanks, primary treatment plants or secondary treatment plants. Each treatment type results in a different level of reduction to the loading. The ecological response model only accounts for sediment loadings. Any level of treatment has an associated cost that also includes the cost of installing a sewage system. Disposal is either in the near−shore, where any remaining sediment will be discharged over the reef, or through a deep water outfall, which is assumed to result in no additional sediment on the reef. This version of the model does not allow for specification of environmental measures per island or per section. Later versions could include a different option for each level of treatment (e.g., secondary wastewater treatment) that is more appropriate to each population. Current data limitations meant that this would not have produced realistic or useful results.

Control of Sediment Movement

One major impact from construction activities, such as harbor development and land reclamation, is the spread of sediment during the construction phase. One method to minimize this impact is through the use of sheet piling. This is used to surround the land reclamation works or harbor dredging activities. It is assumed this will reduce the sediment loading onto the reef by 80%. In order to maintain natural sediment movements around the islands and reduce any potential for erosion through the construction of jetties, design standards can be enforced, specifying that all jetties should be built on piles. This reduces the erosion effect of the jetties.

Restricted and Protected Areas

In the model, coral is mined over the reef flats or concentrated to a single reef or faro. Mining a faro may be a more costly procedure, but will, however, reduce the overall area of reef destroyed. The user is able to define which percentage of coral rock is mined from which location. Setback policies can be implemented on the tourist islands. This limits the number of resort rooms through the size of the island. It is assumed that, by implementing a setback policy, no land reclamation is allowed to take place. Protected areas can also be defined for each section. It is assumed that, on each area, the impact from sediment and physical damage is reduced to a minimum. In some cases, this may result in regeneration of the reef.

Coral Mining

The user can limit the use of coral in construction of resorts and housing and in the construction of coastal protection structures. The alternative available for housing and resort construction is concrete block. This is a less expensive option than coral rock; the costs of the measure are, therefore, negative. However, it will reduce the demand for coral rock, increasing unemployment among miners but reducing the reef areas subject to physical damage. This also applies to coastal protection options, where the alternatives are the more expensive imported materials. The actual price of these imported materials can be regulated by taxes and duties defined by the user in the scenarios.

Cost of the Environmental Interventions

Each environmental intervention has a cost. This is modeled in terms of investment cost and maintenance cost and discounted to the base year. The discount rate is defined by the user as part of the scenario. In most cases, the maintenance cost is a percentage of the investment that is set in the definitions of the model parameters. In some cases, such as sewage treatment plants, scale factors are applied (i.e., the smaller the installation, the more expensive it is per unit capacity).

Summary of the Impacts from Economic Development and Environmental Protection

The major impacts on the reefs in the Maldives are through sedimentation and the production of rubble (Meesters and Westmacott 1996). In addition, constructions such as harbors and jetties cause erosion. Some impact coefficients used in the model are based on observations, while others are based on best estimates due to lack of more detailed data. The project fieldwork report (Westmacott 1996) outlines the data collected in detail.break

Sediment and Rubble Impacts

Sediment and rubble are produced by the socio−economic activities and limited through the environmental protection options. The extent of the impact is dependant on the options chosen and the scale of the developments or mitigation efforts. Rather than modeling the dispersion of sediment and production of rubble in a dilution/dispersion model, Coral−Maldives makes use of impact zones. This style of modeling was selected due to the relatively little data available on the spread of the sediment and production of rubble. Three impact zones are defined—high, low and minimal. The distance these extend from the construction or outfall depends on the activity's size. The area of each impact zone is then calculated using the average reef width. The impact zones are calibrated using as many actual sets of observed data as possible. The resulting impact zones are then combined with the data−base formulated from the results of the ecological response model, providing, for example, total areas of reef lost.

Erosion

As with the modeling of sediment and rubble, there was little data available to develop a deterministic model of erosion. The results of the model are again based on a scaling, making use of field observations. Areas eroded are computed on the basis of exposure of the island and previous observations of eroded areas where human influence has played a role. During the fieldwork, there was no specific measuring of eroded areas. As a result, the data used in this version of the model is very approximate.

Reef Health

The ecological response model of reef health under impact of sediment and rubble is described in Meesters and Westmacott (1996). The model was developed using fuzzy logic, a method able to capture expert knowledge on the behavior of a system. Experience of the Jamaica case study (Ridgley and Dollar 1996; Chapter 8) was utilized. The main impact factors considered in the Maldives were those relating to sedimentation and the production of rubble. These are outputs of the socio−economic activities. Levels of sedimentation and rubble are directly dependant on the user's definitions of both island development and environmental protection.

A set of base reef conditions are defined for each section. These combine with the sediment and rubble values resulting from the environmental protection measures taken and the economic development options and are used as the input values for the ecological response model. The outputs of the model are the reef health descriptors used in the cost−effectiveness analysis (i.e., coral cover and rugosity). Rugosity is subsequently used as an input for the fisheries module, affecting the density of reef fish to be found on the reefs.

Case Studies in Coral−Maldives

Cases pre−defined in the model are developed as examples to show the user the options available in the model and to illustrate how the model can be used to explore different economic developments and environmental protection options. The user is entirely free to define those scenarios and alternatives of interest to him or her. The structure of the decision support system should assist the decision−maker in the selection of the "best" strategy. This may be a decision on where to locate certain developments or which environmental protection options are the most cost−effective. Coral−Maldives allows combinations of scenarios and strategies to be examined. The following cases have been selected by the authors to illustrate the potential and the limitations of the model.

Scenarios

Scenarios can be used to explore different population growth patterns and set the boundaries for different levels of economic activity. Three scenarios have been developed as an example. First is a reference scenario (REF) that is based on past trends in the population with high growth on Male and lower growth on the surrounding islands. Different levels of economic activity have also been examined. REF is based on the growth rates seen in 1995 with a slow increase in the fishing fleet of 5 boats per year. Foreign aggregate is also assumed to be slowly increasing by 1%/yr.

A second scenario (POP) reflects a decrease in population growth rate to 3%/yr. This may be related to sustained high levels of economic growth and the desire to have less children. There is also a move away from fisheries into, perhaps, the tourism industry. This is seen by the low increase in the fishing fleet of 2 boats per year. The increase in price of foreign aggregate is negative; this represents policy options to reduce import tax or subsidize its import to increase the use of imported materials above that of coral rock.

The third scenario (OUT) examines the changes in population caused by a gradual 2%/yr out−migration. This could be the result of a decentralization policy or lowcontinue

economic growth rates, making areas out of Male more attractive again. The values used in these scenarios can be seen in Table 4.1.

The impacts of the scenarios can be seen in Table 4.2. The estimates are simulated over the 10 year period. The different population growth rates make significant differences, particularly when looking at housing demand. The POP scenario would require provision of half the number of houses compared to the REF scenario. The population growth on the outer islands is relatively small compared to the high growth that can be seen on Male. These scenarios indicate that the housing situation on Male, currently reaching its maximum capacity, is a high priority issue in island development.

The demand for resort rooms indicates that, if this growth in tourist numbers is going to continue at a rate of 14%/yr, the capacity is unlikely to be totally satisfied. Even at the lower growth of 8%/yr, as seen in the OUT scenario, the capacity demand remains high. With the size of resorts in general varying between 100 to 200 rooms, satisfying the 8%/yr growth could mean the construction of 100 to 150 resorts. This rate of construction is unlikely to be reached in the next 10 years. The current total number of resorts in North and South Male is 70.

The fisheries are, as of 1996, not threatening the fish stocks; however, with a large increase in the fishing fleet (e.g., 150 boats in 10 years), the catch of reef fish closes on the maximum sustainable catch. These results are based on the majority of the human population migrating to Male and there being no additional construction on the island.

The change in the price of foreign aggregate is controlled by the user. A 1% decrease per year leads to a price of $150/m3 . In the model, the price of coral rock increases at a fixed rate of 5%/yr. It may be that the user will also want to change this parameter in future versions of the model to reflect certain taxes on the use of coral rather than simply prohibiting its use. In the model, the price of imported aggregate will not affect the use of coral until either there are measures taken that prohibit the use of coral rock or the price falls below that of coral rock. In a 10 year period, this will occur at a decrease in price of over 15%/yr.

Economic Development Strategies

There are four main options available to the user for economic development of the islands. These are the provision of housing, the development of resorts, an increase in the island's accessibility and coastal protection. Three strategies relating to housing development have been formulated to show the different options available. In addition, several different options relating to the development of resorts and coastal protection have been examined. The first strategy, REF, is again a reference strategy that does not include any specific measures to be taken. NOMIG aims to provide housing for the natural population growth on each island. There are several variations of this strategy allowing a comparison of developing the northern or southern islands. The final strategy, RECLAIM, looks at the possibility of reclaiming large areas of land for housing. The model enables the user to look at the impact this will have on the housing situation on Male as well as on the environment. In addition to the basic strategy, a variation that includes coastal protection for reclaimed areas is examined. These strategies are described in Table 4.3.

A few selected criteria (Table 4.4) highlight the main differences between the economic development strategies.break

Table 4.1. Example growth scenarios (REF=reference scenario; POP=population growth rate scenario; OUT=out−migration scenario).

	Units	*REF*	*POP*	*OUT*
Overall economic growth rate	%/yr	6	6	4
Growth in number of tourists	%/yr	14	14	8
Investment in boats	number	50	20	100
Change in price of foreign aggregate	%/yr	3.5	1	3.5
Population growth on Male	%/yr	6	3	6
Population growth on inhabited islands	%/yr	4	3	4
Out−migration from Male	%/yr	0	0	2
Discount rate	%	6	6	6
Number of years	number	10	10	10

Table 4.2. Impacts of the growth scenarios (REF=reference scenario; POP=population growth rate scenario; OUT=out−migration scenario).

	Units	*REF*	*POP*	*OUT*
Population in 2005	number	125,000	96,000	104,000
Population on Male in 2005	number	112,000	84,000	95,000
Housing demand	number	6,700	3,000	4,000
Demand for resort rooms	number	7,000	7,000	2,800
	%	77	70	87

Fisheries catch as percent of maximum				
Price of foreign aggregate	US$/m3	230	150	230

Table 4.3. Description of economic development strategies.

Scenario	*Housing*	*Resorts*	*Accessibility*	*Coastal protection*
REF	No specific action, resulting in the population moving to Male	No tourist developments	No further developments	No coastal protection
NOMIG	Construction of houses on local islands to meet demands of natural population growth; remaining population stays on Male although no specific housing or reclamation is carried out	NOMIG: no tourist developments; NOMIG−N: four tourist developments in the North of 100 rooms each; NOMIG−S: four tourist developments in the South of 100 rooms each	Expansion or construction of the harbors where additional houses are built; jetties built for the tourist resorts	No coastal protection
RECLAIM	Large reclamation projects, housing the Male population growth on Vilingili (500) and Hulule (2,000)	No tourist developments	Expansion or construction of the harbors where additional houses are built	RECLAIM: no coastal protection; RECLAIM−C: sea walls constructed around reclaimed areas

Table 4.4. Results of the economic development scenarios (REF, NOMIG and RECLAIM defined as in Table 4.3).

Criteria	*Units*	*REF*	*NOMIG*	*RECLAIM*
Population of Male	number	86,300	84,000	60,300
Density on Male	number/km2	51,000	50,000	36,000
Density on Hulule and Vilingili	number/km2	480	630	40,000
Density on other inhabited islands	number/km2	3,100	4,200	4,200

Housing demand	number	2,960	2,700	300
Area reclaimed	m2	0	7,400	341,000
Area of reef lost	m2	173,000	186,000	266,000

As yet, none of these have any environmental protection measures to minimize the impacts. The model can also be used to see which areas are more heavily impacted through certain developments. For example, the development of four new resorts of 100 rooms each in the south is predicted to result in the loss of 208,000m2 of reef, while if occurring in the north the loss is predicted to be 206,000m2 of reef. Thus, the costs of retaining coral reef health can be expected to be greater in the south due to the more fragile systems that exist there as predicted by the model.

The REF economic development scenario, with sustained high population growth, leaves a housing demand of approximately 3,000 houses. The reclamation of 0.8km2 , along with the loss of 340,000m2 of reef through mining and sedimentation, could satisfy that demand. Over a 20 year period, the demand is predicted to rise to 18,000 houses. Satisfying this through reclamation would require a total of 2km2 of land to be reclaimed. This would keep the housing density of Male and on reclaimed land at approximately 50,000 people per square kilometre. The model indicates a potential high risk of coastal erosion. However, further verification is required due to the preliminary nature of the data. Protecting the coastline, now extended to 5km due to the reclamation, would cost in the region of US$14 million based on the use of coral rock. Imported aggregates would cost approximately US$60 million. The coral reef loss would be 500,000m2 , as opposed to 600,000m2 if coral were to be mined. These areas are, however, less than 1% of the total reef area of North and South Male.

Environmental Protection Options

As described previously, there are a series of environmental protection options aimed to minimize the impacts of developments on the reefs. These can be examined on an individual basis or combined into strategies (i.e., groups or combinations of measures). In order to formulate effective strategies, the user can begin by examining each measure on an individual bases. Table 4.5 describes a series of measures defined for this analysis. As the first step in the analysis, the aim is to explore the effectiveness of each of the measures in terms of changes to reef health and impact areas affected.

Figures 4.3 to 4.5 show the results of the cost−effectiveness analysis for the three indicators of coral reef health (i.e., rugosity, coral cover and area of reef lost or gained). There is some difference in the ranking of the strategies, depending on the indicators chosen. In all three cases, however, sheet piling is the most expensive option when considering coral reef protection. The wastewater treatment measures are also high in cost. Sheet piling would not, at a first glance, seem a useful option. However, it may create protection for the reefs surrounding the islands. This could provide a valuable natural coastal function and an additional attraction for the island as a resort. These issues go beyond the initial costing carried out in this version of Coral−Maldives.

Wastewater treatment measures are expensive when considering the range of options available for coral reef management and protection. However, what is not seen in only examining these indicators is the public health impact of clean wastewater and disposal beyond the reef. With the cost−effectiveness utilizing social indicators as a gage, these options may be higher in the ranking. It may be that no level of risk is acceptable for the public.

The most cost−effective measures would appear to be those focusing on land use regulations. This may be in the restriction of coral mining areas or the provision of alternatives to the coral mining industry. Likewise, protection of certain areas predicts an improvement in the reef health, assuming that impacts from sedimentation and physical damage are reduced to a minimum. These have similar cost−effectiveness; however, the exact ranking varies considerably between each indicator. This demonstrates the differences due to the selection of the particular indicator of coral reef health.

The effects of the individual measures are not cumulative. The results given above can be used as an indicator to prioritize which measures to take. The next step in the formulation of environmental protection options is to look at combinations of measures (i.e., strategies). The user may have specific information on the budget available for these interventions. The costs shown in this analysis are the total discounted 1995 dollar costs over the 10 year period. Table 4.6 provides descriptions and the values used for the combinations of measures formulated for the analysis. Each strategy aims to focus on a specific issue, goal or type of measure, covering control through land use regulations, reduction in sediment reaching the reef, and regulations focusing on the tourist resorts.

Figures 4.6 to 4.8 show the cost−effectiveness results of implementing the environmental protection strategies. Sediment mitigation through the use of sheet piling appears to have limited effect. This may be for two reasons. First, the developments in this example are small harbor extensions and, in some cases, the associated reclamation is only a few hundred square metres. Surrounding works with piling is going to have a more dramatic effect the larger the reclamation and harbor works. Second, the area of coral gained clearly reflects the implementation ofcontinue

Table 4.5. Description of environmental protection measures.

Measure	*Description*
Outfall (OUT)	Disposal of sewage through outfalls on each island; orientation of the outfalls is towards the inside of the atolls.
10 marine parks (10MP)	A marine park is established in each section of 0.5km2 each.
Setback (SET)	Setback policy for tourist islands is implemented, generating no cost but may limit the number of rooms able to be constructed.
Prohibit coral use for resorts (RES)	This measure does not allow resorts to use coral rock for construction of resort rooms or sea defenses on resorts.
Prohibit all use of coral rock (ALL)	Neither locals nor resorts are permitted to use coral rock for construction of houses and rooms or sea defenses.
Mining 100% from Faro (100F)	Mining demand is satisfied through the selective mining of one reef to a depth of 15m.
Prohibit local use of coral (LOC)	This measure does not allow local islands to use coral rock for construction of houses or local sea defenses.
5 marine parks in the South (MPS)	A marine park is established in each section of South Male of 0.5km2 each.
5 marine parks in the North (MPN)	A marine park is established in each section of North Male of 0.5km2 each.
Mining 50% from Faro (50F)	50% of the mining demand is satisfied through the selective mining of one reef to a depth of 15m.
Secondary wastewater treatment (2WWT)	Sewage collected in a pump driven sewage system and treated through the construction of secondary wastewater treatment plants on each island; subsequent disposal in the

	near−shore.
Septic tanks (SEP)	Sewage is treated through individual septic tanks and excess liquid collected in a gravity run sewage system before being disposed in the near−shore.
Sheet piling (SHP)	All coastal construction works are surrounded by sheet piling to restrain sediment flow.

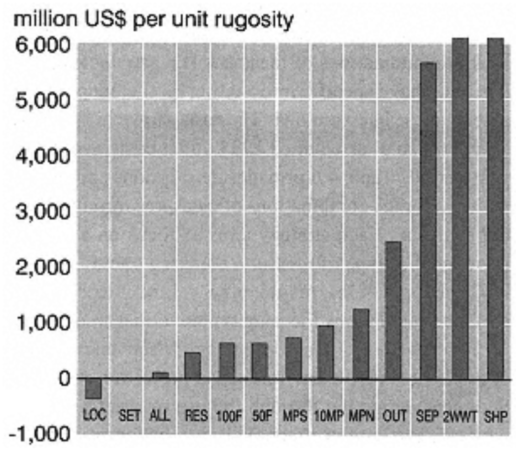


Figure 4.3.
Cost−effectiveness of environmental protection measures defined in terms of rugosity as an indicator of coral reef health
(environmental protection measures defined in Table 4.5).

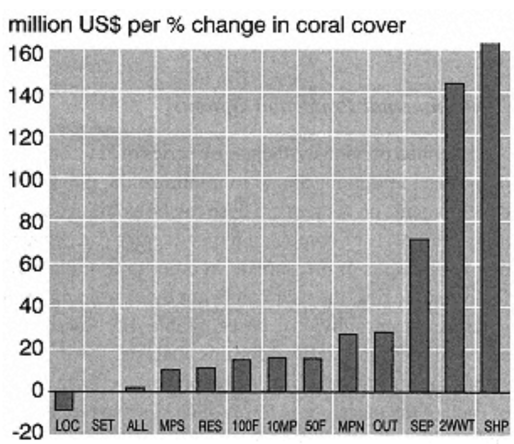


Figure 4.4.
Cost−effectiveness of environmental protection measures defined in terms of coral cover as an indicator of coral reef health (environmental protection measures defined in Table 4.5).

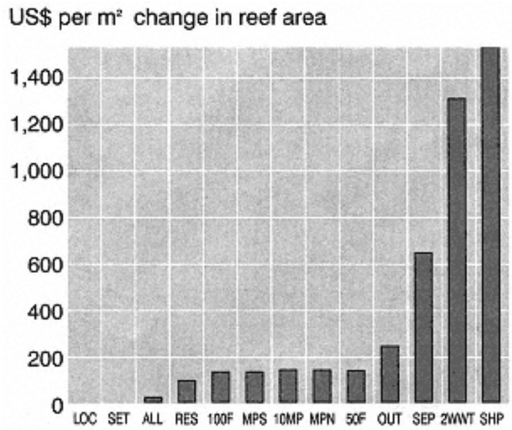


Figure 4.5.
Cost−effectiveness of environmental protection measures defined in terms of reef area as an indicator of coral reef health (environmental protection measures defined in Table 4.5).

marine parks. In these areas, any impacts are assumed to be reduced to a minimum, resulting in an improvement of the reef in many cases.

Again, one should also consider the public health issue. Although the options of treating sewage are expensive when considering reef health, they should not be ruled out as valuable alternatives in terms of public health. Likewise, the indicators of housing densities are important when considering social issues.

One could also consider indicators of social acceptability through the use of user−defined criteria. For example, the ZERO option does not require any specific actions to be taken and, as such, may be more acceptable. LANDUSE requires people to be retrained, potentially resulting in the loss of jobs. It may also prohibit use of certain areas for traditional activities. In addition, for both of these strategies there is assumed to have been no awareness programs to inform the public as to the need for these strategies. The strategy ALL considers this aspect. The total cost of the proposed awareness program is estimated at less than 1% of the total costs.break

Table 4.6. Description of environmental protection strategies.

	Landuse	Sediment	Tourist	All
Description	Protection of reefs through land use regulations	Reduction of sedimentation reaching the reefs	Restrictions for tourist resorts regarding building regulations and waste disposal	Combination of all measures to improve the environment
Sewage treatment	None	Secondary treatment	Disposal through outfalls on tourist islands	Disposal through outfalls
Setback policy	On tourist islands	None	Yes	Yes

Marine parks	10 marine parks of 0.5km2 each	None	10 marine parks of 0.5km2 each	10 marine parks of 0.5km2 each
Mining locations	None	None		100% Faro
Use of coral rock	Prohibit all	None	Prohibit in tourist industry	None
Awareness raising	None	None	None	US$1 million spent on environmental awareness
Sheet piling	None	For all construction	On tourist resorts	For all construction
Open jetties	None	All	On tourist resorts	All

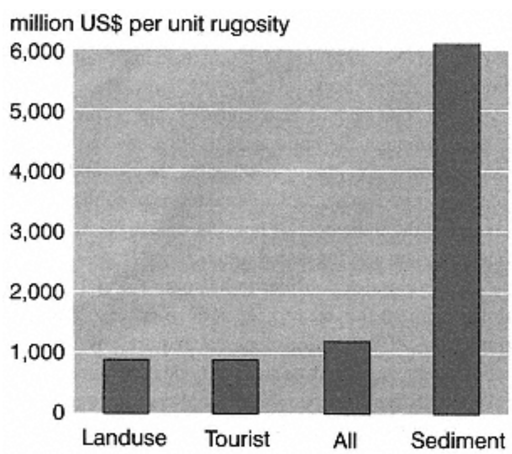


Figure 4.6.
Cost−effectiveness of environmental protection strategies defined in terms of rugosity as an indicator of coral reef health (environmental protection strategies defined as in Table 4.6).

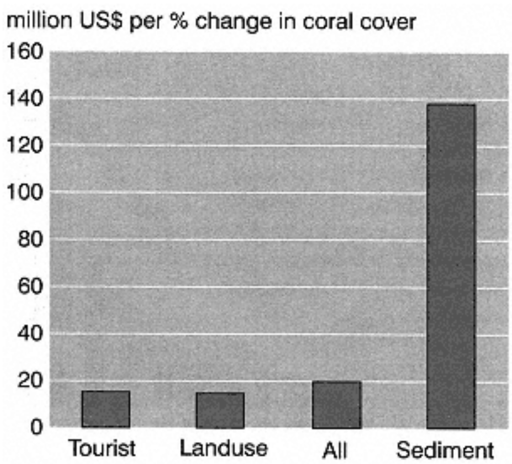


Figure 4.7.
Cost−effectiveness of environmental protection strategies defined in terms of coral cover as an indicator of coral reef health (environmental protection strategies defined as in Table 4.6).

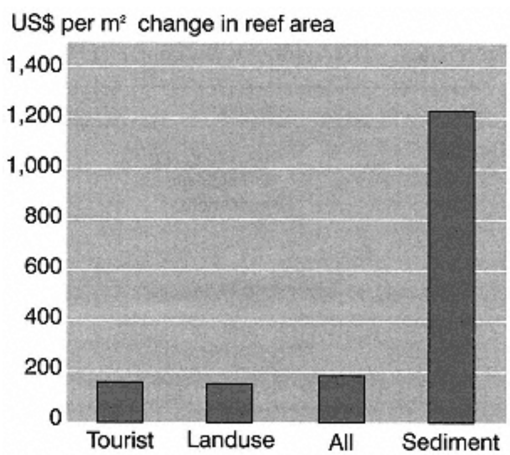


Figure 4.8.
Cost−effectiveness of environmental protection strategies defined in terms of reef area as an indicator of coral reef health (environmental protection strategies defined as in Table 4.6).

Conclusions

The two objectives of the Coral−Maldives model were to test and validate the cost−effectiveness analysis model of coral reef management and protection and to investigate whether the cost−effectiveness analysis model can be a useful tool for decision support for coastal zone management in the Republic of the Maldives. This chapter has described the model and examined different analyses. The model was presented to the decision−makers within the Ministry of Planning, Human Resources and the Environment of the Republic of the Maldives in late 1996. As a result of the work completed up to that time, the following conclusions can be drawn and further recommendations made as to future developments of the model.

Cost−Effectiveness Analysis

Ranking the interventions in terms of their cost−effectiveness for coral reef management and protection is a useful and potentially valuable tool for reef managers. The results from the Coral−Maldives model should provide reef managers with a clearer picture of the different options available and the likely benefits and costs associated with these management interventions. There are, however, an array of potential indicators describing the success or failure of a coastal zone management strategy. These may be ignored by focusing only on the costs of environmental protection measures and changes in coral reef health. For instance, the issue of public health or coastal erosion and flooding risk may not be taken into account. These are important factors when analyzing options for coastal zone management.break

The Maldives case study shows different results from the case studies carried out in Jamaica (Ruitenbeek *et al.* 1999a; Chapter 8) and Curaçao (Rijsberman and West−macott 1996; Chapter 4). The three case studies take geographically different areas. In the Jamaica case study, the construction of an outfall appears to be a cost−effective measure; however, this is a stand−alone intervention that, in the Maldives, is connected to either a pumped sewage system or a gravity sewage system in combination with septic tanks. The land use zoning programs in the Jamaican case are some of the most cost−effective measures. This pattern is also seen in the Maldives case study.

The Curaçao case study focuses much more on land−based pollutants as these were identified as the major local threats to the reefs. In the Maldives, industrial activity is very small and damage from sewage is low due to the high flushing from the relatively strong water movements; thus, the focus is on minimizing physical damage to the reefs. The Curaçao study primarily examines the different options for treating wastewater flows. Land use regulations are again different. In the Maldives, the protected areas are assumed to be away from sources of pollution and are feasible due to the large area of reefs. It is assumed these areas are able to be protected from physical damage. The situation in Curaçao is different in the sense that the water quality standards that may be imposed for maparine parks are entirely dependant on the ability of industries and local government to pay for the interventions to reach these standards. The cost of implementing a marine park can be taken into account; however, the total cost, including wastewater treatment facilities to reach marine park standards, should also be examined.

Cost−effectiveness is a useful indicator to rank the different strategies and start to prioritize individual measures. This could play a substantial role in assisting decision−makers in formulating environmental protection strategies. These, in turn, can be compared as to their effectiveness for coral reef management. Taking the broader view of coastal zone management, the use of such an indicator for the assessment of projects and plans can be complimentary to other coastal zone management indicators. Coral−Maldives demonstrates the use of these additional indicators.

Decision Support System for Coastal Zone Management

The second objective of the model was to develop a decision support system for coastal zone management that could eventually aid the decision−makers in the Maldives in the formulation of their coastal zone management plans. The model was formulated during discussions with various government agencies where the main issues currently of concern and the alternatives available to management were identified. The issues in the decision support system should, therefore, be a fair representation of the current concerns of the Maldives. The model should be able to highlight these issues and show the different impacts alternative strategies may have on a series of coastal zone management indicators. Within these indicators, the user can examine the cost−effectiveness of each strategy as described above.

The decision support system is aimed at decision−makers as well as analysts. The structure is such that analysts can prepare and save case studies that can be later assessed and utilized by the decision−makers. During the comparison of cases, there is a ranking option that can be used to centralize discussions around the selection of cases. These rankings can also be saved and retrieved for later discussions or analyses. The following sections discuss the potential use of the model as a decision−making tool and suggest ways to improve or further develop the model.

The following areas were identified as potential uses of the model:

1. Coastal zone management workshops and training programs. Coral−Maldives would be suited to a training workshop for coastal zone management. Participants could include analysts, where model capabilities, data needs, formulation of the scenarios and strategies, and selection of the more successful measures or strategies are discussed. Alternatively, workshops may be held for decision−makers who can examine the alternatives formulated by the analysts and use the decision support system as the discussion forum where specific objectives and indicators, as well as the eventual ranking of alternatives, is the focus.

2. Preparation of scenarios for environmental reports. Coral−Maldives can be used to illustrate the impact that different future development scenarios may have on the environment. The decision support system provides a quick method of viewing and comparing different scenarios. These can be used to illustrate environmental reports showing the likely impact of certain development options. The model is not, however, formulated at a level of detail capable of carrying out individual project assessments. Rather, it can indicate trends over the simulation period. The data used has had to be adapted and, in many cases, estimated. For more detailed results, new data sets will be required.

3. Analysis of different regional development plans. Similar to the preparation of scenarios for reports, the model can be used to input and examine the impacts of alternative regional development plans. The modelcontinue

focuses on coastal zone management issues and may, however, miss some social issues such as provision of schools and hospitals, and the provision of fresh drinking water. The spatial extent of the model is also limited to North and South Male in this version and is not able to show the impacts of, for example, decentralization strategies. The model will give graphical information on the likely impacts of the different plans and will allow the decision−makers to compare the results under a series of different indicators.

4. Identification of areas to protect or develop. Coral−Maldives can show trends likely to be seen rather than point to specific reefs that should be protected or identify certain islands more suitable for development than others. It will, however, show the differences at the level of the sections defined in the model of the impacts of protection measures or development. Likewise, the model distinguishes between developments on the islands of the inner and outer sections of the atoll and the orientation of developments actually on the island.

5. Environmental impact assessments. Environmental impact assessments (EIAs) tend to be carried out for a specific project. As the model stands, the scale is too general for specific project evaluations. However, the concept and much of the techniques used for modeling could be used to create a project−based EIA tool, given further detailing and verification by ground data collection. This could be a useful tool for non−professionals to carry out analysis of environmental impacts. For example, a tool freely available to resort developers may allow certain developments to be redesigned on the basis of more firm environmental evidence.

6. Indicators for coastal zone management. Coral−Maldives contains a series of coastal zone management indicators. These can also be added to by user−defined criteria. This allows the user to include recently arising information or issues. The structure of Coral−Maldives also allows the user to focus on the objectives of the management plan through the selection of the indicators. It may also stimulate discussions of gaps missing in the analysis and identify issues that may not otherwise have been discussed.

7. Establishment of an environmental database. The Ministry of Planning, Human Resources and the Environment (MPHRE) of the Republic of the Maldives is working towards the establishment of an environmental database. Coral−Maldives contains data that has been collected from a variety of sources. The data used in the model can be either used to add to the database or as a basis for a new database. Updating the data, both in the MPHRE environmental database and in the model database can be achieved through the training of MPHRE staff.

Further Developments of the Model

The model was received well in the Maldives. Several suggestions were made as to how the model could be expanded and improved. One of the first tasks should be to achieve wide acceptance of such a decision−making tool and, through training of different departments, allow the tool to be updated and further developed. The following sections highlight the issues brought to light for use of the model and its further development.

Cost−Effectiveness Analysis

Studies were continued in the case study sites of Curaçao and Jamaica (see subsequent chapters), including valuation studies and consideration of the benefits and costs associated with changes seen in the reef health as a result of environmental protection measures. These studies provide additional valuable indicators for decision−makers, leading to a clearer understanding than information regarding a change in the physical state of the reef alone may do.

Spatial Extent of the Model

One main comment received was to expand the model to cover the whole of the Republic of the Maldives. This would allow the user to examine the possibilities of assessing the development of different atolls. At this level of regional planning, users would be able to obtain a clearer picture of alternative development plans. This would require additional data at the same level as is currently in the model. The data would cover population and other socio−economic data, and physical data such as island size, reef conditions, and exposure of the islands. Such a model would allow the user to assess the impacts and explore the alternatives to various regional development plans.

Inclusion of Additional Issues

In addition to expanding the spatial extent of the model, certain additional issues were also identified as important for coastal zone management in the region:

Solid waste. The issue of solid waste was not included in the current version of the model. It was omitted due to the focus on environmental impacts that were quantified in terms of sediment and physical damage. The issue of solid waste and the impacts of dumping or incineration in selected sites is a current topic of concern for the Maldives. For example, limitations on the amount of land area available has resulted in the infilling of a lagoon close to the capital, Male. The alternatives are limited; however, the full impacts of these actions have not been fully examined.break

Vulnerability to flooding. Another issue that is not included in the current version of Coral−Maldives is the increased risk of flooding resulting from reclamation works. Impacts of reclamation are seen in terms of increased coastal erosion that can be mitigated through the construction of coastal protection works. A useful method of including the effects of erosion and the likely risk of flooding is for the user to select a risk level that is acceptable and the costs of achieving this will be computed through the model. To fully implement such a model, data and information would need to be collected on the current erosion patterns on the islands. In addition, if longer time scales were examined, the ability of the reefs to keep pace with sea level rise could be incorporated.

Database

The data included in the model will require continued updating and expanding. Certain parts of the database are based on expert judgment, rather than actual field measurements. This may be adequate for the current model; however, this could be improved in subsequent revisions, particularly if more detail was required for more project−orientated analyses. In particular, data on erosion rates, sediment loadings from construction, impact areas surrounding land reclamation works, reef health parameters available on a larger scale, reef areas surrounding islands, and those areas utilized for mining activities are suggested points of focus for data improvements.

Development of the Decision Support System

Certain areas of the decision support system could also be improved. Optional ways of defining the environmental protection measures, for instance, could assist the decision−maker. For example, selecting the type of wastewater treatment for each island does not give a clear indication of the level of treatment that will be received. The user could, in theory, also select the public health risk that he or she is willing to accept or the reduction level required and the model could select for each island the least expensive and most effective method for that particular capacity. The user could also be able to spatially define the mining areas and, with more detailed information on reef health, the user could expand these to include defining more specifically the actual reefs targeted for protection.

GIS Options for Display of Results

The analysis stage in the decision support system allows the users to examine the result in tabular format as well as more detailed information in charts. Geographic information system (GIS) tools and applications may be able to improve this display of results, linking the datasets to the graphical locations. The feasibility of achieving this should be examined from the perspective of additional data requirements and software availability. Such a development to the current Coral−Maldives model could be carried out as a capacity building exercise.

Environmental Impact Assessment and Project Evaluation

The present version of Coral−Maldives is not designed to be used for project evaluation. The level of detail has been generalized and the islands grouped into sections. If such a model were to be available for project evaluation, the level of detail required would need to be far greater. It could be that data is collected for certain project evaluations and that a model is developed for that island or situation only. The detail contained in the model would again be more in−depth and relevant to the specific purpose. The structure of the analysis could, however, follow the same structure as that of the current decision support system.

The current version of the model shows the major trends in the socio−economic conditions and environmental health of one section of the Republic of the Maldives. The model is capable of facilitating discussions and being utilized as a training tool, and is valuable in the identification of areas requiring additional information and data collection. The model can be seen as the basis of an environmental database and, through its further development, could be used in a capacity strengthening exercise for various government ministries within the Maldives. Additional issues and indicators can be added in a similar manner. Updating of the model could be achieved through trained personnel within the country who would be responsible for maintenance and development.break

Chapter 5—
Values Associated with the Local Use of the Montego Bay Marine Park

Kent Gustavson
Gustavson Ecological Resource Consulting, Gabriola, BC, Canada

Local residents and tourists alike derive direct local use benefits from coral reef ecosystems in the developing tropics, most often associated with recreation and near−shore fisheries. Other marketed benefits may include participation in the aquarium trade, mariculture, crafts, coral sand extraction, and bioprospecting. In addition to these direct benefits, in which components of the marine system input directly and explicitly into the economic activity, there are also local indirect uses. Indirect benefits can be defined as ecosystem functional contributions to economic production value, providing implicit and integral support of economic activities. The most significant of these in terms of the developing tropics is likely the coastal protection that coral reefs afford. Other indirect benefits that may be enjoyed include support of the offshore fisheries through ecological interactions.

The issue of valuing marine system structural and functional diversity (or biodiversity) can be concerned with the creation of artificial markets (e.g., option, bequest and existence values revealed through contingent valuation, in which estimates of individual or society's utility associated with the system are made), or the creation of new markets (e.g., bioprospecting, in which estimates of system value through a distribution of profits or value−added associated with marine product development are made). Both the creation of new and artificial markets to estimate marine system values help ensure that the total economic value of biodiversity is taken into account when management decisions are being made. While it is indeed important to create or reveal markets to measure the full benefits of marine biodiversity, direct and indirect use values reflected in existing, well established markets are similarly important to consider. Indeed, particularly in developing nations where government accounting systems may be less than adequate, local use values associated with particular marine systems tend to be inaccurately or inadequately represented in resource decision−making and policy development.

This chapter will outline the nature of those direct and indirect local use values as they apply to the Montego Bay Marine Park (the Park), Montego Bay, Jamaica. A methodology is outlined and applied which derives the net present values of those direct and indirect uses for as many base years as reliable and adequate data is available. It is through consideration of the local use values as reported here, in conjunction with subsequent analyses regarding the ecological condition of the reefs and the sustainable level of reef use, that management authorities will be able to obtain more complete information on the extent of the reef−derived economic benefits at risk of being lost if conservation efforts prove inadequate.

Methodology

Theoretical Context:
The Production Function Model

Before the local use values are derived, it is important to place this exercise within the context of a theoretical model. In this case, the marine resources themselves are envisioned as contributing to an economic productive process as traditionally described with a production function. Economic valuation studies of natural systems most often distinguish use from non−use values, and direct use from indirect use values. Rather than maintaining the distinction between direct and indirect use values based on using either a direct or indirect method of estimation, this study will consider both to ultimately be *supply−oriented production function contributions of marine systems to economic value* . In other words, we are concerned with measuring the contributions of marine ecosystems to the value of output in a produced good or service. The isolation of direct from indirect benefits is only useful from the point of view of measurement. Thus, the direct and indirect use value distinction was maintained only so far as we discuss *how* the values were estimated.break

The contribution of marine systems to economic value through a production function is most readily envisioned using a Cobb−Douglas model:

$$Q = Q\{L, K, R\}$$

where L = labor;

K = capital; and,

R = resource base (or biodiversity).

In such a model, the value of marine systems or bio−diversity is the marginal change in Q as R changes. Thus, the economic value of the contribution of the coral reefs in Montego Bay associated with one unit of reef of a given quality is the change in the value of the output that is achieved with a one unit increase in reef, holding all other inputs constant. This benefit model, along with separately modeled costs (Chapters 8 and 9), facilitates the examination of economic efficiencies associated with reef management decisions which result in changes in reef quality. This report will not explicitly derive specific production functions, but make the first step by describing the inputs and the values attributed to the use of the resource.

Information Sources

Direct and indirect uses of the Montego Bay Marine Park waters were identified for the purposes of value estimation during a site visit in January and February 1998. The primary means of data collection was document analysis and database search. The types of documents and databases analyzed included government department records and reports, census and survey statistics, non−government organization and academic reports, Montego Bay Marine Park documents, and consultants' reports. This study also benefited from the information made available through a concurrent project—a rapid socio−economic assessment of fishers, water sports and hotel operations—the results of which are reported elsewhere (Bunce and Gustavson 1998a; Chapter 11).

Direct local use values that can be attributed to the benefits achieved through the use of the Park were estimated on an annual basis for two broad categories of uses—the near−shore fisheries and tourism. Indirect use values associated with coastal protection were also estimated. These local uses of the Park waters were identified as the most significant during the final study site application, as well as being of the highest policy priority. Table 5.1 shows the primary sources of the data used and describes the nature of the information.

The focus of this study on the three primary categories of uses, and thus avoiding detailed examination of other minor local uses, is in keeping with the experience of other investigations into the local use benefits of coral reefs (e.g., Dahuri 1996; Dixon 1992; Pendleton 1995; Sawyer 1992; Tomascik 1993; Weber and Saunders 1996) which demonstrate that analyses should focus on a small number of benefits. Recognizing limitations and constraints on research resources, it is through the detailed documentation and modeling of a small number of local uses that more valuable information can be gained regarding the changes in benefits realized through changes in the quality of the resource. Furthermore, more detailed modeling of a few direct use values will provide a benchmark from which to examine other, less significant local use values for which less detailed information is available. This approach will ultimately lead to a model which provides the maximum amount of information, given practical research limitations, for input into Park management decision−making and the establishment of policy.

Net Present Values of Direct and Indirect Local Uses

To arrive at the annual value of the contribution of the coral reefs of Montego Bay Marine Park to direct and indirect economic activities, the net value of those activities was calculated. The net value is the remainder of the total monetary value of the benefits once all existing economic claims to the production have been deducted. This remainder is the economic production claim which can be attributed to the marine system.

To calculate the net value associated with coral reef use, all variable costs which represent a claim on economic production were first deducted from the gross receipts of the economic activity. This included the costs of utilities, operating services sold to the businesses, repairs and maintenance, goods and materials, government license and registration fees, insurance, and the opportunity costs of labor. It does not include such items as government taxes and subsidies (transfer payments) as these are not payments for activities which involve economic production *per se* . Similarly, any internal financial transactions, such as depreciation, or external financial transactions, such as bank interest payments, are not included.

The net operating values were then translated to true net values where the available data allowed by converting the value of capital investments or stocks to annual flow values to be deducted from the annual net operating values. The equivalent annual capital cost can be estimated through the use of an annuity factor:break

$$E = \frac{C}{AF}$$

where E = equivalent annual capital cost;

C = value of capital at cost; and,

AF = annuity factor.

An infinite time horizon is assumed, such that $AF = 1/i$, where i is the discount rate used in the specific value calculation. Total values of capital investments considered available values at cost of buildings, equipment, and land. Information regarding the value of capital at cost was not always forthcoming or possible to reasonably estimate. In those instances, a full−cycle analysis was not possible, and the net operating values are reported. These cases are explicitly noted in the results.

For the next step in the calculation, we assume that a continuing, sustainable use is possible at the level of use for the given year, and that the total value in which we are interested takes into account an infinite stream of net annual benefits. Thus, the net present value (NPV) for each direct and indirect benefit is calculated. The NPV can be simply thought of as the current equivalent net value associated with use of the Park waters, or the contribution of marine biodiversity to productive economic output summed annually over an infinite time stream. Future values are discounted in order to reflect the social time preference rate. To illustrate the sensitivity of the analysis to the chosen discount rate, three rates are separately assumed in the calculations—5%, 10% and 15% per annum. The NPV is thus represented as

$$NPV = \frac{(R - C)}{i} = \frac{NV}{i}$$

where R = revenue;

C = costs;

i = discount rate (5%, 10%, and 15%);
and,

NV = annual net value.

In all instances, conversion from Jamaican to US dollars assumed J$35.5 = US$1 based on the average of the median bid and the median asking price in world markets on the first of the month for the first five months of 1998. Where it was necessary to convert from 1998 values to equivalent 1996 dollar estimates, an average annual domestic inflation rate of 28% was assumed based on a 10 year average of the annual implicit price deflator for total GDP for Jamaica from 1987 through 1996 (source: Statistical Institute of Jamaica).

Interpreting Optimal or Sustainable Level of Use

It must be emphasized that the derivation of NPVs here is not a cost−benefit analysis *per se* . In a cost−benefitcontinue

Table 5.1 Information used for deriving local use values associated with the Montego Bay Marine Park

Use value	*Information source*	*Nature of the information*
Tourism	OAS (1994)	detailed revenue and expense analysis for the tourism sector in Jamaica as whole for 1992
	Annual Travel Statistics, Jamaica Tourist Board	annual tourist arrivals, tourist expenditures, and accommodations sales
	Jamaica Promotions Corporation	capital cost models for accommodations
Near−shore fisheries	Registration of Fishermen Database, Fisheries Division, Jamaican Ministry of Agriculture	number and type of fishers and number of boats
	Bunce and Gustavson (1998a)	types of fishing activities in Park waters, fishing revenues and costs
	Nicholson(1994)	fishing revenues and costs
Coastal protection	Jamaica Promotions Corporation	shoreline land values
	Urban Development Corporation	shoreline land values
	various local real estate agencies	shoreline land values

local land developers	shoreline land values

analysis, one would compare the economic value of the resource after an intervention (e.g., a management strategy which would improve reef conditions) with the economic value before an intervention. This chapter does not consider the effect of possible management interventions on the economic value derived from the reefs of Montego Bay Marine Park, or the changes in derived value with changes in reef quality. The NPVs reported here represent the *value at risk* . In other words, it is the direct and indirect local use values which would be lost if the resource was completely degraded.

The validity of the assumption that the benefits will continue to be received in perpetuity must ultimately be checked against biophysical information regarding the conditions of the reefs in Montego Bay as they have changed over time. Moreover, any future or continuing changes in reef ecological conditions will necessarily have an effect on the current levels of local use. There are two notable documented ecological surveys (Hitchman 1997; Sullivan and Chiappone 1994) which examine reef conditions in the Montego Bay Marine Park. As well, there is additional information available on the reef conditions as perceived by the primary user groups; this latter information is outlined in Chapter 11.

This report will not attempt to make assumptions regarding the sustainable level of local use, but instead will report NPVs for as many base years as there is reliable information. The coral reefs of Montego Bay are part of a highly complex system, involving interactions between ecological components, user groups, and land−based activities. Although there are certainly negative ecological impacts associated with increases in the levels of certain types of local uses, the relationship is not simple, nor can the ecological impacts be easily isolated from other coastal and land−based activities. The high degree of system uncertainty, as well as system links, synergisms and feedbacks, make assumptions regarding the sustainable level of use difficult. Such an exercise is best tackled through a synthesis of these results with other modeling strategies and biophysical information.

Net Present Values of Local Uses

Direct Local Use:
Tourism

Direct economic account information was not available for the tourism sector. For statistical purposes, the Jamaica Tourist Board places tourists who visit Montego Bay into two categories—stop−over (airline arrival) and cruise−ship passengers. Tables 5.2 and 5.3 show the conversion of the average daily visitor expenditures of stop−over and cruise−ship passengers into estimated total annual expenditures in Montego Bay. The total number of stop−over visitors arriving in Montego Bay that remain in the greater Montego Bay area was not available; thus, it was assumed to be equivalent to the average number of bed−nights sold in hotels divided by the average length of a stop−over tourist stay. Cruise−ship passengers arriving in the Montego Bay terminal are assumed to spend their shore time in the greater Montego Bay area and spend an average of one day in port.

Rather than rely on estimates of tourist expenditures from departing−tourist surveys, a study by the OAS (1994) based its economic analysis of the tourism sector in 1992 on a survey of the actual revenues and costs associated with tourism−related businesses. As noted by OAS (1994), using tourist expenditure information is limited mainly due to the fact that expenditures outside of the country for the vacation (e.g., vacation packages) may not coincide with the amount actually received by the domestic businesses involved, and the information itself may be compromised by tourists' abilities to recall expenditures accurately during surveys. The main disadvantage associated with the approach of the OAS (1994) is that some businesses, such as street vendors and miscellaneous retail establishments, were excluded from the analysis as they were not specifically targeted for information collection.

The OAS (1994) study reported results for Jamaica as a whole; thus, the specific revenue and cost profiles cited could not be used in this investigation. It was assumed, however, that the cost structures and net values reported for Jamaica remain *proportionately* the same for the Montego Bay area. Table 5.4 shows net values as a percentage of total revenues for 1992 by the type of business, and the reconciliation of the categories used by the Jamaica Tourist Board (JTB) with those used by the OAS. Where more than one OAS category was placed in the same JTB category (i.e., transportation and entertainment), the net value as a percentage of the total revenue that was assigned to the JTB category was determined by weighting each OAS component according to the OAS category's share of total revenue for all OAS categories within the JTB category. For tourist expenditures registered as "miscellaneous" for which there is no specific cost and revenue structure available in OAS (1994), the weighted average of 20.1% for the whole tourism sector was used.

Table 5.5 shows the annual net values for 1985 through 1996 attributed to stop−over and cruise−ship passenger expenditures, as well as for the tourism sector as a whole. Table 5.6 shows the annual net values broken−down for each tourism sector for 1996 using available informationcontinue

Table 5.2 Estimated total annual expenditures by stop−over visitors remaining in Montego Bay

Year	*Total Montego Bay stop−over arrivals* a	*Average length of stay (all Jamaican stop−over visitors)* b	*Number of bed−nights sold in Montego Bay hotels* c	*Proportion of Montego Bay stop−over arrivals remaining in Montego Bay* d	*Average individual daily expenditures (current US$)* e	*Estimated total annual expenditure (current US$)* f
1985	278142	9.8	1239990	0.45	73	9.1×107
1986	315824	10.2	1494526	0.46	78	1.2×108
1987	290404	10.2	1684754	0.57	77	1.3×108
1988	349831	10.3	1374281	0.38	76	1.0×108
1989	273817	10.6	1421957	0.49	78	1.1×108
1990	299301	10.9	1647016	0.50	80	1.3×108
1991	290712	10.9	1558927	0.49	79	1.2×108
1992	304022	11.2	1676197	0.49	84	1.4×108
1993	317078	11.0	1764017	0.51	85	1.5×108
1994	270711	10.7	1511778	0.52	84	1.3×108
1995	280790	10.9	1644600	0.54	87	1.4×108
1996	294466	11.1	1666043	0.51	85	1.4×108
Average	**287995**	**10.4**	**1530376**	**0.52**	**n/a**	**n/a**

a Statistics for 1994, 1995 and 1996 from the Jamaica Tourist Board included non−resident Jamaicans. As these numbers were not included prior to 1994, the number of non−resident Jamaicans arriving in Montego Bay for the three latter years was removed. This specific number was not available; thus, it was estimated from national level statistics assuming that the proportion of non−resident stop−over arrivals to total stop−over arrivals was comparable. Source: Annual

Travel Statistics, Jamaica Tourist Board.

b Source: Annual Travel Statistics, Jamaica Tourist Board.

c Source: Annual Travel Statistics, Jamaica Tourist Board.

d Estimated by dividing the average number of bed−nights sold by the average length of stay and expressing this number as a proportion of the total number of stop−over arrivals in Montego Bay.

e Source: Annual Travel Statistics, Jamaica Tourist Board.

f Estimated by multiplying the total number of bed−nights sold in hotels by the average individual daily expenditure of stop−over tourists.

by type of expenditure. Table 5.7 shows the NPVs for the years 1985 through 1996 using the results from Table 5.5.

Due to the unavailability of capital cost information (land, buildings and equipment), the NPVs reported here represent a partial cycle analysis. It should also be noted that the estimated labor costs used in this analysis are the accounting costs of labor and not necessarily the opportunity cost. The extent of the available information did not allow for the reasonable estimation of the accounting labor cost components and the subsequent derivation of the opportunity costs. Given the large size of the tourism sector and the predominant use of relatively low−skilled labor, any discrepancies are not expected to be large.

Direct Local Use:
Near−shore Fishery

Historic systematic and reliable information on the size of the near−shore, artisanal fishery in Jamaica is not available (e.g., see survey by Sahney 1982). Regular records of the number of fishers and the method of fishing began when the Fisheries Division of the Government of Jamaica initiated a Registration of Fishermen Database in 1995. Economic information regarding fisheries in Jamaica is even more limited. Espeut (1992) and Espeut and Grant (1990) provide information, yet this information is not directly applicable to the near−shore fisheries in the Montego Bay area. Nicholson (1994) conducted a spring 1994continue

Table 5.3 Estimated total annual expenditures by cruise−ship passengers arriving in Montego Bay

Year	*Total Montego Bay cruise−ship arrivals* a	*Average length of stay*	*Average individual daily expenditures (current US$)* b	*Estimated total annual expenditure (current US$)* c
1985	72251	1.0	49	3.5×106
1986	93846	1.0	52	4.9×106
1987	77356	1.0	50	3.9×106
1988	92712	1.0	50	4.6×106
1989	97250	1.0	48	4.7×106
1990	70485	1.0	70	4.9×106
1991	136395	1.0	73	1.0×107
1992	221997	1.0	51	1.1×107

1993	181207	1.0	69	1.3×107
1994	154238	1.0	83	1.3×107
1995	193392	1.0	83	1.6×107
1996	200491	1.0	85	1.7×107
Average	**119475**	**1.0**	**n/a**	**n/a**

a Non−resident Jamaicans included in statistics from 1989 through 1996. Source: Annual Travel Statistics, Jamaica Tourist Board.

b Source: Annual Travel Statistics, Jamaica Tourist Board.

c Estimated by multiplying the total number of cruise−ship visitors by the average individual daily expenditure of stop−over tourists.

Table 5.4 Results of OAS (1994) analysis showing the net values as a percentage of total revenues for the main private sector tourist firms in Jamaica for 1992, and the reconciliation with the Jamaica Tourist Board categories

Type of business	*Net value as a percentage of total revenue*	Reconciliation with Jamaica Tourist Board categories	Net value percentage by Jamaica Tourist Board category
All−inclusive hotels	19.0	—	—
Other hotels	24.8	—	—
Guest houses, villas and apartments	18.9	—	—
Other accommodations	17.8	—	—
All accommodations	20.9	Accommodations	20.9
Restaurants and bars	13.4	Food and beverage	13.4
Tour operators	14.5	Entertainment	37.1
Recreation, attraction and sports	47.9	Entertainment	37.1
Taxis	3.1	Transportation	16.7
Car rentals	36.1	Transportation	16.7
Other transportation	17.7	Transportation	16.7
In−bond shopping	5.3	Shopping	5.3
Weighted average	**20.1**		

socio−economic survey of fishing activities in the Montego Bay Marine Park. This represents the only pre−existing source of economic information for this study. A rapid socio−economic assessment of the primary user groups of the Park also provided valuable information (Bunce and Gustavson 1998a; Chapter 11).

Typical of artisanal fisheries in Jamaica, there is an income share arrangement between the crews, captains, and owners of the boats. Understanding this share arrangement is critical to understanding the distribution of the economic benefits. The arrangement at White House and River Bay, the two largest landing beaches, typically involves 50% of the gross value of the catch or weight of the catch going to the owner of the boat to cover operating expenses, equipment maintenance expenses, and as a return for the capital investment. The remaining 50% is distributed equally among the captain and crew who operated the fishing vessel (the captain is also usually, but not always, the owner of the boat). As there are usually two individuals fishing from one boat, each captain and crew member take 25% of the catch. Where there are more than two fishers, the income is accordingly less (e.g., if there are two crew members and one captain, individuals take one third of 50% of the catch, or approximately 17%). This share arrangement, however, is varied at times. Owners may decrease the percentage share retained for the boat when the catches are low so that the crew receive higher incomes.

Estimates of revenues from fishing based on the number of fishing trips per week, average catches, average price of fish per pound, and the boat sharing arrangements are shown in Table 5.8. Of the methods of fishing for whichcontinue

Table 5.5 Annual net values (millions of current US$) for tourism in Montego Bay, 19851996

Year	*Annual net value derived from stop−over expenditures*	*Annual net value derived from cruise−ship passenger expenditures*	*Total tourism sector annual net value*
1985	18.3	0.704	19.0
1986	24.1	0.985	25.1
1987	26.1	0.784	26.9
1988	20.1	0.925	21.0
1989	22.1	0.945	23.0
1990	26.1	0.985	27.1
1991	24.1	2.010	26.1
1992	28.1	2.210	30.3
1993	30.2	2.610	32.8
1994	26.1	2.610	28.7
1995	28.1	3.220	31.3
1996	28.1	3.420	31.5

Table 5.6 Annual net values (millions of current US$) by sector category for tourism in Montego Bay for 1996

	Accom−modation	*Food and beverage*	*Enter−tainment*	*Trans−portation*	*Shopping*	*Miscel−laneous*	*Total tourism sector sector annual net value*
Stop−over visitors	17.73	0.88	5.82	1.50	0.73	2.05	28.70

Cruise−ship passengers	0.00	0.02	0.75	0.08	0.65	0.41	1.91
Total	**17.73**	**0.90**	**6.57**	**1.58**	**1.38**	**2.46**	**30.60**
% of total	**57.9**	**2.9**	**21.5**	**5.2**	**4.5**	**8.0**	**100**

Table 5.7 Net present values (millions of current US$) by year for tourism in Montego Bay, 19851996

Year	*i = 5%*	*i = 10%*	*i = 15%*
1985	380	190	127
1986	502	251	167
1987	538	269	179
1988	420	210	140
1989	460	230	153
1990	542	271	181
1991	522	261	174
1992	606	303	202
1993	656	328	219
1994	574	287	191
1995	626	313	209
1996	630	315	210

there is sufficient economic information, hand line, trap, net and spear fishing occur within Park waters. Using the 1995 statistics for the total number of fishers by fishing method by beach and applying them proportionately to the 1998 estimated total number of boats and fishers by landing beach, we can arrive at an estimate for the number of boats and fishers using Park waters (Table 5.9). We can then use these results to arrive at an estimate for the total number of "owners" (owners of boats for hand line, trap, and net fishing; sole operators for spear fishing).

Nicholson (1994) estimated that total operating costs for fishers (less labor payments) were between 11% and 34% of gross revenues. 25% was assumed here for the calculation of net operating values for all forms of fishing (indications from interviews with fishers during the field portion of the study supported this approximation). In other words, approximately 75% of the gross receipts for net, trap, hand line, and spear fishing can be assumed to be operating surplus less the deduction for the payment to labor.

In 1996, the average hourly wage for large establishments, all sectors for Jamaica as a whole was J$56 in 1996, equivalent to approximately J$92 in 1998 (source: Statistical Institute of Jamaica). Assuming a 40 hour work week (source: Statistical Institute of Jamaica), an average weekly wage in Jamaica is J$3670. To arrive at an estimate for the opportunity cost for labor, this average weekly wage is discounted by 25% to a final figure J$2750 per week per individual to reflect the value of the marginal product of labor. The opportunity cost of labor is then estimated to be J$5500 per boat for net, trap, hand line fishing (assuming an average of one captain and one crew member per boat), and J$2750 per spear fisher. These costs are deducted from gross fishing earnings along with the previously cited estimate of 25% of gross for operating expenses. The derivation of the overall net operating values are shown in Table 5.10.

Nicholson (1994) estimated the average value of the boat capital assets (including vessels and engines) to be on average J$58,000 (current 1994 dollars) per owner. This is approximately equivalent to J$156,000 in current 1998 dollars. The equivalent annual capital costs are thus J$7,800 for i = 0.05, J$15,600 for i = 0.10, and J$23,400 for i = 0.15 for each boat owner. These figures are then deducted from the annual net operating values for net, trap, and hand line fishing owners (but not for spear fishers) as shown in Table 5.10, yielding 1998 net annual values. Total deductions for annual capital cost equivalents are thus J$5.46×105 for i = 0.05, J$1.09×106 for i = 0.10, and J$1.64×106 for i = 0.15. The resulting net annual values are then converted to NPVs (Table 5.11). Note that the negative resource rents arise largely due to the opportunity costs of fishing labor, which can be greater than the actual accounting returns to labor.

Other Direct Local Uses

The other possibly significant direct use values which were explored for this project included the aquarium trade, mariculture, coral crafts, other crafts derived from marinecontinue

Table 5.8 Estimates of catches, gross incomes per boat, and individual incomes of fishers by method of fishing for early 1998

Method of fishing	*Number of outings per week*	*Approximate catch per outing (lbs)*	*Approximate weekly gross income per boat assuming J$100/lb* a (current J$)	*Approximate weekly individual income* b (current J$)
Troll	3 to 5	10 to 20	3000 to 10000	750 to 2500
Trap	1	10 to 20	1000 to 2000	250 to 500
Net	3 to 5	10 to 15	3000 to 7500	750 to 2250
Hand line	3 to 5	10 to 20	3000 to 10000	750 to 2500
Spear	5 to 7	10	5000 to 7000	5000 to 7000c

a In general, "table fish" (fish 1.5 lbs each and up) will sell for $J100 per lb, while "frying fish" (fish under 1.5 lbs) will sell for $J50 per lb. Species caught by trolling command specific prices: for example, $J100 per lb for dolphinfish, $J70 per lb for blue marlin, $J60 per lb for tuna (noted as one of the harder fish to sell), and $J100 per lb for kingfish. J$100 per lb was used for calculations assuming that higher value fish are caught.

b Weekly individual incomes per fishing activity were estimated as 25% of the approximate weekly gross incomes per boat. This assumes a typical sharing arrangement and an average of one captain and one crew member per boat.

c Spear fishing typically has no sharing arrangement, with relatively few expenses or required capital investments; thus, although their net will be less than the gross due to expenses, no adjustments were made to the gross incomes as reported on this table.

Table 5.9 Total number of fishers and boats by landing beach estimated to be fishing in Park waters in 1998 (Bunce and Gustavson 1998a; Registration of Fishermen Database, Fisheries Division, 1998)

Landing beach	*Number of boats*	*Number of fishers*
River Bay	51	161
White House	5	15
Bogue	1	8
Reading	8	23
Spring Gardens	5	8
Unregistered spear fishers	—	150
Total	**70**	**365**

materials, and coral sand extraction. In all cases, the benefits associated with these activities were found to be negligible during the final site application. The Natural Resources Conservation (Marine Parks) Regulations of June 5, 1992, proclaimed under the Natural Resources Conservation Authority Act of Jamaica, make it clear that a person shall not "destroy, injure, deface, move, dig, harmfully disturb or remove from a marine park any sand, gravel or minerals, corals, sea fans, shells, starfish or other marine invertebrates, seaweeds, grasses, or any soil, rock, artefacts, stones or other materials" (4.1.a; note that fishing is dealt with separately under the Regulations and is a permitable activity). Thus, the policy direction of the government and the management authorities is to prevent all forms of coral sand extraction or extraction of other marine materials for use in crafts.break

Table 5.10 Annual net operating values (current J$) by method of fishing for 1998

Method of fishing	*Weekly gross income*	*Total number of owners*	Weekly net operating value per owner	Total annual net operating value (without capital deduction)
Trap	1000 to 2000	13	4750 to 4000	3.21×106 to 2.70×106
Net	3000 to 7500	10	3250 to 125	1.69×106 to 6.50×104
Hand line	3000 to 10000	47	3250 to 2000	7.94×106 to 4.89×106
Spear	5000 to 7000	154	1000 to 2500	8.01×106 to 2.00×107
Total	**n/a**	**224**	**n/a**	**4.83×10** 6 to 2.23×107

Table 5.11 Net annual values and net present values for the fisheries of Montego Bay Marine Park, 1998 (brackets indicate midpoint of estimate)

	i = 5%	*i = 10%*	*i = 15%*
Net annual value (millions of current 1998 J$)	4.83 to 21.8 [8.5]	5.92 to 21.2 [7.6]	6.47 to 20.7 [7.1]
Net present value (NPV) (millions of current 1998 J$)	96.6 to 436 [170]	59.2 to 212 [76]	43.1 to 138 [47]
Net present value (NPV) (millions of constant 1996 J$)	59.0 to 266 [104]	36.1 to 129 [46.5]	26.3 to 84.2 [29.0]
Net present value (NPV) (millions of constant 1996 US$)	1.66 to 7.49 [2.92]	1.02 to 3.63 [1.31]	0.741 to 2.37 [0.815]

A minor, but ultimately indeterminate, amount of extraction of materials for crafts or direct sale through the informal economy is believed to occur illegally. This is reflected in the contingent valuation results (Chapter 6) in which one individual respondent out of 1,058 noted that one of the benefits derived by the Park was getting shells and stones for natural crafts. The selling of conch shells collected from Park waters is perhaps the most prevalent, yet likely a relatively minor problem. Park rangers actively enforce the "no take" regulations, stopping collectors as they are discovered (Malden Miller, Director of Montego Bay Marine Park, pers. comm. February 1998). Such items are not readily available for purchase in markets, at hotels, or other public areas in the immediate vicinity of the Park, but are readily available from road−side stands outside of Montego Bay.

Coral sand extraction is similarly illegal within the Montego Bay Marine Park boundaries. Sand is extracted from beaches and rivers throughout Jamaica for use in construction materials, primarily as a component of cement. No indications of sand extraction were found during the final site application, but Park authorities noted that there have been signs of some activity near River Bay in the past (Malden Miller, Director of Montego Bay Marine Park, pers. comm. February 1998). Nonetheless, as it is currently the law and policy of the managing authorities to prevent coral sand extraction from occurring, those benefits, believed to be small and unsustainable, may be negated for the purposes of this study.

Mariculture currently does not occur within Park boundaries. Authorities are not pursuing the establishment of mariculture, but would be open to considering the implementation of a program if approached with a serious and viable proposal (Malden Miller, Director of Montego Bay Marine Park, pers. comm. February 1998). The capture of fishes for sale on the aquarium market is also effectively non−existent. No individuals were known or identified during the final site application who participate incontinue

this activity. No other direct use activities of potential economic significance, not associated with either fisheries or recreation and tourism, were identified during the final site application.

Indirect Local Use:
Coastal Protection

This study considered the coastal protection that coral reefs afford as the sole indirect use value which can be quantified. Support of the offshore fisheries through ecological interactions may also be significant, but there are as yet no theoretical tools available to quantify the role of the coral reefs in offshore fisheries production. The literature which examines the biological contribution of coral reefs and the interactions with offshore fishes and pelagic production does not allow translation to quantifiable economic contributions. There are also indirect values associated with coral reefs theoretically linked as a component of natural historical event records; however, the investigation of this information function, while a potentially interesting academic exercise, is of low policy priority and thus not explored. Assimilation of wastes, pollution and discharge from anthropogenic sources is yet another potential indirect benefit, yet coral reefs are highly sensitive to nutrient and sediment inputs and as such these latter benefits are not considered to be *viable* or *sustainable* indirect uses to be considered in the local use model.

The value of coastal protection is estimated from the value of land that is vulnerable to erosion. Investigation into potential sources of information on land values proved that detailed information would not be forthcoming. Information on current land prices was solicited from various sources (Table 5.1). Relying on real estate market information for land value information is limited by the nature of the properties which are available on the market at the time of the survey, and thus for which there is information, and may not yield results representative of the entire region. Moreover, information is not available for many of the prime shoreline areas of the Montego Bay Marine Park.

The average shoreline value of land vulnerable to erosion within Montego Bay Marine Park was be estimated to be J$350 (US$9.86) per sq. ft. or J$15.2 million (US$0.428 million) per acre in early 1998. The NPV of the total amount of land at risk, based on approximately 250 acres being vulnerable to erosion, is thus US$107 million (1998 dollars) or about US$65 million in constant 1996 dollars. Using 250 acres as being vulnerable to erosion along the 21 miles of shoreline within the Montego Bay Marine Park assumes that approximately the first 100 feet of shoreline property are at risk of erosion should the protective function of the coral reefs be compromised.

The Capture of Value from Marine System Contributions to Economic Production

The NPVs reported for direct uses in this study represent what would typically be considered to be producer surplus or rent. In other words, it is the difference between the total business revenues taken in through the use of the coral reefs, and the total costs associated with operating the business or activity. Of great interest to the management authorities of the Montego Bay Marine Park, as well as to managers of any coastal marine system, is to capture at least a portion of this rent to pay for the necessary management, and potential enhancement, of the resource. In other words, there are social costs associated with conservation of the resource which should be paid by the users.

As a component of the study, current existing government charges which may capture a portion of the rent were explored. Currently, it is not the policy of the Montego Bay Marine Park to charge user fees (a recognized, explicit mechanism for rent capture), although at the time of publication the Park was in the early stages of beginning such a program. Other government charges which are specifically linked to either tourism or fisheries related activities may capture a portion of either producer or consumer surplus, but are not necessarily designed explicitly to do so. This includes business license fees, fisheries license fees, beach fees and tourist departures taxes. No other government or management agency fees or charges are specifically linked to either tourism or fisheries related activities in the area. Corporate profit taxes, or personal income tax in the case of the fishers or of individually distributed profits from tourism−related businesses, may also capture a portion of the rent. However, taxes are paid to the general collectorate and thus are not explicitly available for use in Park management. The extent to which taxes may capture tourism or fisheries rent is not explored further here.

Rent capture instruments are an effective means of aligning private costs with social costs, such that the operators "feel" the true costs associated with using the reefs. The collection of a fee allows management and government authorities to collect funds to pay for the resource management costs that they incur, as well as to help move toward an economically optimal level of use. The capture of rent is most effective if fees are tied to profits orcontinue net incomes (before interest and taxes) and, secondarily, to the level of use. The beach fee charges as currently set are minimal and, although they vary roughly according to the type of use, are not linked to varying levels of producer surplus. The current interest of the Montego Bay Marine Park in implementing user fees should be encouraged. An *independent* administration of a program of rent capture that ultimately varies at least according to the level of use and the type of business will help ensure that the funds are accessible by management authorities and don't disappear into the general government collectorate.

License Fees

In principle, license fees are collected to pay for the government costs of regulating and administering the business or activity. No information was available on the actual costs associated with regulating the reef−related activities, yet it is likely that in all cases these costs are not recovered based on existing fee schedules.

Tourism Related Business License Fees

The Jamaica Tourist Board receives business license fees from tourism related businesses, with the exception of accommodations. As of February 1998, this includes the following:

J$3000 (US$84.51) per operator per year for water sports, attractions, tour operators, and car rental companies;

J$100 (US$2.82) per operator per year for craft vendors; and,

J$4000 (US$112.68) per machine per year for gaming operations.

The accommodations license fee (the Hotel License Tax) is charged by the Inland Revenue Department of Jamaica and goes into the general collectorate. The fee schedule is based on the category of the accommodation (A, B, C, or D). This system is being phased out, but the premise on which it is based is being maintained—a schedule of fees that varies roughly in relation to the size of the accommodation's revenues. The more deluxe or expensive hotels are currently classified as A or B and are charged an annual fee of J$600 (US$16.90) per room per year. Less expensive forms of accommodation and villas are assessed a fee of J$300 (US$8.45) per room per year, while the least expensive accommodations pay J$150 (US$4.23) per room per year. No information was yet available as to how the fees will be assessed in the future, or how the room rates will translate to a particular accommodation's license fee that is charged.

Fisheries License Fee

There is no fishing license fee, although registrants must pay a one−time fee of J$150 (US$4.23) to cover the cost of the required identification card. The fee is collected by the Fisheries Division of the Ministry of Agriculture. As there are no other fishery−related businesses directly tied to the activity in Montego Bay (e.g., processors, packers, transport companies) and all fish sales are directly to the consumer (Bunce and Gustavson 1998a; Chapter 11), there are no other relevant government license fees or charges that may be considered to capture any rent from fishing.

Beach Fees

The Natural Resources Conservation Authority (NRCA) currently charges a "beach fee", which is a license fee charged under the Beach Control Act of Jamaica for use of the foreshore and the seafloor (usually to a point 25m seaward of the high water mark) for either commercial or private purposes. The Beach Control Act of 1956 established all rights of the foreshore and the floor of the sea to the Crown. Rights to the foreshore granted to private individuals before 1956, the date the Act was proclaimed, are maintained, along with rights by prescription granted to fishers (NRCA 1997, p.3 and p. 13). The law requires that a license be obtained ". . . for the use of the foreshore in connection with any commercial enterprise along the coast which involved the use of or encroachment on the foreshore and/or the floor of the sea and the overlying water" (NRCA 1997, p.5). Licenses are renewable on an annual basis and can grant either exclusive or non−exclusive use of the foreshore (the granting of exclusive licenses is no longer practiced, although existing exclusive licenses are renewable). Relevant sections of the fee schedule as stated in the amended Beach Control Authority Regulations (licensing), 1993, are shown in Table 5.12. Those not listed include various fees that are charged for encroachments on the foreshore or floor of the sea (e.g., breakwaters, pipelines, pools, buildings, fences, steps, platforms) and those associated with moorings.

The policy direction of the NRCA is for the use of these fees primarily for the ". . . rehabilitation of public bathing beaches and the monitoring of beaches generally" (NRCA 1997, p.24). It is also the position of the NRCA that current license fees are "trivial" relative to the profits generated by the use of the public resource. The authority is very conscious of finding ways to raise more revenue, particularly that associated with use of a public resource. The beach fee is a direct mechanism for rent capture; however, none of these funds are explicitly directed to pay for the management of the Montego Bay Marine Park.break

Table 5.12 Schedule of fees as stated in the amended Beach Control Authority Regulations (licensing), 1993 of Jamaica

Category	*Fee per operator per year (J$)*	*Fee per operator per year (US$)*
Hotels (100 rooms and over)	5,000	140.85
Hotels (under 100 rooms)	3,000	84.51
Guest houses (30 rooms and over)	2,000	56.34
Guest houses (under 30 rooms)	1,000	28.17
Commercial recreational beaches, public recreational beaches, proprietary and member clubs	3,000	84.51
Beach used exclusively in connection with a dwelling, house or building rented for recreational purposes	2,000	56.34
Commercial or industrial beaches (other than commercial recreational)	5,000	140.85
Fishing beach (10 or more boats or with a fish depot)	100	2.82
Fishing beach (less than 10 boats)	50	1.41
Beach reserved exclusively for the use of owners of lots in a subdivision	2,500	70.42
Beach reserved exclusively for the use of schools, churches, or other bodies or persons for charitable or educational purposes	100	2.82

Departure Tax

As of early 1998, all individuals departing Jamaica from either the airport or a cruise ship terminal are charged a departure tax of J$500 or US$15, depending on visitor preferred currency of payment (at the time of publication, this fee had increased to J$750 or US$20). As it relates to the use of the waters of the Montego Bay Marine Park, the departure tax as a charge to tourists captures at least a portion of the consumer surplus. In other words, the collected funds represents a portion of the amount that visitors would be willing to pay for their visit to Montego Bay (and for some visitors, other regions of Jamaica) above the amount that they actually had to pay. Resource rent captured by the tourism industry through the provision of reef−related services is not addressed by this fee mechanism.

Conclusions

In summary, this study has identified the following net present values associated with the use of the Montego Bay Park waters (for the most recent year that data was available):

US$210 million (using a 15% discount rate) to US$630 million (using a 5% discount rate) in 1996 associated with tourism;

US$1.66 million to US$7.49 million (constant 1996 dollars; using lower and upper estimate, respectively, of annual net values and a 5% discount rate; 10% and 15% discount rate estimates fall within this range) in 1998 associated with fishing; and,

US$65 million (constant 1996 dollars) in 1998 associated with the coastal protection function of the coral reefs.

As stated previously, one of the purposes of focusing on the most significant local use values associated with the coral reefs of the Montego Bay Marine Park is the added usefulness of providing a detailed benchmark to feed into subsequent modeling of the complete set of benefits and costs. This includes consideration of the results from the bioprospecting and contingent valuation components of the larger project to arrive at an overall coral reef benefit model (Chapter 9). The current values of the resources at risk reported here must be placed within the broader context of considering the complete set of true social costs and benefits when examining the economic efficiency of possible coral reef management interventions.break

Under the current open access Park management regime, one would predict that all rents would have dissipated—that the profits of operators would be zero. As outlined in this report, this is clearly not the case, although fishing rents are certainly minimal. The two most compelling explanations as to why there are still rents generated through the use of the Montego Bay Marine Park waters are that there are socio−cultural and expertise barriers to entry, and that the rents of the marginal or newer operators are zero due to the high costs associated with entry and lower marginal returns.

Fishing rents are most likely maintained through socio−cultural and expertise barriers. The results of Bunce and Gustavson (1998a; Chapter 11) indicate that fishing activities are associated with a particular socio−economic class and that fishers themselves do not become proficient at fishing until they have gained the necessary experience. Those outside of the fishing communities would likely find it difficult to fish profitably. It was even noted during interviews with Montego Bay fishers (Bunce and Gustavson 1998a; Chapter 11) that wealthier individuals not associated with the fishing communities will at times try fishing, but will soon cease operations due to low catches, being unfamiliar with how or where to fish. The experience gained by the older fishers seems largely to be passed on through persistent involvement in fishing and interaction within the fishing communities themselves.

Spear fishers, who enjoy the largest rents, are less tightly linked to the fishing communities, and thus might be expected to be subject to fewer socio−cultural barriers of entry. However, experience and the unfamiliarity of many Jamaicans with the marine environment would still factor largely into their level of fishing success, and even their willingness to begin fishing in the first place. The overall effectiveness of any barriers of entry into fishing, however, is not absolute. More individuals are fishing (especially spear fishing) as is evidence by the relatively recent and rapid increase in the number of fishers in Montego Bay (Bunce and Gustavson 1998a; Chapter 11). This increase in the number of fishers is expected to continue.

The persistence of rents associated with the tourism sector is most likely due largely to new entrants facing higher costs and receiving lower yields or returns. For example, interviews with water sports operators (Bunce and Gustavson 1998a; Chapter 11) indicated that for some tourist services, such as the independent party cruise and glass−bottom boat operations, the market seems to be saturated or even declining, reducing gross returns. Existing, reportedly more marginal operators even expressed a desire to get out of the business, some unable to do so due to an inability to liquidate their capital investments. In such a market, there would be little opportunity for new entrants as they would likely be faced with even lower marginal yields. Furthermore, for many tourism−related businesses, such as the hotel sector and the water sports operators, there are significant start−up costs and capital outlays necessary, further deterring new entrants.

It must be added that the analysis of NPVs presented here was not able to distinguish between different types of operations within the tourism sector, with the exception of the aggregated sectors of accommodations, food and beverage, entertainment, transportation, and shopping for the year 1996. Although there was an overall positive NPV associated with each, there may be dramatic differences between different types of operators within each category.

The existence of price distortions due to failures in the market may compromise the validity of the local use values reported here. The above analysis, if to be reflective of social values, assumes that competitive markets are operating—that is, that no one individual or group of individuals can affect the price at which a good or service is sold, and that the price revealed by the market is the social price. Competition can be compromised through the operation of monopolies or oligopolies, or through specific government interventions or policies. Problems associated with imperfectly competitive markets are predominant in developing countries. Under severe price distortions, shadow pricing should be used. In other words, true social prices or values should ideally be found by looking for indicators which reveal the extent of the distortion. The extent to which market prices accurately reflected social values could not be explored in this study, yet the final site application indicated that overall there was a great deal of open competition between and within user groups, both domestically and internationally. The extent of price distortions is not expected to be large enough to compromise the validity of the results reported here.break

Chapter 6—
Lexicographic Preferences and the Contingent Valuation of Coral Reef Biodiversity in Curaçao and Jamaica

Clive L Spash
Department of Land Economy, University of Cambridge, Cambridge, United Kingdom

Jasper D van der Werfften Bosch
Resource Analysis, Delft, The Netherlands

Susie Westmacott
Resource Analysis, Delft, The Netherlands

Jack Ruitenbeek
H.J. Ruitenbeek Resource Consulting Limited, Gabriola, BC, Canada

The contingent valuation method (CVM) is a stated preference method that directly surveys individuals to obtain their preferences rather than analyzing their actual behavior as revealed in the market place. In contrast to other methods for cost−benefit analysis (CBA), CVM has received considerable and increasing attention in the literature. The main advantage attracting this attention is the ability of CVM to estimate option, existence and bequest values in addition to direct use values.1 The travel cost method, production function analysis, and hedonic pricing are all restricted to assessing only the direct use values of the environment (Hanley and Spash 1993).

There are several stages involved in conducting a CVM study—designing and pre−testing the survey, carrying out the main survey, estimating willingness−to−pay (WTP) and/or willingness−to−accept (WTA), bid curve analysis, data aggregation, and final assessment. In making decisions at each stage of the studies' design and conduct, economists impose their implicit value judgments as to what seems appropriate. While the art of survey design may make CVM more controversial, similar judgments are required in the application of any CBA method. What CVM adds is the ability to probe motives and attitudes.

Issues in Survey Design

Practical CVM survey design must be carefully conducted with awareness of the need to make the trade−off being described both realistic and easy for the general public to understand. This is often a careful balancing act between depth and comprehensibility. Thus, for example, the lengthy technical discussions of ecologists about coral reef degradation have to be simplified to a set of stylised facts. In addition, the length of the survey must be controlled to achieve an administration time that maintains the average interviewee's attention.

The Design Process

The design of a CVM study includes the way information is presented to individuals, the order in which it is presented, the question format, and the amount and type of information presented. There is a wide body of evidence to suggest that survey design can affect responses. Survey design requires framing a realistic decision concerning the environment where the monetary question to be asked is accepted as a possible state of the world in which individual respondents might find themselves. Thus, the analyst must take several decisions, including acontinue

reason for the payment, how funds will be raised (i.e., the bid vehicle), and the arrangements for and regularity of payments. For example, Rowe *et al.* (1980) found that WTP to preserve landscape quality was higher when an income tax increase was suggested than when entry fees were used. The technique for bid elicitation may be an open−ended question (with or without a bidding card), a dichotomous choice, or a bidding game. Also, information on physical changes will need to be summarized and the method of their description chosen (e.g., text, graphics, maps).

Due to the sensitivity of responses to the information supplied, the pre−testing of the survey has become of increasing importance. This can be conducted via a small sample test run to see if respondents have problems and special sections can be included to pick out the occurrence of difficulties. A focus group is another method now in use for pre−testing. Generally, the pre−test will enable the identification of problems with regard to the framing of the decision problem, as well as divergence between encoding and decoding of information.

The conduct of the main survey can use several variations. The in−house interview is now most favored in developed country surveys, although the expense of this approach often means surveys are completed in the street, by telephone interviewing, or by mail. In the Caribbean, the difficulty of obtaining a representative sample via in−house interviews and obtaining a tourist sample meant the equivalent of "in−street" surveying was required (i.e., approaching people in the street, at shopping centers and on the beach) in addition to the developed country preference for in−house interviewing. While random samples are recommended, in practice a truly random sample is difficult to obtain. This is especially true in developing countries where large sections of the population may lack telephones or have no postal address. Again, sampling tourists can pose problems in terms of predefining and selecting a random sample. Even in developed countries, the sample is often based on a quota as it is less expensive (although a random element may be included, such as the random walk method).2 The sample is also often weighted in terms of the local or regional population, whichever is seen as politically more important to the decision and likely to have strong direct economic connections to the outcome.

Responses to the survey may include "protest bids", and these are often omitted from the mean WTP or WTA calculation without adequate reason. Protest bids are zero bids given for reasons other than a zero value being placed on the resource in question. For example, a respondent may refuse any amount of compensation for loss of an environmental asset, which they regard as unique, or a species that they feel should be protected at all costs. Respondents may refuse to state a WTP or WTA amount because they reject the survey as an institutional approach to the problem, or because they have an ethical objection to the trade−off being requested (e.g., a lexicographic preference; Spash and Hanley 1995). Another potential problem is the outlier who bids a very large amount and so has a strong influence on the mean. This should only be regarded as a problem when the bid is unlikely to occur because the individual lacks the income to pay (under WTP) or would actually accept a much lower amount (under WTA). In this case, the respondent would be acting strategically, thus creating a bias.

Analysis of the bid curve is used to test construct validity (i.e., that the socio−economic variables have the expected signs and the regression is statistically significant). Other relationships can also be investigated at this stage. In general, bid curve analysis has tended to be of academic rather than policy interest. However, this analysis can provide useful insights into the behavior of respondents and the determinants of their bids. In this chapter, such analysis is used to investigate the importance of ethical positioning.

Final reflection upon the CVM study can include convergent validity and success of repeatability where there exist other similar studies. The overall success of the exercise will also become apparent as the results are being analyzed (e.g., a high number of protest bids). There are several specific problems that are recognized as possible causes of bias, some of which have been mentioned (e.g., strategic bias, design bias). More problematic are the impacts of the information, as this is, by necessity, restricted but can have serious influence upon the resulting bids and the problem of embedding as raised by Kahneman and Knetsch (1992).

Information Provision

In a hypothetical market, respondents combine information provided to them regarding the good to be valued and how the market will work with information they already hold on that good. Either the hypothetical market or commodity−specific information given to them in the survey may influence their responses. This phenomenon implies that WTP and WTA values are endogenous to the valuation process. Thus, bids to preserve different animal species may vary significantly according to the information provided by researchers (Samples *et al.* 1986). Ajzen *et al.* (1996) concluded from experimental research that the nature of the information provided in CVM surveys cancontinue

profoundly affect WTP estimates and that subtle contextual cues can seriously bias these estimates under conditions where the good is of low personal relevance. However, Randall (1986) has argued that CVM answers should vary under different information sets, otherwise the technique would be insensitive to significant changes in commodity framing.

Indeed, the effects of information may be inappropriately labelled as bias, depending on the way in which WTP or WTA is changed. Information that improves the knowledge of an individual concerning the characteristics of a good can be regarded as informing a consumption decision. Information that alters the preferences is more problematic in the neo−classical framework and could be regarded as creating a bias. For example, Baron and Maxwell (1996) show that individuals' WTP can be biased by information on the cost of provision of public goods and suggest eliminating information from which costs could be inferred from CVM surveys so that respondents can focus more easily on benefits alone. While such redesign may avoid some types of bias, a more general issue, which remains, is how far individual preferences can be regarded as exogenous to the valuation process and, especially so, when goods are unfamiliar and/or never traded in a market.

Part−Whole Bias and Embedding

This problem arises when the component parts of an individual's valuation are evaluated separately and, when summed, found to exceed the valuation placed upon the whole. CVM studies have found part−whole bias, also termed embedding, and this has been attributed by some to valuation of the moral satisfaction from contributing to a worthy cause ("warm glow") rather than the good itself (Kahneman and Knetsch 1992). The counter reaction has been that CVM surveys finding embedding are flawed in some way that creates the part−whole bias and that this can be corrected by careful survey design (Carson and Mitchell 1993, 1995; Hanemann 1994). However, Bateman *et al.* (1997) have provided experimental evidence for the existence of part−whole bias for private goods outside of the CVM context. They therefore suggest that the problem lies with economic preference theory rather than the CVM approach.

Hypothetical Market Error

Valuations in a hypothetical market could make responses differ systematically from actual payments in actual markets. Random over and under statement would be a non−systematic error term and, therefore, would not represent a hypothetical bias (Mitchell and Carson 1989). In general, CVM studies avoid actual trade−offs, unless they are specifically testing for a hypothetical bias, and so the evidence on the impact of this bias is limited. A CVM study will be different from actual markets because there is no debate over the value of goods, no sequential learning from a series of purchasing decisions, and no enforcement of actual purchases. Thus, the extent to which hypothetical market bias occurs will be dependent upon how realistic the trade−off described is felt to be by respondents. Also relevant is whether the design has considered the type of incentives that might unintentionally be given to respondents.

WTP Versus WTA

WTA formats can generate more protest bids and outliers than WTP. Protest bids may occur because people are unwilling, on ethical grounds, to accept monetary compensation for the loss of an environmental asset (an implied loss of property rights). Outliers may be due to a rejection of the notion of compensation resulting in a large request for compensation based upon rejection of the implied trade−off, rather than an amount intended to represent their welfare loss.

Willig (1976) showed that these two welfare measures would be close if the ratio of consumer surplus to income was sufficiently small and if the income elasticity of demand for the good in question was sufficiently low. Where these conditions failed to hold, precise limits on the difference between the two measures could be calculated. While some criticized the applicability of Willig's findings to environmental benefits (Bockstael and McConnell 1980), others extended Willig's theorem to the quantity changes more commonly encountered in environmental valuation (Randall and Stoll 1980).

However, stated WTP has been found to be significantly lower than stated WTA (e.g., Hammack and Brown 1974; Rowe *et al.* 1980). In addition, experimental work has also found that WTA exceeded WTP (Gregory 1986;

Knetsch and Sinden 1984). Several reasons have been given as to why WTA may be greater than WTP. First, actual WTA is greater than actual WTP when loss aversion occurs. Individuals value a given reduction in entitlements more highly than an equivalent increase in entitlements (Knetsch 1989). Second, income constrains WTP bids, unless limitless borrowing is possible, whereas WTA bids are unconstrained, making bounded trade−offs hard to enforce. Third, the availability of substitutes provides theoretical evidence for a difference. If private goodscontinue

are poor substitutes for public goods, then WTA can be greater than WTP (Hanemann 1991). A public good with few private goods as substitutes will be valued differently because under WTP the loss of public good is prevented, while under WTA the private goods are meant to provide compensation and the public good is lost. Fourth, risk−averse consumers find they have only one chance to value the good under the typical CVM and will tend to overstate WTA and understate WTP. They do so due to uncertainty concerning the value of the good and in order to avoid a potential loss (Hoehn and Randall 1987).

On practical grounds, the status quo reference position is preferable in terms of the property rights structure. If an alternative is imposed by the blanket imposition of WTP formats in all CVM surveys, the result can be to create an unrealistic trade−off, hypothetical market bias and protest bids. Thus, rather than follow a generic prescription to always use WTP formats as a conservative estimate of values, the property rights prevalent in a given situation should be used as guidance. This reinforces the theoretical argument for using WTA to measure a loss and WTP for a gain (Knetsch 1994).

Dichotomous Choice Versus Open−Ended Formats

The dichotomous choice format has been recommended because those supporting the approach regard a one−off yes or no decision as closer to a free market. This is debatable in itself with the yes or no decision being closer to a political referendum. There should be some concern for the rejection of such an approach in countries where prices are often discussed and argued about rather than given as fixed. Also, to bind the range of choices when conducting dichotomous choice, an open−ended CVM is required as a first step. This means that those advocating dichotomous choice must defend the open−ended CVM. Neither format is clearly superior on *a priori* grounds. However, the dichotomous choice format does suffer problems in practice. The "yea−saying" problem may be evidence of an anchoring bias and has raised questions as to the usefulness of the format. Desvouges *et al.* (1993) found dichotomous choice exceeded the open−ended format and had greater variability. The results are sensitive to the choice of bids by the analyst, and the choice of functional form for mean estimation adds to variability in results.

The NOAA Panel:
A Comment on Generalized Guidelines

As the use of CVM has increased, so has the debate between supporters and detractors. Sagoff (1996) has critically attacked CVM and, in particular, what he terms the "Wyoming experiment" of the late 1970s and early 1980s. He sees the technique as economist venturing into the political realm, which he regards as totally separate. Applications to Kakadu National Park in Australia and the assessment of damages arising from the Exxon Valdez oil spill in Alaska created public controversy. In the Exxon case, one result was the suggestion that a specific set of guidelines for conducting a CVM should be followed.

A panel of experts was convened by the National Oceanic and Atmospheric Administration (NOAA) to fight pressure from Exxon coming via the Bush administration. The panel, which included Kenneth Arrow (Exxon consultant) and Robert Solow (State of Alaska consultant), gave qualified support for CVM. They produced guidelines which suggest there is one correct approach to conducting a "good" CVM study (i.e., methodologically similar to Cummings *et al.* 1986). Blind adoption of the NOAA guidelines has become a defense of the validity of specific work, although this ignores the variation in case study circumstances, such as whether property rights prescribe a WTP or WTA approach. In addition, merely quoting the use of NOAA guidelines seems inadequate defense and some regard for independent testing of the validity and applicability of both these guidelines and CVM results is required.

The extent to which CVM can be generalized is easily overstated. According to Cummings *et al.* (1986), CVM works best in only a limited range of circumstances. The most important rules are that respondents understand and be familiar with the commodity to be valued; that respondents have prior valuation and choice experience with respect to the commodity; that uncertainty about the operation of the hypothetical market is low; and that WTP is used in preference to WTA. However, the quantitative results of violating these conditions remain largely unspecified.

The NOAA panel guidelines include the use of WTP; in−house interviews on a random sample; full information on the resource change (including information on substitutes) and checks for understanding; closed−ended referendum formats (dichotomous choice); reinforcing budget restrictions; and careful pre−testing. They have also recommended reducing any resulting valuation, which raises questions over the derivation and credibility of this particular set of rules. In this regard, those using the guidelines should remember that the NOAA panel was politically appointed to adjudicate over the use of CVM in the USA as a result of the Exxon Valdez accident. The procedure for deriving the guidelines, with a Nobel laureate from each of the opposing camps on the panel, wouldcontinue

be interesting to discover, along with the underlying justification for some of these rules.

A more general problem is the extent to which any one set of rules can dictate CVM research. The NOAA guidelines have not resolved the debate around CVM because they assume a technical solution regardless of the problem at hand. The rules try to impose a set behavioral model upon individuals (economic rationality) and reject divergent behavior (e.g., see the discussion of part−whole bias in Bateman *et al.* 1997). However, there can be general guidelines as to good practice rather than set formats for an idealised CVM survey that is universally applicable. Regard to bias problems, appropriate testing and conduct of the survey, and learning from past experience are obvious steps to adopt.

Designing the CVM for the Coral Reef Case Studies

Two separate CMV surveys were designed—one survey for Jamaica and one for Curaçao. The main difference between the surveys, besides geographical and institutional context, arose in the development of the biodiversity improvement scenarios and management options to achieve them. The Jamaican survey was designed and tested first and this informed the Curaçao survey, but feedback on the Curaçao experience was also possible before either of the final surveys. This resulted in some simplification of the information presented and the development of show−cards that could be used in either country.

Developing the Information Pack

The term "information pack" is used to summarize reference to all the descriptive materials included in a CVM survey to convey information about the environmental changes. Maps were sought to show the islands, the reefs by quality, mangroves, endangered or rare species, and main source points of pollution. This was to inform respondents as to the current areas of interest in terms of marine biodiversity, the threats to biodiversity, and the context for the proposed project. In addition, the area covered by the case study needed to be described along with some detail on what it would be protecting.

The final surveys included colour maps, descriptions to be read aloud by the interviewer, and show−cards for the interviewee to study. For each survey area, two maps were used. One showed the whole island and explained the location of the proposed project (i.e., the park) and identified other coral and marine resources (i.e., reefs, seagrass beds and mangroves), and, for Curaçao, the location of the endangered sea turtle. The second map detailed the use zones proposed within the parks themselves (e.g., recreation, fishing, multiple use, and shipping).

Institutional and Environmental Setting in Jamaica

For Montego Bay, Jamaica, background information was gained from available documents which allowed a characterisation of both the environmental quality and the institutional setting. The aim was to find a realistic scenario in which to describe a reason why the general public might need to pay for biodiversity improvement. The choice of an institutional setting was interconnected with the environmental problem that would be selected. There appeared to be several anthropogenic causes of reef damage that could be used in a CVM approach:

1. *Overfishing* . A policy would need to be presented which gave an institutional setting under which over−fishing would be reduced. This would need to be combined with knowledge of the system of regulation to assess whether a realistic reason for asking the general public to contribute to such a scheme was feasible. Problems with this approach were the institutional setting, fishing being related to use values creating confusion when separating non−use values, and the difficulty of blaming one cause for marine biodiversity losses.

2. *Mining the reef* . This is an extreme scenario where the entire reef is lost. The difficulty was that the total value, rather than marginal quality change, in the reef in its present state would be estimated. The problems were the hypothetical nature (i.e., the creation of a problem which did not exist), the high probability of protests, and the failure to relate to the current institutional setting. In addition, WTA compensation as the appropriate measure of welfare loss would add another aspect of experimentation to the study.

3. *Waste treatment plant* . The need to improve water quality was the focus here. Problems arose in that many individuals were probably not connected to sewage systems and so would have no obvious payment mechanism. These individuals might resent paying for others' externalities. The institutional setting in terms of who pays and who benefits from wastewater treatment would have needed clarification. In addition, the extent to which the issue would be connected to coral reefs rather than human health was unclear and separating out the effects could be difficult.

4. *Trust fund for restoration* . This was realistic and could be given an institutional setting within the Montego Bay Marine Park. A range of management options for restoration could be outlined and their expected consequences described. Thus, the CVM survey wouldcontinue

outline expected biodiversity benefits related to Park provision. No one issue was needed as a cause to be blamed for reef decline; rather, a range of causes could be identified. There were no obvious problems with this option. However, the credibility of the trust fund was identified as a potential problem because it would be dependent upon whether, for example, the government or a non−government organization (NGO) was seen as most trustworthy to manage such funds. Similar funds in existence in Jamaica (e.g., Portland Environment Protection Association) implied this would be unproblematic.

The Montego Bay Marine Park (MBMP), which had already formed a point of interest in reef management, immediately had the advantages of an actual institution with a record of marine ecosystem management and provided a realistic context within which a WTP scenario could be developed.

Institutional and Environmental Setting in Curaçao

The best options raised for Curaçao were either: i) a trust fund to protect marine biodiversity to be used for the establishment and maintenance of a marine park along the south coast; or, ii) the improvement of the existing underwater park. The present underwater park, at the eastern end of the island, was deemed to be more substantive on paper than in fact. The site borders private property, effectively restricting access. Dive operators in the vicinity and the ecological institute (Carmabi/Stinapa) are the main users of the area. The limits on site access and the proximity of private property raised the following issues:

The site might be seen as private property rather than a public good;

Familiarity would be low;

Use would be restricted, which would limit the survey more to indirect benefits; and,

The possibilities for biodiversity improvement appeared limited.

At the time this project was being established (early 1997), a plan for a marine park along the whole south coast of Curaçao was developed by the agency responsible for the management of national parks (Stinapa). Thus, the best option was to base the CVM survey on this new plan. A major advantage was adopting an actual project proposal with an expected range of biodiversity improvements.

Information on the current state of Curaçao reef systems was gathered. There are very few mangrove areas and these are mainly surrounding inland lagoons. The main endangered or rare species identified were sea turtles, which have nesting grounds in one area of the islands. The main sources of pollution were industrial, primarily around the Willemstad refinery and the town itself. The main threat of physical damage was through the construction of artificial beaches. In terms of development, new tourist and population centers in the west and east were seen as potential threats.

Describing Marine Biodiversity

Biodiversity is a difficult concept to explain quickly and simply. Previous experience has shown the very term is often poorly understood by the general public and even among sub−groups with high education levels (Spash and Hanley 1995). However, people are quite often familiar with the ideas that lie behind the concept and these need to be brought out before any WTP questioning. The survey downplayed academic wording while portraying the same information.

Defining and Describing the Coral Quality Change

A major concern in designing the CVM survey was the characterisation of the environmental change and its cause and impacts on biodiversity. There was a period of consultation with marine biologists, ecologists and conservationists familiar with the sites and biodiversity degradation of coral reefs in general. Experts advised on the characterisation of the problem for the survey. On this basis, the Jamaican pre−test tried to explain the concept of coral reef abundance. Coral reef abundance was felt to be the best approximation to a measure of coral reef species diversity and health. The description of coral reef degradation and improvement in the WTP preamble and question was in terms of percentages from a maximum (100%). The general public was able to comprehend the idea of percentage changes from a hypothetical maximum without going into the detailed scientific reasoning. The aim was, therefore, limited to describing the environmental trade−off and the benefits from the proposed project.

The Benefit Payment Scenario

In order to design a payment scenario, the project being paid for must be described in enough detail to allow respondents to understand the net benefits. This requires an understanding of the current environmental status quo and the institutional context. The overall aim must be a realistic, if hypothetical, proposal. As explained above, environmental quality within the proposed parks was characterized to give a background picture.

In order to achieve a stated improvement in marine biodiversity, a set of management actions needs to becontinue

described. This requires some knowledge of the powers and jurisdictions of institutions so that management options attributed to the manager of the trust fund are realistic. For example, such things as tourist development projects and designation and enforcement of shipping lanes may be regarded as outside park management's jurisdiction.

The reduction of the nutrient and sediment loading onto the reef was seen as the main problem. This could be achieved through sewage treatment and industrial pollution control. However, a marine park is more likely to be involved in monitoring to determine whether such standards are being met and the occurrence of physical damage (e.g., due to anchors from fishing and diving boats). In these cases, the park is unlikely to be actually installing or running mitigating measures. However, the enforcement of the measures and provision of data and information to ensure the measures are enforced could be within park jurisdiction. The management options selected as examples for the survey were, in the end, found to be common to both the South Coast Marine Park in Curaçao and the Montego Bay Marine Park in Jamaica. These were:

Planting mangroves and coastal plants to reduce impacts from run−off;

Establishing monitoring of water quality, fish, plant life and mangroves;

Establishing mooring buoys for fishers;

Enforcing and patrolling use zones; and,

Enforcing fishing regulations.

Several other possible management strategies were dropped as being outside of the jurisdiction of the parks:

Treatment of sewage;

New drainage systems for storm waters;

Encouraging proper disposal of chemicals, garbage and other waste to improve water quality;

Promoting higher industrial effluent treatment; and,

Limiting inshore dumping by ships.

The current state of the reef system to be included in the park must be given and the expected improvements detailed. Knowledge of the existing situation can be used as the "business as usual" scenario and predictions made about the quality of the environment at some point in the future. This is then compared to the situation at that time with environmental measures in place.

In terms of environmental changes, the "business as usual" scenario is given by the current policy. The CVM survey could use the characterisation of reef quality to imply either stability of the reef system or, more realistically, degradation by a given percentage over a given period of years. The parks would then be described in terms of a "policy on" situation where degradation is avoided or coral abundance is increased. Thus, the management aim could be to either improve reef biodiversity or prevent biodiversity reductions and reef deterioration that would otherwise occur. In the survey, a mixed approach was felt to be most realistic. That is, the current situation of the coral reefs was estimated to be one of deterioration, but in both countries institutions had been identified which were working on reef maintenance. This allowed the current situation to be described as one in which the reef would deteriorate without any action, but that some action was already ongoing. This ongoing management would then allow the reef quality to be maintained at present levels, which had been characterized as degraded. The proposed project for which individuals would be asked to pay would increase the coral abundance from this level. The two scenarios were both for a 25% improvement.

Survey Sections and Questions

The layout for the CVM survey used here has been developed over several years. The design makes use of individual sections to separate a group of issues. In this instance, five main sections were included:

1. *Framing and background information* . The public policy context is described in terms of related issues that are of concern. That is, by a series of questions, the interviewees are made aware of a range of issues among which the environment is but one. They are asked to think about and reflect upon their own priorities. This also helps reinforce the concept of society having limited resources and there being a set of possible public policy issues requiring attention. The idea of framing is to place the problem of coral reef degradation within a broader context. Thus, the questions move from a very general level, with no mention of the environment, to environmental issues and the specific case study sites. Failure to frame the issues may be regarded as promoting one specific issue without any context and has been cited as a cause of embedding problems. Besides being concerned with framing the issue, this first section also gathers background information on the interviewees' knowledge of the site and provides information. The site information is given via maps and a short description. This aims to give all respondents a basic level of knowledge about the area and places it within a geographical context. Such information also acts as another framing device by showing other areas of coral reef and environmental habitat that may be regarded as substitutes. Background information on the interviewees' knowledge and use of the area is also gathered at thiscontinue

stage. By the end, the context has been set and the interviewee has had to think about the coral reef case study area, their knowledge of the site, the benefits they gain from the coral reef, and their knowledge of biodiversity and, in particular, marine biodiversity.

2. *WTP into the trust fund* . The information forming the background to the WTP question has been described above. The scenario is to improve coral reef biodiversity by 25% given a set of management strategies to be adopted by a marine park. The park will have a trust fund set up explicitly for the purpose. Payment could have been on several bases, but a per annum payment for five years was felt to be reasonably realistic. Beyond five years, people are unlikely to regard actual payment as likely. The main alternative would have been to request a one−time payment and then try to estimate the time period or interest rate over which this might represent a discounted present value. This introduces unnecessary complications and, therefore, the per annum five−year payment mechanism was employed. The bid question was open−ended. Following the bid question, respondents were asked to explain the reason for their response. Tourists claiming no spare income had been noted to be an unusual group in the pre−test for Jamaica and interviewers were directed to probe these respondents. Probing was also requested in the case of those making extremely high bids. A coding table was developed for the zero bidders from the pre−tests. A separate question explores the embedding problem. The approach was to ask respondents whether they would increase their bid if a greater reef area were to be included in the project. Respondents should

be prepared to do so unless they place no value on other reef systems. If they state that their bid was to cover all reefs, then a case of embedding has occurred. Subsequent questions probe indirect use values. Respondents are reminded of the uses they make of the area and the expected direct benefits of the project for them. Once the respondents are thinking of the uses they are asked to imagine leaving the island never to return. They are then asked whether this would lead to a reduction in their WTP and, if so, by what percentage. In the pre−test, a few respondents actually increased their bid despite being told their circumstances would be the same. In the final survey, the interviewer was requested to probe such respondents for their reasoning. Next, payment by volunteering hours was requested. This allows the unemployed and those on a low income to contribute to the project. In developing economies, payment by hours may be seen as more practical for many. The respondents were asked to make a commitment over five years, the same period as for the WTP question. The final question in this section was on the impact of information on the individual's preferences. The concern here was to see if the survey was informing the respondent, forming their preferences on coral reef degradation, or both.

3. *Rights and responsibilities* . This section had four questions. The first question splits the sample by the degree to which they attribute the right to be free from harm to five categories of potentially morally considerable groups. The five groups were: i) other humans now living; ii) future generations; iii) marine animals; iv) marine plants; and, v) marine ecosystems. Rights were attributed using a three−point scale with each point being associated with a position. The three positions can be summarized as: i) rights apply absolutely; ii) rights depend upon the circumstances; and, iii) no rights apply. Respondents could also answer "don't know". Those who responded by attributing a right under any category were then probed regarding their readiness to make trade−offs that might occur by the claimed attribution of a right. Thus, within the context of the park, the respondent was asked to agree or disagree with a personal responsibility to prevent harm regardless of the cost. They were then further probed to consider their answer. Those claiming such a responsibility were asked to reconsider if the cost was their current standard of living. Those rejecting the responsibility were asked to reconsider if their current standard of living was maintained. The final question asked how the individual thought the rights they had identified for the park should be protected.

4. *Socio−economics* . The collection of socio−economic data allows population statistics to be calculated and aids bid curve analysis. A set of standard questions was included to cover gender, age, education, and income. In addition, occupation was requested as a check on income and a few experimental variables added, namely dietary preference and religion.

5. *Interviewer response* . The interviewer was asked to give some feedback. The first question was whether others had been listening while the survey was conducted as this can lead to respondents saying what they think others want to hear and being reticent about their own beliefs. Next, the interviewer was asked to rank the difficulty the respondent had in answering each section. Finally, they were requested to note any specific questions that were found to create a problem for the respondent.

Pre−test Results and Survey Redesign

The survey was designed to derive estimates of non−use biodiversity values and test for the importance of a refusal to make trade−offs of money for environmental quality (i.e., the occurrence of lexicographic preferences). The survey for Curaçao was adapted from the Jamaican case study. This survey was pre−tested and updated prior to the survey being applied in Curaçao. Although the survey had already been pre−tested in Jamaica, the redesigncontinue

and new cultural and geographic context meant a pre−test was also recommended for the Curaçao case study. Thus, survey pre−tests were conducted in both Jamaica and Curaçao.

The pre−test survey is a crucial stage in the development of a CVM survey and requires sampling the population from which the main test sample will be drawn. Typically, a pre−test is performed on 100 to 150 people with qualitative feedback being the central aim, rather than attempting to gain quantitative results. The aim of pre−testing is to identify any areas where the survey may be misinterpreted, where questions produce unexpected results, and, more generally, to identify areas requiring improvement. For example, misinterpretation can occur due to the use of excessively technical language in the description of environmental quality changes and probing a sample of the general public can make the analyst aware of divergence from the common use of language.

Both the interviewer and interviewee are important sources of feedback during the pre−test. Where survey design requires optional sections, the interviewers must be able to understand the sequencing of questions they are to relay. The CVM surveys used here required the design of questions to probe sub−samples and, therefore, were reasonably complicated and care was taken to redesign the format in light of interviewer comments. The pre−test was also a learning experience for the survey coordinators who were responsible for training the interviewers. This allowed the coordinators to revise the method of training and improve on the selection procedure for interviewers. In countries where market research companies, who are practiced in such matters, are unavailable, selection and training of the domestic coordinators takes on specific importance.

The results of the pre−test were used to make several improvements prior to the implementation of the main survey. Among the lessons for survey coordinators, which as mentioned above may be particularly relevant in the context of developing countries, are the following:

Use older, more mature individuals able to understand the local language and probe the respondent when necessary;

Increase the level of in−depth individual training of the interviewers;

Increase the intensity and quantity of feedback given to the interviewers after surveys have been completed;

Carry out the surveying over a longer period of time to allow quality control after a batch of surveys have been completed;

Keep a close record of what each interviewer has received and done; and,

Feedback the survey quota results to the interviewers to keep them informed.

In Curaçao, the survey required re−translation in selected areas. Changes were also made to the original translation in order to maintain direct comparability across different language versions. The administrators in each country selected and trained a set of interviewers (i.e., conducted sessions on familiarisation with the survey and an assessment of the interviewer as a competent but neutral purveyor of the survey information and questions). In addition, close quality control was undertaken to ensure at least 1,000 completed surveys were collected. The outcome was 1,152 surveys in Curaçao and 1,058 in Jamaica.

Detailed results of the main surveys for Jamaica and Curaçao (i.e., population sample statistics and data results for specific sections of the questionnaires) can be found in Spash *et al.* (1998). The remainder of this chapter will be concerned with the analysis of the WTP data and lexicographic preferences.

Lexicographic Preferences and WTP

One major difficulty with using CVM in the context of coral reef biodiversity is related to the existence of "lexicographic preferences". Stated simply, lexicographic preferences exist where decision−makers are unwilling to accept any trade−offs for the loss of a good or service. The literature demonstrates that, where such preferences are prevalent, CVM techniques are methodologically flawed. The first step of an applied CVM procedure should, therefore, be to determine the potential extent of such preferences. Recent work suggests that lexicographic preferences for biodiversity are exceedingly widespread in developed countries and that, moreover, the actual "definition" or "understanding" of biodiversity differs significantly among respondents. Under such conditions, the use of CVM techniques is questionable. Thus, this research tries to address the question of how to adapt CVM and test for refusal to make trade−offs in the context of coral reef valuation, taking account of possible lexicographic preferences.

Monetary valuation of the environment requires the definition of commodities in a way fundamentally identical to marketed goods and services. That is, when an environmental improvement occurs, an individual must give up some consumption of other commodities to maintain a constant utility level. This gives an individual's WTP amount, which can then be summed across all affected individuals to obtain an aggregate WTP figure. Similarly, the minimumcontinue

quantity of other commodities demanded to accept a reduction in environmental quality is the WTA compensation. In this case, expenditure on other goods must be increased to compensate for the reduction in environmental quality, so maintaining the individual's initial level of welfare. Whether the other commodities are regarded in terms of a single numerate (i.e., money) or remain as a diverse set of goods and services is inconsequential.

The essential message of the normal indifference curve is that individuals are able to swap one bundle for another and can do so for a set of bundles without affecting their welfare level. As mentioned, a problem arises if, for example, an individual believes that aspects of the environment have to be protected without regard to the cost in terms of other commodities. That individual will refuse all money or commodity trade−offs that decrease what is regarded as an environmental commodity in the neo−classical framework. In theory, WTP to prevent the loss would be all the available commodities the individual could command (i.e., their income) and WTA compensation would be infinite. The respondent believes the aspect of the environment in question should remain at or above its current level in terms of either quantity or quality.

Such preferences mean that utility functions, including environmental aspects that are to be protected at all cost, are undefined for an individual (since the axiom of continuity is violated) and that indifference curves collapse to single points (denying the principle of gross substitution). These preferences are termed lexicographic by neo−classical economics because they give absolute priority to one commodity over all others and, therefore, imply a strict ordering as in a lexicon. The position described is, however, best regarded as extreme because its implications for the individual are total sacrifice for the environmental aspect to be protected (e.g., coral reef biodiversity). Economists have tended to regard the denial of continuity and violation of gross substitution as of little relevance because lexicographic preferences are unrealistic and unlikely to occur (Malinvaud 1972, p.20).

The extreme lexicographic position does indeed seem likely to be uncommon because of this overriding ranking of a good above even the individual's own life. The modified lexicographic position might be drawn−up in terms of first attaining a minimum standard of living prior to being prepared to defend the environment. Following Pigou (1920, p.759) this minimum might include, but not be restricted to, a defined quantity and quality of housing, medical care, education, food, leisure, sanitation and safety at work. Sen (1988), appealing back to notions of Adam Smith, goes further and defines functionings (the various living conditions we can achieve) and capabilities (our ability to achieve them) as essential parts of living standards rather than commodities. Such a living standard might be relatively materialistic in societies where being a functional member of society is defined in such terms (e.g., requiring ownership of a car and a television). As Sen (1988, p.17) states: "The same capability of being able to appear in public without shame has variable demands on commodities and wealth, depending on the nature of the society in which one lives". In this formulation, the concept of lexicographic preferences becomes more readily acceptable, but the definition for empirical purposes becomes far more difficult because the minimum living standard is expected to differ among social groupings.

Rights and Lexicographic Preferences

Lexicographic preferences are signified by a discontinuity in the preference function giving a single point, or bundle of goods, as the indifference set in goods space. The aim of the surveys reported here was first to identify the occurrence of such preferences and then see how far these might be indicative of a refusal to make trade−offs. This was achieved by direct questions on ethical beliefs that signify behavior incompatible with a continuous preference function, follow−up questions and consistency checks. The approach to dealing with lexicographic preferences taken here was based upon previous work (Spash 1993b, 1997, 1998c; Spash and Hanley 1995). The general approach to lexicographic preferences is reviewed next in light of the few key studies previously conducted.

The dominant economic theory of decision−making requires a fundamental philosophical assumption—namely, that individuals believe the net utility from the consequences of an action determines whether that action is right or wrong. Cost−benefit analysis and its tools, such as CVM, assume that individuals are able and willing to consider trade−offs in relation to the quantity and/or quality of public goods. Debates in environmental ethics have raised the issue of individuals refusing to make these judgments and so raised serious problems for the application of economic efficiency arguments (Sagoff 1988; Spash 1993a, 1994). One aspect of refusal can be a basis of belief in inviolable rights so that actions are intrinsically of value or deontological.

Neo−classical economists reject the notion of deontology because there is an assumed rationality attributed to the ability to make trade−offs, whatever the commodity, as long as enough compensation is offered in return. This can be summarized by the old colloquialism that everybody has his or her price. However, some individualscontinue

may treat certain aspects of the environment differently from the manner suggested by this theoretical framework. If an individual believes that aspects of the environment, such as wildlife, have an absolute right to be protected, then that individual will refuse all money trade−offs that degrade what is regarded as an environmental commodity in the neo−classical framework. Thus, the prevalence of the deontological position seems likely to be high among those who claim absolute rights to life for humans and other animals, future generations, trees or ecosystems. In contingent valuation, evidence exists in developed countries to suggest individuals express lexicographic preferences for wildlife (Stevens *et al* . 1991) and these relate to rights for animals, plants and ecosystems (Spash and Hanley 1995).

The Coral Reef Survey Results

Previous work on lexicographic preferences has relied upon a statement of belief in a position without consistency checks or developing a series of probing questions. In the current study, the survey instrument was designed to accommodate the presence of lexicographic preferences and to probe those claiming such a position more fully. This approach allows for the adjustment of a CVM survey instrument to detect the presence and extent of such preferences in the surveyed population, and also allows for the inclusion of variables reflecting those preferences for use in bid curve analysis. The methodology used had not been previously tested in a developing country context. Thus, among the results, the comparison between the tourist and local sub−samples is of interest as a reflection of the relationship between contexts and preferences and, in turn, their relationship to stated WTP.

The method used in the surveys takes a rights−based ethical position as signifying an ethical stance compatible with the lexicographic preference hypothesis. In the survey, respondents were asked to state the extent to which they saw rights as relevant to present and future generations of humans, marine animals, plants and ecosystems. These general attributions of rights were then probed further in the context of the marine park in question because a general discontent with trade−offs may disappear upon the specification of circumstances. Beyond this, respondents were asked to reflect upon the extent to which their refusal to trade was absolute by considering a potential conflict with their own standard of living. This allowed some refinement in the definition of various positions being adopted by the respondents and their stated acceptance of a position compatible with lexicographic preferences.

More specifically, respondents were initially asked to use the following categories in attributing or denying rights: an absolute right to be protected from harm applies to this case; a right applies that depends upon the circumstances and may, therefore, be withdrawn under certain conditions; or, no such rights to protection from harm applies to this case. The case where they had to decide which of these categories applied were: i) other humans now living; ii) future human generations; iii) marine animals; iv) marine plants; and, v) marine ecosystems. Respondents could answer that they just did not know, but only 0.2% in Jamaica and 2.1% in Curaçao found this necessary. Table 6.1 shows that almost all the sample are prepared to attribute rights to the first of these categories and that, for Curaçao, this declines moving from i) to v), while, for Jamaica, no decline occurs. More than just attributing rights, the respondents in the majority of cases are attributing an absolute right to protection from harm. Marine animals, plants and ecosystems are attributed these absolute rights by approximately 60% of the Curaçao sample and over 80% of the Jamaican sample.

People may fail to consider whether they are actually prepared to defend this position by making choices in their daily lives. Also, in over 60% of the cases, other people were listening while the interview was being conducted, which might stimulate a social norm. In order to address this issue, those who attributed a right to any of the five categories above were then asked a set of follow−up questions.

The follow−up questions were design to introduce the potential for needing to make trade−offs and to confront the respondent with a reasonably extreme case. The question was also made more specific and related to the marine park in question in order to give the rights−based position a context linked to the WTP questions. The respondents who had attributed any rights to one of the five categories were therefore initially asked whether, in the case of the relevant marine park, they believed the rights they had attributed meant a personal responsibility to prevent harm regardless of the cost. This is equivalent to reflecting that a duty for an individual would result from enforcing a right. The result was approximately 79% of the Jamaican and 68% of the Curaçao respondents answered affirmatively.

Next, respondents were channeled into two separate questions. Those affirming that they have a personal responsibility regardless of the cost were asked whether they would accept harm to the relevant island's marine life and habitat if trying to prevent it would threaten their current living standard. The other group of respondents, who had denied rights in this case, was also asked to reconsidercontinue

Table 6.1. Rights to protection from harm (% of total survey sample of 1,152 for Curaçao and 1,058 for Jamaica).

	Absolute right applies		*Right applies depending upon the circumstances*		*No right applies*		*Don't know*	
	Curaçao	Jamaica	Curaçao	Jamaica	Curaçao	Jamaica	Curaçao	Jamaica
Other humans now living	84	82	9	16	5	2	2	0
Future human generations	81	82	12	15	4	2	3	1

Marine animals	57	82	32	13	5	2	6	3
Marine plants	58	85	29	9	5	3	8	3
Marine ecosystems	60	84	25	10	4	3	11	3

given a more specific scenario. In their case, they were asked whether they would accept a personal duty to avoid harming the relevant island's marine life and habitat if their current standard of living would be unaffected. The outcome of these questions is to enable the sample to be split into four categories (in addition to those denying any rights to any of the five categories described earlier):

1. Those who attribute rights and accept a strong personal responsibility to protect marine life and habitats from harm even when their standard of living is threatened;

2. Those who attribute rights and accept a personal responsibility to protect marine life and habitats from harm only if their own current standard of living is unaffected;

3. Those who withdraw rights and any personal responsibility to avoid harm to marine life and habitats when the cost of doing so is in terms of their current standard of living; and,

4. Those who reject rights and any personal responsibility to protect marine life and habitats from harm regardless of whether their own current standard of living is unaffected.

The results for the two countries are shown for locals and tourists in Table 6.2. The two middle categories, 2 and 3 above, show a willingness to make trade−offs that is consistent with a modified lexicographic position (i.e., once a basic standard of living is obtained, a stronger ethical position for other species is adopted). A readiness to consider the trade−off circumstances and the subjectivity of the relevant standard of living means that individuals in these categories may be regarded as acting as utilitarians and weighing−up the trade−offs. The situationcontinue

Table 6.2. Personal responsibility to protect life and habitats in the marine park.

	No rights in this case	*No duty*	*Remove duty if cost high*	*Attribute duty if cost low*	*Strong duty*	*Total*
Curaçao						
Number of locals	2	91	262	120	173	648
Number of tourists	8	77	185	75	135	480
Total number	10	168	447	195	308	1128
Total (% of sample)	0.9	14.9	39.6	17.3	27.3	100a
Jamaica						
Number of locals	10	64	328	74	88	564
Number of tourists	0	46	342	34	70	492
Total number	10	110	670	108	158	1056
Total (% of sample)	0.9	10.4	63.3	10.2	14.9	100a

a Row may not add to 100% due to rounding errors.

for Jamaica shows a dramatic reduction in those attributing absolute or strong rights from 79% down to 14%. Similarly, although slightly less dramatic, for Curaçao the reduction is from 68% to 28%. Despite this large reduction, there is still a sizeable hardcore of individuals taking a position consistent with strong lexicographic preferences. This leaves the question open as to how these individuals expect to protect the rights they hold so strongly and how they would avoid having to make a trade−off decision, for example, where material goods are equated to the discharge of the moral duty being described. In order to try and address these issues, another set of follow−up questions was asked.

How to Protect Rights?

Those protesting in terms of a zero bid and a strong duty position are in favor of legal and educational approaches to increasing the quality of biodiversity in the marine parks. In Jamaica, 50% of these individuals opted for a purely legal approach, while in Curaçao, 53% wanted either a legal and/or an educational approach.

As mentioned earlier, both zero and positive bid strong duty holders are potentially signifying lexicographic preferences. The way in which this entire group, which is prepared to protect the marine environment at personal cost, believes the rights they have identified are to be protected is shown in Table 6.3. The biggest grouping of responses falls upon two methods for protecting the rights identified within the marine park. In Jamaica, 66.4% and, in Curaçao, 48.3% of respondents wanted rights to be protected by either a legal approach or education, or a combination of the two. Some of those holding a strong duty position felt the trust fund was also a good idea and would help in the protection of the rights they had attributed to the marine environment. Others gave responses combining more than one category. The miscellaneous category includes a variety of actions to be taken by various bodies or unspecified groups (e.g., NGO initiatives), unspecified schemes, and restriction of specific activities (e.g., harpooning, anchoring, creation of beaches, diving, allowing technology to prevent pollution, economic development).

The overall picture can be viewed as a proportion of these individuals externalising the cost to other parties or organizations. Alternatively, there may be a genuine failure to consider the cost of the proposed solution. The main category that avoids externalising the cost and maintains a position consistent with a strong lexicographic preference is that of the "lifestyle change". Education may also cover a range of activities that go beyond thecontinue

Table 6.3. How to protect a strong duty position (code method of protection: 1=legal enforcement, regulation and policing; 2=international community funded initiatives; 3=lifestyle and fundamental behavioral changes; 4=education, formal and informal (e.g., media); 5=user fees; 6=government responsibility and tax funded initiatives; 7=combined education and legal approach; 8=combined various approaches; 9=other miscellaneous approaches; 10=don't know).

	Method of protection by code total										
	1	2	3	4	5	6	7	8	9	10	Total
Curaçao											
Number of locals	51	2	12	30	17	14	8	12	8	19	173
Number of tourists	28	6	7	28	8	10	4	16	5	23	135
Total number	79	8	19	58	25	24	12	28	13	42	308
Total (% of	25.6	2.6	6.2	18.8	8.1	7.8	3.9	9.0	4.2	13.6	100a

sub−sample)											
Jamaica											
Number of locals	42	2	5	18	1	2	6	5	1	6	88
Number of tourists	20	1	5	15	1	4	4	2	10	8	70
Total number	62	3	10	33	2	6	10	7	11	14	158
Total (% of sub−sample)	39.2	1.9	6.3	20.9	1.3	3.8	6.3	4.4	7.0	8.9	100a

a Row may not add to 100% due to rounding errors.

classroom and remain consistent with the ethical position. However, given the limited extent of allowance for open−ended responses on the subject possible in the current survey, little more can be read into this.

The implication for stated WTP is that, in many cases, those holding a strong duty position are prepared to pay for a different institutional framework (e.g., a judicial approach) if required to do so. This, of course, creates a practical problem for a CVM survey that, as part of the design, selects one institutional approach to the problem at hand. In addition, there is the theoretical problem that, where respondents are prepared to pay for an institutional framework, this fails to be a reflection of the resource value, but is rather a contribution to a social construct. An extension to the current research would be to experiment with alternative institutions to see how WTP or WTA varies.

Internal Consistency of Responses

The characterisation of the change in biodiversity as an improvement also has implications for the trade−off. That is, the expectation of a lexicographic preference is that individuals will bid all their spare income in such a situation for even a small improvement. In fact, individuals may reject the institution that imposes such a condition upon them. This behavior has the advantage for the individual of avoiding acceptance of an institution, which may lead to a potential irreversibility. That is, if the improvement were reversed and the WTP bid had been made, the individual would now have no spare income to give a positive WTP and would then be classified as a zero bidder. The approach taken by Spash and Hanley (1995) was to identify zero bids for non−zero value reasons, identify protest bids and see how many of these were consistent with a lexicographic preference. The hypothesis was then that individuals protest against CVM and bid nothing rather than take part in a process which implicitly buys and sells improvements in what are seen as rights and duties. This approach is followed below and allows the results to be compared with the earlier work.

However, a qualification is necessary. We note that a positive bid by a believer in strong duties can still be consistent with a lexicographic preference. Such individuals are rejecting neo−classical choice theory but are acting in a way consistent with the expectations of mainstream economic theory by giving a WTP amount. If the less extreme modified lexicographic preference position is adopted, positive bids are expected to be the amount above a minimum standard of living. An additional complication is then that while the position seems more reasonable because it is less extreme, that lack of extremity means it is also difficult to identify. That is, positive bids may be given that reduce income to a subjective minimum living standard but this minimum is unknown. One way we try to address the positive bid issue is by using scaling and dummy variables in the bid curve analysis reported later.

First, consider the zero bids, which are taken as a rejection of a trade−off. The only data that is of interest with regard to the lexicographic position is taken to be that defined by the strong duty category. Note that this assumption may be questioned for a modified lexicographic model where a minimum living standard is defended first and, if threatened, takes priority. Positive and zero bids can split this category. The survey allowed for bids by both time and money as shown in Table 6.4. That is, the project gave the scope for including voluntary work to improve marine biodiversity and this was seen as an important alternative in a developing country context where many may be on a low wage or in a non−monetary economy. The impact of this approach is to reduce the zero bid category considered here beyond that of the monetarily defined. Remember, those who show a positive WTP in time and/or money may be indicating that they would be prepared to make a trade−off (indifference) or that they are giving up a substantive part of their current living standard (lexicographic). The zero bidders as a sub−group of strong duty holders are quite small in contrast to previous findings of 3.4% to 7.5%.

Next, the reasons for giving a zero bid are analyzed. These are divided into accepted economic reasons for a zero bid (i.e., income constraint or no value). The remaining reasons, shown in Table 6.5, are taken as indicating non−zero value. The outcome is to reduce the protest zeros, which are consistent with a strong lexicographic preference as defined by the strong duty, to 1.7% for Curaçao and 4.8% for Jamaica.

Bid Curve Analysis

Analysis of the determinants of WTP is particularly relevant to the purposes of the coral reef valuation project. The variables, which are hypothesised to determine variations in WTP, can be specified and studied via econometric analysis. In this section, bid curves are reported for the two case studies. The approach used in this section relies on a "tobit" analysis of the sample. Although many bid curve analyses rely on ordinary least squares (OLS) procedures, such techniques may be flawed when applied to data sets such as those generated by our surveys. The procedure is detailed in standard texts on limited dependent variables (e.g., Maddala 1983) and has been appliedcontinue

Table 6.4. WTP of individuals holding a strong duty position.

	Zero bid	*Positive bid time*	*Positive bid money*	*Positive bid time and money*	*Total*
Curaçao					
Number of locals	38	19	82	34	173
Number of tourists	46	16	41	32	135
Total number	84	35	123	66	308
Total (% of sample)	7.5	3.1	10.9	5.9	27.3
Jamaica					
Number of locals	10	8	39	31	88
Number of tourists	26	7	29	8	70
Total number	36	15	68	39	158
Total (% of sample)	3.4	1.4	6.4	3.7	14.9

Table 6.5. Identifying reasons for non−zero bids by strong duty respondents.

Zero bidders by reason	*Curaçao*	*Jamaica*
Zero Economic Value Reason		
Low income or unemployed	20	13
Reef improvement unimportant	5	0
Non−resident	25	5
Total (% of sub−sample)	59	50
Non−Zero Value Reason		
Paying incorrect solution	6	1
Improvement will occur anyway	2	0
Mistrust marine park institution	3	2
Government is responsible	21	3
Could not place a money value	0	3
Other	2	6
Refused to answer or don't know	0	3
Total (% of sub−sample)	41	50
Total number	84	36

within the context of environmental economic household and individual choice decision models (e.g., Ruitenbeek 1996). A maximum likelihood estimation (MLE) procedure sets up a likelihood function and through iteration provides an efficient solution to the tobit specification. The procedures are analyzed based on the significance of individual explanatory variables (through t−statistics) and, when comparing models, through a likelihood ratio test based on a chi−square distribution. All tests of significance are reported at a 95% level of confidence.

WTP Determinants for Curaçao

A range of variables was available from the survey and those considered most important are shown in Table 6.6. A bid curve analysis, using a semi−log linear form, for Curaçao shows determinants of WTP as a set of standard socio−economic variables, knowledge and the position taken towards rights (i.e., a lexicographic type preference).3 The socio−economic variables are gender, age and education. Income would be another standard variable expected to determine WTP, but is excluded here.break

Table 6.6. Variable definitions and basic statistics for Curaçao.

Variable	*Mean*	*Min*	*Max*	*Valid number*	*Label*
TL	0.43	0	1	1152	Tourist (1) or local (0)
LANGDUTC	0.36	0	1	1145	Language Dutch
LANGENG	0.18	0	1	1145	Language English
LANGPAP	0.46	0	1	1145	Language Papiamentu

BENUM	1.41	0	5	1151	Number of benefit categories
VISITF	0.88	0	1	1152	Visit site in future
KNOWMBD	4.68	1	10	1152	Knowledge of marine biodiversity
PREFINFO	0.37	0	1	1152	Preference change and information effects
HARMMA	1.45	1	3	1078	Anti−rights to marine animals
HARMMP	1.43	1	3	1060	Anti−rights to marine plants
HARMME	1.38	1	3	1022	Anti−rights for marine ecosystems
RIGHTSEA	4.84	0	6	988	Marine animal/plant/ecosystem rights
NODUTY	0.16	0	1	1128	No rights/duty to marine environment
STRDUTY	0.27	0	1	1128	Strong duty
SEX	0.50	0	1	1152	Gender (male=0; female=1)
AGE	4.24	1	10	1151	Age by category (1=low; 10=high)
EDUC	2.86	1	5	1139	Level of educational attainment
INCOME	3.25	1	10	642	Level of gross income (coded)
WTPALL	49.16	0	2000	971	WTP (NAF)
LNWTP3	1.88	0	7.6	971	Natural log of (WTPALL+1)
PROBC	2.39	1	10	1149	Ease/difficulty with Section C of survey

This is because income is correlated with age and education and, therefore, little is added to the explanatory power of the equation if both sets of variables are included. In addition, the income variable only had 642 responses so that its inclusion would severely reduce the number of degrees of freedom in the estimation. Even the responses gained for income were suspected to be suffering from under−reporting, which is especially problematic when others are listening to the interview. The inclusion of a dummy variable for tourists versus locals was strongly insignificant, showing no difference. A set of dummies were also tried to test for the impact of language because the survey was translated into Dutch and Papiamentu, but these were also found to be strongly insignificant by the t−test. The final model results are shown in Table 6.7.4

The knowledge and use variables proved significant determinants of WTP. Knowledge of marine biodiversity (KNOWMBD) was derived from a survey question where individuals used a 10 point scale to signify their prior knowledge of the concept after having had a description. Greater knowledge increases WTP. This is also true for the use related variable, giving the number of benefits the individual derives from the marine park (BENUM; e.g., swimming, diving, site seeing, sunbathing).

A set of variables was also included to measure the ethical stance being taken by the respondent. First is the attitude of the individual towards rights. A seven point scale was developed from the questions of the survey covering the attribution of a right to be protected from harm to marine animals, plants and ecosystems (RIGHTSEA). The idea was to create a scale on the basis of the consistent attribution of rights. Respondents who answered "don't know" to any of the three groups were treated as missing data and so no position on the scale was given to these respondents. Those attributing absolute rights to all three aspects of the marine environment were ranked highest, and those denying rights in all three cases ranked lowest, with a graduating scale between these two extremes. As can be seen, rights for the marine environment are positively related to WTP, which means these individuals could be misconstrued as making an implicit trade−off of their rights position and this was implied earlier by the development of the "strong duty" category. Here, the data on personal duties is also incorporated in the equation.break

Table 6.7. Preferred tobit model for Curaçao. The dependent variable is LNWTP3. Model has 463 limit observations (zero) and 508 non−limit observations. The predicted probability of y > limit given average xi is 0.5868. The observed frequency of y > limit is 0.5232. At mean values of xi , E(y)=1.5657.

Variable	*Normalised coefficient*	*Standard error*	*Asymptotic t−ratio*
SEX	0.17322	0.073843	2.3459
AGE	0.054646	0.018042	3.0288
EDUC	0.18416	0.039794	4.6278
KNOWMBD	0.051143	0.013414	3.8126
BENUM	0.18653	0.039808	4.6857
RIGHTSEA	0.15628	0.024749	6.3143
NODUTY	0.31661	0.11346	2.7904
STRDUTY	0.16615	0.080436	2.0656
PROBC	0.041131	0.019463	2.1133
PREFINFO	0.60101	0.074180	8.1020
CONSTANT	2.0385	0.21111	9.6561
LNWTP3	0.33092	0.011671	

The role of ethical positions is confirmed by the significance of the dummy variables on the personal duty to protect the life and habitats of the marine park. The dummy variables represent those respondents taking the strong duty perspective (STRDUTY) and those rejecting any duty (NODUTY). As can be seen, a strong personal duty, regardless of the cost, is positively correlated with WTP, while the rejection of this duty reduces WTP. This shows that WTP for biodiversity improvement is partially related to the ethical concern people show for marine animals, plants and ecosystems. Also, a variable on the difficulty found with these sets of survey questions was included in light of the results for Jamaica. This is also significant and positively correlated, which can be seen as supporting the no duty position in that these individuals care less about marine biodiversity and also find little problem in stating their lack of belief in rights. In contrast, those concerned about biodiversity improvement struggle with their precise ethical position and the extent to which duties are weak (tradable) or strong (lexical).

Thus, the overall results for Curaçao show a model of WTP being dependent upon standard socio−economic variables plus rights and duty−based variables. The RIGHT−SEA variable is a recognition at an aggregate level of rights in the marine environment. The STRDUTY and NODUTY variables are specific to the marine park itself and the extent to which individuals are prepared to prevent harm at the risk of a loss in their own living standards.

In addition, a dummy variable called PREFINFO was included to account for whether individuals felt their preferences about marine biodiversity preservation had been changed by the survey. This variable was found to be highly significant and positive.

WTP Determinants for Jamaica

A similar semi−log linear form of model was developed for Jamaica with a set of socio−economic variables, knowledge and the position taken towards rights (i.e., a lexicographic type preference). The range of variables considered most important, along with some descriptive statistics, are shown in Table 6.8. The socio−economic variables, in this case, are gender and income. Income replaces the age and education variables of the Curaçao model. Income data for Jamaica was far more complete with 839 observations. This time, the inclusion of a dummy variable for tourists versus locals was strongly significant and negatively correlated with tourists. The final model results are shown in Table 6.9.

The knowledge and use variables again proved significant determinants of WTP. Knowledge of marine biodiversity (KNOWMBD) was found to be similar to that concerning reef degradation (KNOWCD) in terms of the equation and, in this case, the latter was used. This is derived from a survey question where individuals used a ten point scale to signify their prior knowledge of the causes of coral reef degradation after having had themcontinue

Table 6.8. Variable definitions and basic statistics for Jamaica.

Variable	*Mean*	*Min*	*Max*	*Valid number*	*Label*
TL	0.47	0	1	1058	Tourist (1) or local (0)
ENVIROAT	1.53	0	23	1058	Number of environmental concerns
VISITC	0.47	0	1	1058	Ever visited marine park
VISITF	0.88	0	7	1056	Visit site in future
KNOWCD	4.67	1	10	1058	Knowledge of coral degradation
KNOWMBD	3.29	1	10	1056	Knowledge of marine biodiversity
PREFINFO	0.19	0	1	1058	Preferences changed and informed
INFO	0.74	0	1	1058	Informed only
RIGHTSEA	5.51	0	6	1028	Marine animal/plant/ecosystem rights
NODUTY	0.11	0	1	1056	No duty to marine life/habitats
STRDUTY	0.15	0	1	1056	Strong duty marine life/habitats
SEX	0.56	0	1	1056	Gender (male=0; female=1)
AGE	3.63	1	10	1058	Age by category (1=low; 10=high)
EDUC	3.04	1	5	1058	Level of educational attainment

INCOME	3.47	1	10	839	Level of gross income (coded)
PROBC	1.83	1	10	1058	Difficulty with Section C of survey
WTPALLX	26.24	0	2866	833	WTP (US$)
LNWTP3	1.54	0	7.96	833	Natural log of WTPALLX

Table 6.9. Preferred tobit model for Jamaica. The dependent variable is LNWTP3. Model has 317 limit observations (zero) and 516 non−limit observations. The predicted probability of y > limit given average xi is 0.6544. The observed frequency of y > limit is 0.6194. At mean values of xi , E(y)=1.4304.

Variable	*Normalised coefficient*	*Standard error*	*Asymptotic t−ratio*
TL	0.19667	0.083661	2.3508
ENVIROAT	0.053173	0.024215	2.1959
INCOME	0.061696	0.015320	4.0273
NODUTY	0.48570	0.13237	3.6693
VISITC	0.22942	0.076518	2.9982
VISITF	0.47212	0.12543	3.7641
KNOWCD	0.038592	0.012067	3.1980
PREFINFO	0.36412	0.18868	1.9298
INFO	0.49011	0.17434	2.8112
PROBC	0.085788	0.028718	2.9872
CONSTANT	0.81805	0.23137	3.5356
LNWTP3	0.43953	0.014998	

described. As with KNOWMBD, greater knowledge increases WTP. This is also true for the positive likelihood of future use of the marine park (VISITF). Also, the relationship between WTP and having visited the park in the past is negative (VISITC). This result is not uncommon for such surveys in that it implies that, once an initial curiosity is satisfied, an individual's utility from subsequent visits will tend to drop off (this is consistent with decreasing marginal utility in individual preference functions).

In Jamaica, the set of variables on ethical stance were less relevant. However, some role for ethical positions is confirmed by the significance of the dummy variable rejecting any duty (NODUTY). This is also negatively correlated to WTP as was the case for Curaçao. The contrast with the results for Curaçao in terms of the role of ethical variables led to the inclusion of survey difficulty variables, and this showed a strong positive correlation with WTP. However, as this was then included in the Curaçao model and a similar result occurred, this alone seems unable to explain the difference in results.

Finally, PREFINFO is a dummy variable for whether individuals felt their preferences about marine biodiversity preservation had been changed by the survey. This was found to be highly significant and positive as in Curaçao. What was different here was the strong positive relationship of a second dummy representing the case of individuals whose preferences had remained unchanged but who felt they had been informed.

Thus, the overall results for Jamaica are in line with those for Curaçao, except in that the model lacks significant rights and strong duty variables.

Prediction of WTP

The expected WTP will depend on the location of the individual, their individual socio−economic characteristics, and their attitudes towards rights. Simulations using the preferred models were conducted to estimate WTP and the probability that they would return a non−zero bid. Results are shown in Table 6.10.

First, we note that at the sample means, WTP in Curaçao is about US$2.08, while in Jamaica it is US$3.24. This difference is readily explained through the differences in the mix of tourists and locals in the sample. Tourists generally had the same WTP in Curaçao and Jamaicabreak

Table 6.10. Predicted WTP for Curaçao and Jamaica as a function of individual characteristics. Local and tourist statistics taken at population means. For strong duty simulation (Curaçao): RIGHTSEA=6; NODUTY=0; STRDUTY=1. For no duty simulation (Curaçao): RIGHTSEA=0; NODUTY=1; STRDUTY=0. In Jamaica, the simulation turns on and off the NODUTY variable.

	Probability of non−zero bid (%)	*Expected WTP (US$)*
Curaçao		
Sample means—all	58.33	2.08
Sample means—typical local	56.18	1.85
Sample means—typical tourist	61.15	2.46
Locals with strong moral duties/rights	69.08	4.05
Locals with no moral duties/rights	17.82	0.19
Tourists with strong moral duties/rights	74.18	5.82
Tourists with no moral duties/rights	22.01	0.26
Jamaica		
Sample means—all	65.77	3.24
Sample means—typical local	68.49	3.75
Sample means—typical tourist	62.51	2.73
Locals with moral duties/rights	70.72	4.26

Locals with no moral duties/rights	52.37	1.66
Tourists with moral duties/rights	64.22	2.98
Tourists with no moral duties/rights	45.17	1.17

US$2.46 and US$2.73 respectively. Jamaicans, on the other hand, were willing to pay almost double their counterparts in Curaçao.

The importance of perceptions relating to rights and duties, however, is again seen in the WTP results. The tobit model simulations were conducted with the duty and right variables tuned to their highest and lowest possible combinations. The Curaçao set permitted a more extreme case because of the three variables, while the Jamaica is a "softer" comparison. The results show that people with some duty and rights perceptions are willing to pay approximately two to three times as much as those who have no such attachments; people with very strong perceptions will pay at least an order of magnitude more. Interestingly, in the Curaçao case, those with absolutely no moral attachment are expected to pay virtually nothing.

Conclusions

The goal of this study was to undertake a contingent valuation analysis of coral reef quality for amenity, biodiversity, and other values in Montego Bay, Jamaica, and reef areas along the south coast of Curaçao. Coral reef conservation benefits were to be valued in monetary terms with a view to identifying various economic and demographic characteristics of this valuation and its determinants (e.g., education, gender, and knowledge of bio−diversity, local versus tourist). Although CVM is well developed and routinely used in assessing environmental benefits, two broad areas of innovation were part of the current study in the context of coral reefs. First, a rigorous developing country CVM analysis was undertaken of an environmental resource that had previously been neglected (i.e., coral reef quality); most developing country CVM studies having focused on other issues, such as water quality, or on specific urban locations. Second, and more significantly from a research perspective, the recent CVM literature had identified the existence of lexicographic preferences as one of a number of outstanding methodological questions associated with biodiversity valuation that required further analysis. The research addressed itself directly to this issue.

The lexicographic preference can be consistent with a positive or zero WTP. The expectation of protest responses associated with zero bids for reasons of non−zero value has been studied in a developed country context and has shown that around one fifth of respondents reject trade−offs when asked to pay to prevent environmental deterioration. A similar approach was adopted here in that the consistency of claiming a strong duty to protect the environment was contrasted with stated WTP in terms of a zero bid for reasons of non−zero value. In this case, WTP was for an environmental improvement.

Zero bid reasons were identified as those which are in accord with economic theory and those which are more problematic, representing a protest which cannot be taken as reflecting zero value. The combined result of all the reasons falling under the second category is to bias downward WTP because many of the respondents are concerned about biodiversity and place a positive value upon it. In the survey sample, this proved to be a substantial group with 32% and 27% of zero bids for Curaçao and Jamaica, respectively, reflecting non−zero values. This excludes those in the "other" and "refuse/unable to answer" categories who may also place a positive value on biodiversity improvement.

Those claiming a strong duty accounted for one third to one sixth of the sample, as shown in Table 6.11. When the data were analyzed for zero bids, in terms of time and money being given for reasons of non−zero value (which also excludes those unable to pay—the low income earners and the unemployed), the sub−sample falls to a few percent. There was no apparent difference between the tourist and local sub−samples as might be expected if the result was due to the developing country context. Another explanation may be that, because the study took the case of an environmental improvement, less controversy arose than if a WTP were asked for preventing an environmental deterioration (i.e., the low percentage of protests among zero bidders consistent with a strong duty). However, as Table 6.11 shows, the process adopted here for confirming respondents' adoption of a strong duty was also effective in reducing the proportion claiming absolute rights. Respondents claiming a strong duty to protect the environment were identified after probing questions confronted the respondent with a hypothetical trade−off in terms of their current living standard. The result contrasts with those attributing general but absolute rights to aspects of the marine environment, being two thirds or more of the sample.

While the finding of only a few percent of respondents in the protest−zero−lexicographic position does conflict with that of earlier studies, some caution should be taken in generalising the result. As mentioned, a positive bid for an environmental improvement can be consistent with a lexicographic position because any increase in the highly ranked good will increase welfare regardless of the loss of those goods ranked as inferior. A second improvement or a reversal of the improvement would both elicit a zero WTP because the individual has no income left (or no spare income under modified lexicographiccontinue

Table 6.11. Type and consistency of rights and duties for zero bidders.

	Curaçao		*Jamaica*		*Total*
	Locals	Tourists	Locals	Tourists	
Sample size	656	496	565	493	2210
Absolute marine rights (number)	322	251	385	441	1399
Absolute marine rights (% of sample)	58.9	56.9	71.8	89.6	63.3
Strong duty (number)	173	135	88	70	466
Strong duty (% of sample)	26.4	27.2	15.6	15.0	21.1
Strong duty and zero bid for reason of non−zero value (number)	20	14	6	12	52
Strong duty and zero bid for reason of non−zero value (% of sample)	3.0	2.8	1.0	2.4	2.4

preferences). This raises the interesting possibility that those refusing to bid more for the improvement of other reefs that were classified as showing part−whole bias (see Spash *et al.* 1998) may have lexicographic preferences. In addition, the rights−based position and implied duty does seem to influence bids as shown by the bid curve analysis. This result is very strong for Curaçao, but more limited for Jamaica. This Jamaican result led to consideration of the difficulty respondents may have had in answering the survey. In both countries, the levels of difficulty respondents were observed to have in answering the rights and duties section of the survey has a significant and positive influence on WTP. As this was an unexpected finding, explanations are purely speculative. However, one possibility is that people who dismiss rights and duties for the environment can answer quickly without problems and are also likely to give a low WTP bid. Those who are more concerned, with a higher WTP, struggle when confronted by the idea that they make trade−offs but, when pressed to do so, conform but still regard the language of rights as a more appropriate description of their actual position. Placing a set of right questions prior to the WTP question may, therefore, result in the respondents finding the bid section problematic rather than the ethics section.

In terms of the design of CVM, the study shows a methodology for classifying lexicographic type preferences. The second stage is then to develop checks for consistency in terms of WTP, and this was only partially achieved here because of the concentration on zero bidders and relative neglect of positive bidders in the analysis. However, the consistent results for the strong duty holders across the two countries shows they are in favor of alternative institutional approaches such as education, legal enforcement and, to a lesser extent, lifestyle changes. This poses a problem for CVM as currently practiced because it places the problem in a specific institutional setting when framing the WTP or WTA question and fails to allow for such alternatives.

Endnotes

1 Option value arises when there is uncertainty about the continued supply of a good or service and an individual is prepared to pay to keep a future option open for use of the good or service. Bequest value refers to the welfare from endowing future generations with goods and services. Existence value is more controversial and varies in definition in the literature, but essentially tries to capture the welfare related to knowing something exists; this welfare is independent of any use which might be made either directly or indirectly (i.e., by future generations).

2 A quota sample is conducted so as to take into account specified population characteristics such as the ratio of male to female respondents, age distribution, and income distribution.

3 Note in the table that to prevent estimation biases and provide a basis for conducting the tobit runs, the dependent variable is specified as LNWTP3, which is the natural logarithm of the WTP plus one. The addition of 1NAF introduces a bias of about +0.1% in the estimates but provides a truncation point on all of the relevant data (i.e., LNWTP=0 if and only if WTPALL=0).

4 Unlike OLS estimates, the estimators in this table cannot be used directly to derive a WTP through simple multiplication. Actual estimation of the WTP requires transformation of this function and application of density function for any given set of characteristics. This is most readily done in a simulation environment, dealt with later in this section.break

Chapter 7— Montego Bay Pharmaceutical Bioprospecting Valuation

Cynthia Cartier and Jack Ruitenbeek
H.J. Ruitenbeek Resource Consulting Limited, Gabriola, BC, Canada

A preliminary review of issues and valuation methods showed that *utility*, *production* , and *rent* valuation approaches can all be used to estimate the value of marine products through bioprospecting (Huber and Ruitenbeek 1997). The review confirmed that, for marine organisms, the biochemical *information* derived from these organisms is as important as the actual use of the organism itself. Appropriately, a key recommendation was that any chosen methodology should be capable of addressing information content in coral reef or marine organisms. Most *utility* oriented approaches are incapable of separating this information value. A second aspect of the review confirmed that institutional structures and revenue or rent sharing arrangements are key influencing variables in the valuation of marine products.

For these approaches to be successful, data must be available to translate sampling information (e.g., species types and counts) into final commercial products; these are usually translated through a series of "hit rates." While such hit rates are known for advanced stages of research and development (R&D), most of the literature relates to terrestrial organisms. A preliminary survey of primary marine bioassay data was therefore specifically conducted, with the confidential cooperation of a number of private companies and private research institutes (Putterman 1997; Chapter 12). The exercise demonstrated that data collection of this sort was viable (Table 7.1).

Table 7.1 Preliminary survey of primary screening hit rates (%) from a collection of 20,000 Caribbean marine organisms

Antiviral data	0.3 to 10.9
Antimicrobial data (bacteria)	3.6 to 24.2
Antimicrobial data (fungi)	9.0 to 9.6
Enzyme data (protein phosphatases)	0.25 to 0.93
Enzyme data (other)	0.05 to 0.65

Source: Putterman (1997).

Appropriately, a more detailed analysis was pursued to place an economic value on marine pharmaceutical bioprospecting opportunities at Montego Bay, Jamaica. The study consisted of:

Specific methodology selection and development based on a literature review and analysis;

Further contracting of firms active in Caribbean bioprospecting to obtain confidential information relating to hit rates;

Estimation of sales and cost information specific to Montego Bay;

Development of a hypothetical sampling program for Montego Bay to form the basis for simulation studies; and,

Economic modeling of values.

Model Selection and Key Valuation Issues

The review of methods and models relevant to pharmaceutical bioprospecting benefit valuation (Cartier and Ruitenbeek 1999; Annex A) provides a basis for demonstrating how modeling techniques have evolved, as well as for selecting a technique relevant to the Montego Bay situation. The literature review highlighted a number of factors that have tended to be crucial in the derivation of values in terrestrial bioprospecting valuation models (Table 7.2). First, it is clear that different models generally have different policy applications and, above all, selection of a relevant technique should be suited to the policy problem at hand. In the case of Montego Bay, the valuation research was primarily intended to assist in site specific priority setting and planning, although a key aspect was also to build awareness.

The model specification issues include: i) estimation of gross vs. net economic values; ii) estimation of private vs. social returns; iii) capture of rent shares by local governments; iv) estimation of average vs. marginal returns, and the role of redundancy and substitutability incontinue

Table 7.2 Comparative summary of pharmaceutical bioprospecting models

	Farnsworth and Soejarto (1985); Pearce and Puroshothaman (1992a, 1992b); Principe (1989a, 1989b)	Aylward (1993)	Mendelsohn and Balick (1995, 1997)	Simpson and Craft (1996); Simpson and Sedjo (1996a, 1996b); Simpson et al. (1996)	Artuso (1997)	Polasky and Solow (1995); Solow et al. (1993)	Ruitenbeek and Cartier (1999)
Model Attributes							
Analytical specification only						✔	
Terrestrial system application	✔	✔	✔	✔	✔		
Marine system application							✔
Policy Applications							
Education and awareness	✔						
National level policies	✔	✔	✔		✔		✔
Private profitability analysis		✔		✔	✔		
Site specific planning				✔		✔	✔
General Economic Attributes							
Gross economic value	✔						
Net economic value		✔	✔	✔	✔	✔	✔
Private costs	✔	✔	✔	✔	✔	✔	✔
Social costs (including institutional)		✔			✔	✔	✔
Time delays		✔	✔	✔	✔	✔	✔
Average species value	✔	✔	✔		✔	✔	✔
Marginal species value				✔		✔	
Average habitat value		✔	✔		✔	✔	✔
Marginal habitat value				✔	✔	✔	✔
Specific Model Parameters							
Discovery process stages (hit rates)	1	1	1	1	9	1	3
Discovery process stages (costs)	1	1	1	1	9	1	1
Revenue sharing treatment	■	■		✔	■	✔	✔
Redundancy/ interdependency				✔	■	✔	
Ecosystem yield (species-area relationship)				✔	✔	✔	✔
"Price function" (once differentiable value)				✔	✔	✔	✔
Industry structure/ behavior						■	
Risk preference/ aversion behavior					■		■

✔ explicitly relevant or incorporated
■ treated qualitatively or partially

each of these; and, v) treatment of complexity through interdependence of discoveries and ecosystem yields. The relevance of these issues to Montego Bay, and their treatment within the model selection, is as follows:

Gross versus net values . The primary policy planning issue for Montego Bay is to look at net potential benefits accruing to bioprospecting and to other reef uses (Chapter 5). This requires some ability to deal with site specific costs, realizing, however, that expected sales revenues are likely to be common with any type of drug development, irrespective of product source.

Social versus private valuations . One component of the modeling literature is concerned with the general private profitability and incentive structures associated with drug production and marketing, as well as with R&D. These models typically incorporate taxation provisions within their various analytical stages. For Montego Bay, such analyses are of low priority concern. Of greater consequence is the magnitude of social benefits and the potential for capturing these efficiently. Private profitability is of concern to the extent that any revenue sharing arrangements must not discourage bioprospecting. A related aspect is the potential institutional overhead cost involved in maintaining a structure that oversees bioprospecting contracting. The social costs associated with such activities should be considered in any model that is developed for Montego Bay.

Average versus marginal values . This issue relates to whether the policy problem at hand is concerned with expected average values or marginal values of species and habitats. Much early literature was pre−occupied with average species values, even though site specific planning problems generally require translation of such values into marginal habitat values attributable to an ecosystem (e.g., rainforest or coral reef). Analysts have addressed this problem through various means. Simpson *et al.* (1996) attribute the marginal species value to the value of a collection and translate these to marginal habitat values. Artuso (1997) essentially derives expected (average) values for species or samples and translates them to marginal habitat values using species−area relationships for hypothetical habitats. We will in essence be following this latter approach, with a view to eventually deriving a marginal habitat benefit or "price". Consistent with earlier literature in cost−benefit analysis, we refer to such prices as "planning prices" to the extent that they are the relevant shadow prices to use for land use, investment, and other allocation decisions.

Redundancy . The literature deals with related issues such as "redundancy", "substitutability", and "conditional probabilities" within the R&D process and discovery sequence. There remains, at this stage, debate over the extent to which redundancy of discoveries is an important issue. One perspective is that if new discoveries have redundant attributes with those already discovered, then marginal species values will go down as more drugs are developed. A second perspective is that some bioprospecting in fact relies on looking for product redundancy, with a view to discovering cheaper sources of existing materials. For Montego Bay, we do not explore the redundancy or substitutability issue.

Phase−specific costs . Most of the literature has assumed a single discovery phase and cost for the R&D process when, as noted by Artuso (1997), a more accurate modeling of the process would recognize that many of the success rates are in fact endogenously determined and the cost and success rates are co−determined within a firm's or industry's optimizing behavior. If one recognizes this separation, it implies that there are mechanisms that will tend to maintain the activity at some profitable level. Using a nine stage R&D process, Artuso (1997) shows that this has important implications for genetic resource values and industry behavior, as well as for risk mitigation within the sector. For Montego Bay, we are primarily interested in the ecosystem values, although we acknowledge that some separation of R&D success rates and costs is important. The Montego Bay data are, however, constrained such that optimization studies are not feasible, although we do use a three stage R&D process to incorporate a number of the phase−specific results obtained from industry sources.

Revenue sharing . Many analysts have addressed "capturable value" but our concern here is to pay somewhat greater attention to institutional financial mechanisms such as royalty rates, revenue shares, and sample fees, as well as to show how these mitigate risks in the bioprospecting process. Our model should, therefore, be capable of conducting some simple trade−off analyses to demonstrate the effectiveness in risk mitigation of different mechanisms.

Model Specification, Assumptions and Information Sources

In summary, the estimating model for Montego Bay bioprospecting focuses on a model of average social net returns using localized cost information for Jamaica and benefit values and success rates based on proprietary information for marine products in the Caribbean. The institutional costs associated with rent capture are included for Montego Bay. The adopted model uses some of the concepts incorporated in the terrestrial bioprospecting valuation models and builds on these for the marine environment by explicitly introducing parameters relating to *rent distribution and complexity* , as reflected by *ecosystem* continue

yield . Sensitivity analyses demonstrate that these two parameters are likely to have the most significant impact on captured values and on planning problems. Rent distribution is introduced as a policy variable, while ecosystem yield is a measure of species and sample yield potentially available from the Montego Bay reefs. We derive likely estimate ranges for the latter based on typical species−area relationships postulated in the island biogeography literature (Quammen 1996; Reaka−Kudla 1997; Simberloff and Abele 1976). Finally, the results are once differentiated to derive a marginal benefit function, which relates value to coral reef abundance or area and can be interpreted as our estimate of coral reef "price" that would be applied within a planning framework. Similar to other models of this genre, social values are inferred from the behavior of private agents and the model excludes any explicit estimation of option values.

Model Structure

While many of the models in the literature isolate terminal values of the R&D change, the model here is regarded as a current ecosystem planning model and thus discounts all values to the present, using the "sample" as the initial basis of analysis. The expected net sample value ($ENVN_t$) of N_t samples collected in year t , including collection costs, is thus

$$ENVN_t = pN_t(1+r)^{-t} EVD_{t+\tau}(1+r)^{-\tau} - CN_t(1+r)^{-t}$$

where p = the cumulative probability of developing a commercial drug from a given sample;

$EVD_{t+\tau}$ = expected future value of a commercial drug net of R&D costs;

τ = length of the R&D period;

C = individual sample costs; and,

r = discount rate (10% real).

Essentially, we take a future value of a drug and translate it into present value terms, recognizing that the sample is collected as part of a broader sampling program of N samples over a sampling program $\{N\}$.

We now introduce an ecosystem yield and capability function that constrains the total sampling of N available samples in a given area to a sustainable annual level (N_{max}). The expected value (EV) of the sampling program of length T is then

$$EV = \sum_{t=0}^{T} ENVN_t$$

subject to $N_t \leq N_{max}$ for all t

$T = N/N_{max}$

$N = sS$

$S = cA^z$

where S = number of species in an area, defined by the species area relationship parameters c and z ; and,

s = average number of samples available for any given species.

In addition, we introduce the following cost and revenue sharing parameters to reflect captures of values:

α = contingent royalty on final drug sales expressed as a net profit share;

f = a per sample fee that involves a transfer to local authorities for sample collection (or for multiple sample rentals); and,

I = institutional costs attributable to collection.

The rent capture, or local value to Jamaica, in this case is

$$EV_J = \alpha EV - I + \sum_{t=0}^{T} fN_t(1+r)^{-t}$$

We also define global and Jamaican planning prices (P G and P J respectively) as the change in value as a result of a change in reef area, such that

$$P_G = \partial EV / \partial A$$
$$P_J = \partial EV_J / \partial A$$

We note here that because institutional costs are regarded as fixed, the planning prices are independent of such costs.

Revenues and Costs

Revenue and R&D cost estimates for product development are chosen to be in line with most of the received literature for bioprospecting on terrestrial species. Based on the models surveyed in Chapter 3, the expected value of new drug development, excluding R&D costs, is estimated to fall in the range of US$173 million to US$354 million, with a mean of US$233 million. This value is the net present value (NPV) in 1998 dollars discounted to the time at which a sample is taken. R&D costs, excluding sample collection, are estimated to fall in the range of US$116 million to US$201 million, with a mean of US$170 million. In our study, we use an R&D cost of

US$160 million and a sales value of US$240 million. This ratio of 1.5:1 is consistent with many of the other estimates in the literature, with the exception of Mendelsohn and Balick (1995, 1997), who calculate a moderate loss in NPV using their model for an individual firm.

The costs for sample collection were based on proprietary cost estimates relating to tropical sampling programs. These estimates place "material only" costs in the rangecontinue

These estimates place "material only" costs in the range of US$6 to US$35 per sample for Florida, and "all in" local costs of US$40 to US$80 per sample for the Indian Ocean and South Pacific. Costs for the Caribbean are in the range of US$50 to US$100 per sample using scuba; the survey indicated that samples that had undergone some primary screening could attract a premium of US$75 per sample. Costs using submersible techniques were considerably higher, approaching US$350 per sample. We note, however, that in all of these cases the surveys showed costs below those cited by Newman (1995) for National Cancer Institute (NCI) bioprospecting programs in the South Pacific. The NCI programs typically involved costs of US$500 per sample, which included shipment to and cold storage in the United States. For the purposes of our study, we have chosen a mid−point of US$75 per sample for the Caribbean collection costs.

Institutional Parameters—Costs and Revenue Sharing

Cost estimates for the institutional requirements are based on discussions with the Government of Jamaica following an assessment of local capacity in various ministries. Based on current salary scales, overheads and training requirements, it is estimated that the system of permit validation, and associated checks, will involve annual costs of approximately US$23,000. This is equivalent to one part−time professional along with associated administrative and travel overheads. At a 10% discount rate, this amount is equivalent to US$230,000 NPV and would be adequate to cover most of the country's requirements in the marine bioprospecting area. Allocation of this amount to any given area is methodologically problematic but, as noted later, the amount is small relative to other values and thus would not have a significant impact on planning decisions.

Revenue sharing simulations essentially show three scenarios in addition to the implicit status quo in which no revenue is collected by Jamaica. As a reference case, we select a net profit share level (α) of 10% as a *maximum* capturable under typical regimes negotiated in the industry. This is also consistent with levels typically assumed by other analysts (Aylward 1993; Pearce and Puroshothaman 1992a, 1992b). Two sensitivity scenarios are solved for within the model. One involves the "equivalent fee only" level that would generate approximately the same level of captured rent as in the base case; this is somewhat over US $250 per sample and could be collected either through licensing or through multiple rentals of samples. In that scenario, the country foregoes any contingent compensation in the form of royalties. A second sensitivity scenario involves a similarly "revenue neutral" mix in which the net profit share drops to 8% and the sample fee is set at US$50 per sample.

Sampling and Hit Rates

The model requires estimates of N max and p. Sampling rate is perhaps one of the most overlooked parameters in other modeling efforts, yet it plays an important role in establishing ecosystem value. A very slow sampling rate depresses present values, while a very high sampling rate may not be ecologically sustainable; some observers have criticized aggressive marine bioprospecting for endangering some species. To ensure that a reasonable level of sampling occurs, a hypothetical program for Montego Bay was laid out using typical methodologies used by the NCI (Colin 1998). The NCI observes that a team of up to four divers would generate at most 15 samples a day. This is regarded as a sustainable effort for Montego Bay (which has a relatively limited area of about 43ha) and is also consistent with logistical constraints of servicing a collection program. Assuming full−time regular employment of the team over a ten month period (avoiding the hurricane season), the model assumes a maximum annual sampling rate of 3,300 samples. In sensitivity analyses, we subsequently relax this constraint to illustrate the impact of an accelerated sampling program in which all samples are collected in a single year.

Various firms were contracted to provide information relating to marine bioprospecting success rates. Although the detailed information is proprietary, summary statistics adequate for modeling are presented here. The firms' programs generally implied success rates to final product development in the range of 1:25,000 to 1:50,000; these success rates incorporated screening against multiple targets (up to ten). Two specific examples serve to illustrate:

FIRM A. A set of 13,779 samples were analyzed for ten targets. Not all samples were subjected to each target. At the primary screen, 5,137 were isolated and then passed on to subsequent screening and analysis. Through the following stages, six to seven drug leads were eventually identified and were at various stages of preclinical trials and licensing prior to clinical trials. This implies a cumulative hit rate to the preclinical trial stage of 1:2,120. We use Artuso's (1997) estimates for subsequent success rates for typical testing programs (0.4 for preclinical; cumulative 0.25 for three clinical stages; 0.9 for new drug approval) to arrive at a cumulative probability of 1:23,600 from that set of samples.break

FIRM B . A set of 5,400 samples was analyzed against multiple targets. Through two stages of screening and further analyses, four leads were isolated and dereplicated. This implies a cumulative hit rate to the synthesis/modification stage of 1:1,350. Using Artuso's (1997) estimates of success beyond this stage (same as above, and 0.5 for successful synthesis/modification), a cumulative probability of 1:30,075 is estimated for that set of samples.

In the base case, we use a cumulative success rate of 1:30,000. This is higher than most terrestrial estimates, which are typically of the order of 1:100,000, and also higher than reported programs for shallow water marine invertebrates from the Pacific Ocean analyzed by the NCI (Newman 1995). The latter were estimated to generate commercial products at a rate of 1:80,000 at best. We utilize this poorer hit rate as a sensitivity case in our analyses.

Role of Coral Abundance

The amount of intact and live coral reef available in Montego Bay is the subject of some controversy, and the causes and extent of degradation remain the subject of open debate (Chapters 1 and 8). Literature has placed coral abundance as high as 74% and as low as 5% (Table 7.3). No systematic comprehensive surveys have been undertaken over the entire zone, and the nature of the estimates often differ methodologically. Moreover, there is significant local concern that overstating the amount of degradation may inadvertently deter tourists, even though most divers and tourists feel that the reef quality is quite good. For our purposes, we primarily rely on two results.

First, total coral area was analyzed based on GIS interpretation of polygons as presented in the Coastal Atlas of Jamaica (Natural Resources Conservation Authority ofcontinue

Table 7.3 Selected live coral estimates for Montego Bay

Source	*Coral abundance (%)*	*Basis*
Discovery Bay Marine Laboratory	10 to 74	1982 baseline estimate of 9 transects
Hughes (1994)	5 to 12	shallow water surveys of 2 sites
	15 to 25	rapid ecological assessment

Sullivan and Chiappone (1994)		
Hitchman (1997)	<13	14 sample sites in high impact area of Montego Bay and Bogue Lagoon
Hong Kong University of Science and Technology, Reef Check 1997	22 [1997] <22 [preliminary 1998]	Caribbean wide, the 1997 Reef Check survey noted that low levels were "possibly reflecting losses due to bleaching and disease"
Kent Gustavson, pers. comm. 1998	25 of substrate	personal estimate
Stephen Jameson, pers. comm. 1998	15 of substrate	personal estimate
Jill Williams, pers. comm. 1998	25 to 50+ of substrate	reports from local fishers, divers, and other resource users; many good sites "at depth"
Ruitenbeek *et al.* (1999a; see also Chapter 8)	24 to 38 of substrate	model equilibrium predictions for low stress and high stress conditions, excluding fishery sector reforms
Ruitenbeek *et al.* (1999a; see also Chapter 8)	29 to 43 of substrate	model equilibrium predictions for low stress and high stress conditions, including fishery sector reforms

Jamaica). This shows a total area of coral substrate of approximately 42.65ha. Second, long−term coral cover was based on fuzzy logic model calculations of the ecosystem under various stress assumptions (Chapter 8). At current levels of fishing pressure, the equilibrium abundance level was predicted to be 39.8%. With expected reforms to the fishery, it is expected that damage will decrease and abundance would increase to 42.7%. We note that under sustained economic growth as forecast by local authorities, the model predicted that coral quality would decline to the region of 20% to 25% abundance. For the purposes of simulation, therefore, we take a 43% abundance level as a status quo scenario and a 25% abundance level as a degradation scenario. In terms of reef areas, these levels correspond to 18.34ha and 10.66ha respectively.

Ecosystem Yield and the Species−Area Relationship

Following Reaka−Kudla (1997), we take a standard species−area relationship for marine organisms of the form $S=cA^z$. In the reference case, we take $z=0.265$, but a plausible range for this parameter is $z=0.2$ to $z=0.3$. Consistent with other findings, we assume each species yields on average three testable samples, each of which may in turn be assayed for multiple targets. The resultant number of "described species", "expected species", astabilizeed samples" is shown in Table 7.4. The actual value for z for marine systems has continued to be the subject of lively debate, ever since Simberloff and Abele (1976) observed for a coral reef site that two small areas could harbor more different species than one of the same total area. This would imply that a certain amount of fragmentation, or even die−back, was not necessarily undesirable, and that such isolation may in fact lead to increased speciation under certain conditions. The sensitivity of sample yield to this parameter is, however, of critical importance in deriving value estimates. For example, Table 7.4 shows a variation from 10,600 to 47,400 expected species in the reference case.

Valuation Results and Discussion

Using typical cost estimates for Jamaica and using typical hit rates and end−use values, scenario analyses were conducted using the parametric model. The referencecontinue

Table 7.4 Estimated coral reef species and sample numbers based on species−area relationships

	Reef area (ha)	*Described species*	*Expected species*	*Expected samples*	*Survey length (yrs)*
z =0.200					
100% cover	42.65	5,501	56,076	168,227	51.0
43% cover (reference case)	18.34	4,647	47,366	142,099	43.1
25% cover (degradation case)	10.66	4,169	42,497	127,492	38.6
5% cover (collapse case)	2.13	3,022	30,801	92,404	28.0
z =0.265					
100% cover	42.65	2,195	22,370	67,110	20.3
43% cover (reference case)	18.34	1,755	17,887	53,660	16.3
25% cover (degradation case)	10.66	1,520	15,492	46,477	14.1
5% cover (collapse case)	2.13	992	10,113	30,340	9.2
z =0.300					
100% cover	42.65	1,338	13,638	40,915	12.4
43% cover (reference case)	18.34	1,039	10,588	31,763	9.6
25% cover (degradation case)	10.66	883	8,998	26,994	8.2
5% cover (collapse case)	2.13	545	5,552	16,656	5.0

Note: The benchmark global value from which these are derived is from Reaka−Kudla (1997) using 93,000 total described coral reef species from an area of 588,960km2 . This implies by solution *c* =2,750 in the reference case, where *z* =0.265. A ratio of 10.2:1 expected species to currently described species is also based on Reaka−Kudla (1997, p. 93f), who suggests this as a most likely ratio based on assessments of rainforest and coral reef species−area dynamics. Survey length is based on a maximum of 3,300 samples annually.

case places marine bioprospecting values at just under US$2,600 per sample or US$7,775 per species. The per species values are somewhat higher than the typical estimates for terrestrial species, primarily because of the higher demonstrated success rates in terms of product development.

Using base case estimates of ecosystem yields for the Montego Bay area, coupled with the hypothetical sampling program that would be consistent with the NCI standards for marine sampling, a base case value of US$70 million is ascribed to the Montego Bay reefs. Of this, approximately US$7 million would be realistically capturable by Jamaica under typical royalty regimes or sample rental arrangements. None of this value is captured under existing institutional arrangements.

The base case value of US$70 million corresponds to equilibrium coral abundance levels of 43% on available substrate. Ecosystem model predictions set this as a long−term equilibrium in the event of no additional stresses on the reef. Where current economic growth places new stresses on the reef, a predicted "degradation" to approximately 25% is set as a comparative case. Under this latter case, the global value of the reef would be US$66 million, a loss of about US$4 million.

The first differential of the benefit function is calculated to arrive at an ecosystem marginal "global planning price" of US$530,000/ha or US$225,000/% coral abundance. For Jamaica's share, the relevant "local planning price" computes to approximately US$22,500/% coral abundance. The model demonstrates the sensitivity of total and marginal values to ecosystem yield and institutional arrangements for capturing genetic prospecting value. For example, sensitivity analyses within the plausible range of species−area relationships generated global benefits for the Montego Bay reef of US$54 million to US$85 million, with reef prices ranging from US$698,000/ha to US$72,500/ha.

The relatively low "price" and the apparently small drop in benefits from significant coral reef degradation underlines the importance of the ecosystem yield. In effect, two factors contribute to this result. First, because of the non−linear relationship between species and area, a decrease in coral abundance does not translate one to one into a decrease in species or available samples. Second, the loss in available samples is not experienced immediately; annual sampling constraints under a sustainable program using the NCI standards at Montego Bay would yield approximately 3,300 samples annually. The economic effect of these "lost samples" is therefore discounted substantially and would consequently have less of an impact on current management decisions.

Detailed sensitivity results are shown in Table 7.5. The analysis confirms that the impacts of the incremental institutional costs for operating a national program consistent with the recommendations by Putterman (1998; Chapter 12) are minimal. It would appear, therefore, that such institutional investments are warranted.

The first significant conclusion is that ecosystem values, in terms of prices that would enter a planning function for land allocation and investment decisions, are more sensitive to assumptions regarding ecosystem yield than they are to most economic parameters considered. At low values of *z* , implying relatively little response of species to changes in area, marginal values drop to as low as US$3,000/% coral abundance. This can also be demonstrated through the first differential of the value function (Figure 7.1). The marginal benefit curve is very steep at low levels of coral abundance, implying high values when the resource is about to "collapse", but at the levels relevant for planning (generally taken to be between 20% and 50% coral abundance), planning prices are relatively low.

Second, the results show a number of important potential risk mitigation strategies. In the base case of a 10% net profit share, the expected value of the sampling generates a marginal benefit to Jamaica of US$22,600/% coral abundance. Conversion of this share to a US$250 sample collection fee, or to rentals equivalent to this fee, would generate a similar price of US$21,800/% coral abundance. This price is maintained, of course, even if hit rates are lower or R&D costs go up as the value is linked only to the sampling program. It is probable that, in general, an appropriate risk mitigation strategy for Jamaica would likely involve some combination of royalty or profit share payment (α >0) and modest sample fee. Such a strategy would guarantee captured values of the same order as those expected in the reference case, but would reduce exposure to hit rate uncertainties, product marketing uncertainties, and ecosystem dynamics.

In addition, we note that even with this sampling program there is, of course, no guarantee of a hit. One can, in fact, calculate the expected number of samples that must be collected to generate at least one hit. When the hit rate is 1:30,000, this corresponds to 21,000 samples, and when it is 1:80,000 the expected number of samples is 55,000. This higher number is almost identical to the base case expectation that the system will yield 53,660 samples. In the mineral prospecting literature, the situation of not achieving a "hit" is referred to as "gambler's ruin" and, while venture capital markets act to take on risks like this, governments are often reluctant to enter into such arrangements. In this case, therefore, a public body wouldcontinue

Table 7.5 Model results for Montego Bay marine pharmaceutical bioprospecting valuation. Parametric assumptions relate to the z−factor within a species−area relationship (*S*=*cA* z), a contingent net profit share (α), and a fixed sampling fee level (*f*). Model solves for total samples (*N*) available at Montego Bay and the typical length (*T*) of sampling program that would be required to harvest these. Economic calculations relate to the expected net present value of the program to the world (*NPV* G) and to Jamaica (*NPV* J). A first differential of the function yields a global "price" (*P* G) and Jamaican "price" (*P* J) for coral reefs that could be applied within a planning framework equating marginal benefits to marginal costs.

Case	*z*	α (%)	*f* (US$ per sample)	*N*	*T* (yrs)	*NPV* G (million US$)	*NPV* J (million US$)	*P* G (US$%)	*P* J (US$%)
Base Case Scenario at 43% Coral Abundance									
Referencea	0.265	10	0	53,660	16.3	70.09	7.01	225,614	22,561
High *z*	0.3	10	0	31,763	9.6	54.46	5.45	297,516	29,752
Low *z*	0.2	10	0	142,099	43.1	84.61	8.46	30,901	3,090
Fee only	0.265	0	250	53,660	16.3	70.09	6.76	225,614	21,763
High *z*	0.3	0	250	31,763	9.6	54.46	5.25	297,516	28,699
Low *z*	0.2	0	250	142,099	43.1	84.61	8.16	30,901	2,981
Blended revenue shares	0.265	8	50	53,660	16.3	70.09	6.96	225,614	22,402
High *z*	0.3	8	50	31,763	9.6	54.46	5.41	297,516	29,541
Low *z*	0.2	8	50	142,099	43.1	84.61	8.40	30,901	3,068

High R&D cost [R/C ratio=1.1:1]	0.265	10	0	53,660	16.3	17.64	1.76	56,783	5,678
	0.265	0	250	53,660	16.3	17.64	6.76	56,783	21,763
	0.265	8	50	53,660	16.3	17.64	2.76	56,783	8,895
Low hit rate [1:80,000]	0.265	10	0	53,660	16.3	25.02	2.50	80,525	8,052
	0.265	0	250	53,660	16.3	25.02	6.76	80,525	21,763
	0.265	8	50	53,660	16.3	25.02	3.35	80,525	10,795
Unconstrainedb	0.265	10	0	53,660	1.0	139.07	13.91	1,054,202	105,420
High *z*	0.3	10	0	31,763	1.0	82.32	8.23	699,475	69,948
Low *z*	0.2	10	0	142,099	1.0	368.27	36.83	2,145,937	214,594
Institutionalc	0.265	10	0	53,660	16.3	70.09	6.96	225,614	22,561
Degradation Scenario at 25% Coral Abundance									
reference *z*	0.265	10	0	46,477	14.1	66.12	6.61		
high *z*	0.3	10	0	26,994	8.2	49.37	4.94		
low *z*	0.2	10	0	127,492	38.6	84.06	8.41		

a Uses study result hit rate of 1:30,000 and sales:R&D cost ratio of 1.5:1. *P* G and *P* J may be converted to US$/ha basis by dividing by 0.4265.

b Assumes all samples are collected and subjected to preliminary screening within 1 year.

c Includes institutional overheads of central government agencies.

likely prefer some guaranteed income, even if it means giving up some future royalty position.

Third, it is instructive to consider how values shift under an accelerated unconstrained sampling program. As noted by Evenson and Lemarié (1998), geographical considerations in optimal global search programs may imply intensifying searches in those areas with lower costs and higher potential yields. While we have not compared the Montego Bay site to other sites, the economic implication of such an intensified search is that samples should normally be gathered and screened as rapidly as possible in the preferred sites. Simulation results for Montego Bay show that relaxing the sampling constraint causes the base case expected value to double, from US$70 million to US$139 million. This comes as a consequence of accelerating expected discoveries, and thus diminishing the effects of discounting. The effects on planning prices are, however, more profound. In the base case, these increase from US$225,000/% coral abundance to just over US$1 million/% coral abundance. In the case where *z* =0.2, planning prices could exceed US$2 million/% coral abundance, equivalent to some US$5 million/ha.

Logistically, this latter result would require extraction of some 142,000 samples from the site over a ten month period. This would in turn require having almost 200 divers in the water daily, with their itinerant support structures for sample storage and analysis. In the case of Montego Bay, such activity levels far exceed the capacity of the support infrastructure, saying nothing about the potential impacts that such activities might have on the reefs themselves. Such collection realities are, in many cases, likely to constrain optimal search programs even at the most promising sites. But the results of the sensitivity analysis show us that concerns such as yield, and how a single site fits into a larger global picture, are important aspects of valuing coral reef biodiversity.break

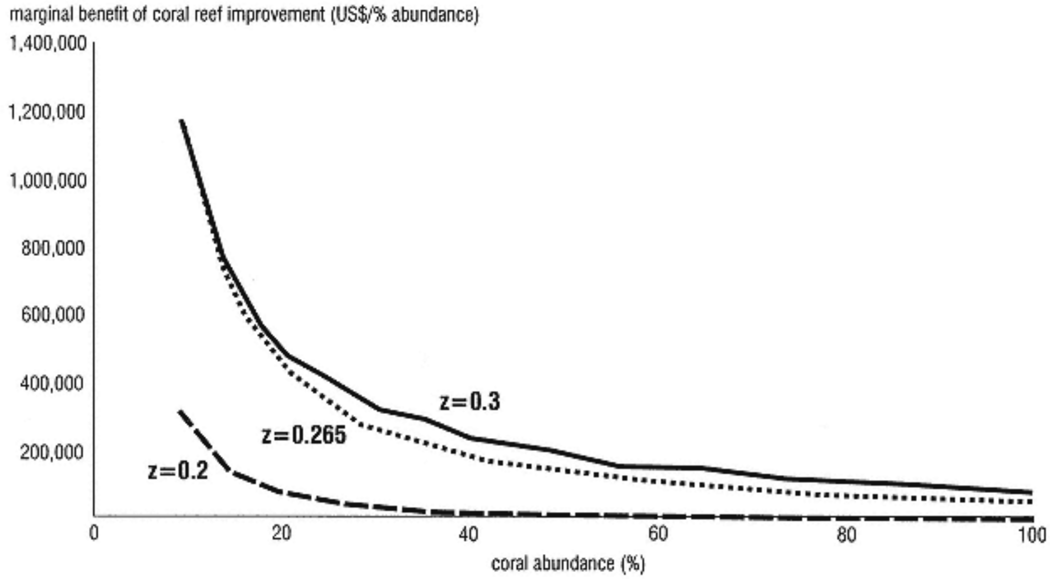


Figure 7.1
Marginal benefit function for Montego Bay bioprospecting values

Chapter 8—
Interventions for Coral Reef Conservation—A Least Cost Model

Jack Ruitenbeek
H.J. Ruitenbeek Resource Consulting Limited, Gabriola, BC, Canada

Mark Ridgley
Department of Geography, University of Hawaii at Manoa, Honolulu, HI, USA

Steve Dollar
School of Ocean and Earth Science & Technology, University of Hawaii at Manoa, Honolulu, HI, USA

Richard M Huber
Environmentally and Socially Sustainable Development Sector Management Unit, Latin American and Caribbean Region (LCSES), The World Bank, Washington, DC, USA

This chapter provides a description of the methods and results of studies undertaken using a least cost modeling framework for coral reef management and protection. The primary site investigated was the Montego Bay Marine Park (Montego Bay, Jamaica) and the surrounding area with a view to identifying the least cost interventions for coral reef management.

The Montego Bay site was chosen for a number of reasons. Foremost, recent political commitment in the region has resulted in the establishment of the Montego Bay Marine Park (the Park) as a protected area that will be managed to promote sustainable reef−based tourism while still accommodating a local fishery (Chapter 2). Impacts on the Park are varied, ranging from over−fishing to pollution impacts from sedimentation, ocean dumping from cruise−ships, and influx of nutrients through ground and surface water transport. From an ecological perspective, the area has been studied over a long period of time as there is continued interest in the precise extent and cause of reef degradation (Hughes 1994; Lapointe *et al.* 1997; O'Callaghan 1992; Sullivan and Chiappone 1994; USAID 1996).

The area is economically important, supporting a recently established free trade zone. Valuation work by Gustavson (1998; Chapter 5) places tourism and recreation values at a net present value (NPV) of US$315 million and coastal protection at US$65 million. Artisanal fisheries are valued at US$1.3 million. Contingent valuation work undertaken by Spash *et al.* (1998; Chapter 6) place the non−use benefits of the Montego Bay Marine Park area at almost US$20 million. Finally, Ruitenbeek and Cartier (1999; Chapter 7) estimate that the area's biodiversity resources have an expected NPV of US$70 million to the pharmaceutical industry through marine bioprospecting, although none of this value is currently captured under existing institutional regimes.

While this paper focuses its empirical work on Montego Bay, the models developed here are generic in nature, are transferable to other sites, and are relevant to management problems associated with optimizing the benefits achievable from coral reefs and their contiguous coastal ecosystems. These ecosystems frequently act as the backbone of local economies, and perform other useful functions such as filtering organic waste and mitigating coastal erosion. They yield medicines and tools for biomedical research, and serve as an irreplaceable source of genetic biodiversity, educational and scientific knowledge, and aesthetic pleasure. Coastal ecosystems are fragile, and are adversely affected by local sewage pollution, excessive tourism, and the accumulation of wastes generated by upland agriculture, logging, or industrial activities. Effective management of these resources requires usable analytical tools that help understand the economic and technical linkages between the ecosystems, on the one hand, and human activities that affect them, on the other. Such tools are largely lacking at present.

Some coral reef areas in the tropics are under particularly heavy pressure and are deteriorating (Chapter 1).continue

Reversing this progressive degradation, in both an economic and ecological sense, requires successful management. But apart from numerous practical issues, a key conceptual problem facing policy−makers is a lack of quantitative models and procedures designed to facilitate a comprehensive economic and ecological analysis, including identification, measurement and prediction of the effects of economic activity on coastal marine ecosystems. In particular, the degradation of coral reefs has not been extensively analyzed in a framework amenable to economic policy analysis. This has made it difficult to develop a priority ranking of policy and investment interventions in terms of their cost−effectiveness (i.e., there are no means by which to formulate least cost plans to control continued deterioration).

A cost−effectiveness analysis framework is therefore being developed—the focal point being to render cost−effectiveness in terms of coral reef management and protection opportunities. The potential scope of the overall general model includes all potential economic activities, interventions, and environmental impacts in the coastal zone. The models developed to date, however, are somewhat more limited as they are intended to explore selected methodological and practical issues in economic and ecological modeling of coral reefs. Specifically, three research problems are addressed simultaneously within the current framework:

Normalization of impacts . First, we ask whether it is feasible to render the impacts of various economic activities in terms of a single biophysical parameter. Conventional ecological approaches to this problem such as those employed by Tomascik and Sander (1985, 1987) yield "dose−response" functions, but such functions are not typically capable of covering the full range of economic activities.

Separability of benefits and costs . Second, we ask whether it is economically meaningful to separate economic benefits from costs in analyzing management choices. Conventional economic approaches to this problem rely on integrating benefits and costs (Cesar 1996; Dixon 1993) or, when benefits are not quantifiable, on ranking choices within a cost−effectiveness framework (Eskeland 1992; Ruitenbeek 1992).

Identification of preferred options . Third, we ask whether one can identify any clear preferred management options for a specific site. As noted above, we have selected Montego Bay, Jamaica.

To place this research in perspective, it is useful to illustrate the management problem in terms of how it is often dealt with using conventional cost−effectiveness frameworks. Conceptually, a conventional analysis framework would provide a ranking of the cost−effectiveness of various policy or project interventions. The outcome of any modeling effort would be a cost curve of the type shown in Figure 8.1. The step−wise cost curve representscontinue

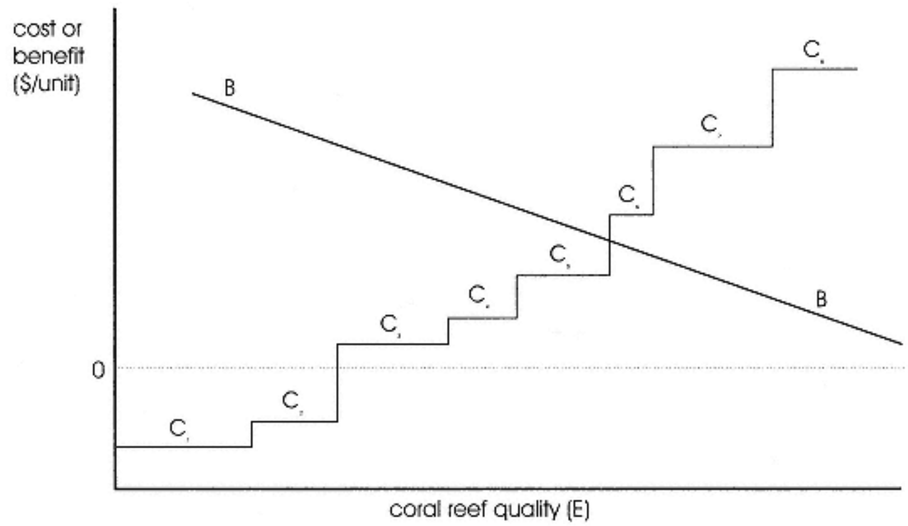


Figure 8.1
A conventional framework for optimization or cost−effectiveness analysis (Cx =measure of cost−effectiveness of intervention X in reducing effect or impact; X=policy intervention or investment; B=marginal environmental benefit curve associated with quality indicator E).

a series of interventions, each of which results in a reduction of negative environmental impacts; these interventions will, over time, cause an increase in coral abundance. The first few interventions are relatively inexpensive, and may have no net costs associated with them if, for example, they concomitantly generate economic benefits not associated with coral reef improvement. Subsequent interventions become more expensive, on a cost per unit basis. Figure 8.1 also shows a declining benefit curve, which illustrates what is typically called a "damage function." The damage function shows the marginal benefit associated with the reduced environmental damage (e.g., increased fishery productivity, higher tourism potential, or reduced shoreline erosion). Under this conventional construct, an economic optimum occurs where the benefit and cost curves intersect. The framework is often regarded as useful even if benefits are uncertain or not known. In such a case, it is often argued that the most cost−effective interventions should be undertaken first and that, from a management perspective, one need only systematically move up the cost curve.

This research, however, places in question this simplified conventional approach. The cost curve of the type contemplated in Figure 8.1 depends on the separability and independence of individual interventions. In complex systems, such independence rarely exists. Cumulative or synergistic impacts of pollutants on reef health, for example, must be reflected in management decisions. Reliance on a conventional cost−effectiveness model can, in such cases, lead to incorrect decisions. We demonstrate this empirically through developing a generic complex systems model that does not rely on the separability assumptions inherent in the conventional model, and through applying this generic model to a practical case study site in Montego Bay, Jamaica.

Early Modeling Results

The research process permitted testing of a number of methods for linking different ecological and economic models, and for experimenting with different types of fuzzy logic based predictive systems (Table 8.1). Empirical work was conducted at three sites—the Maldives, Curaçao, and Montego Bay, Jamaica. In all cases, predictive simulation models were created using fuzzy logic systems to analyze a series of potential interventions. The primary purpose of these prototype models was to explore different model forms and test the sensitivity of results to such forms. While in all cases the models generated empirical results relating to specific indicators of cost−effectiveness, the results themselves were often not regarded as reliable because of the preliminary nature of cost estimates or ecological linkages developed in each prototype.

The following outline key lessons learned from these modeling exercises:

Treatment of economic policy . Model structures could readily incorporate either investments or policy interventions in their impact modeling.

Ecological complexity . Early model structures were computationally limited in the number of input variables that could be managed. Also, models that incorporated feedback loops through recursiveness in the ecological parameters (i.e., treating an output variable from one period as an input variable to the next period) were often unstable and provided poor predictive capability. Final model structures were therefore selected that avoided recursiveness and introduced multiple stages to improve computation efficiency.

Water quality transforms . Data deficiencies and localized complexities make this element the "weak link" in most models. For Montego Bay, the complexity of the mixing functions does not lend itself well to typical linear transport models, and continued experimentation with model structures persists through the final stages and is likely also to form an on−going research requirement.

Time delays . Early models specified different functional forms for translating current impacts to future equilibrium reef quality, including the specific dynamic trajectory of changes in reef quality as it approached this equilibrium quality. Sensitivity tests undertaken at the prototype development stages showed that ranking results were relatively insensitive to assumptions regarding this trajectory, and that the major factor was simply the time delay required to reach equilibrium. Given the significant scientific uncertainty in addressing such dynamic elements, final model development focused simply on the "long−term equilibrium" reef quality taken at some fixed future time period determined by expert opinion.

Computation . All of the prototype model results provide cost−effectiveness comparisons of single interventions from a common starting point using a simulation environment. Experimentation with multiple interventions showed that these interventions, at times, provided improved cost−effectiveness because of non−linearity in the ecological response function. Final modeling structures therefore concentrated on the adoption of an optimization framework that could reflect such non−linearities.

Interface . The educational value of the early models was demonstrated through incorporating all of the computational routines into a user−friendly interface for the Maldives and Curaçao. The interface provides a simulation environment that permits decision−makerscontinue

Table 8.1. Basic model structure and early empirical results for three study sites.

Location	*Montego Bay, Jamaica (prototype)*	*Curaçao, south coast*	*North and South Male Atoll, Maldives*	*Montego Bay, Jamaica (final)*
Year completed	1995	1996	1996	1998
Economic Sub-Model				
Number of economic sectors	8	7	4	8
Number of investment interventions	8	4	11	7
Number of policy interventions	2	0	2	1
Non-linear (scale-dependent) cost estimating functions	●			●
Ecological Impact (Fuzzy) Model				
Number of levels	1	1	1	3
Number of inputs	7	7	6	9
Recursiveness in model		●		
Output - coral abundance	●	●	●	●
Output - coral rugosity			●	
Output - recruitment	●			
Output - reef fish			●	●
Water Quality Model				
Single part linear	●		●	
Single part non-linear		●		●
Zonal differentiation		●	●	
Fuzzy logic estimator				●
Integrated Model Structure				
Non-linear time delay	●			
Fixed delay	●	●	●	●
Time horizon (yrs)	85	10	10	25 and 55
Simulation model - single intervention	●	●	●	●
Simulation model - multiple intervention	●	●		●
Optimization				●
User-Friendly Interface		●	●	●
Empirical Findings				
Low cost intervention	outfall	protection	mining bans	
Moderate cost intervention	sewage treatment	outfall	outfall	
High cost intervention	reforestation	sewage treatment	sewage treatment	

to ask "What if?" types of questions in reef management decisions.

Empirical results . Empirical results relating to prototype development (for any of the three sites) were used primarily as a pedagogical tool in explaining how economic activities and interventions interact with reef quality. The results themselves were not regarded as adequately robust to provide strong policy guidance. Empirical results for the final modeling at Montego Bay are, however, regarded as suitably robust to provide some limited policy guidance.

From the prototype development stage, two critical research issues were identified for further model development at the Montego Bay study site: (i) developing a more computationally efficient ecological predictive model; and, (ii) developing an "optimization shell" for the core model. Two other issues—water quality transform models and improvement of the "time delay" components of the ecological response to system stresses—remain important research issues, but could not be pursued in the Montego Bay site model because of data and other constraints.

Methodology

General Statement of Problem and Model Structure

The model developed in the final stages of this research consists of two distinct sub−models: (i) a biophysical or ecological reef impact model relying on fuzzy logic; and, (ii) an economic model describing current and future economic activities, policy interventions and pollution loads in Montego Bay (Figure 8.2). The sub−models are linked and run side by side either in a simulation mode or an optimizing mode to predict future reef quality, economic activity levels, and economic policies.

The objective of the model is to achieve a target coral reef quality (Q) by identifying an optimal set of interventions ($\mathbf{S}°$) such that the cost (C) of implementing this intervention set is minimized. The nature of the analytical construct is such that this is equivalent to maximizing coral reef quality subject to a budget constraint. As noted above, conventional approaches to this type of problem have used a cost curve formulation, in which the cost of each potential intervention is analyzed along with its resultant impact on reef quality. A measure of cost−effectiveness (in terms of $/% of coral cover improvement, for example) is then derived. An optimal set of interventions then involves selecting first those interventions with a low cost−effectiveness measure ($/% improvement), and subsequently moving into higher measures. A supply curve is then derived similar to that shown in Figure 8.1.

But this conventional approach is flawed in many real life circumstances. The flaw relates to the non−linear nature of the response function, and the effects of cumulative interventions. It is readily shown, for example, that such an approach can lead to non−optimal results if the response function is unresponsive to small changes in inputs (such as sediment or pollution loads) but very responsive to large changes in inputs. In such circumstances, the first intervention will inevitably have very low cost−effectiveness (as it will generate zero response) while subsequent interventions will have higher cost−effectiveness. The appropriate analytical framework is, therefore, not to look at the problem from the point of view of individual interventions, but from the point of view of a group of interventions having a cumulative effect.

Generalized Optimization Problem

The overall optimization problem involves selecting an optimal level of coral reef quality ($Q°$) such that net benefits are maximized. To derive this result, we generate a cost function $C\{Q\}$ and a benefit function $B\{Q\}$. The focus of this work is on the cost function. The benefit function is treated in Ruitenbeek and Cartier (1999; see Chapter 9).

In the generalized conceptual cost model, we consider the following:

Q = scalar indicator of coral reef quality (% coral abundance);

$\mathbf{F}$ = vector of biophysical factors that influence coral reef quality;

F_j = level of factor j such that $j = 1, 2, 3, \ldots, J$;

S = vector of economic interventions;

S_k = level of economic intervention type *k* such that $k = 1, 2, 3, \ldots, K$;

I_k = unit level of economic intervention type *k* ;

n_k = number of units of intervention type *k* such that $S_k = n_k * I_k$ and $n_k = 0$;

$\mathbf{n} = \{n_1, n_2, n_3, \ldots, n_K\}$;

C_k = cost of intervention S_k ; and,

r = discount rate.

The following describes the full least cost optimization problem. For a given target $\hat{Q}$, minimize *C* by choosing **n** subject tobreak

$$C = C_1 + C_2 + \ldots + C_k$$
$$Q\{\mathbf{F}\} \geq \hat{Q}$$
$$F_j = F_j\{\mathbf{S}\}$$
$$C_k = C_k\{n_k, r\}$$

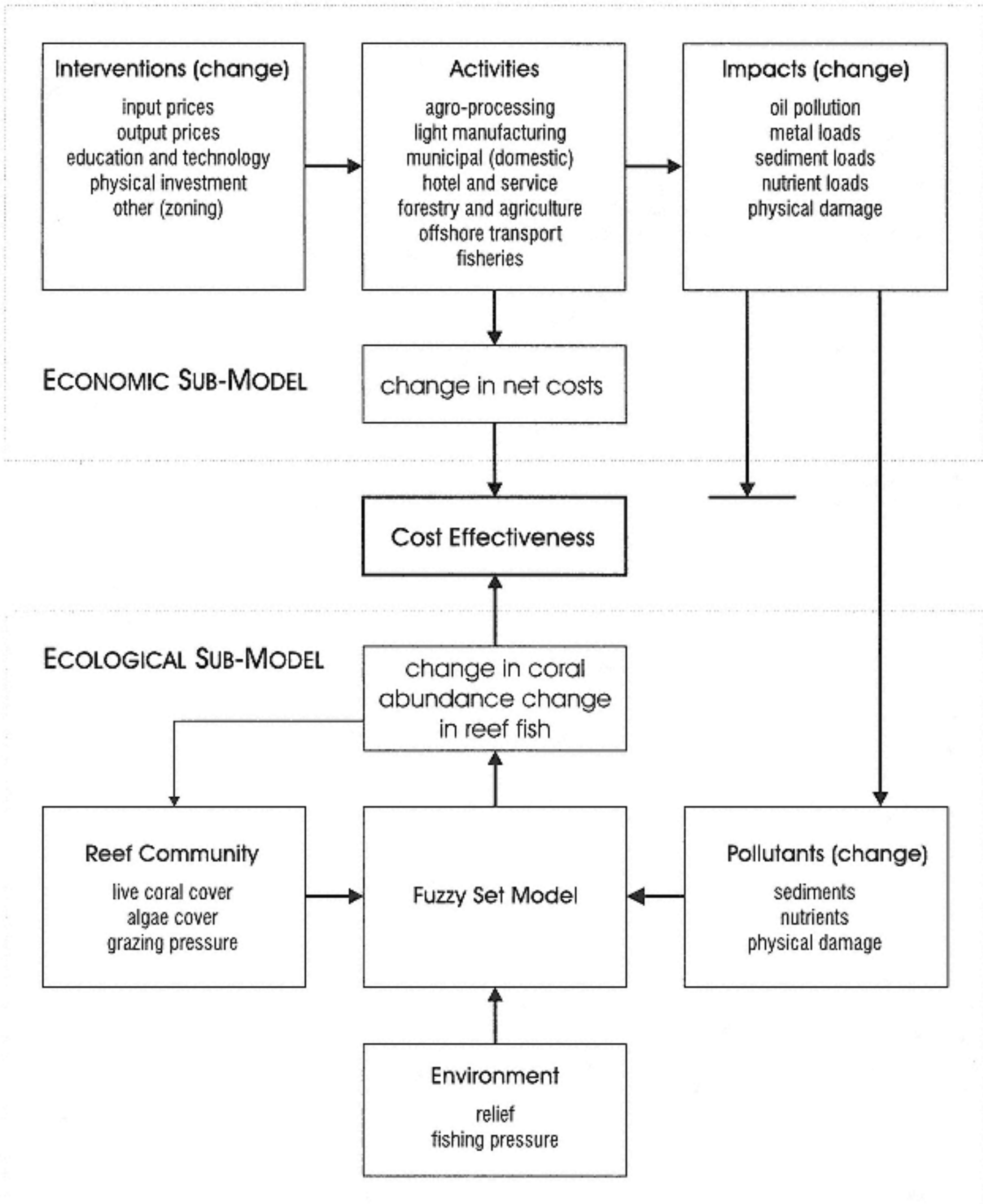


Figure 8.2.
Generalized fuzzy logic based cost−effectiveness model. The model structure shows two components: an economic sub−model incorporating pollution impacts arising from economic activities, and an ecological dose−response sub−model that (potentially) incorporates recursive feedback loops. A cost−effectiveness measure is expressed in terms of a change in net costs divided by a change in reef quality.

The cost function, which can subsequently be used in an overall benefit−cost optimization, is then simply $C = C\{Q\}$ for all technically viable levels of Q. Through simulation or iteration a cost curve envelope can be derived with each point on this curve representing a vector of interventions.

Biophysical Model Structure

The purpose of the biophysical model is to describe the relationship $Q = Q \{F\}$ in the above optimization problem. The general biophysical model is based on a generic coral reef system model (Figure 8.3). It relies extensively on fuzzy logic based systems in describing a complex dose−response function.

In general, a reef impact model should exhibit at least two key features. First, it should represent existing knowledge of reef ecology at a detail and within the bounds of accuracy sufficient for project evaluation. A particular requirement to achieve this aim is the model's ability to show the effects of non−linear relationships among pollutants, coral reefs, and the reefs' larger marine environment. Second, the model should be operable and provide useful results with the information available at or for any location of potential application. This is a crucial requirement since quantitative data on many oceanographic and biotic variables are frequently sparse, inaccurate, patchy, of short duration, or otherwise deficient for conventional analytical (i.e., exhibiting closed−form solutions) or numerical modeling. On the other hand, considerable qualitative data are available for almost all reefs of the world. Much of these data are in the form of expert knowledge or human judgment, derived either from formal education or from first−hand experience. In poor tropical countries, the latter may well be the dominant form of information available, in terms both of quality and abundance (Johannes 1981). In some locations, it may be the only form available.

These two desiderata correspond to two defining characteristics of the model: (i) the recognition of the role played by the physico−chemical environment in influencing the interaction between inputs (such as pollutants) and reef biota and other processes; and, (ii) the use of a fuzzy logic approach to represent cause−effect relations.

How material inputs affect a reef is a function not only of the magnitude and concentration of the inputs and the condition of the reef at the time, but also of oceanographic variables such as those characterizing the hydrodynamics (e.g., mixing and residence time). These determine the concentration and ultimate exposure of the input to the reef, and the supply of chemical reactants, upon which the uptake and utilization of nutrients by biota depends.

Data deficiencies, coupled with marked limitations on resources for reef research and management in the developing tropics, led to the adoption of a fuzzy logic (or fuzzy sets, fuzzy systems) approach. With the theory first introduced in the 1960s (Zadeh 1965), fuzzy logic has proven adept at describing and helping to manage a variety of complex non−linear systems, initially those dealing primarily with electromechanical control of industrial and manufacturing processes (Kosko 1993; McNeill and Freiberger 1993), but more recently geophysical, ecological and economic systems (Ayyub and McCuen 1987; Bardossy and Duckstein 1995; Kainuma *et al.* 1991; Meesters *et al.* 1998; Munda 1995). Fuzzy methods possess a number of features that make them particularly applicable to the prediction and management of these latter systems. First, they enable rigorous, quantitative system modeling even though the variables and their interrelationships are described initially (i.e., as inputs to the model) in qualitative terms. This is especially appropriate when human knowledge about the behavior of systems, such as reef ecosystems, is approximate and imprecise at best, rendering adequate parameterization all but impossible. The ability to accommodate qualitative data concerning reef systems means that more information about them, from more and different kinds of sources, is likely to be available. Since fuzzy logic allows systems to be described as sets of "if−then" (linguistically specified rules relating inputs to outputs), it thus offers great potential to utilize human judgment and experiential knowledge, rather than being dependent upon mathematized theory or quantitative databases.

A brief, qualitative reprise of the bare essentials of fuzzy rule−based modeling is provided in Box 8.1. More detail is given in Ridgley *et al.* (1995) and Ridgley and Dollar (1996), as well as in standard references (Bardossy and Duckstein 1995; Kosko 1992; von Altrock 1995).

Figure 8.3 depicts the variables and structure of the fuzzy model. Variables, variable names, and fuzzy set ranges are defined in Table 8.2. The model specifies 13 variables explicitly. Three fuzzy sets are used for each input variable, while output variables are described with up to five fuzzy sets. This allows more differentiation of outputs without an increase in the number of rules. The organization into levels slows the proliferation of rules with the addition of variables. With three fuzzy sets per input, and a deterministic water quality transform function, not more than 747 rules would ever be needed to completely saturate the knowledge base. If this system were to have been modeled as a single level system, over 177,000 rules would have been required.break

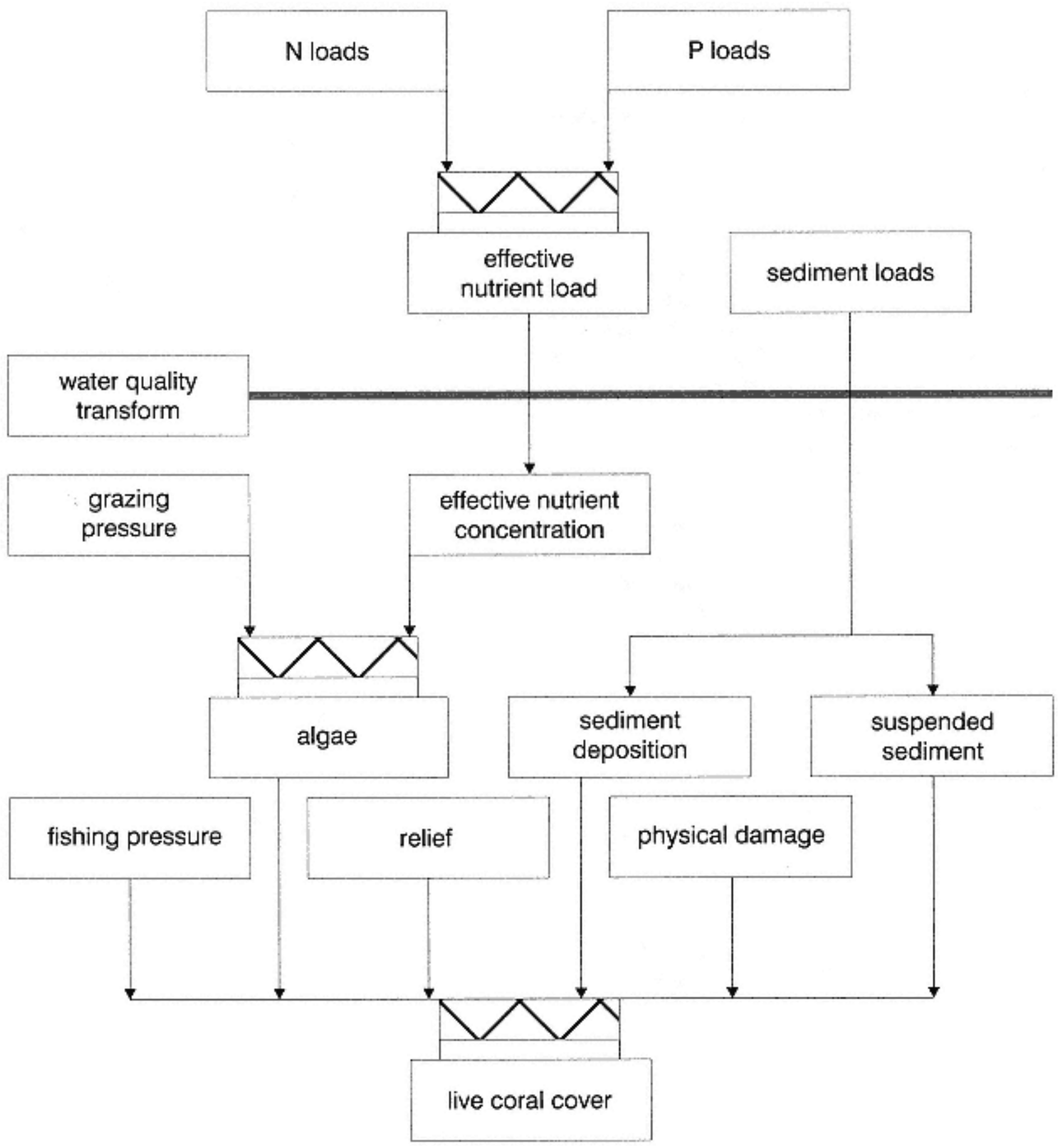


Figure 8.3.
Coral reef impact model structure. The generic final ecological sub−model consists of four stages: (i) nitrogen (N) and phosphorus (P) loads are converted to effective nutrient load in a fuzzy logic transform; (ii) sediments and nutrients are converted to nutrient concentrations, sediment deposition and suspended sediment at the coral reef site using a water quality transform function that can consist either of a deterministic linear transform, a deterministic non−linear transform, or a fuzzy logic based transform; (iii) nutrient concentration and grazing pressure are converted to algae cover in a fuzzy logic transform; and, (iv) six primary determining variables are converted into live coral cover using a fuzzy logic transfor
Where a deterministic water quality transform is used, and where each input takes on three potential values (low, medium,

and high), the system requires a maximum rule base of 747 rules (32 + 32 + 36).

Box 8.1—
An Informal Introduction to Fuzzy Modeling

Fuzzy rule−based models relate a set of inputs to a set of outputs. The inputs in this case refer to nutrient and sediment influx, physical oceanographic characteristics ("mitigators"), and biotic state variables. Outputs also refer to biotic state variables, although not necessarily the same as the biotic inputs. Once inputs and outputs have been identified, the first step is to define the range of possible values (measurements) for each one and to divide that range into a set of overlapping intervals. Each interval defines a *fuzzy set* , referring to a relative magnitude of that input (e.g., high, medium, or low); fuzzy sets are thus sometimes referred to simply as "adjectives". Such intervals are based on expert judgment.

Fuzzy sets are so named because of the ambiguity associated with the membership of certain values in those sets. Such ambiguity is characteristic of the linguistic terms we use to label the sets (e.g., high, medium, and low). A particular quantitative value (e.g., 25%) could be associated with more than one fuzzy set (e.g., both low and medium). How plausible it is that the value in question belongs to a particular fuzzy set is termed its degree of membership, represented by a number between 0 and 1.0, inclusive. Most quantitative values are associated with more than one fuzzy set, usually to different degrees. A value's membership in a given fuzzy set is determined by its *membership function* . Membership functions are usually represented as geometric figures—triangles or trapezoids being the two most common—whose "tops" correspond to the full membership of 1.0, bases (the intervals defining the fuzzy sets) to a value of 0.0, and sides to intermediate values. Thus, we can conceive of each membership function as having a certain area associated with it, a view that is helpful in understanding the operation of scaling discussed below.

Given a set of inputs and outputs, their fuzzy sets, and corresponding membership functions, input−output rules are specified in terms of the fuzzy sets. The set of such rules, called the *knowledge domain* , defines a mathematical relation and constitutes a *fuzzy system* , also called a *fuzzy associated memory* (Kosko 1993). For example, a hypothetical two input, one output rule could be the following: "If nitrogen influx is high and residence time is low, then coral abundance is high." Each input in a rule is called an *antecedent* , and each output a *consequent* .

With the knowledge base established, one now needs a way to transform a given set of quantitative inputs, with their corresponding membership degrees, into quantitative outputs. Three steps are followed to do this, often referred to as *scaling, combination* , and *defuzzification* :

1. *Scaling* . Scaling is the process of determining the degree to which each rule applies, called the rule's *activation level* . If a rule has a single antecedent, the activation level is the value's membership in that fuzzy set. If the rule has two or more antecedents with different membership degrees, fuzzy logic operators are used to determine the most appropriate activation level. If the antecedents are connected with the "and" conjunction (as in the example of nitrogen and recruitment above), then the minimum membership degree is used; if "or" is used, then it is the maximum membership. However it is obtained, the activation level is then used to scale the output fuzzy set by reducing its area and shape accordingly. The amount of reduction and the shape modification varies with the scaling method used.

2. *Combination* . In this step, all scaled consequents from active rules (i.e., whose activation levels are positive) are combined via superposition—that is, superimposing the scaled fuzzy outputs on top of each other. The composite fuzzy output is then determined through *max combination* (the point−wise maximum membership degree of the superimposed consequents) or via *sum combination* (the point−wise sum of the membership degrees of the overlapping consequents). The latter is the newer of the two approaches, equivalent to a weighted average of the active rules.

3. *Defuzzification* . The fuzzy composite consequent is transformed to a single quantitative ("crisp") output value, either that corresponding to the centroid of the consequent set, or that having the maximum degree of membership.

Table 8.2. Input and output variables and their associated fuzzy sets, showing typical values. Square brackets indicate range. Asterisk (*) signifies an output variable. Where no values are shown for a specific fuzzy set, that set is not used. All input variables are defined by three fuzzy sets, while output variables are defined by four or five fuzzy sets.

Variable	Low	Medium−low	Medium	Medium−high	High
N loads (mmol m2 day1)	2 [0 to 6]		15 [5 to 50]		80 [40 to 200]
P loads (mmol m2 day1)	0.5 [0 to 1]		4 [0.8 to 6]		7 [5 to 10]
Effective nutrient load*	0.25 [0 to 0.5]	0.75 [0.4 to 1]	1.5 [0.8 to 3]	4 [2.5 to 6]	8 [5 to 10]
Effective nutrient concentration (mM)	0.02 [0 to 0.05]		0.1 [0.04 to 0.15]		0.3 [0.14 to 0.5]
Grazing pressure (kg ha1 day1)	10 [0 to 30]		40 [25 to 100]		110 [80 to 150]
Algae (%)*					

	5 [0 to 20]		25 [15 to 50]	40 [25 to 60]	60 [40 to 100]
Sediment loads (g m2 day1)	50 [0 to 100]		150 [80 to 500]		600 [450 to 800]
Suspended sediment (g m3)	0.6 [0 to 2.5]		2.5 [1.5 to 5]		5 [4 to 10]
Sediment deposition (g m2 day1)	2 [0 to 10]		20 [8 to 50]		60 [45 to 80]
Physical damage (index)	0.5 [0 to 1]		1 [0.5 to 2.5]		3 [2 to 4]
Algae (%)	5 [0 to 20]		25 [15 to 50]		60 [40 to 100]
Fishing pressure (kg ha1 day1)	2 [0 to 5]		6 [4 to 15]		20 [12 to 25]
Relief (rugosity index)	1.2 [1 to 1.5]		2 [1.25 to 3]		4 [2.5 to 5]
Live coral (% on available substrate)*	8 [0 to 15]	18 [10 to 25]	35 [20 to 50]	50 [40 to 65]	70 [60 to 100]

The system of fuzzy logic rules, in effect, represents a multi−dimensional dose−response function. We can represent a "slice" of this function by generating a surface representing one output variable as a function of two input variables, with all other variables held constant (Figure 8.4).

Effective Nutrient Concentrations

It is generally considered that nutrients (primarily nitrogen and phosphorus) are one of the most important potential anthropogenic impacts to coral reefs (Chapter 1). While nutrients may or may not have a direct impact on coral growth and physiology, depending on the concentration, the major effect of increased nutrients on corals is likely a decrease in their competitive advantage over benthic algae, which can exhibit increased growth rates with increased nutrient concentrations. However, we recognize that the "effective nutrient concentration" that can affect algae abundance is not necessarily the same as nutrient loading, when loading is distinguished between N loading and P loading. The reasoning for this differentiation is based on the unifying concept in biological oceanography that plants (whether phytoplankton or benthic plants) have a definite atomic ratio of C:N:P. In phytoplankton, the ratio is commonly expressed as the "Redfield ratio" with a numerical value of 106:16:1. In benthic marine plants, the ratio is variable, but has an estimated median value of 550:30:1 (Atkinson and Smith 1983). A corollary to this standard compositional ratio of marine plants is the observation that the net uptake and release of nutrients through biochemical processes also tend towards the same ratio. Thus, the nutrient in shorter supply to make up the appropriate tissue ratio will generally be the limiting nutrient to plant growth. As a result, if only one nutrient (N or P) is elevated while the other remains at low concentrations, the effect in terms of plant growth is likely to be substantially less than if both nutrients increase correspondingly. With this concept of uptake ratios as a basis, the input of "effective nutrient loading" is determined by the ratio of N loading to P loading. The rule base states that when loading of N and P is unequal, the effective loading remains equivalent to the nutrient in shortest supply. There is, however, a caveat to this rule. Coral reefs are capable of fixing atmospheric nitrogen to form organic nitrogen. There is no equivalent biochemical process for phosphorus. Thus, if the ratio N:P of the water flowing over a reef is low relative to the uptake ratio of plants on the reef, the capability exists for nitrogen fixation to raise the potential uptake of phosphorus. On the other hand, if phosphorus is the nutrient in low relative concentration, there is no potential to increase uptake potential through atmospheric supply. As a result, we consider phosphorus the limiting nutrient in our rule base, and the input variable of "effective nutrient concentration" as being equivalent to the "effective phosphorus concentration."

Water Quality Transform Function

This model converts sediment and effective nutrient loadings at specified locations into effective nutrientcontinue

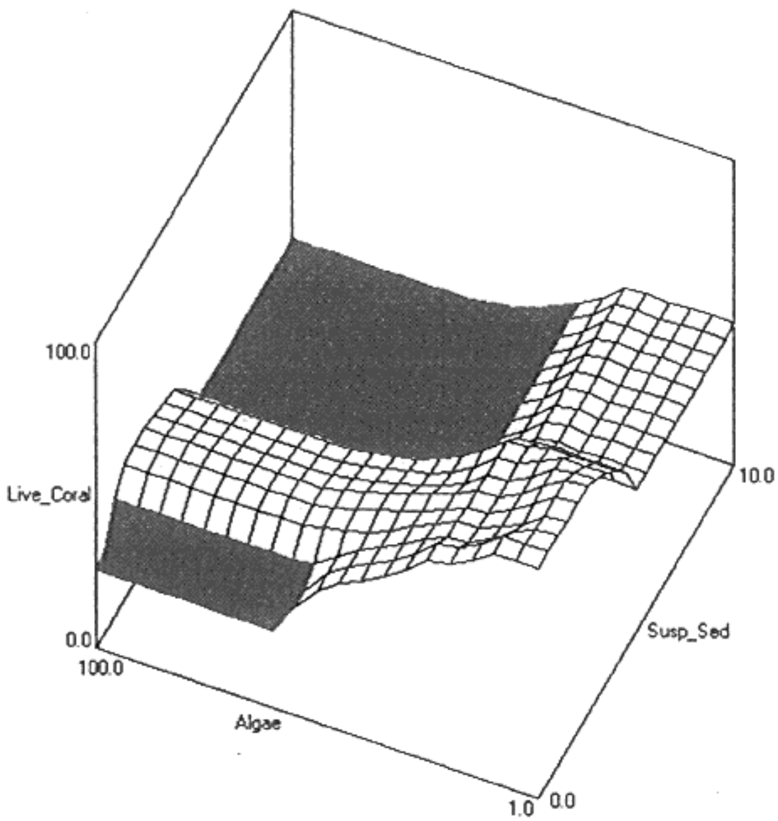


Figure 8.4.
A typical fuzzy−logic generated dose response surface. This example shows live coral cover as a function of suspended sediment and algae cover, with all other variables fixed.

concentration, depth of sediment deposition, and concentration of suspended sediment over the reef. The model uses a simple fuzzy rule−based water quality transform that approximates a conventional (non−fuzzy) water quality model described in Rijsberman and Westmacott (1996; see Chapter 3).

Algae−Nutrient−Grazing Subsystem

The reasoning behind inclusion of this subsystem is, simply, that the primary effect of elevated nutrient levels on coral is the enhanced growth of algae which, *ceteris paribus* , may compete with coral for hard substratum or perhaps even smother existing live coral. However, grazing by fish, sea urchins, and other fauna will help check the proliferation of algae. Thus, a quite parsimonious function for determining algae levels is derived from nine rules describing the interplay between the effective nutrient concentration and grazing pressure.

Sediment Deposition Versus Suspended Sediments

Distinction is made between the input variables sediment deposition and suspended sediments because these factors can be considered to affect coral community structure differently. While suspended sediment is often considered a detriment to coral growth and reproduction, it has been documented that many reef areas contain a high percentage cover of coral in areas where suspended sediments is also normally considered high. Species composition in such areas may be substantially different than in areas with low suspended sediment primarily as a result of the physiological capability of some species to efficiently eject sediment from living polyps. As a result, reef composition may vary dramatically between areas of differing levels of sediment suspension, but one reef assemblage cannot necessarily be considered inferior to the other. Coral cover then, in contrast to coral species mix, may not vary significantly with suspended sediment.

On the other hand, sediment deposition appears to be universally more detrimental to living coral reef structures. Coral planulae (larvae) cannot settle in areas where soft sediments continually cover the bottom, and may not survive in areas where sediment deposition is episodic but a regular occurrence. In areas of highly variable water motion, sediment deposition may occur occasionally during periods of high input and low water motion, with subsequent clearing of the deposited material when water motion increases. While adult colonies of some species may tolerate coverage by settled sediments for short periods of time (hours to days), coverage for longer periods is lethal to virtually all species. As a result, in our model, sediment deposition has a considerably stronger adverse effect upon reefs than suspended sediment. It is also important to understand that while these two input variables can co−vary (e.g., high sediment deposition in areas of high sediment suspension), it is not unusual to find reef areas where the input variables are very dissimilar, generally being a function of water motion. For example, in areas with normal high water motion from wave forces, suspended sediments can be high with virtually no deposition. On the other hand, in areas with low water motion and limited flushing as a result of physiographic structure, sediment input may be low, resulting in relatively low suspended sediment; however, because there are insufficient physical forces to remove sediment, deposition may be high. This is a typical situation in lagoonal areas, which often have soft sediment bottoms with little coral development.

Fishing Pressure

While corals themselves are sometimes the target species (mainly for curio collectors), fishing pressure is generally considered to have an important indirect impact on coral reefs. Removing a large percentage of the grazers or piscivores on any reef may cause changes in the balance between corals and algae, which can result in phase shifts in reef structure. While fishing pressure is considered an important variable, it is inherently difficult to measure and quantify for input into the model. We have chosen to employ the units of measurement presented by McClanahan (1995) in his coral reef ecosystem−fishery model, which is aimed at determining the impacts of fishing intensity and catch selection on reef structure and processes. Based on field data, McClanahan (1995) estimates that a person can catch 25kg ha1 day1 of fish at maximum fish biomass. This clearly depends on the techniques used and should be seen as a relative measure. We use this number as a maximum value and scale downward to create membership classes. It should be acknowledged that this variable is likely to be the most difficult to quantify in any applied situation, but it nevertheless is a necessary input for an effective model.

Economic Model Structure

Accounting for intermediate variables in the fuzzy model, the reduced form of the output and inputs to the integrated complex system function are the following. Parameters that are listed with a asterisk (*) are regarded as fixed for any given site and are not normally affected by the impacts arising from economic interventions.l

$Q = Q\{F_1, \ldots, F_9\}$; coral abundance on available substrate;

F_1 = suspended sediment;

F_2 = sediment deposition;

F_3 = physical damage;continue

F_4 = fishing pressure;

F_5 = relief*;

F_6 = grazing pressure*;

F_7 = initial effective nutrient concentration*;

F_8 = nitrogen loads; and,

F_9 = phosphorus loads.

Various computer modeling and simulation platforms were tested to find an efficient system that could accommodate the biophysical parameters as well as the economic optimization procedures. Final modeling was conducted using MATLAB® 5.2 software relying on the specialized Fuzzy Logic Toolbox and the Optimization Toolbox (Mathworks 1998). In modeling the relationships, fuzzy rule−based systems were initially defined for each system and were subsequently modified to improve computational efficiency. The modifications included use of Sugeno transforms instead of Mamdami transforms and the specification of a fuzzy inference system for the water quality transform. All optimization routines relied on a sequential quadratic programming method, which is the most efficient algorithm for optimizing over non−linear surfaces (Floudas and Pardolos 1992; Gill *et al.* 1981; Han 1977; Powell 1978). Identification of global optima was assured through specification of different starting points to ensure convergence.

The economic model structure consists primarily of two components. One component involves the definition of a "unit intervention set," including the costs of each of the unit interventions. The second component incorporates an economic activity "baseline" that represents a base case level of activity and impact in the absence of any interventions. The baseline level of activity corresponds to $n_k = 0$ for all $k = 1$ to K . Cost information for the various interventions was based on location specific data for Montego Bay (GMRC 1996). In general, the simplified form of the cost function takes the form

$$C_k = 0 \text{ if } n_k = 0$$
$$C_k = n_k C1_k + {}^{n_k C2_k}\!\!/_{r} \text{ if } n_k > 0$$

where C_1 is the capital cost of a unit intervention and C_2 is the annual operating cost of a unit intervention of type k . Each of these at a "unit scale" will have some impact on economic activities and on the inputs to the biophysical model (i.e., on the vector **F**).

The economic baseline component essentially involves projecting all economic activities under the assumption of no interventions. A resultant baseline vector **F0** is generated, with a corresponding level of coral quality that can be calculated as $Q_0 = Q\{F0\}$ through evaluation using the fuzzy model.

At this stage, the model can be used in two different modes: simulation or optimization. In simulation mode, the model determines the consequences of a given intervention set. An intervention set is defined by the vector **n** , and each n_k could take on a user−specified value from zero to some upper bound which is dictated by feasibility constraints (for example, it will not permit replanting more than 100% of the watershed). In optimization mode, the only input is the target reef quality (Q) and the model will generate the least cost combination given constraints on each n k . The output is a vector **n** .

Modeling Scenarios and Interventions

The model forecasts economic activity, pollution and impact loads, and resultant coral quality over a 55 year period. The underlying forecast of economic activity is divided into the following sectors:

Municipal sector (domestic) . Migration into the area is regarded as a significant element in future economic development of the region, and demands on municipal waste treatment services will escalate. Wastes from the domestic sector thus are a potentially significant contributor to overall pollutant loading.

Agribusiness sector . This sector is selected because it is one of the major growth nodes in the area and has high pollution potential. Although agriculture itself is not an important contributor to regional product, value added processing may become increasingly significant in the free trade zone and elsewhere.

Light manufacturing sector . This sector is highlighted because of its high pollution potential for metals, sediments, nutrients and toxic compounds. Also, growth may be expected to increase given the desire for industrial expansion in and around the free trade zone.

Heavy manufacturing and construction sector . This sector also has high pollution potential, although its pollutants have traditionally been mainly sediment loads and solid wastes leading to potential physical damages on the reef.

Hotel and tourist service sector . This sector is an important current component of the local economy and will continue to be a major player in the future. As such, interventions relating to this sector are likely to have a significant impact on water demands and on overall pollution loads.

Forestry and agriculture sectors . These sectors are included for completeness, and because of their high potential pollution loads. In the Montego Bay area, however, their relative contributions to economic output are small.

Offshore transport sector . Offshore shipping contributes to recurrent oil spills in the area. It is expectedcontinue

that these recurrent impacts, as well as the risk of an oil spill, will escalate with increased processing in the free trade zone and elsewhere.

In any particular simulation or optimization, the baseline forecast is chosen as a status quo case. This describes conditions in the absence of any active interventions. We use as a reference case a rapid growth scenario developed on the basis of consultations with and documents provided by the Greater Montego Bay Redevelopment Corporation (GMRC 1996). The forecasts represent relatively rapid growth over a 20 year period, tapering off to lower levels over the remainder of the 55 year period. Specifically, population is expected to grow by about 2.5% annually for 20 years, and 1% annually in the longer term. Growth in real economic output in the manufacturing and processing sectors is expected to range between 3% and 5% in the near to medium−term, and 1% to 1.5% in the long−term. Tourism and hotel industry growth is expected to average about 3% annually for 20 years, tapering off to 1% annually afterwards. Forestry and agriculture are expected to realize only modest growth in the near−term (less than 1% annually) and no real growth over the long−term as land is converted to satisfy municipal requirements.

The model incorporates eight active intervention types for Montego Bay. The interventions, and their approximate costs, are:

1. Sediment trap. This involves placement of a sediment trap close to the Montego River outlet before it empties into Montego Bay. The trap is a physical barrier that slows the water flow and prevents most of the sediments from entering Montego Bay; it also removes some solid litter that might cause physical damage to the reefs. It does not reduce nutrient loads to any significant degree. Effective operation of the trap requires regular (weekly) maintenance and removal of sediments for disposal in clean fill sites. The capital cost of such a trap is estimated to be about US$6 million, with annual operational costs of about US$330,000. Smaller traps, at lower cost and efficiency, could be installed at various upstream locations.

2. Planting of trees in the upper watershed. This scenario reflects reforestation of the most degraded watershed areas around Montego Bay and involves planting about 150,000 acres of trees, at a one time capital cost of almost US$28 million (based on average reforestation costs for Jamaica). This intervention would lead to a substantial (almost 100%) reduction of sediment and nitrogen loads from this area.

3. Aeration of waste. This involves installation of a common waste treatment aeration system in the Montego Bay free trade zone, capable of treating 416 tons per day of waste. It would result in a substantial end−of−pipe reduction in sediment and nutrients from the light industry in this zone. Costs of such a facility are estimated to approach US$1 million, requiring an additional US$1 million annually for operation.

4. Large scale centralized treatment facility. This scenario involves installation of a common waste treatment facility capable of processing about one−quarter of the sewage and waste in the Montego Bay area. Installation of such a facility would reduce nutrient and sediment loads associated with domestic, commercial and hotel waste streams; some modest decrease in physical impacts on the reef would also be evident. In theory, up to four of these might be built over the long−term in Montego Bay; construction of additional units is, however, constrained by difficulties associated with connecting all areas, and with overcoming the common use of disposal wells. In the optimization modeling, therefore, the model limits this to only one such facility being constructed at a capital cost of about US$50 million and annual operational costs of about US$5 million. Smaller scaled down versions of this could also be constructed.

5. Agricultural extension. This intervention reflects the establishment of technology transfer programs along the lines of internationally accepted waste reduction programs. Such programs are aimed at reducing pollutant loads (primarily from nutrients) through providing relatively low cost (often self−financing) technologies to the agricultural and agro−processing sectors. The intervention covers up to 10% of such enterprises in the area, and will cost US$1.2 million to implement with an annual cost of about US$120,000.

6. Outfall and pump . This is a stand−alone intervention that would involve a sewage outfall and pump station to take the sediment beyond the reef edge (approximately 5km). The unit would cost about US$1.8 million, along with US$72,000 annually, and would mainly reduce sediment loads and physical impacts of wastes on the reef. Smaller versions at lower cost and efficiency are available.

7. Household solid waste collection. This scheme involves establishing a small−scale waste collection system to connect about 30,000 people in squatter settlements or low income areas to common waste handling facilities. Although the capital costs for this type of an arrangement are low (US$72,000) the operating costs are relatively high (US$36,000 annually). The effect this has on pollution loads will be to reduce sediment and nutrient loads from the household sector.

8. Hotel tax. This intervention simulates the impact of a 25% land tax on the existing hotel and service sector, and is meant to illustrate the impacts of a policy intervention as opposed to some of the investment interventions considered elsewhere. While this tax is not directly attacking any specific pollutant, the increasecontinue in hotel operation costs is expected to dampen investment and decrease pollution loads. The administrative costs of such an intervention are estimated to be about US$60,000 annually.

Results

While the model provides a dynamic forecasting environment, it was found that decision−makers find it most useful if reef quality can be expressed in terms of a single index relating to a single future reference year (Werners 1998). In all modeling summaries and optimizations, therefore, a "25 year equilibrium" level of coral abundance was selected as a benchmark. Precise interpretation of this figure is somewhat complex, but it essentially describes the long−term level of coral abundance on available substrate arising from the next 25 years of activities and interventions. It therefore consolidates initial conditions (taken as 1998) with future economic development activities (and their associated negative impacts) and any mitigative interventions (and their positive impacts).

The basic technical sensitivity of the reef impact model, calibrated for Montego Bay conditions, is shown in Table 8.3. Under static conditions of no growth and no mitigative interventions, with all stresses essentially remaining at current levels, a long term equilibrium level of 43% coral abundance would be expected. Table 8.3 also demonstrates that the greatest deterioration would arise from changes in pollution loading (N, P and sediments) while reef quality is less responsive to changes in fishing pressure.

The economic impacts of single technical interventions are shown in Table 8.4. The results also show that, in the "high growth" reference forecast, a long−term equilibrium level of about 29% coral abundance would be expected. This decline, relative to the "no growth" case of 43% coral abundance, is attributable entirely to the increased impacts from economic activity in the absence of mitigating interventions. The results also indicate the potential impact of single interventions. No single intervention is capable of completely compensating for the negative impacts on coral abundance, although, if all interventions were executed, a level of about 49% coral abundance could be achieved. This, in fact, represents a 20.23% improvement on what would otherwise happen, and it would result in a present value cost in excess of US$150 million.

The results in Table 8.4 show the impact of single interventions relative to a "do nothing" scenario. Because of the non−linearity of the coral reef response, it is not possible simply to add up these interventions to arrive at a cumulative impact. The model, in optimization mode, permits setting of a target level of coral abundance (or change in coral abundance over a reference case); results for such optimizations are summarized in Table 8.5. Forcontinue

Table 8.3. Changes in Montego Bay (Jamaica) coral reef quality arising from changes in key inputs. Coral abundance levels show long−term equilibrium arising from changes in physical impacts of human−induced activities on the reef ecosystem.

Scenario	Coral cover (%)	Change in coral cover (%)
Base case conditions no economic growth	42.73	
Doubling of:		
Pollution loads (N, P and sediment)	21.83	20.90
Physical damage	25.49	17.24
Fishing pressure	39.80	2.93

All inputs	6.82	35.91
Halving of:		
Pollution loads (N, P and sediment)	56.38	+13.65
Physical damage	51.33	+8.66
Fishing pressure	44.00	+1.27
All inputs	76.18	+33.45

Table 8.4. Changes in Montego Bay (Jamaica) coral reef quality arising from single interventions. Coral abundance levels show 25 year equilibrium, and resultant total cost and average costs.

Intervention	Coral cover (%)	Change in coral cover (%)	Total cost (million US$)	Average costs (million US$/%)
Base case conditions	28.94	0.00		
high economic growth				
Sediment trap	32.13	3.20	9.30	2.91
Planting of trees in upper watershed	30.57	1.63	27.90	17.12
Aeration of waste	30.57	1.63	11.84	7.25
Large scale centralized treatment facility	34.18	5.24	98.40	18.78
Agricultural extension	29.00	0.07	2.40	36.81
Outfall and pump	34.33	5.39	2.52	0.47
Household solid waste collection	30.73	1.80	0.43	0.24
Hotel tax	28.97	0.03	0.60	17.30
All of the above	49.17	20.23	153.40	7.58

any given target level, the optimization provides the least cost combination of interventions, permitting variable intensities from zero to unity. A zero indicates that the intervention is not undertaken, while any positive value shows partial or full implementation of a given intervention.

Discussion and Conclusion

Modeling results provide important insights into methodological issues as well as practical policy issues. A major methodological success of the exercise is that it was found to be feasible to model a large variety of economic and ecological parameters in a predictive system that permits comparison of policies. The fuzzy logic procedures, coupled with economic optimization tools, can take advantage of relatively sparse information sets.

The non−linearity of underlying complex systems also places in question many conventional methods of cost−effectiveness analysis that assume separability of benefits and costs, and separability of the impacts of individual interventions. Inspection of the results illustrates a number of these points.

First, the non−linearity of the coral quality response surfaces to individual interventions is shown in Table 8.4. Both the reforestation alternative and the waste aeration alternative achieve precisely the same level of coral abundance because of a localized "plateau" in the coral quality response surface. Such localized plateaus in the ecological model are relatively common and are surpassed only through more investment through additional interventions; the first intervention in such cases will always have a high cost (in terms of $/% improvement) compared to subsequent investments which move conditions beyond such a plateau.

Second, the fallacy of separating benefits from costs, and of using a continuous ranking of individual interventions, is shown in the optimization results in Table 8.5. In a conventional separable model with monotonically increasing marginal costs (such as that in Figure 8.1), an intervention that was undertaken at a low target level of coral improvement would also always be undertaken at a high target level of coral improvement. But this is clearly not the case here. Reforestation, for example, is part of the optimal intervention set at coral quality improvement targets of 14% and 20%, but it is not part of the intervention set at intermediate targets of 15% or 16%. Similarly, the intensity of the agricultural extension and hotel tax interventions do not increase monotonically. This is reflected also in the marginal cost curve inherent in Table 8.5; while generally it is increasing, there are some localized decreases (Figure 8.5). The most significant implication this has for policy−makers is that one can not simply pursue low cost interventions in the absence of some coral quality target, which will in turn be related to the economic benefits.break

Table 8.5. Optimization results for Montego Bay (Jamaica), showing levels of individual interventions required to achieve target coral reef quality, and resultant total cost and marginal costs. Interventions are as follows: I1=sediment trap; I2=planting of trees in upper watershed; I3=aeration of waste; I4=large scale centralized treatment facility; I5=agricultural extension; I6=outfall and pump; I7=household solid waste collection; and, I8=hotel tax.

Change in coral cover (%)	Intervention I1	I2	I3	I4	I5	I6	I7	I8	Total cost (million US$)	Marginal costs (million US$/%)
0.25	0	0	0	0	0	0	0.13	0	0.06	0.24
0.50	0	0	0	0	0	0	0.26	0	0.11	0.20
0.75	0	0	0	0	0	0	0.39	0	0.17	0.24
1.00	0	0	0	0	0	0	0.58	0	0.25	0.32
1.25	0	0	0	0	0	0	0.71	0	0.31	0.24
1.50	0	0	0	0	0	0	0.85	0	0.37	0.24
1.75	0	0	0	0	0	0	0.98	0	0.42	0.20
2.00	0	0	0	0	0	0.04	1	0	0.53	0.44
2.25	0	0	0	0	0	0.08	1	0	0.64	0.44
2.50	0	0	0	0	0	0.13	1	0	0.76	0.48
2.75	0	0	0	0	0	0.18	1	0	0.87	0.44
3.00	0	0	0	0	0	0.22	1	0	0.99	0.48

3.25	0	0	0	0	0	0.27	1	0	1.10	0.44
3.50	0	0	0	0	0	0.31	1	0	1.22	0.48
3.75	0	0	0	0	0	0.36	1	0	1.33	0.44
4.00	0	0	0	0	0	0.40	1	0	1.45	0.48
4.25	0	0	0	0	0	0.45	1	0	1.56	0.44
4.50	0	0	0	0	0	0.49	1	0	1.68	0.48
4.75	0	0	0	0	0	0.54	1	0	1.79	0.44
5.00	0	0	0	0	0	0.58	1	0	1.90	0.44
5.25	0	0	0	0	0	0.63	1	0	2.02	0.48
5.50	0	0	0	0	0	0.67	1	0	2.13	0.44
5.75	0	0	0	0	0	0.72	1	0	2.24	0.44
6.00	0	0	0	0	0	0.76	1	0	2.34	0.40
6.25	0	0	0	0	0	0.80	1	0	2.45	0.44
6.50	0	0	0	0	0	0.84	1	0	2.56	0.44
6.75	0	0	0	0	0	0.89	1	0	2.67	0.44
7.00	0	0	0	0	0	0.93	1	0	2.78	0.44
7.25	0	0	0	0	0	0.97	1	0	2.88	0.40
7.50	0.03	0	0	0	0	1	1	0	3.19	1.24
7.75	0.10	0	0	0	0	1	1	0	3.85	2.64
8.00	0.17	0	0	0	0	1	1	0	4.52	2.68
8.25	0.24	0	0	0	0	1	1	0	5.18	2.64
8.50	0.31	0	0	0	0	1	1	0	5.83	2.60
8.75	0.38	0	0	0	0	1	1	0	6.49	2.64
9.00	0.45	0	0	0	0	1	1	0	7.15	2.64
9.25	0.52	0	0	0	0	1	1	0	7.80	2.60
9.50	0.59	0	0	0	0	1	1	0	8.45	2.60
9.75	0.66	0	0	0	0	1	1	0	9.10	2.60

(table continued on next page)

Table 8.5. continued

Change in coral cover (%)	Intervention I1	I2	I3	I4	I5	I6	I7	I8	Total cost (million US$)	Marginal costs (million US$/%)
10.00	0.73	0	0	0	0	1	1	0	9.75	2.60
10.25	0.80	0	0	0	0	1	1	0	10.39	2.56
10.50	0.87	0	0	0	0	1	1	0	11.04	2.60
10.75	0.94	0	0	0	0	1	1	0	11.68	2.56
11.00	1	0	0.01	0	0	1	1	0	12.41	2.92
11.25	1	0	0.14	0	0	1	1	0	13.89	5.92
11.50	1	0	0.26	0	0	1	1	0	15.35	5.84
11.75	1	0	0.38	0	0	1	1	0	16.78	5.72
12.00	1	0	0.50	0	0	1	1	0	18.21	5.72
12.25	1	0	0.62	0	0	1	1	0	19.63	5.68
12.50	1	0	0.74	0	0	1	1	0	21.06	5.72
12.75	1	0	0.86	0	0	1	1	0	22.47	5.64
13.00	1	0	0.98	0	0	1	1	0	23.89	5.68
13.25	1	0.09	1	0	0	1	1	1	27.20	13.24
13.50	1	0.22	1	0	0	1	1	1	30.88	14.72
13.75	1	0.35	1	0	0	1	1	1	34.55	14.68
14.00	1	0.34	1	0.04	0	1	1	1	38.27	14.88
14.25	1	0.28	1	0.10	0	1	1	0.20	42.09	15.28
14.50	1	0	1	0.24	0	1	1	0.36	47.67	22.32
14.75	1	0.63	1	0.10	0	1	1	0.57	51.51	15.36
15.00	1	0	1	0.32	0	1	1	1	55.88	17.48
15.25	1	0	1	0.36	0	1	1	1	60.01	16.52
15.50	1	0	1	0.40	0	1	1	1	64.13	16.48
15.75	1	0	1	0.45	0	1	1	0.18	68.32	16.76
16.00	1	0	1	0.48	0	1	1	1	72.35	16.12
16.25	1	0	1	0.53	0	1	1	1	76.43	16.32
16.50	1	0	1	0.57	0	1	1	1	80.82	17.56
16.75	1	0	1	0.62	0	1	1	0.35	85.25	17.72
17.00	0.99	0	1	0.64	0.22	1	1	0.48	87.43	8.72
17.25	1	0.32	1	0.64	0	1	1	0.04	95.89	33.84
17.50	1	0	1	0.77	0	1	1	1	100.49	18.40

17.75	1	0	1	0.81	0	1	1	1	104.68	16.76
18.00	1	0	1	0.86	0	1	1	1	108.85	16.68
18.25	1	0	1	0.90	0	1	1	1	112.99	16.56
18.50	1	0	1	0.94	0	1	1	1	117.10	16.44
18.75	1	0	1	0.98	0	1	1	1	121.20	16.40
19.00	1	0.10	1	1	0	1	1	1	125.78	18.32
19.25	1	0.27	1	1	0	1	1	1	130.64	19.44
19.50	1	0.44	1	1	0	1	1	1	135.39	19.00
19.75	1	0.61	1	1	0	1	1	1	140.06	18.68
20.00	1	0.83	1	1	0	1	1	1	146.31	25.00
20.25	1	1	1	1	1	1	1	1	153.48	28.68

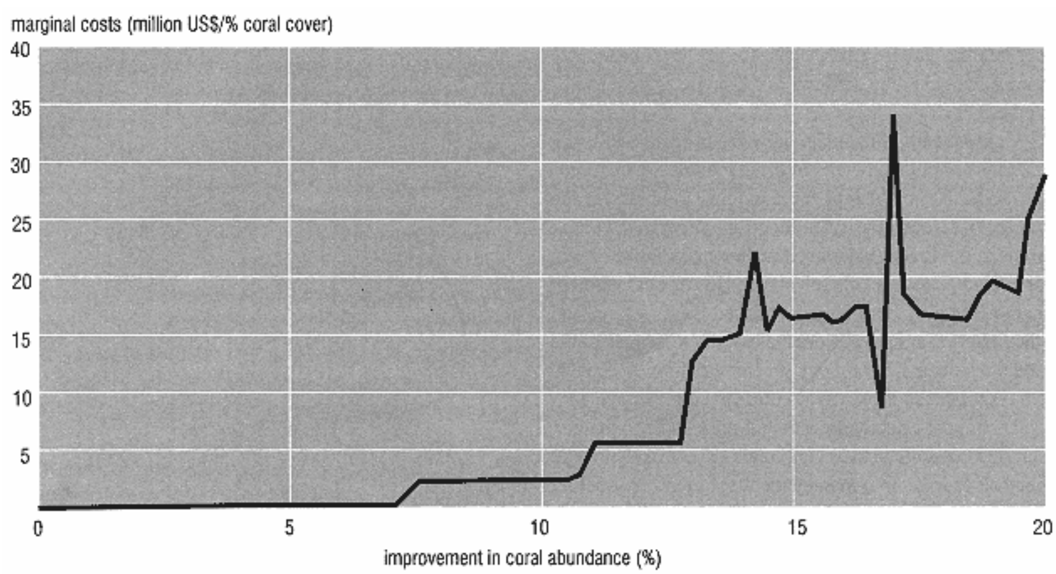


Figure 8.5.
Montego Bay (Jamaica) intervention costs. Relationship shows marginal cost of the optimal intervention set for any given target improvement in coral reef quality.

The fallacy of the conventional ranking procedures is also shown by inspection of the average costs of individual interventions (Table 8.4). Such average costs are often used as a means for ranking alternatives, and are usually calculated based on "initial" conditions. Reliance on such an indicator would lead one to conclude, for example, that reforestation was more economical than a hotel tax; but the optimization results show that at higher coral quality targets (between 15% and 18% improvement), a hotel tax is the most economical option. Again, some knowledge of the economic benefits is necessary before a target can be achieved in association with the available cost intervention.

Apart from the above methodological issues, the model results do provide some practical insights to policy design decisions in Montego Bay. First, the results illustrate that some interventions are common to all optimal policy sets for intermediate levels of coral improvement. Specifically, household solid waste collection, installation of an outfall, and use of a sediment trap on the Montego River are relatively cost−effective interventions; use of these three interventions would impose present value costs of about US$12 million and achieve a coral improvement in excess of 10%. By contrast, achieving the maximum potential improvement of 20% would entail present value costs of US$153 million.

In conclusion, we note that—as with all such modeling exercises—any such prescriptions should be complemented by good judgment on the part of policy−makers. Manipulation of the models can provide insights into the generally desirability and impacts of various interventions, but such models never tell the whole story. In Montego Bay, for example, the model still treats pollutant transport and mixing with a broad brush that neglects seasonal variations and potential localized impacts on, for example, important diving sites. Such considerations are beyond the capacity of this analysis framework, although they may be of key importance to a dive industry that generates considerable local benefits through tourism.

Also, the current models do not adequately capture many of the dynamic elements of coral reef responses to human, and other, stresses. While time delays in reef response were identified as an important parameter, limitations in coral reef science and data availability prevent a thorough treatment of this subject. Consequently, it is extraordinarily difficult to reconcile or benchmark models such as this (which predict long−term equilibrium conditions) against real field data (which measure current reef conditions, often under disequilibrium conditions). Also, these models do not yet incorporate the potential impacts of non−localized stresses on reef quality that have (presumably) resulted in such massive recent die backscontinue

and "bleaching" events. Again, current measurements of reef health, which reflect such stresses in a disequilibrium state, would be difficult to reconcile against model predictions.

Consequently, this again calls for prudence in using and interpreting the results of these models. In our view, the model is most useful for providing guidance in the *changes* in reef quality induced by *localized human impacts* ; the model is less robust in its predictive ability for *absolute* levels of reef quality in an environment characterized by both human−induced local stresses and other external stresses. Nonetheless, the messages of the model results are clear—pay greater attention to ecosystem responses and pay less attention to conventional constructs of cost−effectiveness that assume linear behavior. Complex systems such as coral reefs are not likely to lend themselves to simple management solutions. Modeling tools must strive to capture some of this complexity.break

Chapter 9—
Integration of the Models for Decision Support in Jamaica

Jack Ruitenbeek
H.J. Ruitenbeek Resource Consulting Limited, Gabriola, BC, Canada

To consolidate the findings of the research, this brief chapter provides a synthesis of the various benefit valuations for Montego Bay, Jamaica (Chapters 5, 6, and 7). In addition, we include these within the context of a key policy question for Montego Bay—how much coral reef conservation is economically optimal and how can we best achieve that level? To answer that question, we rely on selected results from the complementary cost effectiveness studies (Chapter 8) against which we juxtapose the coral reef management benefits identified through the valuation work. Specifically, this chapter:

Identifies the relative contributions of direct use values against other values within the context of a synthesized benefit function;

Identifies appropriate policy and institutional reforms for improving the capture of resource values associated with coral reefs in Montego Bay based on an optimizing framework; and,

Assesses implications for future applied research.

Towards a Benefit Function

As a final step, one can aggregate the economic values into a total value and a net marginal benefit (price) function for the Montego Bay reefs (Table 9.1). The use of such values requires making a number of further assumptions regarding the sensitivity of the individual values to reef quality. As seen with the bioprospecting values, the total value of the reef was relatively high (US$70 million) but changes in reef quality within the planning range (approximately 20% to 50% coral abundance) did not have a large effect on this value.

As no specific linkage models are available for the other values estimated, we make a number of simplifying assumptions for purposes of demonstration. In general, as a reference case, we assume a linear relationship between reef quality and value for all values other than bioprospecting. In effect, this places a fixed price for these other uses and functions, and is likely to over−estimate price in some instances, while potentially underestimating in others. For example, a degraded reef will still provide some limited erosion protection for some time; thus, an average price assuming a linear relationship will overstate this marginal benefit. For tourism, however, small changes in quality may have disproportionately larger impacts on arrivals if there is a perception that the reefs are substantially degraded (to a degree, this occurred about ten years ago in Montego Bay after some highly publicized but overstated reports of massive degradation decreased diver visits). In the case of the non−use values, the contingent valuation method (CVM) survey explicitly included a degradation scenario; hence, the end−points were well established (representing a 25% degradation) but the nature of the function between these end−points is somewhat uncertain.

Given these assumptions, it is clear that the total benefit attributable to the reefs in their current condition is approximately US$470 million and that every 1% change in abundance is likely to generate a marginal benefit of approximate US$10 million. Most of the value, and change in value, is attributable to the tourism resource. Coastal protection and non−use benefits are next in terms of planning importance. It is notable that the use benefits related to tourism are at least an order of magnitude greater than the non−use benefits that visitors express. The relative impacts of fisheries and bioprospecting on planning prices are negligible, especially if one considers only the capturable values to Jamaica.

Synthesizing Benefits and Costs for a Global Optimum

We juxtapose these marginal benefit calculations against a marginal cost function for the Montego Bay reefs, as generated by a fuzzy logic based ecological−economiccontinue

Table 9.1 Summary of valuation results for Montego Bay coral reefs

	Benefit	Pricea	
	(NPV; million US$)	*(million US$/%)*	*(million US$/ha)*
Tourism/recreation	315.00	7.33	17.18
Artisanal fishery	1.31	0.03	0.07
Coastal protection	65.00	1.51	3.54

Local non−use	6.00	0.24	0.56
Visitor non−use	13.60	0.54	1.28
Subtotal	**400.91**	**9.65**	**22.63**
Pharmaceutical bioprospecting (global)	70.09	0.23	0.53
Total (Global)	**471.00**	**9.88**	**23.16**
Pharmaceutical bioprospecting (Jamaica)	7.01	0.02	0.05
Total (Jamaica)	**407.92**	**9.67**	**22.68**

a Marginal benefits shown at typical current reef conditions

model (Chapter 8). This related research on cost effectiveness modeling of interventions suggested that up to a 20% increase in coral abundance may be achieved using appropriate policy measures having a present value cost of US$153 million. The cost curve envelope generated by that research showed marginal costs rising from under US$1 million/% of coral abundance to US$29 million/% of coral abundance. Global optimization using the combined cost and benefit functions suggested an "optimal" improvement of coral reef abundance of 13% requiring net expenditures of US$27 million, primarily involving 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. The marginal benefits and marginal cost curves for this solution are shown in Figure 9.1.

Sensitivity tests suggest that net economic benefits would need to increase by US$275 million or decrease by US$300 million for the coral quality target to vary from this by more than 2% (i.e., fall below 11% or above 15%). To justify the full expenditure (i.e., achieving a 20% coral reef improvement) would require additional benefits of US$660 million.

It is notable that the inclusion or exclusion of pharmaceutical bioprospecting values from this analysis does not have an effect on this planning outcome. Even if a strict linear relationship were applied and 100% of the bioprospecting value were capturable by Jamaica, the resultant price (US$70 million/43% coral, or US$1.6 million/%) would not be adequate to justify improvements beyond those stated above.

Implications

While any single valuation will generally be a useful policy input, it should normally be regarded as just one among many potential inputs to such a policy making exercise. It is no accident that wider reliance is being made on multi−criteria analyses, with valuation as one component of that analysis.

In terms of bioprospecting valuation, we would submit that the overall focus on valuation has perhaps distracted analysts from more pressing institutional and socio−economic concerns. Valuation results consistently demonstrate that institutional arrangements between developing countries and the rest of the world are critical components of capturing value and of mitigating riskscontinue

associated with uncertain economic and ecosystem conditions. Yet local institutional capacity remains weak in Jamaica, as it does in most developing countries. Also, both the economic theory of resource utilization and the social realities arising out of extensive stakeholder participation consistently demonstrate that we must move rapidly towards decentralized and communal management of coral reef resources. Failure to do so will likely rapidly dissipate, or totally eliminate, any notional values we might attach to these resources. To address these concerns, we call for the following shift in emphasis in applied research:

Less emphasis on stand−alone cost effectiveness analyses . The joint projects demonstrate that, if economic efficiency is a goal, we must pay attention to both costs and benefits when dealing with complex non−linear systems such as coral reefs.

Greater emphasis at the local level on socio−economic and management dimensions of direct uses . This involves the promotion of practical local management regimes that involve affected stakeholders in the resource base.

Greater emphasis at the national level on institutional strengthening to participate in bioprospecting value capture opportunities . Analytical work should focus on practical mechanisms and should directly address risk management concerns.

Greater emphasis on ecosystem analysis focusing on functional linkages and relationships . The economic discipline has, in many ways, "gotten ahead of itself" in valuation. Large uncertainties in ecosystem behavior continue to undermine attempts at rational economic analysis and, in many cases, it is probably a waste of effort to conduct such analyses. To some degree, this simply requires that planners become accustomed to the uncertainty, but accelerated work in basic ecological analysis (e.g., thorough inventory work) for critical ecosystems would be money well spent.break

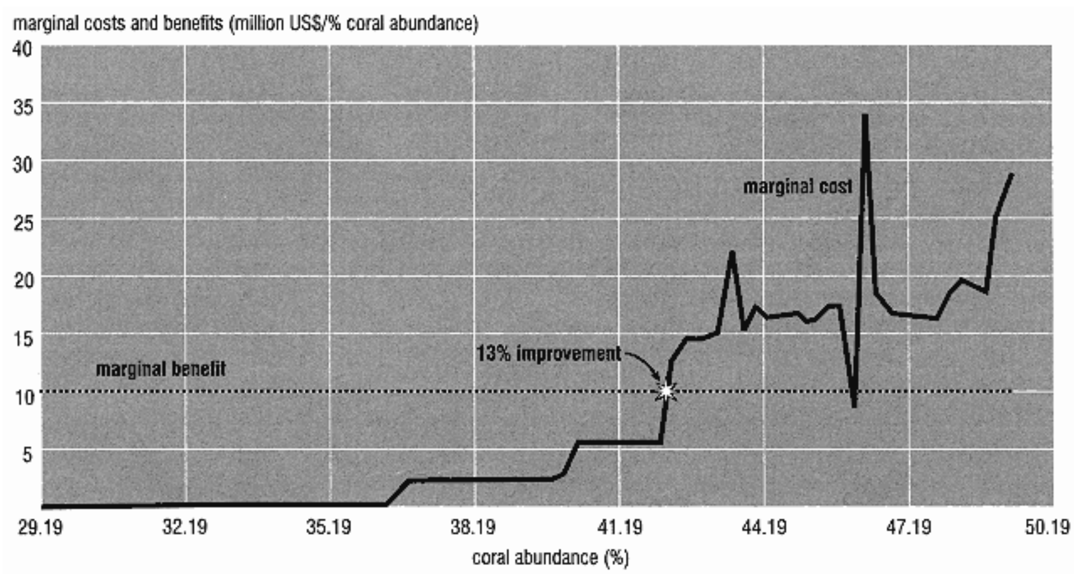


Figure 9.1
Montego Bay intervention marginal benefit and cost curves for the global optimization solution

Chapter 10— Development of the User Interface—Coral−Curaçao, Coral−Maldives, and COCOMO

Christiane Klöditz, Frank Rijsberman, Saskia Werners and Susie Westmacott
Resource Analysis, Delft, The Netherlands

As described in previous chapters, the World Bank has been involved in several projects that aim to improve the protection and management of coral reef coastal systems. Results from each of the three case study sites (Montego Bay, Jamaica; Curaçao, the Netherlands Antilles; North and South Male, the Republic of the Maldives) has led to the development of a user−friendly computer−based application that incorporates a quantitative ecological economic model designed to assist in the formulation, evaluation and ranking of various cost−effective coastal zone management practises. The three integrated coastal zone management decision support models are:

Coral−Curaçao, a decision support system for coral reef management in Curaçao;

Coral−Maldives, a coral reef management model for the Republic of the Maldives; and,

COCOMO, a model for management of COral reef COasts in MOntego Bay, Jamaica.

The models were developed with local input through workshops and meetings and have been tested in further workshops. They have been used successfully as training and education aids and it is hoped that they will be developed further so as to be used later as actual planning tools.

An accompanying CD−ROM contains the three decision support models that have been developed. The CD−ROM demonstrates decision support modeling for integrated coral reef management through realistic examples rather than abstract theory. The three decision support systems aim to create awareness for the integration of different coastal issues, as well as the formulation of integrated management plans. The CD−ROM can be used by stakeholders of the three study areas, as well as to illustrate application of the methodology to other coastal zones. The models are accessible for policy−makers and specialists from various disciplines, including those with minimal or no computer experience or scientific background, as well as a large percentage of the general public. The interface of the models is based primarily on graphic information to provide users with a quick overview with minimal use of text.

Framework for Analysis

Integrated coastal management is a complex issue crossing many disciplines and involving many stakeholders. There is often no clear−cut answer to the problems faced in managing such areas. Traditional sectoral approaches have failed to tackle the interrelated issues posed by user conflicts and interests within the coastal zone. This tends to be because problems are far from structured and objectives are unknown or unclear.

Solutions for such complicated problems can be found through a decision−making and management process that implies learning from other actors. Such an approach allows various stakeholders and decision−makers to explore and understand each other, the problem area and the different perspectives and interests that exist within it. Possible actions are found by learning and developing solutions, normally working in a cyclical, iterative way. When problem solving is approached as a learning process, the thinking processes need to be formally structured. The methodology is supplied by a framework and has been developed as a step−wise approach (Figure 10.1).

One of the components of a decision support system, which the models represent, is the user interface. The design of this will be instrumental in guiding the user through the decision. A step−wise approach is used, leading the user logically from problem definition to the evaluation of alternatives. This step−wise approach is based on 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 integrated coastal managementcontinue

issues are given by, for instance, Baarse and Rijsberman (1986, 1987) and Ridgley and Rijsberman (1992). Following this framework, the main steps in an integrated coastal management analysis within Coral−Curacao, Coral−Maldives and COCOMO 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.

Modeling for Coral Reef Management

The cost−effectiveness methodology utilized in the modeling was initially developed for Montego Bay, Jamaica, and has been tested through two case studies: i) Curaçao, the Netherlands Antilles, where the methodology has been tested and validated in a relatively data−rich environment and a coral reef system with a high level of anthropogenic influence (Chapter 3); and ii) the Republic of the Maldives, where the coral reefs are in many areas still relatively undisturbed, but where development is rapidly changing these coral reef systems (Chapter 4).

In order to cope with the difficulties of assessing the benefits of improved coastal zone management, the modeling research presented on the CD−ROM has been limited to assessing the costs of coastal zone management, using a framework that focuses on four main steps: i) the specification of economic sector interventions; ii) the modeling of the changes of these interventions on production and consumption; iii) the quantification of the physical response of these in terms of the wastes and physical damage generated; and, iv) the modeling of the impact of the wastes and physical damage on reef health. The final cost of each of the interventions is then computed, taking into account potential negative costs (e.g., from production changes). This enables interventions to be formulated in such a way as to incur the minimum costs while retaining a certain quality of reef. Further research was carried out for the Jamaica and Curaçao case studies where the cost−effectiveness analysis was expanded into a full cost−benefit analysis with quantification of the value of benefits due to changes in reef health (see also Chapter 9).

Coral−Curaçao

Coral−Curaçao (see Chapter 3 and CD−ROM) is a computerized planning tool that is able to show the impacts of coastal developments and environmental protection measures on the economy, environmental and social situation in Curaçao. Development of the model started with a preliminary visit to Curaçao in April 1995 (Rijsberman *et al.* 1995a). A subsequent visit involved collection of data and information for the development of the model (Meesters 1995; Westmacott *et al.* 1995). The first version of the model was completed at the end of 1996 and is described in Chapter 3 (see also Rijsberman and Westmacott 1996).

The initial project aimed to develop a method to evaluate the cost−effectiveness of alternative coral reef management strategies. In order to achieve this, three sub−models were developed that linked together forming a single integrated model. The sub−models were an economic activity model, a water quality model and a reef health response model. As the models were developed, additional components were added to expand the focus tocontinue

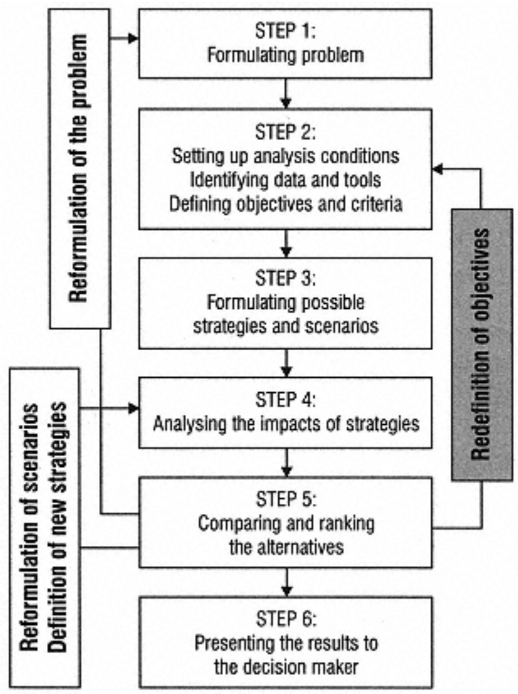


Figure 10.1.
A step−wise framework describing a decision−making and
coral reef management process.

cover a broad range of indicators, rather than simply cost−effectiveness. The aim was to achieve a user−friendly management model where users would input their ideas and plans for integrated coastal management for Curaçao and could analyze the impacts of the different plans in economic and environmental terms. Once developed, the Coral−Curaçao decision support model was presented to the different user groups in Curaçao, who were trained in its use.

Coral−Maldives

The Coral−Maldives decision support system (see Chapter 4 and CD−ROM) is structured in such a way that different users are able to explore a series of different coastal zone management options under varying assumptions for exogenous variables. The analysis allows the users to focus on the most cost−effective options for coral reef management and protection for the various economic development options. The impacts can be seen in terms of economic, social and environmental indicators that are selected at the outset of the analysis by the user. During the analysis, the user compares two situations: i) the reference situation; and, ii) changes in the reference situation as a result of the management options selected. In addition to the selected indicators, the user can explore more detailed information relating to the economy, reef health and coastal erosion. The final step of the analysis shows a score card of all the selected indicators. In addition, the user can use the cost−effectiveness analysis to rank the coastal zone management strategies.

The structure of the Coral−Maldives decision support system was developed and the data for the model collected during fieldwork in November 1995 (Westmacott 1996). The economic development and environmental protection options were also selected during this period through discussions with various government agencies involved in coastal zone management within the Maldives. The first version of the model was completed in 1997 and is described in Chapter 4 (see also Westmacott and Rijsberman 1997).

COCOMO

COCOMO (see CD−ROM) illustrates the relation between human activities and coastal problems in Montego Bay through a graphic user−friendly interface. It attempts to provide the information required to prioritize actions in order to preserve and improve the coastal environment. COCOMO is developed for policy−makers, specialists and anyone interested in coastal issues in Montego Bay. It provides information through maps, pictures, model calculations and texts. The model consists of three main parts:

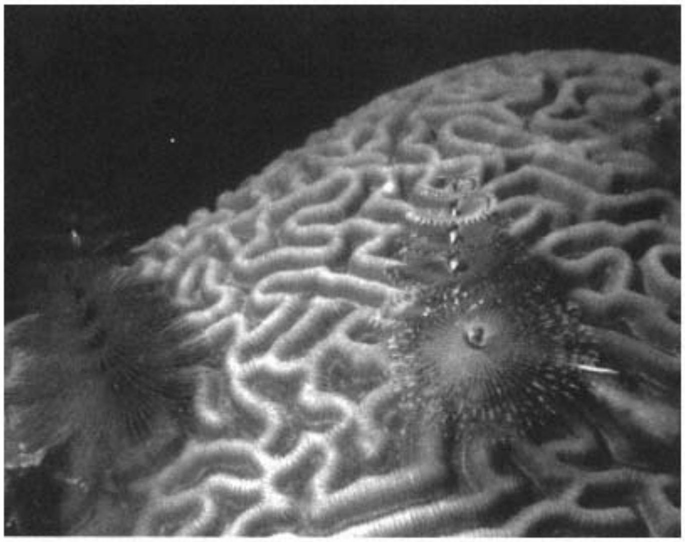
Background information on the objectives and coastal activities in Montego Bay;

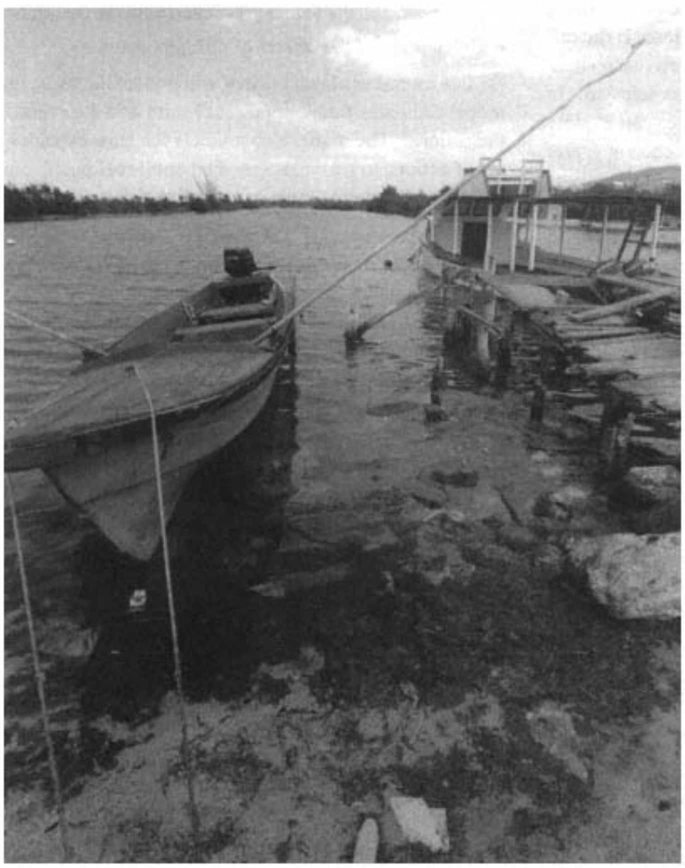
Information on the coral reef coast, including descriptions of the coral reefs and marine life, different coastal problems, and the values associated with the reefs; and,

Calculation of the effects of different actions.

For a number of actions that will protect the reefs, the model estimates future coral reef health and the costs of the actions. The model also predicts the least expensive set of actions to realize a specified coral reef health and helps to evaluate the main causes of reef deterioration.

It is hoped that Coral−Curaçao, Coral−Maldives, and COCOMO will make significant contributions to the development of effective integrated coastal management programs and policies. The reader is encouraged to explore the use of these models through the CD−ROM included with this publication.break





III—
THE CONTEXT FOR POLICY APPLICATIONS AND FUTURE DIRECTIONS

Chapter 11— The Social Context for Local Management in Jamaica

Leah Bunce
International Program Office, National Ocean Service,
National Oceanic and Atmospheric Administration, Silver Spring, MD, USA

Kent Gustavson
Gustavson Ecological Resource Consulting, Gabriola, BC, Canada

Whereas previous chapters have focused on economic analyses of coral reef management, this chapter extends these analyses to consider the socio−cultural implications of reef management by demonstrating the importance, as well as means, of incorporating social and economic information into coral reef management. This chapter presents a case study analysis in which the socio−economic context of the three primary user groups in Montego Bay Marine Park, Jamaica—fishers, hoteliers and water sports operators—were addressed (see Chapter 2 for a description of the Montego Bay Marine Park). The primary tasks of the project were two−fold: first, to conduct a socio−economic assessment of these user groups; and second, to demonstrate the utility of this methodology by considering the management implications of these findings for future Park management. As such, this study serves as a site−specific test case of the socio−economic data collection methodology and the utility of the data for making management decisions.

This project was designed to assist the larger World Bank project (see other contributions in this publication) in identifying an economically efficient outcome that is also socially viable. In addition to contributing to the development of a comprehensive cost−benefit methodology for coral reefs, this study was also designed to meet the needs of the Montego Bay Marine Park (the Park) in documenting the current extent and characteristics of Park use and the socio−economic background of the users in order to determine their concerns and interests, how they would be affected by management alternatives, and opportunities for collaboration. The Park has used this information to reshape Park policies and develop and implement effective management strategies. In a more general context, this study illustrates the importance of socio−economic assessments for reef management.

This chapter: i) presents the methodology used to examine the socio−economic background of the three user groups; ii) briefly describes the socio−economic background of these groups; iii) presents the socio−economic factors that have implications for the development of Park policy and management strategies; iv) discusses guiding principles for future Park management; and, v) presents an analytical framework which can be used to examine the socio−economic implications of future management and policy scenarios.

Socio−Economics in Coral Reef Management

As government and non−government organization resources have become increasingly focused on reef management issues over the past decade, reef management practitioners and theorists have become increasingly aware that to successfully manage these fragile resources sustainably, it is not only important to consider the biophysical conditions that determine system structure and processes, but also to understand the social and economic conditions, contexts, and motivations that are associated with their use (Orbach and Johnson 1989; Renard 1991; White 1989; White *et al* . 1994). As early as 1969, the importance of socio−economic information was stressed by the US National Environmental Protection Act, which states there is a need to ". . . assess or estimate, in advance, the social consequences that are likely to follow from specific policy actions . . . and specific government actions . . ." (ICGPSIA 1994, p. 108). The importance of socio−economic conditions was demonstrated by an examination of the socio−cultural compatibility of 68 World Bankcontinue projects (Cernea 1985, p.323). The 36 World Bank projects found to be socio−culturally compatible with the project population had an economic rate of return more than twice as high as the remaining 32 projects. As Cernea concluded,

Not only does a failure to consider the social and cultural context of a project invite inappropriate design at best (and user hostility at worst), but . . . it usually leads to projects that are ultimately ineffective, wanted neither by their supposed beneficiaries nor by the investing public agencies .
(Cernea 1985, p.323).

As a result of this growing recognition of the important role of user group demographics, perceptions, cultural values, and resource use patterns in determining effective management strategies (Renard 1991; White 1989; White *et al* . 1994), socio−economic assessments have become an increasingly important component of management decisions (Cernea 1985).

The coastal environment poses particular challenges to conducting socio−economic assessments and examining the implications of management strategies due to the diverse activities and user groups, the typically sectoralized government management regimes, and the nature of these traditionally open access resources. It is these characteristics that make understanding the user groups particularly critical. With the long history of open access evident in most coastal environments, users are inevitably thrown into conflict with competing coastal resource users as scarcity becomes an issue. Underlying the superficial issue of conflicts over the resource itself are the often conflicting social, cultural and economic backgrounds of the user groups.

Unlike biophysical assessments of coral reefs, for which established and standardized methodologies have evolved, means for assessing the socio−economic context of reef management are only beginning to be explored. The Caribbean Coastal Marine Productivity Program (CARICOMP), for example, has focused on assessing the biophysical conditions of reefs and associated habitats for over 6 years (Ogden *et al* . 1997). It is only within this year that the network has begun to consider incorporating socio−economic factors into their assessments (J. Woodley, University of the West Indies at Mona, pers. comm. 1999). At the same time, the Global Coral Reef Monitoring Network is developing a manual for conducting socio−economic assessments (C. Wilkinson, Global Coral Reef Monitoring Network, pers. comm. 1999).

The question, then, confronting many reef managers is, "What are the most appropriate, effective and efficient methodologies for conducting socio−economic assessments?" Perhaps of greater importance, "How can these assessments be utilized to receive the maximum benefit for management programs, particularly to facilitate the incorporation of users into the management process?" Due to the relative infancy of research on the socio−economic context of reef management, criteria specific to evaluating activities affecting reef resources have yet to be comprehensively developed. To date, studies have focused on issue−specific research and on the development of standard indicators for assessing the socio−cultural basis of reef uses (e.g., Pollnac 1998). Economic assessments have only recently begun to examine the extent of the benefits directly or indirectly associated with reef use (e.g., Cesar 1998; Dahuri 1996; Dixon 1992; Pendleton 1995; Tomascik 1993; Weber and Saunders 1996).

There is a lack of research concerning rapid quantitative and qualitative techniques for assessing both the social and economic bases of reef use. Yet, methodologies for conducting socio−economic assessments can be adapted from a range of established anthropological, sociological, and economic approaches, including: classical social, anthropological and economic approaches in which outside researchers use structured and often quantitative, resource− and time−intensive approaches, such as questionnaires and secondary data sources, to solicit information (Bernard 1989; Marshall and Rossman 1993; Patton 1990); rapid rural appraisal (RRA) techniques, in which outsiders elicit information from local people using rapid, semi−structured, field−based approaches, such as semi−structured interviews, focus groups, diagrams, direct observation and ranking (Chambers 1994; Pido *et al* . 1996; Schonhuth and Kievelitz 1994; Townsley 1993); and, participatory rural appraisal (PRA) techniques, in which outsiders serve as facilitators for local people to analyze their living conditions, share outcomes and plan activities using a range of community−oriented participatory programs, such as transect walks, matrix scoring, and wealth ranking (Balarin 1998; Chambers 1994; Schonhuth and Kievelitz 1994). These approaches are gradually, but increasingly, being adapted to the marine environment (Pido and Chua 1992; Pido *et al* . 1996), particularly marine fishing communities and coastal communities (e.g., Balarin 1998; Gorman 1995; Pido 1995; Pollnac *et al* . 1997; Townsley 1993). Adaptation of these methodologies to assess coral reef user groups is critical so that managers can better understand the persons who are being affected by management decisions and can best adapt management decisions for the benefit of these individuals.break

Methodology

Data Topics

This study involved a comprehensive investigation of the socio−economic background of the three primary reef user groups of the Montego Bay Marine Park—fishers, water sports operators, and hoteliers. The field portion of the study was conducted during January and February, 1998, in Montego Bay, Jamaica.

The socio−economic assessment of Montego Bay Marine Park examined the current status of social and economic conditions, historic shifts in those conditions, and the extent to which they are anticipated to change. Data on the following socio−economic variables were collected with respect to each user group:

Characteristics of user group activities . This included data on the types of activities (i.e., equipment used, methods employed), the nature of activities (i.e., what's involved, size and level of activity, structure of activity, type of product or output), and the location of activities, including spatial allocation among users.

Characteristics of the user groups . This included demographics (i.e., nationality, age, gender, level of education, ethnicity, economic status, area of residence), cultural value of the activity to the users and to the community, employment and incomes, socio−economic links with other activities, and relations between and within user groups.

Users' perceptions of the reef management . This included perceptions of reef conditions and impacts, concerns for Park management, actions proposed by the users to address concerns, current and past involvement of the user group in management, and their potential role in the future management of the Park.

Means of Data Collection

The data were collected through five principal means: document and database analysis, interviews, focus groups, telephone survey, and participant observation. Triangulation among these sources of information provided an important means to validate the findings (Buzzard 1990; Marshall and Rossman 1989; Patton 1990).

Documents and Database Analysis

An initial review of existing documents and databases established an information baseline from which the subsequent data collection could expand. The following types of documents were examined: government department records and reports, census and survey statistics, non−government organization and academic reports, Montego Bay Marine Park documents, and consultants' reports. This information was primarily used to elicit quantitative data on the user demographics, employment and incomes, and to further substantiate the perspectives revealed through the interviews.

Interviews

Interviews were the principal means of data collection and they provided the core material for developing an understanding of the different user groups. Fifty−two personal interviews were conducted with elite interviewees—persons familiar with, and knowledgeable about, one of the three user groups (Table 11.1; Dexter 1970). Interviewees were selected to provide knowledge about their user group, but to not unnecessarily duplicate information. Each of the interviewees was selected because she or he represents the interests of the group (e.g., the president of a fishers' cooperative), is an experienced par−soft

Table 11.1. Number of interviewees according to user group and sub−group representation.

User group	*Total number of interviewees associated with each user group*	*Sub−groups associated with each user group*
Fishers	35	River Bay landing beach White House landing beach key informants
Water sports operators	11	party cruises glass−bottom boats dive operations small watercraft all−inclusive hotel water sports
Hoteliers	6	all−inclusive hotels small hotels key informants

ticipant (e.g., a hotelier with more than thirty years experience in the Montego Bay hotel industry), or is a central member of the group (e.g., the owner of a dive and catamaran business and well−known community member). In those cases where an individual who met one of the above criteria was not readily apparent, snowball sampling was conducted in which the other interviewees were asked for recommendations of individuals who might fit the sampling requirements (Oppenheim 1992).

In order to gain in−depth information on topics relevant to the study and tailored to the knowledge and concerns of each interviewee, semi−structured interviews were conducted using flexible, open−ended interview guides (Patton 1990). A base interview guide was developed and then tailored for each interview (Table 11.2).

Most of the interviews were conducted in the interviewee's home or place of business, but some were conducted spontaneously in informal settings. All interviews were conducted in person and, with the exception of two group fisher interviews, were one on one. Before each interview began, the interviewee was given a written description of the research. Any questions regarding the study were then answered, and the importance and confidentiality of responses to interview questions explained. Detailed notes were taken during all interviews, which were transcribed as soon after the interviews as possible in order to note further details, observations and reflections.

Although interviews were the basis of the information collection, a significant amount of information came from less formal contacts. Throughout the study period, informal conversations were held with government officials, users and other individuals. These contacts were particularly useful for discovering other sources, contacts, or issues to explore further.break

Table 11.2. Essential elements of the base interview guide.

Characteristics of the activity	Current activity (range of operations; equipment used; size and frequency of activity; individuals involved; time involved); history of activity (changes in numbers and types; types of clients; locations and frequency); expectations for the future; current locations within Park waters.
Characteristics of the users	Structure of the industry or activity; characteristics of manager, employee and/or user (including age, gender, ethnic background, education, and economic status); seasonality and duration of involvement; area of residence; basis of participation; dependency for income (including changes over time); willingness and tendency to shift to other employment; types and acceptability of alternate jobs; individuals or businesses linked to activity; type and nature of indirect ties to other activities.
Users' perceptions of Park management	Perceptions of reef conditions; most significant impacts; perceptions of impacts from water sports, hotels, fishing, farming, cruise ships, manufacturing, littering, city sewage, others; environmental awareness and concern; group involved in marine environmental management; group resources to benefit management; top concerns for the Park; needs for better Park management.
Cultural value of activity	Attitude and outlook towards the activity (of management, staff, and/or users); importance to the user group community; perceptions of larger Montego Bay community's attitude and outlook towards the activity; importance to the larger community and particular groups.
Community and institutional structures	Formal and informal organizations (social and professional) and structures; decision−making processes (including addressing common problems); nature of social relations within group; relations and interactions with other groups (including fishing, water sports, hotels, farming, cruise ships, and manufacturing); other groups' effects on your use; nature of relations with government officials; trust in political institutions; relations and involvement with the Park; perceptions of the Park.
Economics	General industry or activity economic state; profitability of industry or activity; typical cost structures (capital outlays, labor, repairs and depreciation, goods and services, taxes, other); changes over time and perceived reasons behind changes.

Focus Groups

Two focus group meetings were conducted with representatives of fishers and water sports operators to solicit further information with regard to their general concerns for management of the Park, actions they would like the Park to take to address those concerns, and the potential role their user group can play in Park management. These meetings were conducted in part because of the Park's specific interest in learning about the management concerns and interests of the primary user groups. Five water sports operators, representing four businesses, attended the water sports focus group meeting. The fisher focus group meeting was conducted with approximately thirty River Bay fishers.

Telephone Survey

Using the same target questions as the focus group meetings, a telephone survey was conducted of hoteliers to assess their concerns and interests with regard to Park management. The telephone survey was the technique of choice for this user group due to the difficulty in trying to arrange a focus group meeting. Prior to initiating the survey, a fax describing the purpose of the survey was sent to the 23 hotels who border the Park and/or who have expressed a particular interest in Park management. Eight hoteliers participated in the survey.

Participant Observation

Two means of participant observation were conducted throughout the field research period: i) participation in user group activities, and ii) participation in Park management activities. Participation in user group activities included participating in specific user activities (e.g., glass−bottom boat snorkeling) and attending user organizational activities (e.g., the Montego Bay branch meeting of the Jamaica Hotel and Tourism Association). Participation in Park management activities included observations of patrols and daily Park staff activities, and attending Park Trust meetings. These observations provided insight into the mechanics of the user group activities and also helped gain the trust of the interviewees.

Socio−Economic Background of User Groups

In order to comprehend the socio−economic values of coral reefs and the socio−economic implications of reef management decisions, it is important to understand the socio−economic framework that underlies the human behavior affecting the reefs. This section provides the socio−economic background of fishing, water sports activities, and hotel operations, which is necessary for analyzing the socio−economic factors affecting reef management in Montego Bay Marine Park. Each of these activities is associated with several user groups (Table 11.3). The profiles presented here include information on the user groups' current, past and future levels and types of usage, as well as characteristics of each user group.

Fishing

Fishing has been, and continues to be, an important socio−economic component of Montego Bay, particularly to the five landing beaches—River Bay, White House, Reading, Bogue, and Spring Gardens. Over 85% of the approximately 400 registered fishers are based out of the two largest sites, River Bay and White House, while the remainder are based out of Reading, Bogue and Spring Gardens (Figure 11.1). In addition, an estimated 150 unregistered spear fishers operate from indeterminate sites along the coastline. Excluding the number of fishers who fish outside of Park waters, there are approximately 378 fishers fishing in the Park.[1] break

Table 11.3. Users associated with fishing, water sports, and hotel development.

Activity	*Primary users*
Fishing	Full−time and part−time fishers at River Bay, White House, Reading, Bogue, and Spring Gardens landing beaches
Water sports activities	Dive, snorkel, and party cruise operators (including owners, managers and staff), and visiting snorkelers and diversa
Hotel operations	Hoteliers (hotel owners and managers) and hotel staff

a Tourists, including visiting divers and snorkelers, were assessed in a contingent valuation study (Chapter 6); this report focused on the water sports operators, which includes the owners, managers, and staff.

Spear and hand line fishing are the predominant methods of fishing in Park waters, followed by net and trap fishing. Trap fishing typically occurs within a mile of shore, in depths of 30 to 60ft, on sand and near the reefs (Figure 11.1).2 Some fishers set as deep as 80 to 90ft to avoid vandalism by spear fishers, although this approach reduces catch rates. Net fishing typically occurs in sandy areas often between the reef and the shore. The primary net fishing sites are behind Doctor's Cave reef, along River Bay landing beach, and east of Spring Gardens landing beach. Hand line (or hook and line) fishing occurs from offshore to shallow areas and, subsequently, overlaps with many of the other fishing activities, particularly those of trap fishing (Figure 11.1). Spear fishers fish as deep as 60ft and as much as half a mile offshore. Within the Park waters, the most popular spear fishing areas are the reef from the airport to off of Doctor's Cave beach, the reef along the north western side of Seawind, and the reef westward along the coast to the Great River. Although catch per unit effort (per fishing trip) has declined to approximately 10 to 20lbs per trip, the number of registered fishers has increased 68% within the past three years. As catches have declined, fishers with motorized boats are shifting to offshore trolling, which occurs outside Park boundaries. Fishers without engines continue to predominantly fish within Park waters.

Based on the interview data, a realistic average yearly individual net income before taxes for most fishers (with the exception of spear fishers) is approximately J$104,000 to J$156,000 (US$3,000 to US$4,500).3 This results in a total net income of US$1,134,000 to US$1,701,000/yr for all fishers. Weekly individual incomes, before taxes, percontinue

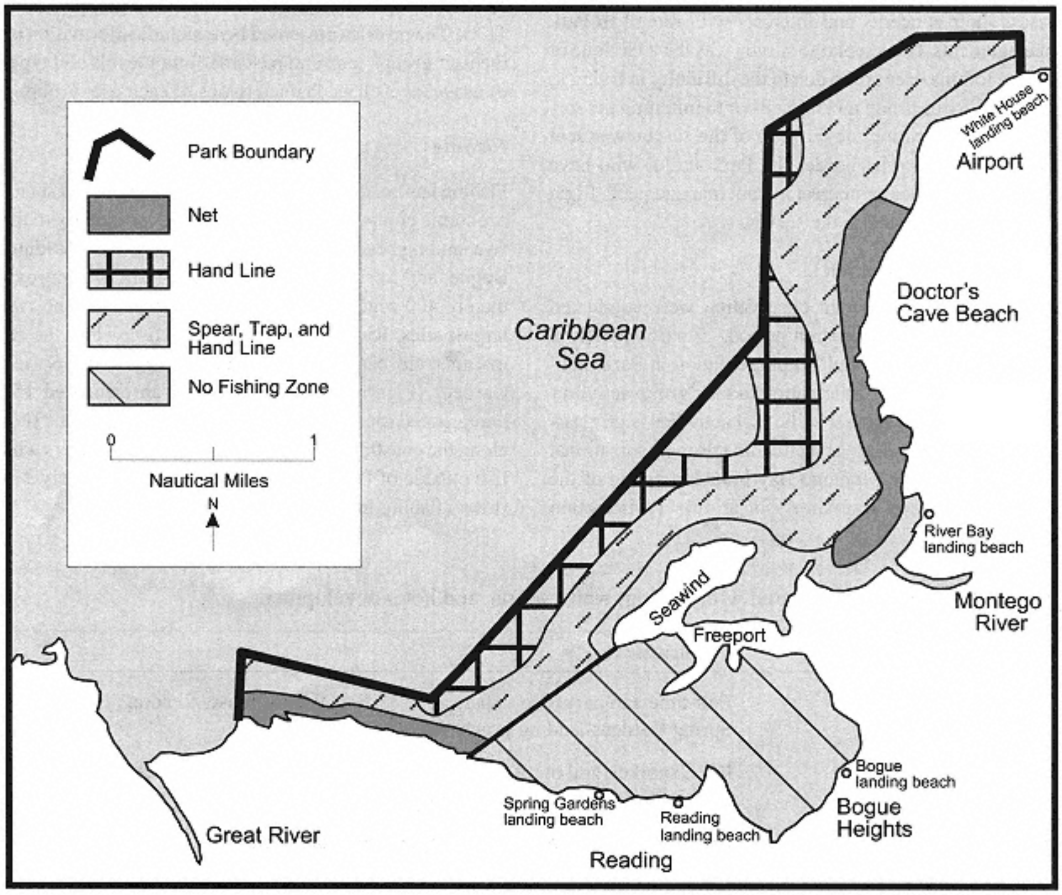


Figure 11.1.
Fishing activities within Montego Bay Marine Park.

fishing activity are estimated as: J$750 to J$2,500 (US$21 to US$71) for trolling; J$250 to J$500 (US$7 to US$14) for trap fishing; J$750 to J$2,250 (US$21 to US$64) for net fishing; J$750 to J$2,500 (US$21 to US$71) for hand line fishing; and J$5,000 to J$7,000 (US$143 to US$200) for spear fishing.

According to Fisheries Division (Ministry of Agriculture, Government of Jamaica) statistics, approximately 69% of fishers depend on fishing as a full−time source of employment. Interviewees estimated that 70% to 95% depend on fishing as their sole source of income; however, fishers also noted that most fishers have a second means of income. Almost all fishers are subsistence or small−scale commercial fishermen who sell their catch directly to the public at the landing beaches.

Fishers are generally characterized as poorly educated, low income Jamaicans with reputations for being highly independent. As one fisher defined his peer group, the "poorer class of people is the fisherman." The young fishers tend to view fishing as a flexible means of making a good living while retaining their independence. Although the older fishers also value their independence, they value fishing as an important part of their lives, more so than the younger fishers. As one older fisher stated, "I love fishing more than I love girls . . . it's in my whole being." In addition to being important to the fishers, fishing is also an important component of the surrounding communities, particularly at White House and River Bay. As one fisher noted, "Fishing plays a major role . . . It's the backbone of social and economic life here."

Water Sports Activities

Water sports activities in Montego Bay include 28 dive operations, snorkel businesses, party cruisers, and small−scale water sports businesses. Based on a survey of these operations, combined they take a total of over 3,100 tourists and nearly 220 trips into Park waters each week. On an annual basis, over 163,000 tourists utilize Park waters through over 11,000 water sports trips.

Water sports operations in Montego Bay began in the 1940s when the first glass−bottom boats began operating. Following the trend of the tourism industry, water sports boomed in the 1970s and 1980s. In the last five years, the number of private water sports operations has stabilized and has started to decline, which operators anticipate will continue. Since the shift towards all−inclusive hotels began 20 years ago, water sports operations, particularly the small watercraft operations, have been increasingly owned and managed by hotels. Currently over 66% of the beachfront hotels run their own water sports. Dive businesses are independently owned and operated under contracts to the hotels, while the party cruises market their businesses through concessionaires at the hotel and water sports desks. Many of the glass−bottom boat and snorkel operations remain independently run; however, these businesses are in dramatic decline, surviving only "by the mercy of God" as noted by one operator.

With the exception of the party cruisers and the independent snorkel operators, the water sports operations are mainly located along the Park coast, particularly adjacent to the strip of hotels north of the Park and, to a lesser extent, southwest of Montego Bay (Figure 11.2). Doctor's Cave reef is the main snorkeling, diving, and cruising destination.

The water sports industry is an entrepreneurial business with strong Jamaican representation. Over 90% of the water sports operations are Jamaican owned and managed. Originally, most operators entered the business because of their love of the water—"you had to love it" and it was something that became "a way of life". However, within the past ten years, there has been a shift such that water sports operations are being increasingly viewed as a business investment. With the decline in business, owners and managers are seeking alternative additional investments.

Total direct employment in the water sports industry is estimated at 200 employees. In contrast to the owners and managers, the typical water sports staff is a young (18 to 37 years of age) Jamaican male with little education, single with two to three children, referred to by a couple of managers as "beach bums". Water sports positions are considered good jobs because they offer a relatively high income while requiring a low level of skill. The employees have the added benefit of being able to work on the water. Turnover is relatively high (one to four years) within individual shops; however, staff tend to stay within the industry as a whole.

Hotel Operations

"The cradle of Jamaica's 20th century tourist industry," Montego Bay plays a major role in Jamaican tourism (GMRC 1996). Montego Bay receives 82% of all foreign national stopovers at its airport, accommodates 38% of those visitors, receives 26% to 34% of Jamaica's cruise ship visitors, and contributes approximately 15% of Jamaica's foreign exchange earnings (GMRC 1996).

Paralleling the growth of the tourism industry in Montego Bay, the hotel industry began in the 1920s, increased in the 1940s and the 1950s, declined dramatically during the socio−political unrest of the 1970s, rejuvenated in the 1980s, and is currently viewed as stabilizing. During this time, there has been a shift in the type of hotels from elite,continue

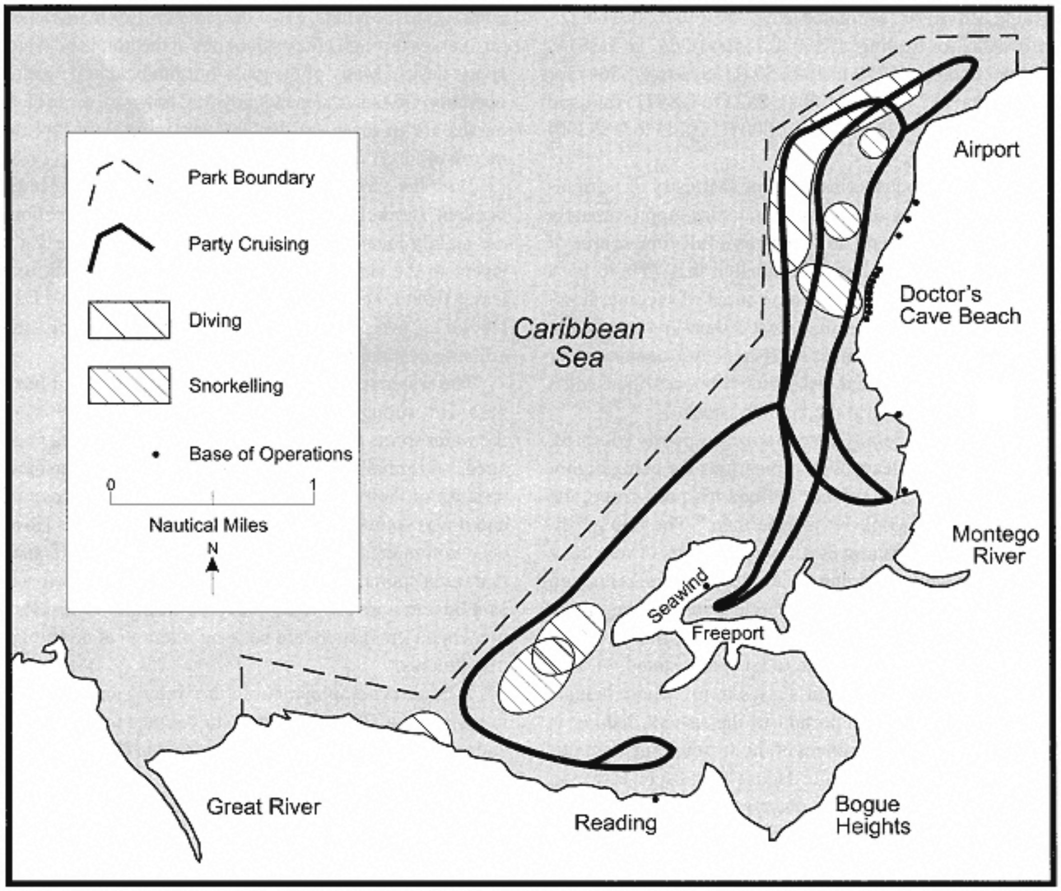


Figure 11.2.
Water sports activities within Montego Bay Marine Park.

high−class, foreign−owned hotels, typical of the 1920s to 1960s, to the current mix of exclusive resorts, small European plan hotels, and large, mass−market all−inclusive hotels. Despite the continued shift towards large, all−inclusive hotels (11 of 56 hotels are currently all−inclusives), the predominate type of hotel is still small and non−all−inclusive (41 of 56 hotels have less than 100 rooms). Currently, there are 56 hotels with 5,371 rooms. Annual occupancy rates average 53.37%, with over 800,000 rooms sold per year.

In large part due to the socio−political changes of the 1970s, the hotel industry, particularly the smaller hotels, are predominantly (over 75%) Jamaican owned and managed. The hotel managers and owners view the hotel industry as both a business and as a way of life. Hotel employment is estimated at over 16,000 employees, including 6,400 direct and 9,700 indirect employees. The hotel employees, who are typically Jamaican with a high school level education, view their jobs as a means of income with few long−term expectations.

These socio−economic profiles highlight the diverse nature of these three reef user groups, all of whose activities affect the reefs and reef environment in some way. The use patterns and characteristics of the groups range from the poor communities of fishers, who have been fishing Montego Bay's waters for generations, to the water sports operators, who in conjunction with the hoteliers, serve a multi−million dollar tourism industry. These socio−economic backgrounds provide the context for assessing the management implications of the user group characteristics and usage patterns.break

Socio−Economic Factors of Importance to Reef Management

Analysis of the socio−economic context of the three user groups indicates that there are several factors of particular significance for reef management programs and policies. These relate to: i) patterns of use; ii) the level of dependence on the resource; iii) the cultural value of reef activities; iv) ethnicity; v) relations within and among user groups; vi) the nature of indirect links to the Montego Bay community; vii) the level of awareness and concern for the resource; viii) relations with the Montego Bay Marine Park; and, ix) the nature and extent of resources of use to management efforts.

Patterns of Use

Comparison of usage patterns reveals a significant overlap between water sports and fishing activities (Figures 11.1 and 11.2). Doctor's Cave, located immediately offshore from the main strip of hotels, is the prime destination for party cruise, dive, snorkel, and glass−bottom boat operations. This area is also one of the most popular fishing areas for trap, hand line, and spear fishers. Since the reefs are immediately offshore from the hotels, the reefs are also at risk from sediment run−off and sewage disposal associated with hotel developments. As the intensity of use by divers and snorkelers has increased with the expanding tourism industry, rivalry has lead to conflicts over resource usage to the point that each group is accusing the other of sabotaging their ability to fish or dive the reefs. The fishers are accused of fishing out the dive and snorkel sites; the water sports operators are accused of opening the fishers' traps. These conflicts may pose the greatest challenge to managers, who are faced with having to maintain a balance of these various activities at sustainable levels, as well as having to limit or mitigate the impacts of one user group's activities on another.

Dependence on Resource Use

As discussed above, there are approximately 400 fishers and 200 water sports operators whose livelihoods directly depend on the reef resources. Approximately 70% to 95% of the fishers depend on fishing as their primary source of income with limited alternatives. The majority of water sports staff are full−time employees dependent on water sports as their primary source of income. Also, there are approximately 6,400 direct hotel employees who benefit from the reefs as a tourist attraction for hotel guests. The fact that such a large group of users is dependent on the fishing, water sports, and hotel industries for employment and earnings illustrates the importance of the reefs. Further, these findings indicate that dramatic changes in reef quality or changes in the management of reef activities could significantly and directly affect a large group of dependent users. These statistics demonstrate the political significance of continuing Park management programs to ensure the long−term sustainability of the reef resources and, subsequently, the user groups they support.

Cultural Value of Reef Activities

In addition to the benefits of reefs through direct employment and earnings and the multiplying economic effects though the larger economy, there are also cultural values associated with the reef activities. The cultural importance of fishing is demonstrated by the older fishers' love for the activity and its importance to the communities surrounding the two main landing beaches, White House and River Bay. The cultural importance of fishing confirms the need to consider the implications of management decisions not only in economic terms, but in the way management decisions may change peoples' way of life and, subsequently, impact their values.

In contrast to the older fishers, the hoteliers, water sports operators, and young fishers are increasingly viewing their activities as businesses. This shift towards a business perception of reef usage illustrates the importance of demonstrating the economic benefits of reef conservation programs in order to gain these users' compliance and support.

Ethnicity

Jamaicans dominate the fishing, hotel and water sports industries. Over 75% of the hotel owners are Jamaican, over 90% of the water sports owners are Jamaican, and all of the Park fishers are Jamaican. Furthermore, most of the hoteliers and water sports operators have been working in the tourism industry for ten to twenty years with little turnover, while most of the fishers have been fishing Montego Bay waters "since they were old enough to walk". As a consequence of their long histories in the region, these groups have direct knowledge of the resource conditions and impacts over time. This knowledge has contributed to their appreciation for the importance of conservation and sustainable use practices. In addition to taking advantage of the users' long−term knowledge to develop a better understanding of changes in resourcecontinue

conditions and appropriate locations for management programs (e.g., high diversity areas for reef monitoring), managers can draw on the users' pride in their natural treasures to develop concern and support for reef management programs.

Relations within and among User Groups

Relations between user groups are generally poor. There are limited interactions between fishers and hoteliers, in large part due to their distinct socio−economic backgrounds. Private water sports operators have feelings of resentment towards some of the hoteliers, particularly the all−inclusive managers, because they are increasingly dominating the water sports industry. Antagonistic relations have developed between fishers and water sports operators because each group feels the other is threatening their livelihood through fishing out the marine life and through opening or damaging fish traps, respectively. Regular encounters in Park waters, while using the resource, compound the problem.

With regard to the relations among users within each of these three user groups, there are strong formal and/or informal professional and social relations within each distinct user group. The two fishing communities at River Bay and White House landing beaches have established cooperatives that lobby for their mutual interests, including improved facilities and duty−free concessions. Hoteliers have both formalized interactions through the Montego Bay chapter of the Jamaica Hotel and Tourism Association, as well as informal relations through social events. Although the water sports operators do not have an organizational structure, as one operator noted, "everyone knows everyone". These formal and informal networks within each user group have provided opportunities for these users to work together towards addressing their common concerns. This framework could provide a basis for developing users' participation in, and support of, Park management programs. Further, the organizational network of each user group could be drawn upon to build ties between groups and, ultimately, develop inter−sectoral, comprehensive management programs that address the diversity of activities affecting the Park resources.

Indirect Links to the Montego Bay Community

There are many indirect links between these three user groups and the larger Montego Bay community that are primarily associated with the tourism and hotel industry. As the GMRC (1996) reported, the hotel industry, "has created significant inflows of foreign currency, generated widespread direct and indirect employment, triggered further rounds of economic activities, provided outlets for cultural and artistic expressions, and impacted positively on Jamaica's government revenue and to the current account of its balance of payments." With regard to water sports activities, the water sports operators are linked to each other, the hotels and the cruise operators through commissions, contracts and ownership. Forward links from fishing to other activities are relatively limited since fishing is largely subsistence with few sales; however, there are important backward links from goods and services sold to the fishers by the surrounding communities. The backward and forward linkages between various sectors indicate that management programs and changes in reef quality can have significant effects on the larger Montego Bay community.

Awareness and Concern

All three user groups recognize that marine resource conditions are deteriorating at an alarming rate. Further, these groups generally agree on the major causes—specifically, pollution from solid waste and sewage disposal. The water sports operators and hoteliers generally recognize, and are concerned about, the impacts of their own activities and their guests' activities. In contrast, the fishers do not see fishing as having a major impact on the reefs. As one fisher noted, "more fishers means catch more fish". Perhaps of greater importance, there are misunderstandings by fishers and some hoteliers regarding Park regulations, particularly boundary locations, and there is a general lack of awareness of Park activities. This lack of awareness regarding Park activities has contributed to the current lack of trust in the Park's ability to effectively manage the Park resources. Future support and assistance from these important user groups depends on better communication regarding Park activities. Further, compliance of the fishers with Park regulations necessitates an awareness program on the short−term effects of intensive fishing on marine resources *and* the long−term benefits of sustainable fishing practices.

Relations with the Montego Bay Marine Park

Water sports operators generally have strong, positive relations with the Park staff. Many water sports managers and owners have been actively involved in Park management, including lobbying for the establishment of the Park, serving on advisory commissions and the current Park Trust, and assisting in Park management programs, such as the reef mooring system and public educationcontinue

programs. This positive relationship is in direct contrast with the Park's relations with the fishers. The common perception of the fishers regarding management is well reflected in one fisher's comment: "Now Park is helping us into trouble . . . need to help us out of trouble." The fishers, who have been fishing the Montego Bay waters for generations, feel that they are being unfairly targeted in the Park's attempts to protect the reefs and the marine conditions.

Relations between the Park and hoteliers vary. Some hoteliers assist in fund−raising efforts by hosting events and sponsoring individual management programs, while other hoteliers are not even aware that the Park exists. The Park's positive relations with the water sports operators and some hoteliers indicate that these two groups can be continued sources of technical assistance and support; however, the poor relations with the fishers indicate that the Park will have to demonstrate its support of fishing activities within Park waters in order to gain the fishers' support for sustainable fishing programs and further management efforts initiated by the Park.

Resources of Use to Management Efforts

The resources of the different user groups can potentially benefit Park management. Both the water sports operators and the fishers are highly knowledgeable of the reefs and have ready access. The water sports operators snorkel and dive specific reef locations on a daily to weekly basis. Although their schedule is less predictable, reef fishers are on the water between one to five times each week and have relatively flexible working schedules. Mooring, monitoring and enforcement programs are three programs that could actively involve the operators and fishers in managing the reefs while taking advantage of their reef knowledge and access.

Hoteliers offer another important resource—funding. Hoteliers already support some community social services, such as the school bus system, as part of their public relations program; eliciting hotel support for coral reef conservation efforts would further promote community relations and contribute to their reputations as environmentally sensitive tourist accommodations. The financial resources of the relatively affluent, increasingly conservation−minded nature of many of the tourists might also be accessed through the hotels. Hosting fund−raising events, selling Park concession items in their gift shops, including a "donation to the Montego Bay Marine Park" option on guest bills, and collecting user fees are some of the ways hotels could utilize their access to the tourist community to solicit funds for the Park.

Guiding Principles for Future Reef Management

The analysis of the socio−economic factors of importance to reef management provides the basis for developing guiding principles for future reef management in Montego Bay Marine Park. The analysis 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) inter−sectoral coordination among user groups. This section discusses the importance of these principles, their current state with regard to Montego Bay Marine Park management, and how they can be developed to maximize the socio−economic benefits of reef use through effective management.

User Group Awareness and Concern

A greater awareness of the Park and its policies and programs is essential if effective management is to be achieved. High levels of user group awareness and concern regarding reef conditions, impacts and management issues serve as a basis to work towards ensuring sustainable use and conservation of the reef resources. The user groups are the individuals with potentially the greatest impacts on the reef quality, but also are potentially the greatest supporters politically, financially, and in kind. Without faith in the Park's abilities and initiatives, user support will not be forthcoming.

Currently the majority of the fishers, water sports operators and hoteliers are aware of the decline in the reef conditions and of the nature of the impacts, but many of the fishers and hoteliers are unclear or unfamiliar with Park regulations, policies and programs. The fishers, for example, perceive the Park to be trying to push them completely out of Park waters; however, Park objectives are to allow multiple, sustainable levels of activities, including fishing. As a result of these misunderstandings, many of the fishers and hoteliers, and a few of the water sports operators, lack trust, or are losing trust, in the abilities of Park authorities to manage the area. This has led to low levels of compliance with regulations and management directives and waning support for the Park. The need to increase Park awareness is at a critical stage as the demand for the marine resources and the levels of use are increasing, yet the environmental conditions are declining. This situation will only lead to an increase in the rival behavior of the users, and animosity and conflict between groups.break

This lack of awareness is attributed, in part, to poor communication between the Park and the users, the lack of visible, tangible products and services from the Park, and a lack of user education regarding Park goals and programs. This analysis indicates that improved awareness requires that Park education programs be targeted specifically to the user groups, perhaps through outreach programs, and that they highlight the Park's management programs, particularly the beneficial, tangible products and services the Park provides (e.g., training for fishers, mooring system for water sports operators).

Park awareness programs also need to demonstrate the value of conservation not only in terms of biodiversity, but also in terms of the social, cultural, and economic values of reefs and their associated activities. Users' general awareness and concern regarding reef conservation may be enhanced by focusing on the benefits to their businesses and way of life, and by taking advantage of their sense of pride in their natural heritage. The owners, operators, and employees of the fishing, water sports and hotel businesses are predominately Jamaicans and long−term participants in the industry. Montego Bay Marine Park management strategies can take advantage of the resident status, nationality and history of these user groups in the area by emphasizing the direct vested interest these stakeholders have in the conservation of the reefs. Further, given that these three user groups are increasingly viewing their activities as businesses, concern for the reefs may also be increased by demonstrating the economic benefits of reef conservation in terms of the number of employees and incomes associated with reef activities. In contrast, for the older fishers, management strategies need to show the potential for maintaining the cultural values associated with fishing. Targeting the social, cultural and economic values of reefs can demonstrate the importance of sustainable use of the reefs to these diverse groups.

Opportunities to Market the Park and to Provide Incentives

In addition to developing a greater understanding of the socio−economic benefits of coral reef conservation through programs that increase awareness and concern, users must also be able to realize those benefits directly. The closer the tie between reef conditions and business earnings, the greater the users' support for reef conservation. The links between coral reef conditions within the Montego Bay Marine Park and the economic and social benefits are not immediately apparent for some user groups. 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 are not necessarily perceived by owners and managers. Consequently, business and management decisions rarely consider the potential impacts of decisions on the reefs.

The Park needs to provide the link between reef conservation and the direct economic benefits to businesses. This may be accomplished by "selling" support for the Park and its reef management programs. Given the tourists' increasing demand for "environmentally friendly" products and services, tourism related industries (e.g., hotels and water sports operations) can utilize their support of the Park to attract tourists to their "eco−conscious" businesses. An example of a mechanism for soliciting support that would allow these businesses to demonstrate their environmental commitment is a "Friend of the Reef" program in which donors are presented framed certificates and given special advertising rights in tourist magazines. Given that hoteliers and water sports operators are increasingly viewing their operations as businesses, this strategy is an appropriate means to tap into these groups' financial resources to the benefit of both the Park and these user groups.

In the case of the fishers, where there are fewer direct, short−term economic benefits from reef management programs, the Park must provide socially and economically realistic alternatives if fishing activities are to be curtailed. In order for fishers to begin to cooperate with management initiatives, the Park needs to demonstrate its support of fishing activities by developing programs that benefit the fishers (e.g., low rate loans, training in alternate occupations), rather than programs that have the apparent intent to alienate their way of life (e.g., more "no fishing" zones). Such programs could be in the form of financial or educational support for an alteration in their fishing patterns or techniques. Regardless of the form, these programs need to be initiated before further restrictions on use are imposed.

User Group Involvement

Another important guiding principle for reef management is user group involvement in which there are cooperative efforts between the public and private sectors. Involvement of individuals affected by management decisions in the decision−making process helps gather political support for, increase compliance with, and reduce oppositioncontinue

to, policy proposals, projects, and other decisions by considering and building in users' concerns. User involvement brings into decision−making more information and a wider range of experiences, both of which contribute to the development of more realistic policies and programs. Further, user involvement ultimately maximizes limited public agency resources by drawing from user resources (e.g, fishers and dive operators' daily access to, and knowledge of, the reefs).

Many users, particularly water sports operators, already play significant roles in management of the Montego Bay Marine Park, primarily through informal and formal relations with the Park. As outlined above, water sports operators generally have strong, positive relations with the Park staff, having been actively involved in Park management. Relations between the Park and hotels and the extent of involvement by hoteliers varies. Existing, positive relations can be used to foster long−term commitments to the Park.

User involvement can be facilitated by focusing on resources that the users can provide to management such as access to, and knowledge of, the reefs and fund−raising opportunities. These resources can be tapped by working through existing organizational structures and networks. For example, the formal organizational structure provided by the Jamaica Hotel and Tourism Association has already provided a means for hoteliers to work together. This can be tapped to develop cooperative programs with the Park. Further, the strong community structure evident within the White House fishing community can provide a base for developing better communication between the fishers and the Park. This community structure can be used as a vehicle for implementing programs in which fishers are directly involved. River Bay fishers are more reticent of new approaches and, thus, will likely be more skeptical of new Park initiatives, yet there is the potential of working through the River Bay Fishermen's Cooperative to gain acceptance and direct involvement. By developing programs that utilize the users' resources and skills, these groups can be positively brought into the management process while contributing to its success.

Finally, successful development of a program of user involvement in Park management needs to demonstrate a commitment to multiple use. Fairness in user treatment needs to be instilled and perceived by users. Fishers predominantly feel that they are being unfairly targeted by management authorities in the Park's efforts to bring under control the continuing decline of the reef conditions, while other damaging activities go unchecked (e.g., party cruises, diving, snorkeling). There needs to be more balanced involvement of all the user groups.

Management of the Park As a Community Resource

The coral reefs of Montego Bay are common pool 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 few 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, with the associated loss in short−term benefits or additional incurred costs, because it will be seen as a sacrifice for the benefit of others. The open access regime needs to be replaced in favor of a management regime that provides for exclusion and the capture of economic rent from users benefiting from the use of the reef.

The issue of managing the coral reefs through the allocation of "property rights" is not only a matter of limiting and licensing users and collecting user fees (or other vehicles for rent capture). Ideally, it also involves changing the social perception of the coral reefs by developing a sense of the reefs as a community resource. This means fostering the belief that each user has an interest in effective management and that their long−term interests are protected. This strategy can strengthen their individual positions as important components of the larger community and as integral participants in Park management, whether they be fishers, water sports operators, or hoteliers.

All three previously discussed guiding principles for reef management will help develop a sense of community around the resource—a sense of community that necessarily arises out of an increase in the awareness and concern over the resource, an increase in the ability to see direct social, cultural, and economic benefits from conservation, and an active role by all users in the development and implementation of management programs.

Inter−Sectoral Coordination

Given the diversity of activities affecting the reefs (e.g., pollution, snorkeling, diving, and fishing; see Chapters 1 and 2), management must be integrated across sectors and across the land−sea boundary. Coordination within and among user groups is important for users to participate in, and contribute towards, comprehensive management efforts of these diverse activities. Building better relations, and eventually coordination, between user groups improves support for management initiatives.break

The study revealed that user groups are sectoralized, with few working or social relationships forged between user groups. This sectoralization is quite evident even within particular user groups. For example, River Bay fishers have few relations with White House fishers, and all−inclusive hotel water sports operators are not on familiar terms with those working in non−hotel affiliated water sports. In many instances, the lack of either social or working relationships, and the lack of an understanding of the other users, has lead to antagonism and conflict, a lack of trust between groups, an unwillingness to comply with management initiatives, and, ultimately, further degradation of the reef.

As discussed with regard to user group involvement, the current network of users can serve as a base for developing further, positive interactions. By focusing on the similar interests of the users and ways to resolve conflicts, coordination between groups can be facilitated. By gradually building positive relations among the user groups, they will ultimately be able to work together to maximize the range of available resources, minimize duplication, and ensure complementary and cooperative programs as part of a comprehensive effort towards reef management.

Conclusions

This study compliments the other components of the larger World Bank project, which is developing and testing methodologies for estimating the benefits derived from the use of coral reefs in the developing tropics (see other contributions in this publication). The potential policy directions arising out of a cost−benefit analysis aimed at achieving an economically efficient outcome can be assessed with regard to the socio−economic implications using the analysis presented in this study. More specifically, the guiding principles, which were developed through the analysis by considering the socio−economic factors of importance for management, can be used to help focus policy and program efforts to achieve an efficient, viable, and sustainable management strategy.

As presented in the previous chapters, the coral reef valuation work focused on: i) an examination of the direct and indirect *local use* values, focusing on the estimation of the contribution of coral reef biodiversity to production values; ii) an examination of the contribution of coral reefs to the utility of individuals through a *contingent valuation* survey to reveal willingness−to−pay for both use and non−use benefits; and, iii) an examination of the potential for biodiversity values to be realized through *marine bioprospecting* , involving consideration of the size and distribution of use values through captured rent, profits, or value added. The link between the socio−economic assessment and the economic valuation studies for Montego Bay Marine Park can most clearly be seen through the identified socio−economic factors of importance for reef management. First, the extent of the dependence on resource use documented by this study outlines the nature of the direct employment and earnings for approximately 8,000 people among the three primary user groups (fishers, water sports operators, and hoteliers), as well as many socio−economic links with other components of the economy and the community at large. The direct production values associated with tourism and fisheries are the subject of the *local use* study (Chapter 5). This socio−economic assessment provides additional cultural and social context for the more detailed modeling of the associated fisheries and tourism production values. Second, the cultural value of reef activities, described here, are also addressed through the *contingent valuation* study, in which the willingness−to−pay for conservation by local residents and tourists is estimated (Chapter 6). The socio−economic assessment again provides necessary detail to assist with the successful implementation of policies and programs by providing the larger context necessary to consider the viability of alternatives. For example, potential mechanisms that can be used to capture tourist consumer surplus (the difference between the amount of money that they would be willing to pay and what they actually do have to pay), as measured through the contingent valuation, are identified through the examination of the potential user group resources.

In addition to the links with other components of the coral reef valuations, this study presents findings not addressed by the other project components. These findings relate directly to considerations necessary for effective management, including the patterns of use, the ethnicity and extent of involvement of the users, the relations within and among user groups, relations of the users with Park authorities, and the identification of user resources that may be beneficial to management. The identification of an economically efficient conservation effort based on the economic valuation and least cost intervention studies alone would not necessarily lead to a successful or efficient program in practice, without considering the implications of critical socio−economic factors such as those presented in this study.break

Endnotes

1 The approximate total of 378 fishers fishing within Park waters is based on the summation of the following: 150 unregistered spear fishers, 10% of all registered fishers in White House, and 100% of all registered net, spear, trap, hand line, and "other" fishers in the other four landing beaches.

2 The fishing zones in Figure 11.1 are not as spatially distinct as depicted. Methods of fishing overlap with adjacent methods, particularly as one moves from offshore to inshore. However, there is an overall pattern of zonation as indicated in the figure.

3 This calculation is based on the estimated J$2000 to J$3000 per week net income, before taxes, per fisher. A figure slightly higher than that calculated based on second−hand catch and price information was assumed based on the judgment that the higher estimate was more "realistic" (based on cross−checking of information from other sources and as provided in other components of the interviews). The net income "nets out" operating costs, maintenance and depreciation, and returns for capital investments (i.e., return to the owner of the boat). The exchange rate assumed throughout this document is J$35=US$1.break

Chapter 12—
Incorporating Genetic Resource Utilization into ICZM—Policies and Institutions in Jamaica

Daniel Putterman
Genetic Resources Consulting, Washington, DC, USA

Biodiversity that is of interest to industry for its potential to provide diverse chemicals, enzymes and genes is known as *genetic resources* . Genetic resources yielding potentially valuable products include terrestrial and marine microbes, plants, insects, venomous animals and marine organisms. The notion that developing countries can integrate the sustainable use of marine genetic resources into coastal zone planning is a new one. Several international treaties empower the Government of Jamaica under international law to enact regulations promoting this. The objectives of this chapter are to: i) provide the Government of Jamaica as well as private organizations, including non−government organizations (NGOs), private industry, and academia, with an assessment of

Jamaican institutions with expertise relevant to the management of marine genetic resources; and, ii) provide a concise set of policy recommendations intended to enable Jamaica to capture the maximum value created by commercial research and development (R&D) with marine genetic resources.

The following section considers two Jamaican case studies involving genetic resources (R&D), then provides a brief review of commerce and policy issues related to genetic resources utilization. Subsequent sections summarize the results of an institutional assessment (conducted late February 1998), define components of a minimal policy on genetic resources utilization, and explore the development implications of claiming different kinds of rights to genetic resources research material. This chapter concludes by revisiting the Jamaican case studies of genetic resources utilization and providing alternative scenarios based upon the policy recommendations.

The development of marine genetic resources into new commercial products can be a powerful tool for conservation and economic development, and as such, marine genetic resources ought to be incorporated into integrated coastal zone management (ICZM) planning. However, while this chapter is intended as a contribution to the study of marine biodiversity, the reviews and recommendations contained herein are equally applicable to terrestrial genetic resources. Utilization of both marine and terrestrial genetic resources involves many common techniques and legal issues, while policy mechanisms to regulate the use of these resources are intimately linked. *As such, the policy recommendations in this chapter are intended to regulate the utilization of both marine and terrestrial genetic resources* .

Two Jamaican Case Studies—Statement of the Problem

To illustrate genetic resources issues with which Jamaica currently grapples, two case studies involving actual use are presented.

Marine Bioprospecting in Jamaican Coastal Waters

Interviews with Jamaican researchers revealed that at least a half−dozen formal foreign research expeditions had collected marine genetic resources in Jamaican coastal waters over the past three decades. In addition, there was a general feeling that a number of unauthorized expeditions had collected in Jamaican waters and on land. In one case, a large US oceanographic research institute had sent a deep−sea submersible to collect sponges in 1993. The project, which was approved by the Jamaican government, listed one of its objectives as the development of new commercial products with pharmaceutical, agrochemical, or other industrial applications.

Although the Government of Jamaica had issued a collecting permit for this project, ironically there was no mechanism to capture a portion of the value of these marine genetic resources for the source country, other than the obligation to leave taxonomic voucher specimens at the University of the West Indies at Mona (UWI). Future expeditions to Jamaica may encounter difficultycontinue

obtaining a research permit from the Natural Resources Conservation Authority (NRCA), given the general anxiety over this inability to share in the benefits of research and the mistrust that it engenders.

Biotechnology Based Improvement of Jamaican Papaya Germplasm

The Jamaican papaya industry has developed into an important source of foreign exchange, with 1995 export sales of approximately US$20 million. A local variety known as Sunrise Solo had been bred in the early 1980s by Jamaican growers, adapted from papayas developed in Barbados and Hawaii. However, by the middle of the 1990s, problems with the Papaya Ringspot Virus, which causes stunting and production of poor quality spotted fruit, had reduced yields by 30% to 40%. During this time, a non−profit industry association, the Jamaica

Agricultural Development Foundation, contacted a Jamaican researcher studying at Cornell University for assistance with developing a strategy to combat the disease. After consultations with Cornell faculty and preliminary tests, a project to develop a virus resistant transgenic plant was initiated with funding provided, in part, by the Jamaica Agricultural Development Foundation (JADF).

Proprietary biotechnology for the development of virus resistance had been previously made available to Cornell researchers by scientists at Dupont, Monsanto, and other agricultural biotechnology firms. JADF on its own negotiated a research agreement with Cornell, which in turn was bound by prior agreements with the companies that had transferred the technology. Under the Cornell agreement, Jamaican researchers and growers would be free to use any improved varieties developed by the collaboration for local research and production for domestic markets. However, production of the transgenic plants for export would require the negotiation of a license incorporating a royalty percentage to be paid to the companies. After the virus resistant varieties had been developed, JADF learned that the companies were likely to charge no more than a nominal royalty, in line with company policy supporting agricultural development in developing countries.

Development of the transgenic papaya variety stimulated the Government of Jamaica to develop a biosafety mechanism sufficient to ensure safe field testing of genetically modified organisms. At this point, JADF's remaining tasks include the negotiation of the licensing agreement for commercial production and export. When the NRCA was interviewed about this topic, it was apparent that the agency did not possess the most up to date information on the project.

Introduction to Genetic Resources Issues—Commerce and Policy

Biologists describe the diversity of biological systems at three scales (for a review see Wilson 1992). Ecosystem diversity measures the diversity of biological processes and organization across a landscape. Species diversity is the level with which most are familiar, and is sometimes misunderstood as the only definition of biodiversity. At the smallest scale there is chemical and genetic diversity, a measure of the biological diversity within species and of the complexity of chemical interactions between species. Biodiversity at this scale is referred to as genetic resources—the source of industrial natural products and of new agricultural varieties. Genetic resources yielding potentially valuable chemicals, enzymes or genes include terrestrial and marine microbes (especially fungi, actinomycetes and archeae), plants, insects, venomous animals and marine organisms.

Although tropical rainforests are well known for high species diversity, numerous ecosystems, including marine environments, are valued for their high genetic resources diversity (also called "molecular diversity"). The molecular diversity among microbes, both terrestrial and marine, is likely to be orders of magnitude higher than that of plants and animals (Paleroni 1994). Harsh environments found on both land and sea are also a major source of molecular diversity, and have yielded valuable "extremophile" micro−organisms adapted to living under extremes of heat, cold, pH, or mineral concentration.

Commerce involving genetic resources can be divided into R&D versus production. Examples of production include sourcing plants or microbes for the manufacturing of pharmaceuticals, agrochemicals or herbal products. Examples of R&D include research to identify new industrial enzymes or new pharmaceutical drugs from genetic resources, also called "bioprospecting".

Biological Diversity in the Sea

Marine genetic resources deserve special treatment, as little information is available on practical strategies for using this valuable biodiversity. Estimates of species diversity in the sea are growing, and one recent deep−ocean study put this number as high as 10 million, roughly comparable to that of terrestrial species diversity (reviewed in Norse 1993b). Higher marine species diversity is found in coastal ecosystems, and by far the greatest diversity is in the tropics, making the waters surrounding tropical developing countries the richest marine source in the world for molecular diversity. Examples of coastal ecosystems include coral reefs (with the highest species diversity),continue

seagrass beds, oyster reefs, mangroves, salt marshes, and continental shelves.

Marine genetic resources known to yield useful chemicals, enzymes and genes include marine micro−organisms, plants, invertebrates and cartilaginous fishes. Coastal genetic resources are generally collected by scuba diving at depths of less than 100m or by dredging at depths of up to 500m to 1000m on the continental shelf (D'Auria *et al.* 1993). Taxonomic inventory of marine organisms differs from that of terrestrial organisms in that collection expeditions are somewhat costlier and samples must be frozen immediately, with the exception of marine micro−organisms, which are usually cultured.

The sea yields extraordinary molecular diversity. Marine genetic resources often contain unusual or highly complex molecular diversity not found in terrestrial organisms (Scheuer 1990). Marine invertebrates, usually sessile and/or soft−bodied, have intrigued marine natural products chemists for decades. Scientists have followed a so−called "bio−rational" approach to screening, arguing that, with such seemingly vulnerable body plans, these invertebrates must have evolved effective chemical defenses as a survival strategy. Preferred marine macro−organisms include sponges, cnidarians, bryozoans, molluscs, echinoderms and tunicates.

The potential molecular diversity among marine microbes is higher still. Many microbes, including dinoflagellates, can be cultured directly from the water column. New techniques are available for culturing symbiotic or commensal microbes such as bacteria, cyanobacteria and algae from the tissues of macro−organisms. Recent work on culturing micro−organisms isolated from the water column, from shallow water marine sediments including oil seeps, or from marine animal hosts has yielded a promising array of new chemicals (Fenical 1993). As the technology for culturing marine microbes develops, it is likely that interesting organisms will be discovered in a wide range of marine hosts. For this reason, conventional predictions about which marine species will yield economically valuable chemicals are probably no longer valid. If it is true that most, if not all, marine species provide critical microhabitats for commensal micro−organisms that may produce bioactive compounds, this would imply a greater value for all marine organisms, compounding the value of highly diverse ecosystems such as coral reefs.

The list of useful products derived from marine genetic resources is too long to chronicle here. Examples include anticancer compounds, antivirals, antibiotics, anti−fungals, anti−inflammatory agents and hormonal modulators (for reviews see Flam 1994; Wright and McCarthy 1994). Marine genetic resources have yielded industrial enzymes such as proteases and collagenases, and are also studied for clues to the development of new agrochemicals (for a review see Zilinskas *et al.* 1995).

Marine genetic resources are also the source of marine biomaterials and of extremely potent toxins, some of which may have applications as anticancer drugs or as diagnostic and research tools. Marine genetic resources are also of interest to the cosmetics industry, and may one day yield new sunscreens and other skin care products. For example, an anti−inflammatory agent derived from a tropical sea fan is currently under development as a skin care product by a major cosmetics firm (Jacob 1996). Finally, even higher marine animals have yielded promising new pharmaceutical leads. One example is squalamine, a potential anticancer drug isolated from cartilage of the dogfish shark *Squalus acanthias* (Moore *et al.* 1993).

Genetic Resources Markets

Large global markets exist for products derived from genetic resources. These are summarized in Table 12.1.

The Value−Adding Process of Research and Development

Unique among commercial uses of biodiversity, genetic resources R&D relies upon trade in information, rather than physical goods *per se* , to generate high value products. The size of samples collected for study can be quite small, typically less than 100g of material. Samples are studied to yield such *value−added research material* as small organic molecules called secondary metabolites, genes encoding proteins such as enzymes, or metabolic pathways linking enzymatic reactions together in a process known as microbial fermentation.

Genetic resources research can be divided into a series of value−adding processes, beginning with a biological inventory requiring accurate taxonomic identification of specimens. Inventory strategies include random inventories, bio−rational inventories which rely upon ecological evidence of inter−specific chemical interactions, and ethnobotanical inventories which gather information on traditional knowledge of useful plants. The choice of inventory strategy depends on the market sector, with nutraceuticals markets relying most heavily on ethnobotany, enzyme and microbes markets utilizing random and bio−rational inventories, and pharmaceuticals and agrochemicals relying on all three, but emphasizing random and bio−rational approaches.

Following inventory, the chemicals or genes are extracted from the genetic resource, and the extracts are screened with laboratory tests known as biological assays or "bioassays" to detect the desired biological activity.continue

Table 12.1. Estimated global sales from existing markets for products derived from genetic resources. The market sectors highlighted use variable percentages of genetic resources as starting material (i.e., approximately 40% for pharmaceuticals; 100% for agricultural seeds, nutraceuticals, enzymes and microbes).

Market sector	*Estimated global sales (billion US$)*	*Source*
Pharmaceuticals	256	Scrip (1996)
Pesticides	47	Burrill and Lee (1993); Moffat (1993); World Bank (1991)
Agricultural seeds (commercial sales)	13	Van Gaasbeek *et al.* (1994)
Nutraceuticals (herbal products, phytomedicines)	12.4	Brevoort (1996); Yuan and Hsu (1996)
Cosmetics (skin care products)	6	Niebling (1996)
Industrial enzymes	1.6	Stroh (1998)
Industrial microbes	0.68	Perez (1995)
Biotechnology enzymes	0.6	New York Times (1993)

Bioassays are used to guide the identification process until a pure enzyme or microbial strain or chemical compound (called a "lead compound") is isolated. Further commercial R&D may involve expensive animal and/or voluntary human testing.

Three Strategies for Research Collaboration

Because genetic resources research and development entails substantial financial risk to private companies seeking to develop commercial products, many firms seek out research collaborations as a risk reducing strategy to maximize their ability to discover promising new chemicals or genes. Three strategies—outsourcing, in−licensing, and joint venture partnering—are employed.

Outsourcing . Outsourcing entails contracting with private organizations or individuals to supply certain value−adding services, such as sample collection, extraction, and bioassay. An entire industry has evolved to supply the outsourcing needs of large companies engaged in genetic resources R&D, involving suppliers such as natural products libraries, botanical garden collectors, oceanographic research institutes, academic researchers, and specialized companies offering bioassay services. Many of the highly publicized biodiversity prospecting contracts negotiated in recent years between private firms and research institutes or NGOs in biodiversity rich developing countries are examples of outsourcing by large R&D companies.

In−licensing . By contrast, in−licensing entails acquiring the rights to valuable chemicals, genes or microbes which have been previously identified by an independent research group. Large R&D companies may in−license promising research material from other firms or from non−profit research institutes, including universities. In many developed countries, it is now common for universities to have specialized offices of technology transfer staffed by negotiators familiar with business contracts and intellectual property law. Technology transfer specialists actively seek private sector companies willing to in−license basic research discoveries, for an agreed on fee.

Joint venture partnering . A third business strategy involves the creation of joint ventures. Typically, a genetic resources joint venture partnership would involve one company in a developed country and one in a biodiversity source country. Joint ventures involve shared financial risks and the proportional sharing of revenue or technology. Note that strong intellectual property protection is usually necessary to encourage joint venture development, particularly when technology transfer is inherent to the partnership (Mansfield 1995).

Benefit Sharing Mechanisms and Options for Compensation

It is customary to define all the obligations of research partners through prior negotiation utilizing legally binding research contracts or material transfer agreementscontinue

(MTAs; Barton and Siebeck 1994; Gollin 1995; Putterman 1996). Numerous mechanisms for compensation exist:

Rental fees . It is customary to charge a rental fee (also known as *up−front* or *guaranteed compensation*) for the use of *value−added genetic resources research material* to private firms engaged in product development. Chemical or biochemical extracts of inventoried genetic resources represent the lowest end of the value−added chain, renting for tens to hundreds of dollars each. The value of extracts with a positive result on a good bioassay may increase two to ten−fold, and so on.

Rural employment . Some genetic resources projects feature collaborations with integrated conservation and development projects (ICDPs) to employ rural people as biodiversity collectors or "parataxonomists". Some projects also feature profit sharing with local communities through trust funds as a way to generate incentive measures for conservation.

Licensing fees . Developing country research institutes that have patented research material, novel uses or processes can charge up−front licensing fees to R&D firms willing to in−license these products for commercial development.

International technology transfer . Technology transfer to developing countries enables these countries to generate value−adding information from genetic resources on their own, stimulating economic activity. Transfer of proprietary bioassays is one valuable option, as most developing countries generally lack the latest, most efficient and cost−effective biotechnology to discover new products with valuable biological activities.

Tropical disease research . An intriguing area for technology transfer is the field of tropical disease research, consistently underfunded despite some 600 million cases world−wide (Gibbons 1992). Genetic resources can provide new therapeutics, such as the drug ivermectin, a fungal compound that has helped prevent some 1.5 million cases of river blindness in Sahelian Africa (World Bank 1993b). Given that some 80% of the world's population makes use of traditional medicine (Farnsworth *et al.* 1985), the opportunity exists to utilize new bioassay technology to evaluate the efficacy of these treatments to facilitate the development of new low cost phytomedicines for the poor (Iwu 1994).

Deferred or contingent compensation . Most commercial firms prefer to lower the financial risk of R&D by deferring a portion of compensation. There are several mechanisms for doing this, including *royalties* , which are a percentage of revenues on final products. *Milestone payments* are lumpsum payments made upon the attainment of important regulatory milestones during the product development process, such as patenting, regulatory approval to commence human clinical trials, or successful completion of these trials. Like rental fees, contingent compensation increase with the amount of value added by the provider. Some genetic resources projects incorporate a benefit sharing mechanism with local communities by sharing royalties using a trust fund.

Sourcing and joint venture agreements . Sourcing agreements made directly with developing countries enable poor rural populations in these countries to grow high value cash crops for processing into such commercial products as phytomedicines, cosmetics, pharmaceuticals, and agrochemicals. Joint venture development of these commercial products from genetic resources allows private companies in the biodiversity source country to market the product regionally, generating potentially large revenue streams and contributing to industrial development.

Relevant International Treaties

Several treaties contain provisions relevant to the utilization of genetic resources, in particular the Convention on Biological Diversity. This treaty, plus relevant provisions of the Convention on the Law of the Sea and the World Trade Organization (WTO) Agreement, are briefly reviewed below.

Convention on Biological Diversity . Article One of the Convention on Biological Diversity describes its three objectives as "the conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of benefits arising out of the utilization of genetic resources." The rationale for the third objective is to create economic incentives to conserve biodiversity. Article 15 highlights the "sovereign rights" of parties over genetic resources, stating that governments have the right to regulate access to these resources on "mutually agreed terms" and with "prior informed consent". Article 15 seems to treat genetic resources as valuable national resources, akin to oil reserves or mineral deposits. This marks a significant departure from previous concepts of genetic resources, which have tended to treat these resources as the "common heritage of mankind". Other relevant issues covered by the convention include access to technology, including proprietary technology and biotechnology (Articles 16 and 19), and knowledge pertaining to traditional uses of genetic resources (e.g., ethnobotanical knowledge of the use of medicinal plants).

United Nations Convention on the Law of the Sea . The United Nations (UN) Convention on the Law of the Sea specifically addresses marine scientific research issues, with implications for coastal areas including the continental shelf and other areas comprising Exclusive Economic Zones (EEZs). The Law of the Sea treaty states that coastal states shall grant their consent for marine scientific research projects by other states or competent international organizations in their EEZs or on their continental shelf, *but that coastal states may* continue *withhold consent to the conduct of a project if that project is of direct significance for the exploration and exploitation of natural resources, whether living or non−living* (Articles 246.3 and 246.5a).

Based on these two treaties, some governments are exploring options to regulate access to marine natural products found in EEZs. Requiring marine research expeditions to negotiate contracts or MTAs when applying for marine collection permits is one relatively simple policy measure that would allow developing countries to benefit from marine genetic resources R&D. This strategy is discussed later in this chapter.

World Trade Organization Agreement . The Trade−Related Intellectual Property subagreement (TRIPs) to the WTO Agreement calls for parties to adopt a wide range of intellectual property right (IPR) regimes, including patents, plant breeders rights, and trade secrets. Developing country parties are allowed a grace period, longest for the least developed countries, for implementing new IPR legislation. TRIPs does not make explicit reference to the rights of indigenous and local communities, although it does allow parties to develop *sui generis* (novel) plant variety protection, which some have interpreted as providing an opportunity to recognize rights to traditional knowledge regarding, for example, traditional landraces comprising subsistence farmers' crops.

Review of Relevant Jamaican Institutions and Policies

Currently, there are no Jamaican policies to regulate access to genetic resources, or even to recognize these as valuable material. The NRCA Act of 1991 does give authority to the Natural Resources Conservation Authority to regulate use of natural resources, as well as the authority to require permits for various kinds of prescribed uses, but genetic resources uses are not specified. A review of Jamaican institutions is presented below. Overall, there appeared to be good appreciation of the value of private investment in genetic resources development as a tool for economic development and biodiversity conservation. Institutional strengths useful for designing and implementing genetic resources policy are highlighted.

The Government of Jamaica

Office of the Prime Minister

The Office of the Prime Minister does not regulate scientific research directly. However, the National Commission on Science and Technology (see below) is chaired by the Prime Minister himself.

Ministry of Foreign Affairs

Officially, all requests from abroad for access to Jamaican biological resources, for purposes of scientific research, are required to be made through the Ministry of Foreign Affairs. The Ministry in turn refers such requests to the NRCA for the issuing of permits. The Ministry of Foreign Affairs has jurisdiction over the EEZ, and will be developing a new policy on ICZM. As part of this process, the Ministry has proposed the creation of an interdisciplinary Council on Ocean and Coastal Zone Management.

Ministry of Commerce and Technology

The newly created Ministry of Commerce and Technology oversees the National Commission on Science and Technology, an interdisciplinary scientific body which advises government on relevant issues. The Ministry is charged with promoting private sector development and technology transfer in Jamaica.

Ministry of Environment and Housing

The Ministry of Environment and Housing coordinates closely with the NRCA over biodiversity issues. The Ministry has created a new Sustainable Development Council which draws upon a wide range of stakeholders including government, the private sector, NGOs, academia, and labor. The Ministry also participates in drafting environmental regulations and in implementing international environmental treaties.

Natural Resources Conservation Authority

The NRCA is the primary implementing agency of such environmental treaties as the Convention on International Trade in Endangered Species (CITES) and the Convention on Biological Diversity. Created by the NRCA Act of 1991, the NRCA has the power to delegate responsibility for managing protected areas to NGOs. The NRCA has jurisdiction over marine natural resources management of submerged coastal lands. The NRCA also issues permits for the import or export of species listed under CITES appendices. The NRCA has created the CITES Scientific Authority, an interdisciplinary advisory body comprised of scientists and conservationists, which advises the NRCA on the granting of permits for the import or export of listed species.

Draft amendments to the Wildlife Protection Act currently under consideration would grant the NRCA the power to regulate all scientific research with Jamaican biological resources. A permit mechanism is now under consideration. On 9 February 1998, the NRCA took an administrative decision to require all scientists, foreign and domestic, to submit a "Wildlife Application Form" to the Authority at least five weeks in advance of anycontinue

scientific research on Jamaican flora and fauna species. The application is in the form of a questionnaire, allowing the NRCA to "maintain an efficient monitoring and inventory data base for living biological resources".

Ministry of Agriculture

Under the Ministry of Agriculture are two government agencies that may be relevant to the regulation of genetic resources utilization. The Fisheries Division has jurisdiction over management of marine natural resources in the water column, but not on submerged lands. A permit is required from the Fisheries Division for harvesting of these resources, mainly commercial fish species. The Forest Department has jurisdiction over natural resources management on public lands, including forest reserves. Note that jurisdiction over natural resources management within protected areas, whose management has been delegated by the NRCA to NGOs, is uncertain and in need of clarification.

Commissioner of Lands

The Commissioner of Lands, a quasi−private corporation, owns land rights to all Crown (public) lands, including forest reserves, and has the sole power to dispose of or acquire such land through sale or lease. Although private property rights are well defined in Jamaica, community land and/or resource tenure does not exist. The sole exceptions to this are the special community land rights defined by the 1739 Maroon treaties that established two special reserves for these communities, the descendants of freed slaves who fought British colonizers, in eastern and western Jamaica.

Ministry of Industry, Investment and Commerce

The Industry Section of the Ministry of Industry, Investment and Commerce processes patent applications in Jamaica for technical examination by other agencies. Existing intellectual property right mechanisms include patents, trademarks, industrial designs and copyrights. No formal trade secrets law exists, nor are there plant variety protection laws. Some 3,000 patents have been granted in Jamaica, and about 80 to 100 patent applications are filed annually, although the overwhelming majority of these are filed by foreign companies seeking pharmaceutical patents to prevent intellectual piracy (the unauthorized manufacture of proprietary products) in Jamaica.

Academia

University of the West Indies at Mona

Relevant academic departments at the UWI include the Centre for Marine Sciences and the Department of Life Sciences, both of which possess expertise in marine taxonomy. The Department of Life Sciences includes a marine invertebrate collection in the process of being catalogued, with at least 2,000 specimens representing over 250 species of coastal and deep ocean organisms. Mariculture expertise also exists within the departments, with current experiments focusing on tilapia aquaculture.

The Department of Chemistry employs natural products chemists and is equipped with most, although not all, laboratory equipment necessary for purification and structural determination of biologically active secondary metabolites. A Biotechnology Centre also exists within the School of Medicine, with expertise in microbiology and tissue culture. Technology transfer expertise also exists within the university through the Office of Planning of the Vice Chancellor's Office. An attorney is available there to provide advice on contracts and MTAs, including such issues as copyrights, patents, and royalties.

Discovery Bay Marine Laboratory

The Discovery Bay Marine Laboratory, the main field research station overseen by the Department of Marine Sciences, is equipped for underwater sampling and possesses a wet laboratory through which sea water is pumped continuously for live organism experiments. A small dry laboratory contains basic chemistry equipment. The marine lab is used primarily by visiting scientists and their students from around the world. Adequate lab space exists to set up a small marine microbial culture project in the wet laboratory.

Institute of Jamaica

The Institute of Jamaica contains a large number of taxonomic collections, and it currently serves as the scientific focal point for Jamaica to the Convention on Biological Diversity.

Non−Government Organizations

Jamaica Conservation and Development Trust

The Jamaica Conservation and Development Trust's (JCDT) three−fold mission involves public education and environmental advocacy, as well as protected areas management. The JCDT manages the National Parks Trust, a trust fund which covers the partial operating expenses of the Blue and John Crow Mountains National Park. This park is also managed by the JCDT under an agreement with the NRCA. The JCDT identified the major threats to the Blue and John Crow Mountains area as subsistence agriculture on marginal lands (primarily steep and easily erodible slopes), as well as the related problem of squatters' settlements on park land.break

Montego Bay Marine Park Trust

The Montego Bay Marine Park (MBMP) Trust manages the MBMP on behalf of the NRCA (see Chapter 2). As is the case with the JCDT, the Trust's management rights and responsibilities have not been well defined by the NRCA, such that, for example, the right of the Trust to experiment with community resource tenure is uncertain. The MBMP Trust has identified the major threats to the coral reef and adjoining Bogue Lagoon in Montego Bay as overfishing by artisanal fishers, as well as land based sources of marine pollution (primarily untreated sewage and a high silt load deposited into the bay by the Montego River and adjacent gullies; see Chapters 1 and 2).

National Environmental Societies Trust

The National Environmental Societies Trust (NEST) is a coalition of 26 active local NGOs in Jamaica which serves as a forum for debate, education and environmental action. NEST is comprised of three "focus groups" concerned with sustainable community development, ecosystems management, and public education. Many NGOs expressed great interest in possible applications of genetic resources, especially high value herbal products such as essential oils and botanical extracts, to the development of community enterprises.

Private Sector

Myers, Fletcher and Gordon

A private sector law firm specializing in corporate clients, Myers, Fletcher and Gordon employs several attorneys with a strong interest in environmental matters and relevant expertise in intellectual property and contract law. These personnel expressed a willingness to participate in genetic resources policy−making and its implementation.

Jamaica Promotions Corporation (JamPro)

JamPro is a quasi−private corporation that promotes economic development in Jamaica, including developing export markets and encouraging new private investment. JamPro has a Chemical Division which assists in such markets as minerals and chemicals, bottled water, herbal teas and other herbal products.

Federated Pharmaceuticals Ltd.

Federated Pharmaceuticals Ltd. is setting up a production line for herbal products under its Natural Products Division. Products to be manufactured include essential oils, extracts, tinctures and gums. Aside from technical expertise in marketing and product development, the company also possesses a small quality control laboratory for microbial testing and dosage standardization.

Genetic Resources Policy Recommendations

The development of marine genetic resources into new commercial products can be a powerful tool for conservation and economic development. The following policy recommendations are intended to incorporate the management of marine genetic resources into ICZM planning in Jamaica. Because the utilization of both marine and terrestrial genetic resources involves many common techniques and legal issues, the policy recommendations are intended to regulate the utilization of both marine and terrestrial genetic resources.

Obligations and Assumptions

In designing a set of genetic resources policy options for Jamaica, it is necessary to incorporate the following obligations under relevant international treaties to which Jamaica is a party:

Convention on Biological Diversity

Create incentive measures to promote conservation and sustainable use of biodiversity (Article 11);

Promote sovereign rights over biodiversity, including genetic resources (Articles 3 and 15.1);

Ensure the fair and equitable sharing of benefits arising out of the utilization of genetic resources (Articles 1 and 15.7) or out of the utilization of knowledge, innovations and practices of indigenous and local communities (Article 8j), a.k.a. "traditional knowledge";

 Regulate access to genetic resources based upon mutually agreed terms (Article 15.4) and upon prior informed consent (Article 15.5);

 Create a mechanism to facilitate access to technology, including that which is relevant to the conservation and sustainable use of biological diversity, as well as biotechnology that makes use of genetic resources (Articles 16 and 19); and,

 Encourage cooperation between government authorities and the private sector in developing methods for the sustainable use of biological resources (Article 10e).

UN Convention on the Law of the Sea

 Develop a mechanism to grant or withhold consent for marine scientific research projects by other states or competent international organizations in the EEZ or on the continental shelf, wherein consent can be withheld if that project is of direct significance for the exploration and exploitation of natural resources, whether living or non−living (Articles 246.3 and 246.5a).

Additional Assumptions

The foregoing necessary obligations are insufficient, insofar as they do not take account of the effect that policy−hard

making will have on private sector activities. Additional assumptions employed herein are summarized as follows:

 Private investment in genetic resources utilization can yield benefits, some of which can be distributed as public goods if properly channeled by government. Examples of public goods include local and national incentives for biodiversity conservation, opportunities for technology transfer, development of local (including community based) industries, and so on.

 Policy−making should avoid creating disincentives to private sector investment in genetic resources utilization. Strong disincentives to investment imply a large opportunity cost to Jamaica in terms of lost access to private capital and to sophisticated biotechnology necessary to develop high value products from genetic resources.

 Policy−making should encourage negotiations among private parties to the maximum extent possible. Private party negotiations (as opposed to centralized negotiations between private parties and the Government of Jamaica) increase opportunities for creative deal−making, enhancing opportunities to capture the benefits of genetic resources utilization. Allowing private party negotiations also creates an incentive to foreign investment.

 A genetic resources policy should be simple and transparent, involve minimal bureaucracy, and provide easy mechanisms for compliance.

Basic Components of Model Genetic Resources Legislation

Based on the foregoing obligations and assumptions, the following policy recommendations are intended to allow a developing country such as Jamaica to fulfill obligations under the Convention on Biological Diversity and the Convention on the Law of the Sea. The overall strategy guarantees benefit sharing and enhances community rights and national sovereignty while avoiding large disincentives to private sector investment. Biodiversity conservation projects and protected area managers can adopt regulations based on these components as well.

Summary of Policy Model

1. *Regulate access to genetic resources up−front with permits and contracts* . Because there are no internationally recognized protocols on rights to genetic resources and traditional knowledge, it is necessary to define rights to these resources by contract before samples are collected or exported. Permits should be issued only after approving contracts.

2. *Establish sui generis (novel) rights to tangible property and traditional knowledge* . In order to define who has the right to participate in and benefit from the negotiation of contracts involving a transfer of genetic resources or traditional knowledge, it will be necessary to create rights to both the tangible and intangible (intellectual property) manifestations of these.

3. *Develop prior informed consent procedures* . In order to give the legal owners of rights to genetic resources and traditional knowledge a means to control use of these resources, it will be necessary to devise a prior informed consent mechanism to be used in the negotiation of mutually agreed terms for the utilization of genetic resources.

4. *Create a national benefit sharing formula* . A national formula to convert a portion of monetary income derived from new product development into public goods is necessary to ensure fair and equitable sharing of benefits from genetic resources utilization.

First Model Component:
Regulate Access to Genetic Resources Up−Front with Permits and Contracts

Because there are no internationally recognized protocols on rights to genetic resources and traditional knowledge, it is necessary to define rights to these resources by requiring a collector or scientist to sign a *contract* before samples are collected or exported.

Contractual agreements have been used by both the biotechnology industry and academia to define rights to unpatentable biological material and "know−how". These contracts can be modified and applied to genetic resources and traditional knowledge to define rights and obligations of parties involved in collaborative research, including benefit sharing obligations.

The issuing of biodiversity collection permits should be made contingent upon the signing of legally binding contracts.

It is recommended that the Government of Jamaica adopt a regulation requiring organizations that issue permits to ensure that an approved research agreement or MTA is signed by both provider and recipient of genetic resources or traditional knowledge *prior* to issuing permits. These agreements describe rights and obligations of providers and recipients of biological material being transferred for scientific research or commercial development (Gollin 1995). Contracts can also be adapted to define community rights to resources or traditional knowledge, the latter through a trade secrets mechanism as described below. Research contracts adapted to this purpose incorporate several basic features, including definition of ownership of the rights to the collected genetic resources or traditional knowledge, terms and conditions of the transfer of the collected resources, and compensation for the transferred material (for examples, see AUTM 1995; Downes *et al* . 1993; Putterman 1996).break

Link the Approval of Biodiversity Collection Permits to the Negotiation of Legally Binding Contracts

Many developing countries already have a *permit mechanism* in place for approving biodiversity collection or export. In these countries, it is probably easiest to require that a signed contract be approved by the government before issuing a biodiversity collecting or export permit.

Even in the case of academic collecting, it is important to require a collecting permit and a research agreement. Many academic natural products research groups engage in "basic" research on collected biodiversity specimens, but retain the right to transfer interesting discoveries to the private sector at a later date for commercial evaluation and product development.

However, if biodiversity collecting is intended solely for educational or basic research purposes, with no possibility of commercial application, it is unnecessary to stringently regulate this activity.

The recommended genetic resources regulation should give legal authority to each permit issuing organization to sign genetic resources contracts on behalf of the Government of Jamaica. Some draft contracts should be reviewed by an independent Genetic Resources Advisory Authority comprised of stakeholders and representing multidisciplinary expertise relevant to the type of genetic resources collection in question. It is not necessary to create a standing committee for this purpose. Volunteers should be called up as needed. Permit issuing organizations should be informed that *under no circumstances* are they to issue collection permits before an approved contract has been signed.

Genetic resources contracts should be available for use not only by the public sector, but by Jamaican private organizations as well, including NGOs, private enterprises, and even rural communities or ethnic groups. In order to enter into a valid contract, it will be necessary to identify a foreign recipient of the genetic resources or traditional knowledge, and a Jamaican provider of these material or information. Both provider and recipient would sign the contract to make it a legally binding document.

Should a recipient and provider sign a contract which calls for collection of traditional knowledge from Jamaican herbalists, it will be necessary to obtain local prior informed consent from the relevant herbalists before collection can proceed. These concepts of rights to traditional knowledge, as well as prior informed consent, are discussed below.

All organizations , public and private, would be required to submit draft signed contracts to the proposed independent and multidisciplinary Genetic Resources Advisory Authority for approval. These draft signed contracts would be made valid by a third signature provided by the Chair of this Authority. *All* contractual agreements would be subject to the same national benefit sharing formula to ensure equitable distribution of monetary benefits.

Guarantee Revenue Sharing through Contractual Means

Research agreements or *material transfer agreements* should be employed to define sharing of benefits generated by development of genetic resources or traditional knowledge, including monetary benefits.

Contracts adapted to this purpose should incorporate several basic features, including definition of ownership of the rights to the collected genetic resources or traditional knowledge, terms and conditions of the transfer of the collected resources (including permitted uses), and compensation for the transferred material.

Two types of contracts, research agreements and MTAs, are recommended (see Box 12.1 for a summary of contractual terms). *Research agreements* are intended to define a research collaboration between Jamaican organizations and foreign for−profit research partners or academic partners engaged in research with clear commercial applications, such as natural products chemistry. It is recommended that draft research agreement be negotiated and signed by the foreign recipient of genetic resources and by the Jamaican provider of these resources. This draft research agreement should then be passed to the Jamaica Genetic Resources Contracts Review Committee (described below) for review and final approval.

MTAs are simple contracts to be used when substantial research collaboration is not anticipated. The MTA would be best used when a Jamaican provider organization is only facilitating access for non−commercial use such as academic collecting for taxonomy or ethnobotany, or for such routine purposes as teaching students. Their purpose is to define permitted uses of biodiversity taken out of Jamaica, and to reserve Jamaica's right to share in any benefits so derived, if any. It is recommended that MTAs not be subject to the same scrutiny as research agreements. It would *not be necessary* to obtain independent review by the Genetic Resources Advisory Authority. All MTAs should be pre−approved by the Genetic Resources Advisory Authority.

The Role of Government in Contract Review and Approval

It is recommended that governments not play a direct role in private party negotiations, but rather retain the right to review draft contracts, and either approve them, reject them, or return them for modification, providing detailed comments and suggestions.break

Box 12.1— Basic Components of Genetic Resource Material Transfer Agreements

The following provisions are derived from published *material transfer agreements* (MTAs), which have been adapted for genetic resources utilization (Putterman 1996). Taken together, these comprise basic terms for a generic genetic resources research contract:

Genetic resources are defined as tangible property, and ownership of this property is according to land use. Samples gathered from Crown land are publicly owned, samples from private land are owned by the landowner, and samples from communal land are owned by the community.

Value−added research materials are defined as intellectual property according to inventorship.

An option is provided to define intellectual property rights to *traditional knowledge* by transferring traditional knowledge confidentially as trade secrets.

An option is provided to allow representatives of indigenous or other rural communities to sign on directly as parties to the MTAs, and a procedure for obtaining *prior informed consent* is outlined.

Monetary and non−monetary compensation to the provider for supplying genetic resources or value−added research material to the recipient is specified.

The recipient is free to conduct research and development with transferred material and to acquire intellectual property rights to inventions. Ownership of intellectual property is awarded according to inventorship, and shared inventorship is possible.

Deferred compensation to the provider upon commercial development of the recipient's intellectual property derived from the transferred material is specified, including royalties and sourcing agreements. Monetary benefits are distributed through a trust fund mechanism where specified.

It is recommended that governments create an *independent multidisciplinary committee* to review draft contracts, because it is highly unlikely that a single government agency has the technical expertise to perform this role.

This proposed Genetic Resources Advisory Authority should include, as appropriate, scientists from relevant disciplines, ministerial staff, a contracts attorney, an NGO, and a representative with expertise in business.

The committee would only convene *as needed to review collecting applications* , keeping regulatory costs low. Members would also pledge their availability to act as advisors to projects under negotiation, to fulfill government's need to maintain a predictable and transparent approach to regulation.

Members of the Genetic Resources Advisory Authority would be required to sign confidentiality agreements.

Depending on the availability of technical expertise, it may be advisable that the government *publish* a set of minimum acceptable terms for contracts to simplify the process of contract negotiations.

It is strongly recommended that government not play a direct role in private party negotiations. Rather, government should retain the right to review draft private party contracts, and either approve or reject them (rejection should be accompanied by a detailed explanation and suggestions for renegotiating acceptable terms). Because no single government agency in Jamaica has the technical expertise to perform this role, it is recommended that the government create an independent multidisciplinary committee to review draft research contracts. The NRCA is the logical agency to coordinate contractual review, given its role in issuing biodiversity collection permits, although this coordination role might also be appropriately placed within the Ministry of Commerce and Technology. A precedent already exists for independent review of regulatory decisions, whereby the NRCA draws upon outside scientific expertise for making decisions on the granting of export or import permits for endangered species, utilizing the CITES scientific authority described previously.

Within the Government of Jamaica, a precedent already exists for linking the review of draft contracts to licenses or permits. As part of a utility privatization strategy, the Office of Utility Regulation grants licenses to private entities wishing to function as electric utilities. The Office of Utility Regulation requires that draft contracts defining the terms under which electricity will be sold to consumers be submitted by applicants for approval prior to the granting of a utility license. Contracts are reviewed with consumer protection criteria in mind.

The Genetic Resources Advisory Authority should provide appropriate multidisciplinary expertise to applycontinue

consistent and independent criteria to review draft research agreements. Upon receipt of a draft research agreement, the coordinator of this Authority would contact one expert in each of the following areas to review the contract:

A scientific representative from the relevant discipline (e.g., natural products chemistry, botany, agriculture, ethnobotany, etc.);

A representative from the permit issuing organization in Jamaica;

A lawyer with expertise in contracts;

A person representing the organization with jurisdiction over lands covered by the proposed genetic resources collection;

If the land in question is being managed with the help of an NGO, it would be appropriate to invite a representative of this NGO; and,

A representative of private enterprise in Jamaica.

Suggested criteria by which the Genetic Resources Advisory Authority should evaluate draft research agreements include the following:

Does the agreement clearly define the proposed research collaboration?

Are rights to the transferred material and to subsequent derivatives or inventions clearly defined?

In particular, and only if applicable, are community rights to tangible property or traditional knowledge clearly defined?

If traditional knowledge is to be transferred, does the agreement include a trade secrets mechanism such as a confidentiality agreement?

Does the agreement adequately describe how community prior informed consent was or will be provided?

Does the agreement define how monetary or other benefits will be shared?

Does the agreement include a reporting mechanism?

Blanket Agreements for Routine Teaching and Research Purposes

Because some collecting activities are purely academic, including collecting done for teaching purposes, it is recommended that the Government of Jamaica offer a simple variation on a MTA which would explicitly forbid the recipient from using the material for commercial purposes, or from transferring the material to third parties without written consent. It is recommended that the government negotiate *blanket agreements* with academic institutions to simplify routine transfers of genetic resources for teaching and research purposes. These blanket agreements would allow the use of pre−approved MTAs without the need for further government review.

For example, the Discovery Bay Marine Laboratory hosts a large number of students and foreign scientists every year, providing research and teaching facilities for a variety of basic research activities. It would be highly impractical to require every visiting scientist or student to apply for a separate permit with the government. Rather, the laboratory should negotiate a blanket agreement which would require every visiting scientist and student to sign a simple MTA forbidding any commercial use of collected material, or transfers to third parties for this purpose.

A Note on Compliance with Genetic Resources Regulations

It is impossible to prevent dishonest people from smuggling genetic resources samples out of Jamaica. The suggested regulations presented here are intended to give a simple framework for those seeking to comply with Jamaican law. For those who intend to break the law, these regulations provide the Government of Jamaica the legal standing to sue in a court of law. With the advent of electronic databases accessible by the internet, it is not difficult to monitor global patent systems. Because patent offices require full disclosure of inventions, it is possible to run periodic checks on patents in the industrialized world, perhaps in collaboration with international NGOs or legal firms willing to provide *pro bono* services. This can be done very inexpensively, without the need to create costly databases and hire dedicated staff.

Second Model Component: Establish Sui Generis (Novel) Rights to Tangible Property and Traditional Knowledge

In order to define who has the right to participate in and benefit from the negotiation of contracts involving a transfer of genetic resources or traditional knowledge, it will be necessary to create rights to both the tangible and intangible (intellectual property) manifestations of these.

It is strongly recommended that governments refrain from nationalizing genetic resources, in order to make room for the creation of local rights, including community rights . Local resource tenure systems are necessary for the creation of local incentives for sustainable biodiversity management.

In order to define who has the right to participate in and benefit from the negotiation of research contracts involving a transfer of genetic resources or traditional knowledge, it will be necessary to create rights to both the tangible and intangible (intellectual property) manifestations of these. Currently there are no regulations in Jamaica defining rights to genetic resources and tradi−soft

tional knowledge. Tangible property includes the physical embodiment of genetic resources and value−added research material derived from these. Intellectual property in this case refers to traditional knowledge rather than conventional notions of intellectual property such as industrial inventions. *In defining genetic resources rights, it is strongly recommended that the Government of Jamaica refrain from nationalizing these rights, in order to make room for the creation of local rights, including community rights* . A large and accumulating body of evidence suggests that local resource tenure systems are necessary for the creation of local incentives for sustainable resource management (for example, see BCN 1997; Posey 1996).

Genetic Resources As Tangible Property

Tangible property includes the physical embodiment of genetic resources and simple research material derived from these, such as extracts.

It is necessary to create tangible property rights to genetic resources found on public land (such as protected areas, submerged lands, etc.), and to define genetic resource rights for private landowners if land can be privately owned.

Community resource rights can be defined for community land, or for land traditionally occupied by rural communities.

Even if national law does not recognize community resource rights, it is still possible to define community rights to genetic resources in a *de facto* manner by contract. A portion of benefits flowing from genetic resources sampled on land adjacent to local communities can be returned to these communities according to the terms of the negotiated research agreement or MTA.

The definition of tangible property includes resource rights to genetic resources found on public land (including national parks, forest reserves, all submerged land including coastal shelves, and other Crown lands), as well as genetic resources found on private land and on community land, such as that owned by Maroon communities. Note that creating community rights to the use of genetic resources may prove the single most important measure available for creating local conservation incentives. Although protected area land may be property of the Crown, it is still possible to define community rights to genetic resources in a *de facto* manner by contract. In this scenario, a portion of benefits flowing from genetic resources sampled on land adjacent to local communities will be returned to these communities according to the terms of the negotiated research contract (for example, see Rubin and Fish 1994).

Treat Local Inventions and Traditional Knowledge As Intellectual Property

"Intellectual property" for this purpose refers to traditional knowledge, innovations and practices, rather than to conventional notions of intellectual property such as industrial inventions.

Numerous legal mechanisms to recognize and create rights to traditional knowledge have been proposed; however, many of these posit costly bureaucracy to track registered "inventions", or they create a legal basis for ownership which would be impossible to verify against fraudulent claims. For this reason, it is recommended to limit protection of traditional knowledge to that which is attainable through a modification of *industrial trade secrets legislation* .

Modification of industrial trade secrets legislation would give communities the right to maintain traditional knowledge as confidential "trade secrets".

A confidentiality clause could be written into research agreements defining use of traditional knowledge, whereby the recipient of such knowledge would be granted the right to use it in research and development, but could not divulge the knowledge publicly.

Should the transferred traditional knowledge yield marketable products, benefit sharing arrangements in the contract would guarantee a premium benefit to the providers of the knowledge.

Use of traditional knowledge, confidentially or otherwise, should be linked to a prior informed consent mechanism .

Numerous legal mechanisms to recognize and create rights to traditional knowledge have been proposed (for example, see Jabbour 1983; Posey 1996; Singh 1996; Swaminathan 1996). However, many of these proposals posit the development of a costly bureaucracy to track registered "inventions", or they create a legal basis for ownership which would be impossible to verify against fraudulent claims. It is recommended that the Government of Jamaica create a simple *sui generis* mechanism based on trade secret legislation to protect the rights of the holders of traditional knowledge. Trade secrets are a form of intellectual property protection, and trade secret legislation is a requirement for signatories to the WTO Agreement (Barton 1994b).

Trade secrets are a class of intellectual property which confers the legal right to withhold information on inventions. In the United States, a model statute called the Uniform Trade Secrets Act has been adopted by a majority of states. Under this legislation, information is eligible for trade secret protection if it derives independent economic value from not being generally known and is the subject of efforts that are reasonable under the circumstances tocontinue

maintain its secrecy. In practice, trade secrecy is attained through *confidentiality agreements* and other contractual mechanisms. Information may be "misappropriated" (and hence, property rights violated) by either unauthorized use or disclosure of the trade secret or by acquisition of the trade secret by "improper means", including theft, bribery, misrepresentation, breach of duty to maintain secrecy, or espionage.

It is recommended that the Government of Jamaica pass a Traditional Trade Secrets Act which confers the legal right to withhold information on traditional knowledge. In this instance, traditional knowledge would be eligible for traditional trade secrets protection if it derived potential economic value in Jamaica from not being generally known and if it were the subject of reasonable efforts to maintain its secrecy. Herbalists and other traditional knowledge holders who wished to share their knowledge for sustainable use of genetic resources, including R&D, would have the right to insist on adding a *confidentiality clause* to relevant research agreements or MTAs. The confidentiality clause, discussed in Box 12.2, would treat the transferred traditional knowledge essentially as any industrial trade secret, allowing the knowledge provider to retain control over who uses the knowledge and how it is used.

Note that this concept of "traditional trade secrets" directly clashes with the notion of *academic freedom* as practiced by, for example, ethnobotanists, whose trade requires them to publish traditional knowledge in scholarly journals. It will be up to the individual knowledge holders, or the wider rural community, to decide whether or not to allow academic publication of traditional knowledge.

Although currently there are no industrial trade secrets laws in Jamaica, their eventual creation is assured given that Jamaica is a party to the WTO Agreement, which requires this under TRIPs. Use of traditional knowledge, confidentially or otherwise, should be linked to a prior informed consent mechanism as described in the following section.

Third Model Component:
Develop Prior Informed Consent Procedures

In order to give the legal owners of rights to genetic resources and traditional knowledge a means to control use of these resources, it will be necessary to devise a prior informed consent mechanism to be used in the negotiation of "mutually agreed terms" for the utilization of genetic resources.

At the national level, setting up a Genetic Resources Advisory Authority, as suggested above, would be sufficient to ensure prior informed consent of the Government of Jamaica. Prior informed consent for collection in national parks, whose management has been delegated to local NGOs, should be coordinated by the managing NGO. It is strongly recommended that managing NGOs enlist local community opinion when weighing prior informed consent decisions. Implementing a workable prior informed consent requirement at the *community level* may be difficult, due to the large number of stakeholders involved. There is a critical role for NGOs in facilitating prior informed consent decisions by local communities. It is highly recommended that the Government of Jamaica encourage NGOs to become involved in the process of obtaining prior informed consent from local communities, and in monitoring subsequent agreements.

Implementing a Local Prior Informed Consent Procedure

Local resource tenure, including *community* resource tenure, has been shown to create local conservation incentives. One way of giving communities the means to control resource decisions is to legislate a requirement for local prior informed consent.

In practice, implementing a workable prior informed consent requirement at the local level may be difficult, due to the large number of stakeholders involved. There is a critical role for NGOs in facilitating prior informed consent decisions by local communities.

National policies on community prior informed consent could range from actually holding community meetings with all local communities involved to merely posting notices in local newspapers or informing local government or community leaders of proposed projects and inviting public comment over a specified time period.

Regardless of the procedure chosen, the owners or trustees of rights to genetic resources or traditional knowledge should understand the goals of the proposed sustainable use, including potential development of new products, their rights to tangible or intellectual property to be transferred, and opportunities to participate in or benefit from the proposed project.

National policies on community prior informed consent could range from actually holding community meetings with all local communities involved to merely posting notices in local newspapers or informing local government or community leaders of proposed projects and inviting public comment over a specified time period.

Regardless of the procedure chosen, the minimum information describing proposed genetic resources projects that is recommended for making prior informed consent decisions is listed in Box 12.2

Note that creating a local prior informed consent requirement for genetic resources sampling may drive collectors to focus their efforts on Crown lands unencum−soft

Box 12.2—
Minimal Information Necessary for Prior Informed Consent Decisions

Responsibilities

It is the responsibility of the collector to ensure that this procedure is followed. In the case of *traditional knowledge* or community genetic resources, all contract negotiations shall include facilitators (e.g., local NGOs) who shall possess the necessary legal and business skills to negotiate fair terms and conditions of the transfer of resources or knowledge on the community's behalf.

Information Requirements for Prior Informed Consent

The collector shall ensure that the following information is communicated to stakeholders, whether through written or oral means, as appropriate:

The purpose of the proposed research, including plans, if any, for commercial research and development;

The research plan, including options, if any, for participation by stakeholders;

Disclosure of the potential value of transferred resources or knowledge;

Potential outcomes, including the likelihood of commercial success;

Rights available to stakeholders under the law; and,

Options for benefit sharing, including a full description of immediate and deferred or contingent benefits, the use of trust funds to capture monetary benefits, the possibility of in−kind contributions such as medical care, and so on.

Confidentiality

Both collectors and stakeholders have obligations regarding confidentiality, and collectors shall inform stakeholders of these obligations:

Transferred knowledge may be regarded by stakeholders as their intellectual property. The collector shall inform stakeholders of their right to insist on treating transferred knowledge as *confidential* trade secrets. If requested to, the collector shall include a confidentiality clause in research contracts or *material transfer agreements* (MTAs) to ensure trade secret protection.

The collector shall inform stakeholders that all contracts may contain proprietary information and if so, must be treated as *confidential* by all parties. While local communities shall be privy to details of contractual negotiations, it is recommended that written copies of signed research contracts or MTAs remain only with the collector and with the local facilitator, such as a local NGO. Redacted versions of contracts should be made freely available.

Reports and Monitoring

Stakeholders shall receive regular research reports, at least every six months, in order to foster trust and to encourage realistic expectations of the possibility of long−term benefits such as the development of commercial products.

Full Disclosure and Authorized Signatures

Full disclosure of how *prior informed consent* was obtained shall be included as an attachment to all negotiated draft research contracts or MTAs. In the case of local communities, this attachment shall include signatures of proper and acknowledged leaders of these communities, indicating that prior informed consent was given by said communities and that facilitators, such as local NGOs, were indeed authorized to negotiate research contracts or MTAs on behalf of these communities. This attachment, providing full disclosure, shall be necessary and sufficient for obtaining a *certificate of prior informed consent* from the government agency issuing collection permits.

bered by community resource tenure claims, including forest reserves and submerged lands of the coastal shelf. This is anticipated because sampling on such lands would require obtaining prior informed consent from only one entity, the government itself or perhaps a managing NGO, while in return the collector stands to gain access to a wide range of habitats or species. The alternative, obtaining prior informed consent from a large number of private landowners or from (at this point, largely hypothetical) managed lands which may have a community resource tenure system in place, could be costly and time consuming by comparison. For this reason, a national benefit sharing formula as described below would be crucial to ensuring that benefits from genetic resources utilization on Crown lands filter back to local communities.

It is recommended that the government require collectors of traditional knowledge to obtain prior informed consent from individual herbalists before being allowed to collect this knowledge. Herbalists should be given the right to insist on signing a *confidentiality clause* defining their right to transfer their knowledge as confidential trade secrets, and defining benefit sharing arrangements as well under the contract and under the national formula.

Note that prior informed consent can be obtained on a case by case basis once collection has been approved and commenced.

Fourth Model Component:
Create a National Benefit Sharing Formula

A national formula to convert a portion of monetary income derived from new product development into public goods is necessary to ensure fair and equitable sharing of benefits from genetic resources utilization.

An ideal revenue sharing arrangement would allow domestic research partners, including private companies, NGOs, and local communities, to keep a portion of their income in order to maintain incentives for private investment and innovation, while the remainder is set aside by government and applied to the creation of public goods.

Developing a set of guidelines or even fixed percentages defining benefits sharing on up−front and deferred income (e.g., royalties on future products) would streamline the process of permit approval.

It is recommended that the Government of Jamaica develop a simple national benefit sharing formula that will streamline the process of contract negotiations and permit approval. For this purpose, it is important to distinguish between the academic and private sector use of genetic resources, and between up−front and deferred compensation.

Up−front monetary compensation in exchange for access to genetic resources is usually not possible with academic collectors. Even for private sector collectors, such as pharmaceutical companies, up−front compensation is usually relatively small. Because it is desirable to encourage research *collaborations* between local scientists and foreign organizations, including private companies, it is not recommended that the Government of Jamaica require the sharing of any more than a small percentage of up−front income realized by Jamaican collaborators. For example, in Costa Rica, the National Biodiversity Institute (INBio, a private non−profit Costa Rican research organization) shares just 10% of its up−front income from its bioprospecting contracts with the private sector. The money is deposited into a fund specifically earmarked for national parks conservation. The remaining 90% is used to pay the costs associated with INBio's research collaborations and for capacity building.

By contrast, deferred compensation, such as royalties, can be relatively large and, in any event, royalty income is usually provided free and clear of business expenses (i.e., it is all net income). For this reason, it is recommended that the Government of Jamaica establish a national benefit sharing formula which allows the original providers of genetic resources or traditional knowledge to keep a portion of this income, and sets aside the greatest percentage royalty income for biodiversity conservation, community economic development, or other government expenses. For example, national regulations might require that 10% of royalty income be due the stakeholders who gave their prior informed consent for collection activities to proceed, 10% be due the providers of the genetic resources (i.e., that Jamaican organization that signed the original contract), 40% of the income be due a biodiversity trust fund earmarked to pay for conservation and sustainable use activities in *all* protected areas, and the final 40% be returned to the national treasury for general government expenditures.

Genetic Resources Policy Applications

Scenario Analysis of Applications of Genetic Resources Policy Options

Four scenarios are analyzed for the manner in which the value of genetic resources varies according to different policy options.

Zero Compensation (Status Quo)

This scenario represents the status quo in Jamaica. Access to genetic resources, where granted, does not result incontinue

compensation to either the people or the Government of Jamaica. While scientists seeking access to Jamaican genetic resources are required to complete an NRCA questionnaire describing the proposed research, the Wildlife Research Application Form does not function as a research contract, nor does it define legal claims to collected resources. The government retains only veto power over proposed genetic resources projects.

Minimal Contingent Compensation (Royalties)

In this scenario, the Government of Jamaica would require all applicants for access to genetic resources or traditional knowledge to sign a research contract or MTA guaranteeing a royalty payment (contingent compensation) upon commercialization of any inventions derived from the transferred resources. Royalty claims are a risk free mechanism to share some of the benefits of genetic resources utilization, in the sense that the provider is not required to invest in research or collecting activities, only to allow access to the resources. However, royalty payments allow biodiversity rich source countries to capture only a relatively small portion of the total value of genetic resources. Because the process of research and development rarely yields successful commercial products, even in the case of the development of new herbal products and phytomedicines, it is unlikely that this strategy of minimal contingent compensation will yield *any* commercial benefits to Jamaica.

Contingent Compensation with Production (Royalties and Sourcing Rights)

In this scenario, the Government of Jamaica would again require all applicants for access to genetic resources or traditional knowledge to sign a research contract or MTA. In this case, the agreement would also require the recipient to consider Jamaica as the first source of supply of raw or processed material for commercial production. These "sourcing rights" create opportunities for the development of new high value agricultural exports, as well as local processing industries. For example, the US National Cancer Institute incorporates language on sourcing rights into its standard natural products collection contract (NCI 1995). This strategy also relies solely upon contingent benefits (that is, it relies solely upon the successful development of new commercial products), and as such, this benefit sharing scheme is also unlikely to yield *any* benefits to Jamaica.

Up−Front Compensation for Value−Added Products (Rental Fees Plus Royalties and Sourcing Rights)

In this scenario, the Government of Jamaica would require all research contracts and MTAs to incorporate up−front or guaranteed compensation in exchange for the transfer of genetic resources samples or traditional knowledge. This would be in addition to the contingent compensation described above. *It is not recommended that developing country governments impose an "access fee" on private companies or academic researchers seeking genetic resources research material* . Due to the highly competitive nature of genetic resources sourcing, arbitrary access fees, which merely serve to increase the cost of Jamaican genetic resources, are likely to price these resources out of the market.

It is instead recommended that the Government of Jamaica encourage the development of local value−adding research services, which could provide biodiversity samples, or advanced research material derived from these, directly to private industry for a fee. Examples of relatively low cost and technologically appropriate research activities, which add significant value to genetic resources, include biodiversity inventories (especially plant inventories), local studies of the efficacy of medicinal and aromatic plants, simple techniques for processing plant samples into botanical extracts, or soil samples into microbial cultures. "Rental" fees for access to this research material can be in the form of monetary compensation, which would ideally encompass the full costs of collection and processing *plus* a margin over and above this. Note that research material can be derived from any source of genetic resources material, whether from plants, insects, or microbes. Research material can be quite basic, such as plant extracts, or it can be quite advanced, such as new plant based medicines with actual data derived from clinical trials. The cost of these different forms of research material to a foreign collaborator will vary according to the amount of value−adding research invested in the source country.

Note that value−added genetic resources research material *is* difficult to come by, particularly marine material. Developing the capacity to supply this material to the private sector would provide Jamaican organizations a clear competitive advantage over other sources of genetic resources material. Genetic resources utilization under this regulatory scenario would require a significant investment to develop the technical ability of private parties to undertake advanced contractual negotiations in Jamaica, and to develop the corresponding technical ability within the Government of Jamaica to review these negotiations. Modest investments in value−adding technology would also be required. Several bilaterial and multilateral agencies have taken an interest in supporting these "bioprospecting" activities in recent years.break

Novel Paradigms for Public and Private Sector Collaboration in the Sustainable Use of Genetic Resources

A new paradigm is emerging globally in which biodiversity rich developing countries seek to participate more actively in the development and marketing of new commercial products derived from natural products. Additionally, awareness among consumers is growing of the potential for good business practice to support environmental conservation, international development, and the welfare of indigenous peoples. However, policy alone is insufficient as marketing biological material for genetic resources development is a competitive business. In order to develop mutually beneficial collaborations, developing countries must be able to offer genetic resources and value−adding services to private firms in a manner which increases the likelihood of finding profitable new products, reducing the financial risk involved.

Advantages that may attract private firms to develop natural products collaborations with developing countries include local knowledge of flora, fauna and habitats, sample quality, sample resupply, adherence to local regulations, lower business costs, the opportunity to leverage additional capital, and access to markets. A novel strategy to encourage local investment in joint natural products enterprises in developing countries includes technology franchising, in which a senior firm grants limited rights to a valuable proprietary technology to a small or medium enterprise in exchange for certain returns generated by that technology. Joint venture creation between firms is another option.

Two Jamaica Case Studies Revisited

Two examples of ongoing and unresolved issues in genetic resources utilization in Jamaica were introduced at the start of this chapter. In the following section, these issues are re−examined in light of the policy recommendations made above, and alternate outcomes based upon application of the recommendations are explored.

Marine Bioprospecting in Jamaican Coastal Waters

Of the half−dozen or so instances of foreign researchers undertaking widespread collecting of diverse marine species for research involving biomedical, agrochemical, and cosmetics applications, not a single project involved sharing of benefits other than sharing of marine taxonomic voucher specimens with the University of the West Indies. Future applications for research permits may languish without a proper policy in place to capture genetic resources benefits. Under the proposed genetic resources regulations outlined in this paper, foreign scientific organizations, whether private companies or non−profit oceanographic research institutes, would be required to contact the relevant government department (e.g., the NRCA or the Ministry of Commerce and Technology) to discuss conditions for obtaining a collecting permit. The government would inform the applicant about current regulations, including the requirement to obtain prior informed consent from the appropriate stakeholder and to negotiate an approved research agreement or MTA. The government would also recommend counterpart organizations in Jamaica for assistance with obtaining a permit, and supply a list of suggestions, with UWI among the most likely candidates.

Assume that collection was planned in a protected area (e.g., the Montego Bay Marine Park) and UWI is functioning as the local counterpart organization. To begin the process, UWI would contact the MBMP Trust to obtain prior informed consent. Depending on the local regulations, the MBMP Trust would either give its informed consent directly following discussions on benefit sharing, or would first hold meetings with local stakeholders to discuss their preferences directly (if collection was planned elsewhere within Jamaica's EEZ, UWI would contact the NRCA directly to obtain informed consent, because such submerged land is administered by this agency).

UWI would negotiate a research agreement with the foreign research organization, consulting with the MBMP in the process to incorporate preferred benefit sharing provisions necessary to obtain their prior informed consent. All parties could consult with appropriate members of the Genetic Resources Advisory Authority for advice on policy requirements at any time.

Benefits requested by the MBMP Trust might include employment for local fishers as field hands, copies of all taxonomic voucher specimens, sourcing rights, and monetary benefits such as a share of rental fees (if any) and contingent benefits, including royalties, to pay for park operations or to set up a micro−enterprise fund. The proportion of monetary income set aside for benefit sharing would be set by law. The MBMP Trust in turn could use this income to fund park operations, to set up a community micro−enterprise fund, and so on.

When a draft contract has been agreed upon, it would be signed by all parties and submitted to the Genetic Resources Advisory Authority along with proof of prior informed consent and a completed permit application for review. The Authority would either approve the contract and sign the permit, or reject the contract. Rejection would be accompanied by a detailed explanation and the opportunity to renegotiate the draft agreement.break

Biotechnology Based Improvement of Jamaican Papaya Germplasm

The case of the biotechnology research project to develop virus resistant local papaya varieties illustrates well the value of certain kinds of biotechnology to Jamaican agriculture. Due to infection with the Papaya Ringspot Virus, crop losses in 1994 were 30% to 40%, while 1998 losses have been estimated at 50%. The biotechnology process used to develop the new varieties (cloning of the viral coat protein gene into the plant cells) has, when used on other crop varieties against different plant viruses, reduced yield losses to nearly zero without expensive and toxic chemical inputs used to control the insect vectors which spread the viral infections.

The research agreement developed between the Jamaica Agricultural Development Foundation and Cornell University incorporates a royalty free license for production for domestic markets. Export production will first require the negotiation of a royalty percentage with Cornell's technology donors, among them Monsanto Corporation, DuPont and others. Although the parental lines of the Sunrise Solo variety were obtained from Hawaiian growers, which in turn were derived from growers in Barbados, they would probably fall under the purview of the genetic resources regulations because the lines were subject to some breeding in Jamaica in the early 1980s. Thus, under the proposed genetic resources regulations, JADF would have had to apply to the NRCA for an export permit to export Jamaican papaya germplasm for scientific research. The NRCA in turn would have apprised the growers association of its obligation to negotiate a MTA with Cornell University.

Given that the purpose of the proposed research was to develop virus resistant varieties for use in Jamaica, there was already a clear public good built into this project. Cornell University was willing to sponsor the research, utilizing the proprietary technology licensed to it. Given that neither Cornell nor the technology donor companies intended to claim rights to the transferred papaya variety for private gain, it would not have been appropriate to charge an up−front fee to gain access to the germplasm. Indeed, in this case it is Jamaica that is seeking access to an extraneous resource (i.e., the proprietary virus resistance biotechnology). As such, it is appropriate for the technology donors to claim certain contingent benefits on any commercial products developed from this research.

The actual agreement negotiated by JADF appears to be quite beneficial to Jamaican growers. However, rather than deferring negotiations on the actual royalty percentage to be charged Jamaican growers, it is recommended that future negotiations be held up−front, prior to the transfer of any germplasm and commitment of biotechnology research funds, to obtain agreement on the size of the royalty charge. Under the proposed genetic resources regulations, this issue would have come up during discussion of the draft MTA submitted by JADF to the Genetic Resources Advisory Authority. The genetic resources regulations would also have allowed the government to monitor—and to learn from—the development of this highly creative research collaboration.break

Chapter 13— Ecological Economic Decision Support Models for Coastal Zone Management in the Developing Tropics—Results, Dissemination, Policy Applications, and Future Directions

Kent Gustavson
Gustavson Ecological Resource Consulting, Gabriola, BC, Canada

Richard M Huber
Environmentally and Socially Sustainable Development Sector Management Unit, Latin American and Caribbean Region (LCSES), The World Bank, Washington, DC, USA

Coral reef ecosystems throughout the world are in serious decline, being threatened by both localized anthropogenic stress as well as regional and global phenomena such as global warming (Bryant *et al.* 1998; Hodgson 1999; Hoegh−Guldberg 1999; Jameson *et al.* 1995; Wilkinson 1998; see Chapter 1). There may be some cause for optimism due to the remote locations of many coral reefs, the effective management of some, and the potential capacity of these ecosystems to recover (Wilkinson 1998), yet it is clear that effective integrated coastal zone management (ICZM) is necessary to help prevent further significant depletion. This final chapter serves to summarize the results of the research presented in this publication regarding the development of decision support models for the management of coral reefs in the developing tropics. The dissemination strategy is outlined and comments are offered regarding potential policy applications and future directions for research.

As introduced in Chapter 1, ICZM guides jointly the activities of two or more sectors or activities in the planning, development and implementation of projects. More formally, it is ". . . the integrated planning and management of coastal resources and environments in a manner that is based on the physical, socioeconomic, and political inter−connections both within and among the dynamic coastal systems . . ." (Sorensen 1997). Or similarly, "ICZM is a process of governance and consists of the legal and institutional framework necessary to ensure that development and management plans for coastal zones are integrated with environmental (including social) goals and are made with the participation of those affected. The purpose of ICZM is to maximize the benefits provided by the coastal zone and to minimize the conflicts and harmful effects of activities upon each other, on resources and on the environment" (World Bank 1996, p.2). Guidelines and procedures have begun to emerge for the development of ICZM (e.g., Bower *et al.* 1994; Chua 1993; Clark 1995; Pernetta and Elder 1993; Sorensen 1997; World Bank 1993a, 1996).

A critical element in ICZM is the *integration* —in particular, the horizontal integration across economic sectors and management agencies in the planning and implementation (e.g., Clark 1995; Sorensen 1997). Coastal activities must be considered jointly because of their interdependence and expected non−additive cumulative impacts. But how are multiple economic sectors or human activities to be considered together? How is concern for the maintenance of the coastal ecosystems, which directly or indirectly support economic activities, to enter into the decisions? What should be the decision−making framework for determining which activities should be allowed to occur within the coastal zone, how should they be developed and operated, and what level of activity should be permitted? On what basis should conflicts between competing coastal resource users be decided? Answering such questions necessarily involves the joint consideration of multiple system parameters, multiple criteria, and diverse value sets.break

Ecological economic decision support models can play a critical role. The family of ecological economic models includes those that recognize the validity of achieving an economically efficient management solution, yet concurrently and explicitly consider the limitations necessarily imposed on the scale and type of economic activities due to the characteristics and capacity of the natural environment. Ecological economic decision support models for ICZM should also allow for the accommodation of information regarding the socio−cultural context of the management environment, which has a critical role to play in the development of policy.

What are the characteristics of a useful decision support model? First and foremost, a useful decision support model needs to be capable of answering specific and relevant policy questions. To aid in the design and creation of such a model, one must be able to draw from an existing body of policy relevant research. As noted by Ruitenbeek *et al.* (Chapter 8), there is a great deal of scientific information available on coral reef biology and ecology. However, much of this information is not directly "policy relevant" and of little help to decision−makers or directly in the creation of a decision support model. Second, a model must be able to be understood and used directly by the targeted client group. Inputs must be relatively easy to provide, runs easy to conduct, and results easy to interpret. Third, a distinction must be made between the use of models intended primarily for scientific inquiry and those intended primarily to inform decision−making and policy—models with highly experimental constructs should be avoided for use as decision support tools. The theory on which decision support models are based should be relatively robust. For example, concerning the use of ecological models intended for use in decision−making, Friedland (1977) notes that "The basic objective in not the discovery of previously unknown truths but the collection and integration of existing knowledge and its presentation in a form useful in the policy−making process." This has direct ramifications for what type of model may be most appropriate. Finally, decision support models should be amenable to modification and revision of the data components, the specified relationships within the model, and the development alternatives or scenarios considered by the model. Again, it is imperative that the needs of the users be kept in mind. A model that uses data that are no longer valid for a particular locale, whose underlying ecological economic relationships are no longer accurate, or allows for no further modification or alteration of the specified development alternatives or scenarios, will prove to be of little use in the long run.

Results of the Modeling Projects

In 1995, work commenced under World Bank Research Committee funding on two streams of research concerning coral reefs in the developing tropics, namely: i) cost−effectiveness modeling of management interventions (i.e., a question of the "supply" of biodiversity as an economic asset); and, ii) marine system valuation (i.e., a question of the "demand" for biodiversity). Essentially, the least−cost modeling attempted to identify the cost curve for interventions to improve coral reef conditions, where the effects of various policy interventions and economic activities are linked to overall coral reef health and costs associated with making improvements (Chapters 3, 4 and 8). The marine system valuation model sought to identify the benefits that can be realized from sustaining or improving coral reef conditions (Chapters 5, 6 and 7).

The broad objective of the research was to assist policy−makers in the management and protection of coral reefs (Huber *et al.* 1994; Huber and Ruitenbeek 1997). The establishment of a cost−benefit methodology appropriate for use on coral reef systems in the developing tropics, and on marine systems in general, will assist in identifying appropriate institutional and policy interventions to help realize economically efficient uses of coral reefs while considering the impacts on and role of the supporting ecosystem. Such a cost−benefit analysis (CBA) "package" is represented by the integration of the cost−effectiveness and valuation models (Chapters 9 and 10). Three case study sites were selected on which to test the methodologies: i) Curaçao, the Netherland Antilles; ii) the Republic of the Maldives; and, iii) Montego Bay, Jamaica.

Coral−Curaçao

Rijsberman and Westmacott (1996; Chapter 3) developed a cost−effectiveness analysis model for coral reef management and protection for the south coast of Curaçao. The decision support model was developed to facilitate communication among stakeholders concerning development directions and environmental management strategies; the analysis of impacts on coral reef health of planned developments through the discharge of waste−water and sediment, thereby integrating land−use, tourism and conservation planning; and, the analysis of the cost−effectiveness of management interventions designed to maintain coral reef health. The model utilizes a structured computer interface.

Results of three modeling scenarios (a reference status quo development scenario and two alternative growth scenarios) indicate that Curaçao is likely to experiencebreak

significant declines in coral reef health and abundance over the next 10 years. However, the modeling also indicates that interventions involving environmental protection strategies can halt this trend and, in some case, lead to the recovery of reefs above their current state of health. Recommended interventions include combinations of sewage treatment, appropriate waste disposal, and reductions of refinery pollution; the implementation of alternative means of beach maintenance and the reduction of waste from manufacturing and shipping were found not to be effective (Rijsberman and Westmacott 1996; Chapter 3). However, Rijsberman and Westmacott (1996; Chapter 3) also note that the modeling results may be specific to the spatial scale examined and that these latter interventions may indeed be cost−effective and appropriate within a smaller, local context.

Rijsberman and Westmacott (1996; Chapter 3) stress that the utility of the modeling tool can only be demonstrated through an application that intimately involves stakeholders in the scenario building and decision−making process. Coral−Curaçao allows one to rank the measures and explore the formulation of various combinations of measures to achieve a specific coral reef cover and diversity target. For example, to achieve a target average coral cover of 14% and diversity of 50% (as indexed by the model), an initial investment of 310 million NAF with a yearly operation and maintenance cost of 6 million NAF would be required (Rijsberman and Westmacott 1996; Chapter 3).

Coral−Maldives

Westmacott and Rijsberman (1997; Chapter 4) developed a cost−effectiveness analysis model for coral reef management and protection for North and South Male in the Republic of the Maldives. As a model developed parallel with Coral−Curaçao, the objective was to investigate whether a model adapted for the Maldives (Coral−Maldives) would provide a useful decision support tool. Chapter 4 describes the model and the results of initial analyses.

As with Coral−Curaçao, the Coral−Maldives model was designed to allow decision−makers to determine the relative cost−effectiveness of various environmental management interventions for various economic development options in terms of the improvements in coral reef health that are achieved (i.e., using indices of coral reef cover and rugosity as proxy measures). In addition, the impacts of the scenarios can be seen in terms of economic, social and environmental indicators that are selected at the outset of the analysis by the model user.

Policy priorities and feasible management alternatives were identified through discussions with government agencies. Given the nature of the impacts on the coral reefs in the Republic of the Maldives, management interventions focus on minimizing physical damage (Westmacott and Rijsberman 1997; Chapter 4). Westmacott and Rijsberman (1997; Chapter 4) illustrate the use of the model through the presentation of example cases.

Westmacott and Rijsberman (1997; Chapter 4) note that there are an array of indicators that may be used to describe the potential for success or failure of a coastal zone management strategy—although the model is somewhat flexible, the set of coastal zone management indicators that can be selected and examined by the user is necessarily limited. Moreover, the use of intervention cost−effectiveness measures as they relate to changes in coral reef health alone may ignore other strategies critical to the success of a particular ICZM program (e.g., public health issues). It is suggested that the results of modeling scenarios for decision support, in the formulation of development or management plans, be placed within the context of social goals and requirements. As with Coral−Curaçao, the model may not adequately reflect localized conditions at a spatial scale below that incorporated within the model's components.

The Valuation of Coral Reef Benefits

In the process of arriving at a measure of total economic value (TEV), economic valuation studies of natural systems most often distinguish use from non−use values, and direct use from indirect use values. These distinctions most often reflect the method of estimation. During the specification of the design of the coral reef valuation for the Montego Bay Marine Park, it was decidedly more useful to distinguish between three classifications of marine biodiversity valuation: i) "supply−oriented" production valuation methods (i.e., production function contributions of marine systems to economic value); ii) "demand−oriented" utility valuation methods (i.e., contributions of marine systems to the utility of an individual or society); and, iii) "profit−oriented" rent capture valuation methods (i.e., contributions of marine systems through the distribution of use values as captured rent, profits or value added; Huber and Ruitenbeek 1997; Ruitenbeek and Cartier 1999). For the latter category, the potential contribution of coral reef biodiversity through the development of a bioprospecting venture was examined.

Production Function Contributions—Montego Bay Marine Park

Direct local use values were estimated by Gustavson (1998; Chapter 5) for two broad categories of uses—the near−shore fisheries and tourism. Indirect use valuescontinue

associated with coastal protection were also estimated. These local uses of the Montego Bay Marine Park waters were identified as the most significant during the final study site application, as well as being of the highest policy priority. The values reported by Gustavson (1998) represent the extent of the reef−derived production contributions at risk of being lost if conservation efforts prove inadequate.

Tourism services in Montego Bay include accommodations, food and beverage services, entertainment (including independent water sports and attractions), transportation, shopping, and other miscellaneous services. Net present value (NPV) estimates associated with tourism range from US$210 million (using a 15% discount rate) to US$630 million (using a 5% discount rate) in 1996. The NPV estimates in 1998 associated with fishing range from US$−1.66 million to US$7.49 million (constant 1996 dollars; using lower and upper estimate, respectively, of annual net values and a 5% discount rate; 10% and 15% discount rate estimates fall within this range). The NPV of the total amount of land at risk of erosion should the protective function of the coral reefs be compromised, based on approximately 250 acres being vulnerable, is estimated as US$65 million (constant 1996 dollars).

The median NPV from all local use values for the Montego Bay Marine Park was estimated to be US$381 million. Assuming a total reef area of 42.65 ha as a reference case, this translates to US$8.93 million/ha or US$0.893 million ha1 yr1 on an annualized basis (assuming a 10% discount rate).

Contributions to Utility—Montego Bay Marine Park and the South Coast of Curaçao

Spash *et al.* (1998; Chapter 6) utilized the contingent valuation method (CVM) to assess utility values associated with coral reef biodiversity in Montego Bay, Jamaica, and along the south coast of Curaçao. The study is particularly notable in that it examined utility values associated with a marine environmental resource (i.e., coral reef quality), which had previously been neglected by previous investigations. Moreover, the research made advances towards explicitly addressing sources of bias due to lexicographic preferences that arise when a respondent is unwilling to accept any trade−offs for the loss of a good or service (i.e., in seemingly refusing to make trade−offs, they are not behaving in accord with economic theory). For zero bids, distinctions were made between those who lack the income, regard the improvement as unimportant, prefer to spend money on other goods or services, or were protesting having to make such a choice. Among those giving protest zero bids, and thus providing a source of bias, were those who are "free riders", feel the payment is not an adequate solution, lack faith in the proposed institution, or reject the payment mechanism. The survey also explored the extent of right−based ethical positions that would be compatible with lexicographic preference. To aid in the comparison with the results of the local use and bioprospecting valuation studies in Montego Bay, the CVM was also designed to allow for the separation of the direct use values from the indirect and non−use values.

Survey respondents were asked to contribute towards a trust fund that would be managed by a marine park to increase biodiversity within the park boundaries. The payment was to be made on a per annum basis for five years and lead to a 25% increase in coral reef cover. Bid curve analysis (i.e., tobit analysis in combination with maximum−likelihood estimation) provided further information regarding the variables determining variations in WTP and refined the WTP estimates. At the sample means, WTP was estimated as US$2.08 per person in Curaçao and US$3.24 per person in Jamaica (Spash *et al.* 1998; Chapter 6). The difference was explained as due to the difference in the mix of tourists and local residents, with Jamaicans willing to pay almost double their counterparts in Curaçao. Using typical visitor and local population profiles and a 10% discount rate, this leads to a total estimated WTP of approximately US$4.5 million in Curaçao and US$20 million in Montego Bay, Jamaica (Spash *et al.* 1998; Chapter 6).

Potential Bioprospecting Contributions—Montego Bay Marine Park

The estimating model for Montego Bay bioprospecting focused on average social net returns utilizing localized cost information for Jamaica and benefit values and success rates based on proprietary information for marine products in the Caribbean (Ruitenbeek and Cartier 1999; Chapter 7). Parametric model assumptions included the specification of the species−area relationship and the institutional revenue sharing relationship (i.e., a contingent net profit share and a fixed sampling level fee). Sensitivity analysis explored the effects of variations in model parameters on the value estimate, including variations in the total area of available reef substrate with live cover and the specification of the species−area relationship as co−determinants of the expected number of samples available for testing. Other model scenarios included a fixed sampling fee only, blended revenue shares, high research and development (R&D) costs, low "hit rates", and a shortened sampling program. A marginal benefit function was derived which related the value or "price" of marine biodiversity to coral reef abundance.break

A "base case" value of US$70 million was estimated for the reefs of the Montego Bay Marine Park, of which approximately US$7 million (i.e., 10%) would realistically be able to be captured by Jamaica under typical royalty or rental arrangements (Ruitenbeek and Cartier 1999; Chapter 7). The marginal value of reef for bioprospecting was found to be US$530,000/ha or US$225,000/% change in coral reef abundance (corresponding to a local Jamaican planning price of US$22,500/% change in coral reef abundance).

The Identification of Least−Cost Interventions—Montego Bay Marine Park

Similar to the Coral−Curaçao and Coral−Maldives models, Ruitenbeek *et al.* (1999a; Chapter 8) applied a fuzzy logic methodology to identify the least−cost interventions that would lead to an increase in coral reef abundance within the Montego Bay Marine Park. Fuzzy logic procedures are utilized within an ecological reef impact model to generate a complex dose−response surface that models the relationship among coral reef abundance and various inputs within the context of the abiotic marine environment. This is linked to a non−linear economic model describing current and future economic activities within eight sectors, technical and policy interventions, and pollution loads in Montego Bay. Optimization provides insights into the most cost−effective means for protecting coral reefs under different reef quality targets.

In Montego Bay, Jamaica, up to a 20% increase in coral abundance may be achievable through the use of appropriate policy measures with a present value cost of US$153 million over 25 years (Ruitenbeek *et al.* 1999a; Chapter 8). The specific policy measures considered included installation of a sediment trap on the Montego River, the planting of trees in the upper watershed, installation of a waste aeration system, installation of a large−scale centralized treatment facility, agricultural extension to provide waste reducing technologies, installation of an outfall and pump station, improved household solid waste collection, and implementation of a hotel tax. Some interventions were found to be relatively cost−effective. For example, household solid waste collection, installation of an outfall, and use of a sediment trap on the Montego River would impose a present value cost of US$12 million and result in an improvement in coral reef cover of over 10% (Ruitenbeek *et al.* 1999a; Chapter 8).

One key demonstration of the research was that conventional methodologies for measuring cost−effectiveness may result in sub−optimal policy solutions when applied to complex systems. This is because cost−effectiveness analyses tend to assume the separability and independence of individual interventions and the ability to treat benefits separately from costs (often when benefits can not be defined). When dealing with highly complex systems such as coral reefs, synergisms, feedbacks and other interdependencies between individual interventions and the resulting level of coral reef health can invalidate the recommendations arising from individually assessed policy interventions that are assumed to be able to be applied in a sequential, step−wise fashion. For example, reforestation was found to be part of the optimal intervention set at coral reef improvement targets of 14% and 20%, but were not part of the optimal intervention set for a 15% or 16% improvement (Ruitenbeek *et al.* (1999a; Chapter 8). As noted by Ruitenbeek *et al.* (1999a; Chapter 8), this means that coral reef health targets, in reference to the extent of the derived benefits, must be established before policy interventions are pursued.

Integrating the Results for Montego Bay Towards an Efficient Level of Intervention

A synthesis of the separate coral reef valuation studies for the Montego Bay Marine Park allows one to arrive at a total value and a net marginal benefit (or price) function (Ruitenbeek and Cartier 1999; Chapter 9). In order to arrive at a marginal benefit function, relating price to changes in coral reef abundance, further assumptions were required regarding the relationship between the categories of values and coral reef abundance or quality. Specifically, a linear relationship is assumed between reef quality and local use values and non−use utility values. This is most likely not the case, but assuming a less simplified relationship cannot be justified given our current knowledge. Only the results of the bioprospecting valuation model (Ruitenbeek and Cartier 1999; Chapter 7) allowed the specification of a different functional form. As noted by Ruitenbeek (Chapter 9), total net marginal values will likely be over−estimated in some instances and under−estimated in others.

The total benefit attributed to the coral reefs of the Montego Bay Marine Park is estimated at US$470 million; every 1% change in abundance is likely to generate a marginal benefit of US$10 million or, alternatively, the marginal price of coral reef is approximately US$23 million/ha (Chapter 9). Most of the value is attributed to tourism. Coastal protection and non−use utility benefits also contribute, but to a much lesser extent. Existing fisheries and the potential development of a bioprospecting program have a negligible effect on marginal values

(Chapter 9).break

Using the marginal cost function as reported in the least cost intervention study for the Montego Bay Marine Park (Ruitenbeek *et al.* 1999a; Chapter 8), in conjunction with the marginal benefit estimates, allows one to arrive at a global optimization. As reported by Ruitenbeek (Chapter 9), an optimal improvement of coral reef abundance of 13% is suggested (i.e., from approximately 29% live cover as estimated from model equilibrium conditions—see Ruitenbeek *et al* 1999a; Chapter 8—to approximately 42% live cover), requiring net expenditures of US$27 million. The required interventions would involve 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. Sensitivity analysis suggests that this optimization is fairly robust to changes in the net economic benefit estimates—benefits would need to be increased by US$275 million or decreased by US$300 million for the target coral reef quality improvement to change by more than 2% (Chapter 9).

The Human Context of Coral Reef Use

In addition to the application of cost−effectiveness analysis, resource valuation or CBA, it is key that decision−makers comprehensively and systematically consider the social, cultural and economic context of policy development and ecological change. Such context or "human framework" information does not traditionally form part of such analyses, in which quantitative monetary indicators or measures are often applied within an "automatic evaluation" decision−making environment (Anderson 1991), restricting further interpretation of the appropriate or optimal levels and types of interventions and policies necessary.

The economic valuation methodologies applied in these projects were designed to enumerate the total benefits currently received from the coral reefs, through both production function contributions and human utility (as well as potential rent or royalty benefits from the development of marine bioprospecting ventures). Such monetary benefits will, in theory, reflect the local set of values. However, much is lost in reducing the social, cultural and economic information to a single value metric. This was demonstrated through the development and application of a rapid socio−economic assessment methodology to provide an understanding of the coral reef user groups of the Montego Bay case study site (Bunce and Gustavson 1998a; Chapter 11). Such information will better enable the adaptation of management strategies to the user groups' use patterns, management priorities, and available resources. In essence, "human framework" information assists in identifying an economically efficient outcome that is also socially and culturally viable. This information has demonstrated utility in the development of effective policies and programs for the Montego Bay Marine Park (Bunce *et al.* 1999; Chapter 2).

Policy Context and Advice

Case Study—The Capture of Rent Generated from the Use of the Montego Bay Coral Reefs

Of great interest to the management authorities of the Montego Bay Marine Park, as well as to managers of any coastal marine system, is to capture at least a portion of rent generated from direct uses to pay for the necessary management, and potential enhancement, of the resource. In other words, there are social costs associated with the conservation and management of the resource that should be paid by the users.

As a component of the local use valuation study (Gustavson 1998; Chapter 5), current existing government charges, which may capture a portion of the rent, were explored. Currently, it is not the policy of the Montego Bay Marine Park to charge user fees (a recognized, explicit mechanism for rent capture), although it is in the early stages of beginning such a program. Other government charges, which are specifically linked to either tourism or fisheries related activities, may capture a portion of either producer or consumer surplus, but are not necessarily designed explicitly to do so. This includes business license fees, fisheries license fees, beach fees and tourist departures taxes.

In principle, license fees are collected to pay for the government costs of regulating and administering the business or activity. No information was available on the actual costs associated with regulating the reef−related activities, yet it is likely that in all cases these costs are not recovered based on existing fee schedules. It was found that the beach fee charges as currently set are minimal and, although they vary roughly according to the type of use, are not linked to varying levels of producer surplus. None of these funds are explicitly directed to pay for the management of the Montego Bay Marine Park. No other government or management agency fees or charges are specifically linked to either tourism or fisheries related activities in the area. Corporate profit taxes, or personal income tax in the case of the fishers or of individually distributed profits from tourism−related businesses, may also capture a portion of the rent. However, taxes are paid to the general government collectorate andcontinue

thus are not explicitly available for use in marine park management. The current interest of Montego Bay Marine Park in implementing user fees should be encouraged.

Case Study—Institutions and Policy Advice for Bioprospecting in Jamaica

Putterman (1998; Chapter 12) offers specific policy and institutional strengthening advice with respect to the incorporation of genetic resource use into ICZM in Jamaica as a potentially powerful tool for conservation and economic development. Genetic or molecular diversity, a measure of the biological diversity within species, can be the source of new pharmaceuticals, industrial products and agricultural varieties. Many strategies for research collaboration, as a risk−reducing strategy to maximize the ability to discover promising new chemicals or genes, may be employed; as well, many benefit sharing mechanisms and options for compensation exist (see Chapter 12). As noted by Putterman (1998; Chapter 12), there are currently no Jamaican policies to regulate access to genetic resources. A review of Jamaican institutions and policies lead to the following key recommendations (Chapter 12):

In the design of a set of resources policy options, incorporate obligations under the Convention on Biological Diversity and the United Nations Convention on the Law of the Sea, as well as take account of the effect that policy−making will have on private sector activities;

Regulate access to genetic resources up−front with permits and contracts to define rights to these resources before samples are collected or exported;

Establish *sui generis* (novel) rights to tangible property and traditional knowledge in order to define who has the right to participate in and benefit from the negotiation of contracts involving a transfer of genetic resources or traditional knowledge;

Develop prior informed consent procedures in order to give the legal owners of rights to genetic resources and traditional knowledge a means to control use of these resources; and,

Create a national benefit sharing formula to convert a portion of monetary income derived from new product development into public goods to ensure a fair and equitable sharing of benefits from genetic resources utilization.

Potential bioprospecting net present values are small in comparison to current local use values associated with tourism and coastal protection (Gustavson 1998; Ruitenbeek and Cartier 1999; Chapters 5 and 7) and, as noted above, are expected to have a negligible effect on marginal coral reef values. However, Ruitenbeek and Cartier (1999; Chapter 7) note that the impacts of the institutional costs associated with the operation of a national bioprospecting program in Jamaica, as recommended by Putterman (1998; Chapter 12), are minimal. The implementation of a bioprospecting program may be warranted. The question becomes one of the willingness of local management and stakeholders of the Montego Bay Marine Park to enter into such a venture.

Modeling Results and Policy Advice for the Use of Decision Support Models

More generally, beyond the specific policy and institutional questions that arise when one considers the potential development of a bioprospecting program in Montego Bay, policy questions arise from the overall least cost intervention and coral reef benefit modeling results. Ruitenbeek (Chapter 9) notes that if economic efficiency is the goal, both costs and benefits must be considered in research when dealing with complex non−linear systems such as coral reefs. Cost−effectiveness analysis alone may not be adequate. Ruitenbeek also calls for a greater emphasis at the local level on the socio−economic and management dimensions of direct uses, including the promotion of practical local management regimes that consider and involve affected stakeholders. This point is also emphasized by Jameson and Williams (Chapter 2) and Bunce and Gustavson (1998a; Chapter 11).

Dissemination

The least cost intervention and valuation approaches of this modeling research are useful decision support, policy and training tools for coral reef managers and government decision−makers faced with significant coral reef management issues. The consolidated dissemination strategy for the projects has the following facets:

The launch of a "road show" to disseminate this publication that includes a CD−ROM of the COCOMO—COastal reef COasts in MOntego Bay decision support model (Chapter 10);

The continuation of workshops supported by World Bank Knowledge Management, at both the national and local level, with the goals of obtaining feedback on the findings of the applied modeling research, identifying priority areas for future research, and identifying potential avenues for strengthening regional and local capacity to manage the coastal resources;

The creation of user−driven programs on the World Bank Knowledge Management web sites (BIONODE and Water Resources) and other websites; and,

Assistance to the Montego Bay Marine Park Trust in the preparation of a regional replicable project entitled ReefFix (Chapter 2).break

The stakeholders involved in the case study sites have expressed their need and interest for a more comprehensive understanding of existing and planned development and conservation activities involving the coastal zone. Whether they be local fishers, water sports operators, hoteliers, local developers and entrepreneurs, local residents or visiting tourists, it is critical to fulfill these information requirements to achieve effective coastal zone management. The dissemination strategy is necessary to increase the involvement of the diverse stakeholder groups in assessing the changes in the marine environment and in mitigating or preventing the negative impacts on the coral reefs. The development of a network of policy−makers and researchers—a "community of practice"—to enable the sharing of international experiences on coral reef restoration and to foster collaborative research is also key.

COCOMO

COCOMO is a decision support coastal zone management model for Montego Bay that illustrates coastal problems and estimates the effects of human activities (Chapter 10). It is also a tool for policy development and capacity building in integrated coastal zone management (ICZM). The Montego Bay case study site was selected for the interactive modeling project because of the critical needs for such a tool. The urban center is experiencing rapid growth, with development often ad hoc and relatively unplanned. Many physical alterations to the coastal zone have occurred, including coastal infilling, mangrove destruction, and sedimentation, in addition to coastal nutrient enrichment, intensive fishing pressures, and extensive use by the water sports, diving, and tourism industries (Chapters 1 and 11). This has resulted in the degradation of water quality and coastal resources, and has caused significant impacts to the valuable coral reef ecosystem.

Specifically, the applied COCOMO modeling research is assisting the Montego Bay Marine Park Trust with a coherent and comprehensive program that:

 Raises awareness and promotes consensus building on the part of the stakeholders with regard to environmental priorities in Montego Bay;

 Identifies the challenges of addressing coastal zone management issues in Montego Bay over the short and long−term with the various government and non−government organizations (NGOs) involved;

 Identifies specific environmental investments with feasible, relatively low cost solutions; and,

 Initiates a process of dialogue with stakeholders.

The model's computer user−friendly interface is developed for policy−makers, specialists and those interested in Montego Bay coastal issues. The interface uses extensive graphics to provide users with a quick overview of coastal issues and how development, fisheries, tourism, agriculture, industry and households impact the coast and the coral reefs of Montego Bay. Stored within the model is information on the coral reef ecosystem and associated marine life, as well as information on what the coral reefs contribute to Montego Bay through fisheries, tourism and coastal protection. Through the user interface, different actions may be taken to protect the coastal zone and coral reefs, some being more cost−effective than others. COCOMO predicts the least cost set of interventions to realize a specified coral reef abundance. Thus, the impacts from development−related activities can be explored and priorities set for future coastal management actions. In the process of using the model, the user obtains a unique awareness of the relationships between coastal activities and communication among stakeholders is enhanced.

ReefFix

An ICZM coral reef restoration, watershed management and capacity building demonstration project—ReefFix—is being implemented through the Montego Bay Marine Park (Chapter 2). ReefFix is the implementation phase of the decision support modeling results. The goal of the program is to design and implement a least cost coral reef restoration and watershed management project and then transfer the information and technology to other tropical American countries facing similar challenges. A key characteristic of ReefFix is that it takes an approach driven by specific policy needs related to the management of coral reefs that suffer from significant impacts (Chapters 1 and 2). The capacity building component includes the strengthening of human and institutional capabilities for integrated management, science, training and education (Chapter 2). It is seen as important not only to transfer the information to the developing country context, but to promote the exchange of experiential learning and to build local expertise in coral reef management.

The program has the following objectives (Chapter 2):

 Utilize the developed decision support model tool for the Montego Bay Marine Park (COCOMO) to provide information to local managers and decision−makers;

 Develop and implement a watershed management action plan for the Montego Bay Marine Park to improve marine water quality and increase live coral reef abundance;

Develop and implement a fisheries management action plan for the Montego Bay Marine Park to increase fish abundance, improve economic conditions for fishers,continue

and help make the Montego Bay Marine Park financially self−sustaining; and,

Implement a demonstration action plan for the tropical Americas that will improve ICZM capacity for the restoration of coral reef ecosystems in other countries. This may include application of a developed least cost ICZM decision support model template that can be custom tailored for other locales.

Process and Policy Applications

A rational economic optimization, considering solely the costs of management interventions in conjunction with the valuation of the total economic benefits received (e.g., Chapter 9), may seemingly reduce the role to be played by stakeholders and management agencies in the setting of goals and the expression of the diverse set of values likely represented by the various user groups. Indeed, it was the general approach of Rijsberman and Westmacott (Chapters 3 and 4) in the development and implementation of the Coral−Curaçao and Coral−Maldives decision support models to focus on the ability of decision−makers to analyze, through various user−defined scenarios, the cost−effectiveness of alternative interventions and the resulting economic, social and environmental conditions as reflected by various indicators. Their initial modeling approach does not go so far as to derive a global optimum, but focuses on providing a means by which decision−makers (and those simply with an interest) can explore management alternatives.

Defining an optimal solution through a decision support model does not necessarily negate local stakeholder involvement in management decisions; however, one must be cautioned against this occurring. The participation of stakeholders and management agencies must not be forgotten. The recommendations stemming from a normative model solution may not be adequate or feasible given the specific institutional and social context. Indeed, the success of any coral reef management program will be greatly affected by the social environment and the decision−making process itself. It is critical that stakeholders be involved in as many stages in the development of a management program as is practical, even if it is simply through an information sharing exercise. As has become increasingly evident in all environmental management processes, it is the *process* itself that often sets the stage for a successful management program. Without an open and participatory process, significant barriers to effective management can be expected to arise.

Decision support modeling should be implemented within a specific policy context. This is especially true concerning the valuation components for, as noted by Cartier and Ruitenbeek (Annex A), the choice of any one of a number of valuation techniques should be driven by the specific policy questions at hand or the analytical issues that need to be addressed. The policy questions define the data that is needed and the analyses that are required.

Although scenarios, resulting from the development of ecological economic decision support models as reported here, have defined specific policy recommendations regarding the types of interventions required and the level of coral reef health that should be achieved for specific study sites, it is as yet too early in the development and use of these models to recommend that the required investments be made. Further work involving the local study site stakeholders and management agencies, as described by the dissemination strategy above, is required to refine the recommendations and develop integrated coastal zone management programs. The design of specific interventions can be expected to require refinement based on a more in depth consideration of local social and institutional conditions through a more participatory process. In addition, although the results reported here derive from truly "state of the art" models, there were notable deficiencies in the amount and quality of the economic and ecological data available and notable deficiencies in the development of the science behind the model construction. In short, the models should not be used to dictate coral reef management directions, but are for use to help *support* such decisions.

Future Directions for Decision Support Models

One significant challenge in the study of complex non−linear systems, such as coral reef ecosystems, is in providing an adequate description of the composition, functional relationships and behavior of the system in question. Ruitenbeek (Chapter 9) notes that research needs to show a greater emphasis on ecosystem analysis, with a focus on functional linkages and relationships. The development of ecological economic decision support models is hindered by a lack of understanding regarding the behavior of ecosystems. Ecosystem uncertainty may prevent useful rational economic analysis (Chapter 9).

Complex system modeling techniques such as fuzzy logic may prove more useful. The least cost intervention component of the decision support models presented here (see also Brown *et al* . 1996; Meesters *et al* . 1995, 1996a; Ridgley and Dollar 1996), demonstrate the utilitycontinue

of incorporating a fuzzy logic modeling environment when examining the behavior of a coral reef ecosystem in response to anthropogenic stress and intervention. Further research into the use of fuzzy sets in similar applications is warranted (Smith 1994). Yet, it may be that a combination of various techniques, be they linear deterministic models, complex simulation models, fuzzy logic models or neural networks, may be required in the exploration of the behavior of and interactions between ecological and economic systems.

The linking of disparate systems within a modeling environment is a continuing challenge being faced by the field of ecological economics, as well as by other trans−disciplinary fields of inquiry. The fields of conservation biology and economics have separately struggled with an inability to provide adequate explanatory links between economic activities and species or ecosystem decline. More generally, often the provision of a concise description or characterization of a complex ecological economic environment is required simply to facilitate decision−making in management. Indicators, as proxy variables or simplifications of a complex reality, often serve this function.

In the modeling efforts presented here, the primary indicator used for coral reef health was spatial coverage (i.e., percent of a total available substrate covered by live coral). This indicator provided a simple descriptive "link" between economic activities and the affected coral reef ecosystem. Moreover, the indicator formed the basis for decisions concerning the "best" management interventions in order to receive the greatest return in benefits and concerning the extent of the interventions warranted to achieve an economically efficient outcome. The obvious questions arise—is this indicator of coral reef health adequate and should other indicators be included in the modeling?

The properties of a "good" indicator for use in decision−making and policy development could be described as the following:

The indicator design corresponds to the selected purpose and application;

The value base behind the indicator design is explicit;

The indicator provides a sufficient simplification or abstraction of the targeted system characteristics;

The theory behind the design of the indicator is relatively robust;

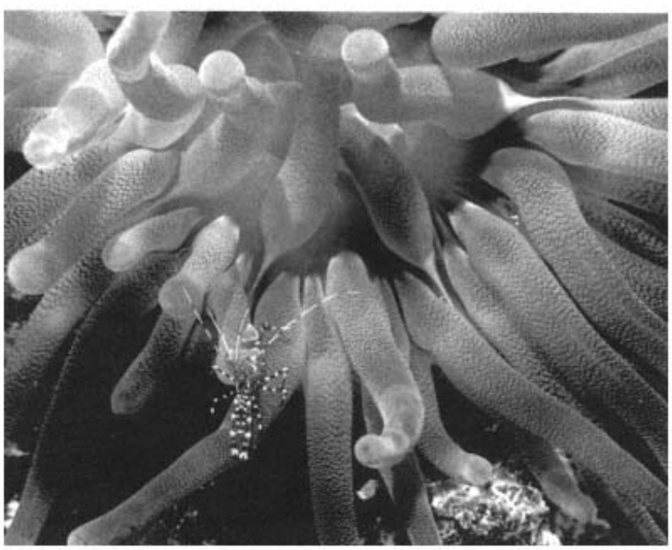
The sensitivity of the indicator to system parameter changes has been sufficiently explored and defined, and the indicator is sufficiently sensitive to meet the design purpose; and,

The information provided by the indicator can be understood and applied by the user.

Most indicators cannot be expected to meet all of the above criteria; however, it remains the goal of indicator development to satisfy as many as is possible given the shortcomings of the level of available scientific knowledge and restrictions on research. It is asserted that coral reef cover is a reasonable indicator of coral reef health given these shortcomings, but future development of these decision support models may need to refine or modify the indicators utilized. The development of ecosystem indicators for use in decision−making and the development of policy is very much in its infancy, although progress is being made (e.g., Jameson *et al* . 1998, 1999; Chapter 1). How such indicators may form the "link" between ecological and economic components of complex systems models, and facilitate awareness and understanding, remains to be explored further.

As a final point regarding the further development and refinement of ecological economic decision support models for ICZM, any analysis must be able to explore the possible variations in the results and subsequent recommendations. It is imperative that decision support modeling involves a sensitivity analysis or some means with which to gage the risk or possible error associated with any one scenario. For example, the bioprospecting valuation modeling showed that the estimates of ecosystem yield were highly dependent on the assumed species−area relationship (Chapter 7). Relatively small variations in such non−linear relationships inherent within a model can lead to sizable variation in the outcome. Recommendations regarding optimal policy must bear these in mind. Caution is prudent until the science of decision support models and their application has developed to a point that warrants great confidence in the results.

As a final message upon closing, it is believed that the ecological economic decision support modeling work will prove useful in the development of effective ICZM programs in the developing tropics. Further research and refinements of the models, along with greater attention to the process of decision−making, should be seen as a necessary challenge, not as a hindrance. Given the emerging evidence that indicates we are facing an ecological crisis world−wide in the decline of coral reefs, management must move forward given the best set of decision support tools currently available.break



Annex A—
Review of the Empirical Biodiversity Literature

Cynthia Cartier and Jack Ruitenbeek
H.J. Ruitenbeek Resource Consulting Ltd., Gabriola, BC, Canada

The primary objective of this literature review is to illustrate the techniques that have been used and the results achieved in empirical studies relevant to marine and coral reef biodiversity valuation. Very little has, in fact, been done that relates only to marine biodiversity, while an extensive amount has been done that covers related areas, such as coastal resource valuation or terrestrial biodiversity valuation. The purpose of this annex is not to provide an exhaustive review of all of the valuation literature that may be relevant; such a review would encompass literally thousands of articles. Recent work to promote benefit transfer techniques in Australia and Canada, for example, has resulted in two searchable internet−based bibliographies that permit users to transfer benefits from one study site to a new study site.1 Also, up−to−date online searchable databases relating to biodiversity issues are available from researchers active in the field.2

A secondary objective has been to audit and expand on some of the early secondary literature (e.g., Aylward 1993; Pearce and Moran 1994) with a view to updating those reviews. These studies have been frequently cited in what is now becoming a third round, or tertiary literature, on the subject and we have referred to the primary articles to ensure consistent and accurate comparable representations of methods and results.

Third, we pay particular attention to pharmaceutical development, and this chapter presents a rigorous comparison of five sets of models that have been used for terrestrial biodiversity prospecting valuation relevant in this area. These range from early models of gross benefits to more recent models that attempt to reflect some of the complexities found in terrestrial ecosystems. This review forms the basis for developing a similar model for marine biodiversity (Chapter 7).

As a preamble to the discussion on pharmaceutical bioprospecting models, we also explore some of the more general findings from the agricultural bioprospecting literature. The agricultural bioprospecting models have developed along a somewhat different path than the pharmaceutical models; while aspects of the agricultural models are relevant to marine bioprospecting, our empirical focus in this study is on the pharmaceutical aspects. This focus is driven by the current policy interest in many developing countries in capturing values from drug research. On balance, marine systems are receiving greater scrutiny for new sources of drugs while bioprospecting for useful maricultural traits is limited (Henkel 1998). For example, in early 1999, more than 30 drugs derived from marine species were under preclinical investigations by private and public research organizations, and by the National Cancer Institute (Mestel 1999).

All existing economic valuation studies pertaining to coral reef habitats were reviewed to determine what types of use and non−use values are typically estimated, and what types of valuation approaches are employed. The studies were generally categorized as falling into either "production value", "utility value" or "rent value" estimates (see summary in Box A.1). Value categories include recreation, harvested products, education and research, ecological functions, and existence and option values. In some categories, valuation studies of other habitats are included because either the study approach is interesting or because few coral reef valuation studies exist for the particular use or non−use value. Such is the case for coral reef studies on existence and option values, and for ecological function valuations.

From the studies reviewed, the value estimates for uses and non−uses of coral reefs are categorized in Table A.1a (for habitats) and Table A.1b (for pharmaceutical genetic resources), and the approach taken for the valuation is summarized. A study by de Groot (1992), an ambitious valuation of the Galapagos National Park, appears in many of the valuation categories. It is included in this review because of its breadth of treatment of a marine area that, although a minor attribute, does include coral reef habitat. It is also included because of its various valuation approaches.

After examining the valuation studies that focused on coral reefs, we find that:

Existence and option valuations are rare (only one study estimated the existence value of a coral reef site, that being the Great Barrier Reef);break

Most valuation studies involving coral reefs are concerned with their recreational and tourism use value;

No studies estimate the genetic resource use value of coral reefs, although all acknowledge it;

The most commonly valued harvested product of coral reefs is fisheries, but the natural systems underlying the harvest (e.g., reef−fish relationships) are simplified, if not ignored;

The education and research values are based on expenditure estimates or on budget allocations from funding institutions; and,

Coastal protection afforded by the coral reef habitat is the only ecological function valued.

Literature Relating to Existence and Option Values

Only one study estimated a combined option and existence value for a coral reef habitat. Hundloe *et al.* (1987) uses contingent valuation methods (CVM) to estimate the value of coral sites within the Great Barrier Reef to "vicarious" users. From adult Australian citizens, willingness−to−pay (WTP) bids to ensure that the reef is maintained in its then current state are used to calculate a consumer surplus of A$45 million/yr. Bids from survey respondents who had visited the reef are excluded, but the motives behind bids from non−users were not distinguished. Therefore, although the estimate represents non−use value, it does not separate option and existence values. In any case, the authors stress that the valuation is an underestimate because it excludes the vicarious value of the reef to overseas residents.

For the Galapagos National Park, de Groot (1992) estimates option value. He also estimates "inspirational" and "spiritual" values that are included here because these could be considered vicarious non−use values. The option value is estimated to be at least equal to the combined value of all the so−called productive and conservation (ecological) uses of the park. The value of cultural and artistic inspirational use is based on the value of book and film sales. The value of spiritual use is based on financial donations because, the author argues, at least part of donated money indicates an ethical or intrinsic value attached to the park.

As existence and option valuations involving coral reef habitats are scarce, studies involving other types of habitats were reviewed for their methodological approaches to valuing non−use benefits. The six non−coral reef studies documented in Table A.1 are frequently cited as examples of non−use benefit valuation; all but one employ CVM to estimate non−use value.

Literature Relating to Harvested Product Valuations

Table A.1a summarizes the results of seven studies involving harvested products from coral reef habitats. All of the valuations use a change in productivity approach with varying degrees of linkage complexity. Two of the studies (de Groot 1992; Driml 1999) do not incorporate ecological economic linkages—the valuations simply represent the gross financial value of harvested products. Four other studies try to link reef quality to fishery productivity—reef quality is viewed as a factor of production, a changecontinue

Box A.1—
Biodiversity Production, Utility and Rent Valuation Measures

1 *Biodiversity production values* . These are measures of the value of biodiversity within an economic production function, and may therefore also be considered as focusing on a supply−oriented approach to valuation. They are frequently used to estimate direct use values for

fishery output, for example, but the approach can also be used to estimate indirect uses such as ecological functions. In the terrestrial biodiversity literature, they often attempt to estimate the value of inputs to specific drugs or agricultural uses.

2 *Biodiversity utility values* . These are measures of the value of biodiversity within an economic utility function, thereby attempting to capture total consumer surplus or demand−oriented value. Contingent valuation techniques are often used to capture non−use values, or other techniques are used to value the final end use benefits of biodiversity.

3 *Biodiversity rent capture values* . These are measures of how much value is retained or captured within a country or region, or by a particular interest group. The methods usually concentrate on one part of a profit function, and are more interested in identifying a specific profit share than in identifying total economic value. The estimates derived by such approaches may be quite small if there are local institutional weaknesses or failures that prevent benefits from being captured.

Table A.1a. Habitat valuation studies relevant to coral reef management

Ecosystem and Original Study	*Approach* Utility	Production	Rent	*Valuation Results*	*Miscellaneous Notes includin Secondary Sources*
Option & Existence Values (for Habitats)					
Existence and Option Value, Great Barrier Reef (Hundloe *et al.* 1987)	★			CVM: A$45 million/yr consumer surplus or A$4/visit WTP to ensure that the Great Barrier Reef is maintained in its current state; based on a 1986 mail survey of Australian citizens 15+ yrs old; estimate excludes respondents who had visited the Reef.	As reported in Hundloe (1990
Inspiration and Spiritual Values, Galapagos National Park (de Groot 1992)	★			Expenditures: $0.20/ha1 yr1 for cultural/artistic inspirational use, based on sales of books and films; $0.52/ha1 yr1 for spiritual use, based on donations.	Inspiration value is classified productive use value; spiritua as conservation value. Both a included here as they are both arguably vicarious use values
Option Value, Galapagos National Park (de Groot 1992)		★		US$120/ha1 yr1 which is equal to the total value of all the Park's conservation and productive use values combined.	Conservation values include i alia habitat/refugia value, recr productive uses include food, construction materials, etc.
Existence Value, Brazilian Amazon (Gutierrez and Pearce 1992)	★			CVM Studies: $30 billion total based on arbitrary WTP estimates from various CV studies; aggregated across the OECD adult population.	As reported in Pearce and Mo (1994).
	★				

Conservation Value, Blanket Peat Bog Scotland (Hanley and Craig 1991)				CVM: $580/ha NPV of conserving the area; based on a mail survey; WTP of non−users was $21.60, WTP of users was $43.70; average WTP ($30/household) was applied to the regional population, put on a per ha basis, and discounted at 6%.	Study was a CBA of two opti conservation of the area; and conversion to block plantation Option (ii) yielded a NPV of $1590/ha. As reported in Barb *al.* (1997).
Minimum Option Value, Massachusetts Wetlands (Danielson and Leitch 1986)	★			$ 343/acre; based on average annual amount paid by US Fish and Wildlife Service in 1980 to owners of unaltered wetlands for preservation easements.	As reported in Pearce and Mo (1994).
Conservation Value, Kakadu Conservation Zone, Australia (Imber *et al.* 1991)	★			CVM: A$124/yr for 10 yrs average WTP to avoid a major mining development impact scenario; and A$52.80/yr for 10 yrs to avoid a minor impact scenario; based on a nationwide in−person survey.	A major criticism of the study the "embedding effect." As re in Munasinghe and McNeely (1994).
Existence Value, Nadgee Nature Reserve, Australia (Bennett 1984)	★			CVM: At least A$20, or A$2/yr in perpetuity WTP of Canberra residents for the continued existence of the Reserve; based on an in−person survey of 544 residents, bid curve analysis, and a 10% real interest rate.	Coastal area with high diversi habitats; managed with empha non−participatory benefits.

(table continued on next page)

Table A.1a. continued

Ecosystem and Original Study	*Approach* *Utility*	*Production*	*Rent*	*Valuation Results*	*Miscellaneous Notes includin Secondary Sources*
Existence Value Prince William Sound, Alaska (Carson *et al.* 1992)	★			CVM: Median $31/household one−time tax for measures to prevent future oil spills like that of the Exxon Valdez; based on in−person survey of 1043 US citizens; WTP aggregated over affected households yielded $2.8 billion in total lost non−use value.	Natural resource damage asse done for the State of Alaska. reported in Pearce and Moran (1994).
Direct Use Values for Marine Areas—Harvested Products					
Fisheries Valuation Great Barrier Reef (Driml 1999)		★		Productivity Change: Gross Revenue A$143 million (1996); based on 1995/96 catch data for major commercial species, and a survey of current fish prices.	Study updates Driml (1994) estimates presented in Driml and Driml *et al.* (1997).
Fisheries Valuation Bacuit Bay, Philippines (Hodgson and Dixon 1988)		★		Productivity Change: PV Gross Revenue $9108 with logging vs $17,248 with logging ban; based on assumed constant returns to scale of natural systems; and on regression analyses of sediment	CBA study evaluates manage options: (i) continuation of lo as usual; (ii) logging ban in B Bay drainage basin.

				loading, coral cover and species, and fish biomass relationships.	
Fisheries Valuation, Taka Bone Rate Coral Reef Atoll, Indonesia (Sawyer 1992)		★		Productivity Change: PV Gross Revenues (billion Rp): 2 to 103 without management vs 47 to 777 with management; based on fishing activity surveys; and sensitivity analyses wherein fish catch declines range 015% and discount rates vary 515%.	CBA study evaluates manage options: (i) no management; (establishment of marine park regulated fishing.
Fisheries Valuation, Indonesia Coral Reefs (Cesar 1996)		★		Productivity Change: NPV of fisheries loss/sq km of reef: $40,000 (poison fishing); $86,000 (blast fishing); $94,000 (coral mining); $81 (sedimentation); $109 (overfishing); based on assumptions about the reef and fishery impacts of these practices.	Study uses CBA to compare t private and social net benefits sustainably managed reef fish with those of a fishery subjec detrimental fishing practices, mining, or sedimentation.
Fisheries Valuation, Philippines (McAllister 1988)		★		Productivity Change: $80 million/yr in lost fish production caused by dynamiting, muro−ami, and poisoning of coral reefs; based on estimates of current and potential production.	Production levels are calculat varying levels reef damage.
Aquarium Trade, Philippines (McAllister 1988)	★			Productivity Change: Global aquarium trade attributable to the Philippine Coral Reefs: $10 million in 1988 could be increased by 50% with sustainable production practices.	The price of Philippine aquar species is discounted internat due to method of capture.

(table continued on next page)

Table A.1a. continued

Ecosystem and Original Study	*Approach* *Utility*	*Production*	*Rent*	*Valuation Results*	*Miscellaneous Notes includin Secondary Sources*
Productive Use Values, Galapagos National Park (de Groot 1992)	★	★		Productivity Change: $0.40/ha1 yr1 (permitted) ornamental product sales; $0.70/ha1 yr1 local fish and crustacean harvest; $5.20/ha1 yr1 construction materials value (terrestrial and coastal areas).	de Groot classifies ornamenta resources, food, and construc materials as having productiv value within the "production function" category of environ functions.
Wetland Valuation, Florida (Bell 1989)		★		Productivity Change: Marginal productivity of commercial marine species: $88/ha1 yr1 ; based on a wetland production function describing wetland/fisheries productivity linkage; and market prices of commercial species.	As reported in Barton (1994a
Direct Use Values for Marine Areas Recreation & Tourism					

Recreation Value Great Barrier Reef (Driml 1999)		★		Productivity Change: Gross Recreation Value A$769 (1996), includes A$647 for commercial tourism and A$123 for recreational fishing & boating; based on volume & price data for hotel stays & reef trips, and survey data for private recreational boat use.	Study updates Drimi (1994) estimates presented in Driml and Driml *et al.* (1997).
Visits to Great Barrier Reef "Region" (Hundloe *et al.* 1987)	★			TCM: A$144 million/yr consumer surplus for domestic tourists and international tourists; based on travel cost expenditure by visitors to the "Reef Region."	As reported in Hundloe (1990
Visits to Coral Sites and the "Reef Region" of the Great Barrier Reef (Hundloe *et al.* 1987)	★			TCM: A$106 million/yr consumer surplus; based on travel costs to coral sites by both domestic and international tourists, and includes all attributes of the "Reef Region."	As reported in Hundloe (1990
Visits to Coral Sites within the Great Barrier Reef (Hundloe *et al.* 1987)	★			CVM: A$6 million/yr consumer surplus or over A$8/adult visitor WTP to see coral sites in their present (198687) condition; based on a survey of visitors to reef sites only, thereby excluding all other attributes of the Great Barrier Reef "Reef Region."	As reported in Hundloe (1990 Driml *et al.* (1997).
Coral Reef Value and Its Impact on Tourist Volume Negril, Jamaica (Wright 1995)	★			CVM: $31/person1 yr1 WTP, for a consumer surplus of $5 million/yr by visitors to maintain coral reef in current condition; and $49/person1 yr1 for a surplus of $8 million/yr to restore reefs to "excellent" condition; based on CVM survey data and 162,000 visitors/yr.	Also, TCM was used to estim demand curve for vacations; t coral reef consumer surplus v netted out of vacation consum surplus to examine the resulta shift in demand and reduction tourist volume if reef quality decline.

(table continued on next page)

Table A.1a. continued

Ecosystem and Original Study	*Approach* *Utility*	*Production*	*Rent*	*Valuation Results*	*Miscellaneous Notes includin Secondary Sources*
Dive Value, Bonaire Marine Park (Dixon *et al.* 1993)	★	★		CVM: $27.40 average WTP for a consumer surplus of $325,000; based on 18,700 divers in 1992 paying a $10/diver1 yr1 fee. Productivity Change: Gross tourist revenue of $23.2 million (1991).	The study also estimated the revenues and costs of dive tou and the carrying capacity of d sites (40006000/site1 yr1 , fo of 190,000200,000).

Ecosystem and Original Study	Utility	Production	Rent	Valuation Results	Miscellaneous Notes includin Secondary Sources
Dive Value Bonaire Marine Park (Pendleton 1995)	★	★		Productivity Change: Net Tourism Revenue $7.9 to $8.8 million (1991); based on ownership & profit data. TCM: $19.2 million consumer surplus. Park NPV: $74.21 million local benefits; $179.7 million consumer surplus; based on 20 yr period, 10% discount rate.	The study compares its net va estimate to the gross value es of Dixon *et al.* (1993). It argu a "project appraisal approach protection valuation.
John Pennekamp/Key Largo, Florida (Leeworthy 1991)	★			TCM: $285 to $426/person1 day1 consumer surplus; based on a survey of some 350 park users in 1990; nine models were estimated; final estimate range taken from the two models which best fit the data.	The inclusion of an "opportur cost of time" variable was fou increase significantly consum surplus estimates.
Tourism Palawan Coral Reef, Philippines (Hodgson & Dixon 1988)	★			Productivity Change: PV gross revenue $6,280 with logging vs $13,334 with logging ban; based on mean hotel capacity, occupancy, and daily rates; and an assumed 10% annual decline in tourism revenue due to degradation of seawater quality from sedimentation.	CBA study evaluates manage options: (i) continuation of lo as usual; (ii) logging ban in B Bay drainage basin.
Tourism Valuation, Indonesia Coral Reefs (Cesar 1996)		★		Productivity Change: NPV of tourism loss/sq km of reef $3000436,000 (from poison fishing); $3000482,000 (blast fishing or coral mining); $192,000 (sedimentation); based on assumptions regarding the rate of reef degradation associated with each practice.	CBAs for each reef−destroyin activity estimate the value of tourism loss. For each activity degradation causes a decrease potential tourism revenue. Al of change are based on assum
Recreation, Galapagos National Park (de Groot 1992)	★			Productivity Change: $45/ha1 yr1 for the total protected area; based on maximum carrying capacity of 40,000 visitors/yr, and average expenditures per visit of $1300.	Classified as a productive use within the "carrier function" category of environmental functions.
Vacation Value, Galapagos National Park, Ecuador (Edwards 1991)	★			Hedonic Demand Analysis: $312/day1 person1 in 1986; based on a nonlinear regression using cost, duration, and itinerary data from travel brochures, as well as cost and duration survey data.	Value of a Galapagos vacatio regressed on duration, accommodation, and itinerary model is differentiated with re to duration to get the implicit of a vacation day.

(table continued on next page)

Table A.1a. continued

Ecosystem and Original Study	*Approach* *Utility*	*Production*	*Rent*	*Valuation Results*	*Miscellaneous Notes includin Secondary Sources*
Education & Research	**Marine Areas**				

Belize Coral Reefs (Spurgeon 1992)	★	$150,000/yr; based on annual expenditures by UK Coral Cay Conservation to maintain 25 researchers on reefs in Belize.	
Panama Coral Reefs (Spurgeon 1992)	★	$2.5 million in 1991; based on a percentage of the Smithsonian Research Institute's budget for work in Panama.	One−sixth of the 1991 $15 m budget is considered attributa coral reefs in Panama.
Galapagos National Park (de Groot 1992)	★	$2.73/ha1 yr1 ; based on research expenditures, and expenditures on field courses, fellowships, training courses, education facilities and materials.	Classified as a productive use within the "information funct category of environmental functions.
Indirect Uses Ecological Functions			
Coastal Protection Philippine Coral Reefs (McAllister 1991b)	★	Replacement Costs: US$22 billion; based on construction costs of concrete tetrapod breakwaters to replace 22,000km2 of reef protection.	As reported in Spurgeon (199
Coastal Protection, Indonesia Coral Reefs (Cesar 1996)	★	Productivity Change: NPV of coastal protection/km2 of reef: $9000193,000 (blast fishing); $12,000260,000 (coral mining); based on replacement costs, the rate of reef destruction from each activity, and the rate of decline in reef's ability to protect.	CBAs for each reef−destroyin activity include the cost of protective function losses. Fo activity, reef destruction redu protective capability of the re reef's loss of protective capab linked linearly to its protectiv value.
Organic Waste Treatment, Galapagos National Park (de Groot 1992)	★	Replacement Costs: $58/ha1 yr1 based on the costs of artificial purification technology; applies to marine area only.	Classified as a conservation v the Park, in the category of "regulation functions."
Biodiversity Maintenance, Galapagos National Park (de Groot 1992)	★	Shadow Price: $4.9/ha1 yr1 which equals 10% of the market value of any activity reliant on biodiversity maintenance.	Classified as a conservation v the Park, in the category of "regulation functions."
Nature Protection, Galapagos National Park (de Groot 1992)	★	$0.55/ha1 yr1 nature protection; based on the park budget and the idea that money invested in conservation management should be seen as productive capital because of the environmental functions and socio−economic benefits provided by conservation.	Classified as a conservation v the Park, in the category of "c functions."

(table continued on next page)

Table A.1a. continued

Ecosystem and Original Study	*Approach:* Utility	Production	Rent	*Valuation Results*	*Miscellaneous Notes including Secondary Sources*
Habitat/Refugia Galapagos National Park (de Groot 1992)		★		Benefit Transfer: $7/ha1 yr1 ; based on the similarities of the Dutch Wadden Sea and Galapagos estuarine areas, it was assumed that 10% of fishery in Galapagos depends on the nursery function provided by inlets and mangrove lagoons.	Classified as a conservation va the Park, in the category of "regulation functions."
Nitrogen Retention & Recycling, Gotland, Sweden (Gren 1995)	★	★		$34/kg NPV for nitrogen abatement from wetland restoration; based on (i) $100/person1 yr1 WTP for improved water quality; (ii) a surface/ground water hydrological model; and (iii) the nitrogen absorptive capacity of wetlands.	As reported in Barbier *et al* . (
Natural Predator, Greater and Lesser Antilles (Narain and Fisher 1994)		★		Productivity Change: $670,000/% decline in Anolis Lizard population; based on value of lost output when the lizard is not there to feed on crop destroying insects.	As reported in Barbier *et al* . (
Watershed Protection, Cameroon (Ruitenbeek 1992)		★		Productivity Change NPV: $12/ha1 yr1 watershed protection value of fisheries; $2/ha1 yr1 , flood control; $1/ha1 yr1 , soil fertility maintenance; based on production losses resulting from Park deforestation, discount rate of 8%, and 513,800 "hectare−years".	Watershed protection benefits part of a social cost benefit an of protecting the Korup Natio Park. Values expressed in 198 constant terms.
VALUATION STUDIES ASSOCIATED WITH WORLD BANK RESEARCH COMMITTEE PROJECT					
Option & Existence Values (for Habitats)					
Non−use Value Montego Bay Coral Reefs (Spash *et al* . 1998)	★			CVM: Survey design specifically targeted to dealing with lexicographic preferences through probing of zero bids and analysis of zero bids using tobit estimation. Expected WTP for tourists ranged from $1.17 to $2.98 for 25% coral reef improvement; for locals range was $1.66 to $4.26. Upper values were for respondents perceiving strong moral duties and rights; lower were for no such duties/rights. Based on population characteristics, non−use NPV of Montego Bay reefs estimated to be US$19.6 million.	Summary available at: http://www.island.net/~hjr
Non−use Value Curaçao Coral Reefs (Spash *et al* . 1998)	★			CVM: Similar survey design as Montego Bay study, above. Expected WTP for tourists ranged from $0.26 to $5.82; for locals range was $0.19 to $4.05. Based on population characteristics,	Summary available at: http://www.island.net/~hjr

				non−use NPV of Curaçao reefs estimated to be US$4.5 million.	

(table continued on next page)

Table A.1a. continued

Ecosystem and Original Study	*Approach* *Utility*	*Production*	*Rent*	*Valuation Results*	*Miscellaneous Notes includin Secondary Sources*
Direct Use Values for Marine Areas—Harvested Products					
Artisanal Fisheries Valuation Montego Bay Coral Reefs (Gustavson 1998)		★	★	Productivity Change: Net Present Value US$1.31 million (1996); includes trap, net, hand line and spearfishing by local fishers. Cost of inputs is deducted from gross values to arrive at net values. Base case assumes shadow price of labor of 75% market rate; 100% market valuation leads to negative NPVs for fishing.	Full text available at: http://www.island.net/~hjr
Direct Use Values for Marine Areas Recreation & Tourism					
Recreation Value Montego Bay Coral Reefs (Gustavson 1998)		★	★	Productivity Change: Recreation NPV US$315 million (1996); includes tourist related accommodation, food & beverage, entertainment, transportation, retail and miscellaneous services. Cost of service provision is deducted from gross values to arrive at net values.	Full text available at: http://www.island.net/~hjr
Indirect Uses Ecological Functions					
Coastal Protection, Montego Bay Coral Reefs (Gustavson 1998)		★		Productivity Change: Net Present Value US$65 million (1996); based on land values at risk or vulnerable to coastal erosion along foreshore. Author notes this is upper value and is dependent on erosion incidence assumptions in absence of reef, which are highly speculative.	Full text available at: http://www.island.net/~hjr
Other Cost Effectiveness Analysis					
CEA of Interventions, Montego Bay (Ruitenbeek *et al.* 1999a)		★		Estimates of cost−effectiveness of 8 specific interventions, with impacts normalized to coral reef abundance using fuzzy logic model incorporating non−linear ecological and economic linkages. CEA approach uses continuous optimization of "intervention sets" and demonstrates non−transitivity of individual	Full text available at: http://www.island.net/~hjr

interventions. Indicates up to 20% coral reef abundance improvement possible at PV cost of US$153 million. Marginal costs rose from under $1 million/% to $29 million/% over a 42 hectare reef area.

Table A.1b. Pharmaceutical genetic resource valuation studies relevant to coral reef management

Ecosystem and Original Study	*Approach* Utility	Production	Rent	*Valuation Results*	*Miscellaneous Notes includir Secondary Sources*
Genetic Resources Terrestrial Systems					
Value of Plants Used in Pharmaceutical Industry (Farnsworth and Soejarto 1985)		★		$203 million per successful species per year; based on 1980 US gross drug sales; survey data showing that 25% of all prescriptions contain one or more active plant−based agents; and 40 plants account for those active agents.	Extended by Aylward (1993) million per untested species p based original study's stated s rate of 1:125.
Value of Plants Used in Pharmaceutical Industry (Principe 1989ab)	★	★		$1.5 trillion/yr total value of plant−based drugs (US & OECD); based on value of a statistical life ($8 million, 1983$); percentage of lives saved by anticancer drugs (15%); and percentage of drug−based anticancer drugs (40%).	Extended by Aylward (1993) billion per per successful spe per year given 40 plants respo for all plant−based drugs; $18 million per untested species p based on original study's state success rate of 1:2000.
Value of Research Discovery in Korup Park, Cameroon (Ruitenbeek 1989)			★	$7500 annual expected value of genetic discoveries to Cameroon; based on average patent values; 10 patentable discoveries per year; and host country's ability to capture 10% of the rent from the discoveries.	Extended by Aylward (1993) per untested species per year assuming 500 species inhabit Korup forest area and a succe of 10:500.
Value of Tree Species Used in Pharmaceutical Industry (McAllister 1991a)		★		$250,000/yr gross value of a tree−derived pharmaceutical; based on global sales of plant−based drugs, and percentage of tree species likely to contain marketable pharmaceuticals (3%).	Extended by Aylward (1993) $7500 per untested species pe (1990$) based on original stu stated success rate of 3:100.
Value of Research Discovery in Costa Rica (Harvard Business School 1992)		★	★	$253,000 expected NPV per research discovery; based on net drug sales, and a 5% royalty on revenue to host country (Costa Rica).	Extended by Aylward (1993) Annual Value $253 per untes species based on original stud stated success rate of 1:10,00 [sic.] {The correct calculation would show NPV $25.30 per untested species.}
Value of Plants and	★	★	★	$390 million per successful plant species per	Extended by Aylward (1993)

Land to the Pharmaceutical Industry, Rainforest Flora (Pearce and Puroshothaman 1992ab)				year based on 1990 US gross drug sales; $7 billion/yr based on the value of lives saved ($4 million per life). Rainforest values: $0.01$21/ha for success rates 1:1000 and 1:10,000; a 5% royalty; and 10% rent capture by host country.	Annual global value per unte species: $819 using drug sale million using value of lives s Based on original study's 5% royalty and 10% rent capture success rates 1:10,000 and 1: and, a 4.2 multipler toconvert estimate to global estimate.

(table continued on next page)

Table A.1b. continued

Ecosystem and Original Study	*Approach* Utility	Production	Rent	Valuation Results	Miscellaneous Notes includin Secondary Sources
Value of Biotic Samples (Reid *et al.* 1993b)			★	$52,500 NPV of agreement to supply 1 000 biotic samples; based on 3% royalty, 5% discount rate, $10 million annual net sales after 10 yrs development, 15 yrs patent protection, and cumulative success rate of 1:40,000.	Extended by Aylward (1993) $52.50 per untested species. I on "sample to lead" success r 1:10,000. [sic.] {The correct calculation would show NPV per untested species.}
Net Private and Social Returns to Biotic Samples and Biodiversity Protection in Costa Rica (Aylward 1993)		★		Net return per biotic sample: $21.23 (private) to $33.91 (social); based on NPV of a new drug source. Social cost model includes costs of biodiversity protection and publicly provided taxonomic information. Success rate is 1:10,000.	Estimates PV of net returns generated by a protected area containing 10,000 species; al species are submitted to a sin screening program and there success in the first year.
Net Private and Social Returns to Biotic Samples Costa Rica (Aylward 1993)			★	Total Net return on 10,000 biotic samples: $.98 million (social) to $4.91 million (private); based on net revenue to a new drug source; 2% royalty, private and social costs as in above model. Success rate is 1:10,000.	Above model is modified to calculated the PV of net roya returns on a collection of 10,0 species.
Net Private and Social Returns to Biotic Samples under Various Distributional Arrangements (Aylward 1993; Barbier and Aylward 1996)			★	Net Returns: $5 million (private); $240 million (social); based on throughput of 2000 samples per year, protection for 500,000 species over 600,000 ha, $233 per sample royalty, $213 per sample in collection and classification fees, 40 prospecting years, and 10% discount rate.	Models the investment choice faced by a developing countr Choices pertain to investmen pharmaceutical prospecting: (biodiversity protection; or, (i capacity expansion to produc species information.
Value of Plants and Land to Pharmaceutical Industry (Mendelsohn and Balick 1995, 1997)		★		IF all potential drugs are discovered: $449 million NPV per successful species for a total $147 billion NPV or $48/ha tropical forest; based NPV of a new drug source, and 328	Extended by Artuso (1997): $ million per tropical forest pla species given 125,000 plant s

				plant−based drugs yet to be discovered and developed.	
Value of the Marginal Plant Species to the Pharmaceutical Industry (Simpson *et al.* 1996)		★		Value of marginal species: $9,000 based on 250,000 species to test, success rate of 1:83,333 and revenue to cost ratio of 1.5. Sensitivity analysis: A success rate less than 1:12,500 reduces value to zero; revenue/cost ratio of 1.10 reduces value to $2.20.	Models the private pharmaceu value of the in situ "marginal species", which is valued on t basis of its incremental contri to the probability of making a commercial discovery.
Value of Marginal Threatened Habitat to the Pharmaceutical Industry (Simpson *et al.* 1996)		★		Maximum private value for endangered habitat: Estimates range from a low of $0.20/ha (California Floristic province) to high of $20.63/ha in Western Ecuador (where there is high concentration of endemic plants).	Uses theory of island biogeog marginal species value results (above), and data from Myer' (1988) 18 biodiversity "hot sp

(table continued on next page)

Table A.1b. continued

Ecosystem and Original Study	*Approach* Utility	Production	Rent	Valuation Results	Miscellaneous Notes includin Secondary Sources
Social Value of Marginal Species (Simpson and Craft 1996)		★		Value of marginal species to consumers: $33,000; value of loss of 25% of all world's species: $111 billion; based on the existence of 10 million species available for screening, and global pharmaceutical sales and cost estimates.	Uses a model of product differentiation which accounts consumer surplus.
Social Value of Marginal Threatened Habitat to the Pharmaceutical Industry (Simpson and Craft 1996)		★		Value of marginal ha: Estimates range from a low of $29/ha (California Floristic province) to high of $2,888/ha in Western Ecuador.	Uses theory of island biogeog marginal species value results (above), and data from Myer's (1988) 18 biodiversity "hot sp
Value of Marginal Species when Research Intensity is Optimal (Simpson and Sedjo 1996b)			★	Value of marginal species when there exist 250,000 species: $2600; when there exist 1 million species: $0.0. Calculations based on 500 therapeutic objectives, $125 million per new product; 5 year testing period and a 4% discount rate.	For each period the model maximizes the value of the co by choosing the optimal colle size, given the number of spec remaining to be tested and the variable costs of testing.
Net Private and Social Value of Biotic Extracts (Artuso 1997)		★	★	NPV per biotic extract before taxes: $487 (private) to $7671 (social); based on NPV of new drug sources, and success rates which vary with different stages of the R&D process. The	Model treats R&D as a series phases, each with specific rev costs, and success rates.

		cumulative success rate of the process is 1:111,111.	
VALUATION STUDIES ASSOCIATED WITH WORLD BANK RESEARCH COMMITTEE PROJECT			
Genetic Resources Marine Systems			
Value of Pharmaceuticals from Coral Reefs (Ruitenbeek and Cartier 1999)	★	Value of Montego Bay coral reef based on model incorporating drug values, local bioprospecting costs, institutional costs, discovery success rates for marine extracts, and a hypothetical bioprospecting program for the area using National Cancer Institute sampling protocols. Model highlights role of revenue sharing arrangements and ecosystem yield in deriving total benefits and marginal benefits. Average Net Social Value of species in base case is estimated to be $7775. Based on base case sampling program, total social NPV of Montego Bay reef area is US$70.09 million. First differential of the benefit function yields US$225,000/% or US$530,000/ha coral abundance.	Authors note sensitivity of res assumptions in ecosystem yiel species−area (SA) relationship which relied on SA estimates Reaka−Kudla (1997) for globa ecosystems. In base case S=cA z=0.265. Within potential rang z=0.2 to z=0.3, NPV shifts fro million to $54 million and ma benefit shifts from $72,500/ha $698,000/ha. Summary available at: http://www.island.net/~hjr

in which leads to a change in reef productivity. The productivity change is measured in terms of output levels. These approaches rely on ecological quantitative analysis and ecological economic linkages.

The harvested products category includes a valuation of coral reef aquarium fish production. The estimate represents the gross financial value of the trade, and includes an estimate of the potential change in value with improved production practices. For its methodological interest, we also include a study of harvested products in a wetland habitat. It uses a relatively complex ecological economic linkage model which treats habitat area as a variable input to fisheries production.

Three types of weakness are often evident in these types of valuations. First, and most serious, is that fisheries value is usually assumed to be its gross revenue, thus ignoring the opportunity cost of capital and labor in fishing effort. Such gross value estimates for fisheries overstate the net benefits from such activities and often make it politically difficult to find other economically benign and sustainable uses of a reef area. Second, the dynamics of the coral reef and surrounding natural systems are often simplified, if not ignored. Perrings and Walker (1995) argue that the dynamics of natural systems are characteristically highly non−linear, discontinuous, and sometimes irreversible around a range of critical thresholds. Third, a less obvious weakness of many of these approaches is that they usually base harvest rates on some level of extraction effort that is implicitly assumed to be value−maximizing. In the simplest cases, current (observed) extraction rates are assumed to occur in perpetuity, even though these may be either above the socially optimal rate (from the usual types of overfishing practices) or, more rarely, below the optimal rate (e.g., where there are barriers to entry). Some analysts are more careful about this aspect of extraction and base their assessments on maximum sustainable yield (MSY) to introduce some form of sustainability constraint (Cesar 1996). Even in such cases, however, it is important to note that MSY does not necessarily coincide with an economic optimum; standard fishery and bioeconomics texts (e.g., Clark 1976) teach us that it may be economically optimal to extract at rates either below or above the MSY depending on the attributes of the specific fishery. In cases where current harvest rates are used, it is likely that the methods overestimate value, while estimates based on MSY will likely underestimate economic value.

A recent study by Driml (1999) estimates the gross financial value for the commercial fishery of the Great Barrier Reef. Effort and catch data on selected major commercial fish species were obtained from the Queensland Fisheries Management Authority. Price data were obtained by a brief survey of the fish and prawn markets. Volume and price data yield an estimated gross financial value of A$143 million (1996 dollars).

The Hodgson and Dixon (1988) cost−benefit analysis (CBA) study estimates the gross revenue value of fisheries in Bacuit Bay, Palawan, with and without a logging scenario. It is the most complex of the coral reef valuations examined in that it first undertakes a quantitative analysis of the natural systems affecting fisheries. Using environmental data, linkage coefficients are estimated to determine: i) the relationships between sedimentation, coral cover and coral diversity; and, ii) the relationships between fish biomass, coral cover and coral diversity. The coefficients were obtained using linear regression analysis; this implicitly assumes constant returns to scale of the natural systems, a considerable simplification of the functioning of natural systems.

A CBA study by Sawyer (1992) estimates the gross revenue value of fish catch on Taka Bone Rate, an Indonesian coral reef. In the absence of empirical natural system linkage models for the area, sensitivity analyses are conducted on the base year value of the fish catch. By simply assuming different rates for fish catch productivity change, net present value (NPV) estimates are calculated.

For Indonesia, Cesar (1996) uses CBA to compare the potential productive value of coral reef fisheries to the value of those same fisheries in the presence of different threats to reef quality and productivity. Threats include poison fishing, blast fishing, overfishing, coral mining, and sedimentation. Each threat is analyzed in isolation from the others, and in terms of its net benefits on a per square kilometre basis. Therefore, a hypothetical reef area faces only one threat that provides a net private benefit to the individuals responsible for it, as well as societal losses due to the detrimental treatment of the reef.

Potential productivity of reef fisheries is that associated with an intact reef area and a level of effort that achieves the MSY of that area. Additional assumptions about fish prices, labor, and other input costs provide a *net* benefit valuation. The private net benefit of destructive fishing practices is based on threat−specific assumptions regarding prices, effort, yield, input costs, the rate of coral death, the rate of yield decline, and the rate of coral recovery, if any. Coral death and fishery yield are assumed to be linearly related. The societal loss to fisheries is the difference between the net private benefit of the destructive fishing practice and the net benefit associated with the MSY level of effort.break

In the cases of coral mining and sedimentation, there are only net losses to fisheries. Private benefits accrue in other sectors—construction and logging. Losses to reef fisheries from coral mining is the difference between the MSY of an intact reef and the yield of a gradually destroyed reef. It is, therefore, based on assumptions regarding the rate of coral destruction from mining and the associated yield decline. For the threat of sedimentation, the calculation of reef fisheries yield decline is based on the ecological linkage coefficient estimates of Hodgson and Dixon (1988).

In an often−cited study of the value of the Philippines coral reefs, McAllister (1988) calculates the change in fisheries productivity as a result of reef damage from dynamiting, poisoning, and muro−ami fishing. The valuation methodology is simply a comparison of current yields with potential yields. The productive area of the reef (some 33,000 km2 out of a total 44,000 km2) is disaggregated according to its condition—poor, fair, good, or excellent. The yield associated with each condition is calculated and the total yield for the productive area is compared with the potential yield were the entire reef in good condition.

McAllister (1988) also estimates foregone earnings in the production of marine aquarium fish. Sodium cyanide, which damages the reef and reduces the price of the final product (net caught tropical fish command a higher price), is typically used for gathering marine fish. Based on the reported value of the Philippines' trade in aquarium fish, the author estimates that a 50% increase in value could be realized if the aquarium fish were produced on a sustainable basis.

For the Galapagos National Park, de Groot (1992) estimates the gross financial value of legally traded ornamental goods, local fish and crustacean harvest, and the value of construction materials. Associated capital and labor costs are excluded from the calculations, as is any consideration of the functioning of the underlying natural systems providing these products.

For methodological interest, a wetland valuation study of marine harvested products is included in Table A.1a. Bell (1989) takes a marginal valuation approach to fisheries in a Florida wetland. The incremental value of a hectare of wetland habitat is assumed to be equal to the marginal productivity of the wetland−dependant fisheries. The study estimates a non−linear bioeconomic production function for fisheries. The approach is similar to those described above for coral reef fisheries, although the specification of the production function is more complex. The area of the wetland habitat input is variable, whereas in the coral reef studies, the area of the coral reef habitat input is fixed. In the coral reef studies, the valuations, therefore, pertain to the total reef area as the input, not increments thereof.

Literature Relating to Recreation and Tourism Valuation

The recreation and tourism direct use value attributable to a coral reef is usually estimated by accounting for the tourism revenue generated by a particular coral reef holiday destination. From a utility perspective, these values ignore the consumer surplus generated by the recreation experience and, as a result, underestimate the value of the recreation experience. From a production perspective, gross tourism revenue—the figure most often calculated—ignores the labor and capital costs of supplying the services, as well as the costs associated with the environmental impacts of tourism.

Another problem with using tourism revenue relates to the bundling of a vacation destination's attributes. When a coral reef is just one attribute of the bundle, tourism revenue cannot be solely attributable to the reef. The more important the reef attribute in the vacation experience bundle, the higher the proportion or tourist revenue that can be attributable to the reef. In any case, the basic problems of using gross revenue and ignoring associated costs persist.

In Table A.1a, most of the studies focusing on coral reef recreation and tourism estimate consumer surplus using a travel cost method (TCM) or a CVM; however, three studies—Driml (1999) for the Great Barrier Reef, Cesar (1996) for Indonesia, and Hodgson and Dixon (1988) for Bacuit Bay—take the gross revenue approach. The study of Negril, Jamaica, by Wright (1995) combines the CVM and the TCM. Two studies valuing recreation in the Galapagos are included for comparison with each other—one uses a gross revenue approach, while the other employs hedonic demand analysis.

Australia's Great Barrier Reef (GBR) is probably the most studied reef in the world. Since 1975, several economic studies of the GBR have been conducted, most commissioned by the Great Barrier Reef Marine Park Authority (Driml *et al* . 1997). Table A.1a includes the most recent estimate of the GBR's gross financial value (Driml 1999), as well as consumer surplus estimates for recreational fishing, visits to the "reef region", and visits to coral sites within this region (Hundloe *et al* . 1987).

Driml (1999) estimates the gross financial value of tourism to the GBR for the 199596 period. It is an update of an earlier estimate by the same author. The calculationcontinue

focuses on commercial tourism (reef trips, accommodation, resort packages) and recreational fishing and boating. Data pertaining to the volume and price of reef visits, total visitor nights at island resorts and elsewhere, and an estimate of average daily tourist expenditure yields a value of A$647 million (1996 dollars) for commercial tourism. The value of recreational fishing and boating was estimated using earlier survey work by Blamey and Hundloe (1993) and current records of registered private boats adjacent to the park. Survey data showed that 63% of registered private boats are used for recreational fishing; the data also provided an estimate of average yearly expenditure on recreational fishing and boating. With these data, Driml (1999) calculates recreational fishing and boating in the GBR to be worth A$123 million (1996 dollars).

Hundloe *et al* . (1987) first uses the TCM to estimate the consumer surplus for both domestic and international tourists to the reef region. The reef region comprises all the islands and reefs within the outer boundaries of the Great Barrier Reef region. The study then isolates the consumer surplus associated with visits to coral sites. Coral sites are areas within the region where coral can be viewed. For this, travel cost data was collected from visitors who had visited or planned to visit coral sites as part of their visit.

The consumer surplus associated with visits to the region is calculated to be A$144 million/yr; the surplus associated with visits to coral sites within the region is A$106 million/yr. However, the researchers felt that the latter estimate still included all the attributes of the reef region valued by those who had come to view coral as part of their vacation package. To calculate the consumer surplus of only the coral sites, with all other attributes of the region removed, a CVM study was conducted that focused only on tourists visiting the reef sites. The resultant consumer surplus was estimated to be A$6 million/yr; this might be regarded as a lower bound of the direct recreational value of the reef.

In another example of isolating the coral reef attribute of a vacation site, a study of Negril, Jamaica, estimates the consumer surplus of Negril as a vacation destination, as well as that part of the surplus attributable solely to the coral reef attribute of the vacation experience. Wright (1995) begins by conducting a CVM survey to determine the value of coral reef quality to vacationers. The study then uses the TCM to estimate a demand curve and the related consumer surplus for a Negril vacation experience. Assuming a parallel shift (downward) of the demand curve, the study then nets out the consumer surplus associated with maintaining coral reef quality in its current condition. From the shift, and further assuming a fixed average cost of supply, the decrease in tourism volume as a result of coral degradation is calculated. The value of the change in tourism revenue is then used as input into a CBA.

Various ecological and economic analyses have been conducted for Bonaire, Netherlands Antilles. Dixon *et al* . (1993) calculates gross revenues from tourism, the carrying capacity of coral sites, and the consumer surplus associated with diving in the Bonaire Marine Park. Arguing that quality diving is the primary attribute of Bonaire, the researchers calculate gross revenues from dive−based tourism of US$23.2 million. Capital and labor costs associated with providing tourism services are not included in the estimate. Dixon *et al* . (1993) also conduct a CVM survey of divers and calculate a consumer surplus of US$325,000 for divers in 1992.

Also for dive−based tourism in the Bonaire Marine Park, Pendleton (1995) estimates *net* revenue and consumer surplus for 1991. Net revenue is calculated using net revenue and local ownership data (obtained from Bonaire's Department of Revenue and its Tourism Corporation). Consumer surplus is calculated using the TCM. The travel demand function uses marine park permit data (which provides tourist origin data) and surveys of vacationers. Net revenue ranges from US$7.9 to US$8.8 million/yr; estimated consumer surplus is US$19 million/yr.

Arguing for a project appraisal approach for the valuation of resource protection, Pendleton (1995) also estimates the NPV of the Bonaire Marine Park to the local economy and to tourists. For the NPV calculation, it is assumed that the park is just being established. Capital and operating cost estimates are taken from Dixon *et al* . (1993); net benefits (revenue and consumer surplus) are the Pendleton (1995) estimates. Over a 20 year period, at a 10% discount rate, the NPV of the park to the local economy is US$74.21 million and the NPV of consumer surplus enjoyed by tourists is US$179.66 million.

Using the TCM, Leeworthy (1991) estimates consumer surplus for the John Pennekamp Coral Reef State Park. Survey data obtained from over 300 people includes the number of trips taken to the park in the past year, round trip mileage, travel time, activities undertaken at the park, and various socioeconomic data. Nine model specifications using linear and semi−log functional forms are estimated. Consumer surplus estimates derived from the semi−log forms are rejected on the basis that the magnitudes were out of range of previous studies. The results of two linear models are accepted based on data fit and respective consumer surplus estimates. The two models differ only in that one included the opportunity cost of time; it is found that inclusion of this variable significantly increased consumer surplus estimates in all the model specifications.break

The Hodgson and Dixon (1988) CBA of logging in Bacuit Bay, Palawan, includes a benefit calculation for tourism. The productivity change and gross revenue approach uses hotel capacity, occupancy, and rate data to calculate base year tourism revenue. In the logging scenario, which involves coral reef degradation, dive−based tourism revenue is reduced by 10%/yr to a level of zero about half way through the forecast period. The present value of tourism revenue is assumed as solely attributable to the condition of the coral reef and is then calculated for inclusion in the CBA.

For Indonesia, Cesar (1996) uses CBA to compare the potential productive value of reef−based tourism to its value in the presence of poison fishing, blast fishing, and coral mining. CBAs are conducted for each threat, in isolation from the other threats. The potential tourism value of a hypothetical reef area is estimated as a range, the bottom of which represents a low potential tourism scenario and the top of which represents a high potential tourism scenario. The low potential value is an average of the net revenue generated in an area of no tourism and that generated in an area of moderate tourism. The high potential value is an average of the net revenue generated in an area of moderate tourism and that generated in an area of major tourism. A case study of tourism in Lombok provides an estimate of net revenue in an area of major tourism potential; data gathered in Ambon provide an estimate of net revenue in an area of moderate tourism potential. The net benefit estimates are on a per square kilometre of reef basis and represent a 25 yr period discounted at 10%.

The societal losses in tourism productivity are based on threat−specific assumptions regarding the percentage and type (low or high tourism potential) of reef area affected. The valuation also incorporates assumptions of rates of tourism declines, from its potential level, in response to reef degradation. In general, tourism declines sharply after poisoning, blasting, or mining begins. The cost to tourism of sedimentation and pollution is based on cost estimates of the abatement measures that would be required to address the problem.

Two recreation valuation studies of the Galapagos National Park are interesting in terms of their different approaches, the impacts of their assumptions, and the resultant valuations. de Groot (1992) calculates gross revenues to estimate the value of tourism; Edwards (1991) also calculates gross tourism revenues but does so via a hedonic demand analysis. Both estimates were done around the same time period—1987.

The de Groot study estimates the price of a Galapagos vacation by adding up average transportation, and park and non−park expenses. Doing so, he arrives at US$1,300 per visitor for a Galapagos vacation experience. The analysis then assumes 40,000 tourists per year to arrive at a gross tourist revenue of US$52 million/yr. For comparison with other park values, recreation value is then put on a per hectare basis using both the marine and terrestrial area of the park.

Edwards (1991) takes a far more complicated approach to the estimation primarily because, for tax policy analysis, a vacation demand curve is needed. Edwards decided that the heterogeneity of the packages (in terms of cost and travel itineraries) precluded the use of the standard regression analysis using time series or travel cost data. Therefore, a two−stage modeling exercise is used to estimate both implicit prices and a demand curve.[3] The average implicit price of a Galapagos vacation day turns out to be US$312, which means, according to the estimated demand curve, that 7.3 vacation days will be demanded. Given these two figures, the average price of a vacation in the Galapagos is US$2,278 per visitor; including a minor tax brings the total price to US$2,318 per visit.

Although the price per visitor in the Edwards (1991) study is almost twice that used by de Groot (1992), gross tourist revenue calculated by Edwards is only US$39 million/yr compared to de Groot's US$52 million/yr. The difference stems from the level of tourist volume used in each calculation. de Groot assumes that the maximum carrying capacity of the islands is 40,000 visitors per year, which also equals tourist volume. However, in the Edwards study, tourist volume is determined by the estimated demand curve, which provides the number of vacation days demanded at any given price, and the 1986 park limit of 125,000 visitor days per year. At the average (implicit) price of US$312, 7.3 days are demanded and the 125,000 visitor days per year limit therefore implies 17,123 tourists.

Literature Relating to Education and Research Values

Gross financial expenditures are typically used to estimate the education and research value of coral reef habitats. The expenditures include food, lodging, and fees for researchers and educators; boats and diving gear; and research and education facilities and equipment. Multiplier effects associated with these initiatives are not estimated. The valuation of economic benefits associated with information generated by the research has not yet been attempted.break

An inherent weakness of all of these studies, which base their methodologies on expenditure estimates, is that they simply provide a measure of direct economic impact and say little about the efficiency of such expenditures or of the optimal level of such expenditures. Their connection to economic benefits is somewhat specious, although they may to some degree be construed as some revealed willingness−to−pay for having access to a particular reef area of research interest.

Spurgeon (1992) places values on the education and research value of coral reefs in Panama and Belize. The estimates are based on coral reef budget allocations of research funding institutions in the United States and the United Kingdom. Costs associated with the research are excluded but, because the payment is coming from offshore, capital and labor are not being reallocated within Panama or Belize and the expenditure, therefore, represents a pure benefit to those countries. Environmental costs associated with using a reef as a research focus are usually considered to be minimal, unless the research involves significant extraction levels of reef organisms.

For the Galapagos, de Groot (1992) estimates separately expenditures on research and expenditures on education. In the calculation, it is not clear who finances these activities. To the extent that the Ecuadorian government provides money, the costs of supply should be deducted from gross expenditures. de Groot (1992) goes on to estimate the potential value of education and research by assuming that only half of the maximum sustainable use level of the islands is currently being utilized. The final value of education and research to the Galapagos is, therefore, double the level of current expenditures.

Literature Relating to Ecological Function Valuations

Ecological functions provided by coral reefs include: i) biological support to other ecosystems and organisms; ii) physical protection to terrestrial and other marine habitats; and, iii) global life support through calcium and, potentially, carbon storage. For Indonesia (Cesar 1996) and the Philippines (McAllister 1991b), values for coastal protection have been estimated. For the Galapagos, de Groot (1992) estimates the value of biological functions. The economic value of coral reefs for their carbon and calcium storage functions has not been attempted, although there exist volume estimates of their carbon and calcium storage capacities. Table A.1a includes valuation studies of ecological functions associated with other habitats—nutrient recycling function in wetlands, biological support for agriculture, and watershed protection by a rainforest.

McAllister (1991b) estimates the protection function value of coral reefs in the Philippines by calculating the costs of replacing the reefs with artificial devices to protect the coast. This type of calculation is considered to be minimum estimate of the protection value afforded by reef because: i) delayed response time could mean that terrestrial productivity is lost in the interim; and, ii) artificial devices will forever need maintenance. The estimate obtained by McAllister (1991b) is based on the per unit area cost of installing a certain type of barrier (concrete tetrapod devices) and multiplying that unit cost by the length of coastline fringed by coral reefs. The estimate does not allow for variations in the protective requirements along the coastline, given varying rates of coastal erosion and levels of economic activity.

For Indonesia, Cesar (1996) uses CBA to compare the potential value of the coastal protection function of a coral reef to its value as it succumbs to the impacts of blast fishing and coral mining. Replacement costs are used to estimate the potential value of the function. Calculated on a per square kilometre basis and discounted over a 25 year period, a range of values is estimated with low and high scenarios. The low scenario is an average of land value and replacement costs in, respectively, remote and moderately built−up areas. The high scenario is an average of replacement costs in moderately built−up areas and those in areas with major infrastructure. The CBAs treat blast fishing and coral mining separately; the hypothetical reef faces only one threat at a time. In each analysis, the value of the societal loss of the reef's protective function is the decline in the potential value of the protective function as the reef is destroyed. The yearly losses in protective function value are based on threat−specific assumptions regarding the rate of reef destruction, the point at which the level of destruction starts to impair the ability of the reef to provide coastline protection, and the ability of the reef to recover.

In the Galapagos, de Groot (1992) estimates values for a number of ecological functions. A fishery nursery function value of the Galapagos refugia is estimated using a benefit transfer approach. Based on similarities of the Dutch Wadden Sea and Galapagos estuarine areas, de Groot (1992) assumes that 10% of the Galapagos fisheries is dependant on the inlets and lagoons of the park. He also estimates the waste recycling function of the Galapagos marine area by calculating the cost of artificial purification technology. The valuation is based on an estimate of the total recycling capacity of the Galapagos sea shelf and the unit cost of recycling organic waste.continue

Finally, de Groot (1992) estimates values of two biological support functions—"biodiversity maintenance" and "nature protection". Arguing that biodiversity maintenance is a necessary precondition to other functions and human activities, de Groot (1992) assumes a shadow price of 10% of the value of any activity directly or indirectly dependant upon this function. Activities included all the productive uses, ranging from recreation to education and research. According to de Groot (1992), the nature protection function relates to the value to society associated with preserving natural areas of particular naturalness, diversity, and uniqueness. The budget of the Galapagos National Park Service is used to estimate the value of this particular function.

The remaining three studies illustrate the valuation of ecological functions in other habitats. Gren (1995) estimates the nitrogen retention and recycling function of wetlands in Gotland, Sweden. The approach is quite complex in comparison to those described above. It involved: i) a natural systems hydrological model; ii) an estimate of the absorptive capacity of wetlands; and, iii) a CVM analysis to determine the WTP for improved water quality by area residents. Narain and Fisher (1994) estimate the value of the biological support function of a lizard in the Caribbean's Greater and Lesser Antilles. The Anolis lizard feeds on insects that are detrimental to various export crops. Using a production change approach, the study estimates the change in agricultural output associated with a decline in the lizard population. In the final study surveyed, the value of the watershed protection function of the Korup, Cameroon, tropical rainforest is estimated by Ruitenbeek (1992). This function provides flood control and maintains soil fertility. Assuming a logging scenario, the study uses a change in productivity approach to value lost agricultural output associated with flooding and loss of soil fertility.

Genetic Resource Valuation Models in Agriculture—Some Lessons

Genetic resources are important for providing the scientific information necessary for the production of new and improved food sources, new pharmaceuticals, new chemicals, and new environmental protection strategies (e.g., micro−organisms to aid the degradation of toxic waste or to reduce agricultural chemical dependence). The economic value of genetic resources has been most studied in the agricultural sector where they enter the production process directly. Valuations attribute actual production changes in particular crops to the improvements brought about by the introduced genetic material. We review a number of these here for completeness, but note that while valuable lessons can be learned from such models, many of the specific empirical valuation techniques are less applicable at this time to coral reef valuation. Most marine genetic product potential is associated with information contained in the resources, rather than with the genetic material itself. This makes the pharmaceutical potential of marine products a more obvious bioprospecting target than the agricultural (or maricultural) potential.

Bioprospecting model development in the literature has tended to be isolated in two distinct areas—agriculture and pharmaceuticals. Both have similar foundations, consistent with the constructs and models of Evenson and Kislev (1976) who described a general model for valuing applied research. But distinct literatures have developed in agricultural and pharmaceutical modeling development. This has arisen because of different technical aspects of bioprospecting in these fields, as well as different policy concerns.

Technical Issues

The manner in which new genetic material enters the production process differs among industries. In agriculture, genetic material is used directly by transferring desirable genes identified in donor species to recipient species. The transfer is done using either traditional *hybridization* methods involving the sexual crossing of closely related species, or it is done using *biotechnology* techniques of modern genetic manipulation. These methods enable the development of crop varieties with improved yield, inbuilt microbial pesticides, particular environmental adaptation traits, nitrogen−fixing capabilities, disease resistance, and retarded spoilage rates.

By contrast, in the pharmaceutical industry, new genetic material is most often used indirectly; the biological material is not transferred from one species to another as in agriculture. Instead, the genetic information provided by the material is used to develop new products unrelated to the original source. Pharmaceutical companies screen life forms, or samples of life forms, in search of chemical compounds with particular biological activities—antiviral, antifungal, antileukemic, anticoagulant, etc. Once identified and if considered to have pharmaceutical potential, such a compound is usually then synthesized from its basic chemical constituents. Should it proceed successfully through the research and development (R&D) process, it then enters production for human use.

Bioprospecting values are, thus, also derived somewhat differently in agriculture and pharmaceuticals. Incontinue

both cases, the actual value associated with biodiversity is closely tied to the type of information provided, as opposed to any particular material good (Swanson 1996). In the case of pharmaceuticals, this information provides a stock of ideas that can be used to synthesize key compounds, often establishing new products and markets (WCMC 1994a). In the field of plant genetic resources, however, the information itself provides direct genetic information that can be introduced into other economic species or crops that already have a market (WCMC 1994b).

Policy Issues

Efforts in agricultural valuation have been driven by policy questions that address issues such as food security, farm incomes, and efficient research methods in a market where end products, such as food crops, are dominated by open competition (Evenson *et al.* 1998). Much of the research work in agricultural prospecting is funded through public institutions and international agencies. In agriculture, modeling has addressed distributional concerns related to the improvement of farm level incomes and the social benefits arising from incorporating traits in improved crop varieties (see Smale 1995, 1998; Smale *et al.* 1995). Also, it has often focused on the valuation of genetic traits and optimization of the search paths for finding economically useful traits within large samples (often maintained in *ex situ* collections; e.g., Gollin and Smale 1998). More recently, policy concerns have focused on genetically modified (GM) crops using transfers of genetic materials.4 Impacts of GM crops and biotechnology in developing countries pose a wide range of policy issues that extend from food security to property rights and institutional capacity (Zilberman *et al.* 1998).

By contrast, the pharmaceutical bioprospecting literature was, initially, dominated by policy concerns relating to the *in situ* conservation of wild genetic resources (e.g., "drugs from the rainforest"). The intensely private—and often seemingly monopolistic—nature of new drug patenting and development, coupled with long testing periods, has meant that institutional questions frequently dominate discussions relating to valuation. Most models remain relatively deterministic; only more recently have concerns such as optimal research paths entered the pharmaceutical bioprospecting literature (Artuso 1998). Moreover, the role of ecosystem and habitat conservation and their potential yields of "new" species add a dimension that is often absent from discussions in the agricultural bioprospecting literature.

In the case of marine systems, the issues are further complicated by ownership concerns and the perceived system yield of useful information. Management and ownership of marine and near−offshore resources is a problematic topic in most jurisdictions, and the entire discipline of integrated coastal zone management (ICZM) is targeting such problems through what are, by and large, institutional reforms and interventions.

Lessons

Numerous studies estimate the economic value of new genetic material to various agricultural crops (Prescott−Allen and Prescott−Allen 1988; WCMC 1992, 1994b). Table A.2 contains a selection of the earlier studies based on a review conducted by the World Conservation Monitoring Centre. Basically, these valuations involve examining the total change in yield and attributing the cause of the change between a technology component (e.g., fertilizer and pesticide use, tillage, machinery) and a genetic component. Most valuations are general in that value is attributed to the "genetic component". However, some valuations are more focused, attributing value to the specific trait transferred in the genetic material. All generally attribute substantial values to the crop improvements and, implicitly or explicitly, to the research and development activities that resulted in such improvements.

More recent work has further affirmed many of these values. Extensive investigations conducted through the International Maize and Wheat Improvement Center (CIMMYT) in Mexico have paid particular attention to economic issues associated with crop genetic resources; these are reported in a comprehensive edited volume by Smale (1998).5 Interestingly, in the preface to that volume, Timothy Reeves and Prabhu Pingali, as Directors of CIMMYT, emphasize the importance both of *ex situ* conservation of genetic resources, which they construe as gene banks, and of *in situ* conservation of genetic resources, which they define as "farmer's fields". This is a key attribute of cultivated agricultural resource; *in situ* resource conservation and stewardship is at a managed farm level and often deals with known traits. By contrast, pharmaceutical genetic resource conservation issues typically deal with wild resources, having unknown traits or characteristics. Agricultural models focusing on known traits have thus found limited applicability in the pharmaceutical valuation literature.

Nonetheless, there are a number of general lessons that can be gleaned from the agricultural bioprospecting modeling. Among the more important lessons are:

Search methods can influence values . Optimal search models consistently show that economic values can change significantly, depending on search methods (e.g.,continue

stages of search). Agricultural models typically try to introduce some methods relating to optimal search; such methods are typically lacking from pharmaceutical bioprospecting models.

Value is a function of complex interactions . Work on cost−effectiveness analysis within agricultural genetic prospecting (Pardey *et al.* 1998) illustrates that optimal search strategies influence concurrently both the costs and benefits of prospecting. It is thus not usually adequate to model costs or benefits in isolation of each other.

Distribution of values is an important policy concern . Much of the agricultural literature is concerned with "who gains" from genetic resource development and what sorts of institutional structures might be most effective and fair. Models that reflect such distributional elements will receive greater policy attention.

Geography is important . In contrast to the early work of Evenson and Kislev (1976), which focused on single trait optimal search models, more recent work by Evenson and Lemarié (1998) has modeled optimal search within a context of multiple traits and multiple potential target geographic locations, where individual site characteristics may have different distributions of traits available for search and may have different cost structures involved with the search. They observe that some sites may be particularly good targets for bioprospecting activities. Specifically, Evenson and Lemarié (1998, p.91) note: "When alternative (substitute) resources exist, collection costs can lead to shifts in sources by regions. If a small region is a relatively rich source for a particular trait, collection costs may be low, and marginal values may be high. It will always pay to collect from such a region when profits are maximized independently and will almost always pay to do so even when they are maximized jointly." From a modeling perspective, this implies one should pay attention to site−specific characteristics and, ideally, how these might relate to global conditions. For systems such as coral reefs, this insight is particularly applicable.break

Table A.2. Early survey of the value of genetic contributions in agriculture.

Crop	Locationa	*Production effect of genetic resources*	Study
Value to Cultivated Varieties			
Maize	USA 1985 to 1989	US$2.3 million/yr to North Dakota	Frohberg (1991)
Rice	Asia Green Revolution	US$1.5 billion/yr	Walgate (1990)
Wheat	Asia Green Revolution	US$2.0 billion/yr	Walgate (1990)
Barley	USA 1930 to 1980	50% of doubled yield increase	OTA (1987)
Sorghum	USA 1950 to 1980	1% to 2% yield increase	Miller and Kebede (1984)
Pearl millet	India 1992	US$200 million/yr	ICRISAT (1990)
Potato	USA 1930 to 1980	50% of a four−fold yield increase	OTA (1987)

Soybeans	USA 1902 to 1977	79% of 23.7 kg ha1 yr1 yield increase	Specht and Williams (1984)
Tomato	USA 1930 to 1980	50% of a three−fold yield increase	OTA (1987)
Value of Specific Genetic Traits Transferred to Cultivated Varieties			
Wheat	Turkey	Disease resistance: US$50 million/yr	Witt (1985)
Barley	Ethiopia	Protection from Yellow Dwarf Virus: US$160/yr to California	Witt (1985)
Hops		Reduced bitterness in beer: US$15 million/yr to British brewing industry	Witt (1985)
Beans	Mexico	Protection from bean weevil: 25% of stored beans in Africa; 15% in South America	Rhoades (1991)
Grapes	Texas	New root stock: revitalized European wine industry after decimation by louse infection	Rhoades (1991)

a In the case of the transfer of genetic traits, location refers to that of donor species.

Source: World Conservation Monitoring Centre (1992).

Genetic Resource Valuation Models in Pharmaceuticals—A Review

Most modeling efforts to value genetic resources for pharmaceutical use have taken a change in production approach. The value of preserving a species for pharmaceutical use is based on the potential value of an unknown or untested species in the production of a new drug. It is clear from the wide range of models that: i) they often attempt to address somewhat different policy problems; and, ii) they attempt, in various ways, to show how selected issues or exogenous factors can influence "values".

The early models use *gross* revenues of all plant−based drugs to impute a value for individual plant species responsible for those drugs. More recent models estimate the *net* revenues from hypothetical new drugs; these make an assumption regarding the number of species or biotic samples required to find a new drug source, and thereby calculate an average value for those species. Another modeling approach is to calculate the marginal value of a species. In this case, net revenues are used to calculate the change in the value of a collection of species when one more species is added.

Some modeling efforts have used a royalty approach to value genetic resources. In one, an assumed royalty is applied to the average patent value of a new drug (Ruitenbeek 1989). In two other models, an assumed royalty is applied to an estimate of net new plant−based drug revenues (Harvard Business School 1992; Reid *et al.* 1993b).

Table A.1b summarizes the approaches and results of genetic resource valuation studies. Below, the frequently cited early and recent studies are discussed in greater detail. Most of the studies take a change in production approach or explicitly attempt to value rents; Aylward (1993) also estimates a royalty−based model.

It should come as little surprise that many of the model results are exceedingly sensitive to key economic or biophysical assumptions; many models that generate positive values in a base case scenario return negative, or significantly smaller, values when tested under different, yet still plausible, sets of assumptions. For example, a great deal of attention is often paid to what are loosely called "hit rates", or the basic probability of success in developing a commercial drug from some randomly sampled species, natural product, or extract. While it is often assumed that such hit rates are exogenously determined, akin to rolling a many−sided die, they are in fact themselves an endogenously determined variable within pharmaceutical screening processes (Box A.2). Such complexities further complicate numerical analyses in an area often complicated by secrecy agreements or other data gathering constraints.

Early Models of Gross Economic Benefits

Farnsworth and Soejarto (1985); Pearce and Puroshothaman (1992ab); Principe (1989ab)

The first group of studies to estimate the economic value of genetic resources to the pharmaceutical industry employed three types of data: total drug sales, an estimate of the number of plant−based drug sales as a percentage of total drug sales, and the number of plant species responsible for the plant−based drugs (Farnsworth and Soejarto 1985; Principe 1989ab). Modifications to these valuations involved the addition of estimates of the value of lives saved through the use of plant−based drugs (Pearce and Puroshothaman 1992ab; Principe 1989ab). These studies produced gross values attributable to the 40 "successful" plants that were responsible for all the plant−based drugs in the pharmaceutical industry.6 A typical calculation is as follows:

$$VPD = (rp \times S \times P_{avg}) / 40$$

where *VPD* = total value of plant−based drugs;

rp = percent of prescriptions containing one or more ingredients derived from plants;

S = total value of prescription drugs; and,

P avg = average price of a prescription.

Using this approach, Farnsworth and Soejarto (1985) estimate that each of the 40 plant species used to derive the plant−based drugs is worth US$203 million to the United States. Principe (1989ab) extends the calculation to include drug sales in the OECD and the value of lives saved from plant−based cancer drugs. From Principe's work, the 40 plant species are potentially worth US$37.5 billion each.

Pearce and Puroshothaman (1992ab) modify and update the Principe (1989ab) data to calculate the average value of the 40 plant species responsible for the bulk of plant−based drugs to be US$390 million per plant, and possibly as high as US$7 billion per plant. The authors extend the model to calculate the average value of a hectare of rainforest:break

$$VRL = (NR \times p \times r \times a \times VP) / H$$

where *VRL* = per hectare value of rainforest land;

NR = number of plant species at risk (60,000);

p = success rate of finding a new plant−based drug source (1:10,000 to 1:1,000);

r = royalty rate on a new drug source (5%);

a = amount of value that a host country can capture from a new drug source (10% to 100%);

VP = value of a plant−based drug source (US$0.39 to US$7.00 billion); and,

H = number of hectares of rainforest (1 billion).

Box A.2— Success Rate Determinants in Pharmaceutical Bioprospecting

For a prospecting program as a whole, a high success rate is desirable. However, given that research and development (R&D) costs per extract increase with each phase, low success rates in the individual screening phases may be desirable to reduce the costs associated with ultimately unsuccessful leads. To some degree, prospecting firms can manipulate the success rates of the early R&D phases by specifying the composition of the collection, and by adjusting the technical parameters of the screens. In general, success rates can be manipulated by:

Using prior information (e.g., ethnobiological, ecological, biomedical) to collect extracts for testing against specific therapeutic targets;

Reducing the chemical similarity of extracts within a collection by increasing the taxonomical diversity of that collection;

Adjusting screening parameters to affect the number of extracts that proceed through to the isolation and dereplication phase of the program; and,

Using new sources of biological material for those therapeutic targets that have been the subject of many prospecting programs.

The prospecting strategy for the collection may be *random* selection, using little or no prior species information, or it can be *rational* selection, using prior ethnobiological, ecological, or biomedical information. There may be numerous therapeutic targets against which the extracts are tested, or there may be as few as one target. There is some empirical evidence that programs utilizing prior information to find leads for a small number of therapeutic targets have higher success rates in the exploratory stage than programs using no prior information. Success rates can also be increased by using a taxonomically diverse collection for investigation. Generally, a diverse collection is more likely to be chemically dissimilar, and will consequently yield a greater number of novel compounds; hence, the discovery of one will not severely reduce the probability of discovering another within the same collection.

Through the treatment of the extracts, the phase−specific success rates are manipulated. Screening sensitivities can be adjusted to obtain relatively low or high hit rates from a given collection. Since R&D costs per extract increase with each phase, reducing the cost of a screening program means identifying and dropping ultimately unsuccessful leads (false positives) as soon as possible. Low success rates in the screening phases would achieve that end. For example, adjusting the screens to identify common compounds early would permit only extracts with relatively rare compounds to proceed to a subsequent isolation and dereplication phase, thereby increasing the success rate of this more costly phase of R&D. However, setting the screens to achieve low success rates will also mean foregoing potentially promising leads (false negatives).

A factor beyond the control of the individual prospecting firm is the amount of existing research that has been conducted involving the particular therapeutic targets. The more existing research there is, the more likely that relatively rare compounds, reactive with the targets, have already been discovered and investigated. However, a different bioassay of the same extract may prompt bioactivity, revealing previously missed compounds. Furthermore, a collection consisting of biological material drawn from under−investigated sources (such as marine ecosystems) is more likely to yield novel compounds than material drawn from more studied sources (such as tropical forests).

The Artuso (1997) model allows for phase−specific success rates that could reflect the prospecting strategy and the screening parameters of an individual prospecting program. A complication to the basic model also allows for a declining rate of success in the isolation and dereplication phase to account for the probability of increasing chemical similarity between the extracts of a given collection. Chemical "similarity" or "redundancy" is the focus of Simpson *et al.* (1996). Related to chemical similarity is the issue of "medicinal" or "therapeutic" redundancy, discussed by Simpson *et al.* (1996) and Artuso (1997). This type of redundancy refers to the situation wherein different chemical compounds from different species produce similar therapeutic effects.

Based on the preceding model and data assumptions, Pearce and Puroshothaman (1992ab) find values of tropical rainforest ranging between US$0.01/ha and US$21/ha.

As shown in the last column of Table A.1b, Aylward (1993) extended the valuation estimates of the above studies by using the success probabilities stated in the original articles to arrive at implied values for an untested species. For example, Farnsworth and Soejarto (1985) found the value of a single successful plant species to be US$203 million. At the time the article was written, the authors believed the probability of a plant becoming an drug source was one in 125 plants tested. Aylward used this probability to calculate the study's implied valuation of an untested species to be US$1.6 million (US$203 million/125 plants).

These early models had a number of common limitations. Their main limitation is that they do not account for the costs of new drug development. Such costs include: i) obtaining biotic samples; ii) R&D of screening samples; and, iii) production and marketing of a new drug. The exclusion of cost and investment information undermines some of the specific policy usefulness of the study results, but the results did serve, and continue to serve, an important educational purpose in raising awareness about the value of critical ecosystems to human well−being. Another limitation of these models is that they do not consider how the use of alternatives to natural product research might affect the valuations. Also, the studies are concerned with estimating the value of known pharmaceutically beneficial plants. There is an implicit assumption that species are not substitutes—benefits from different species are assumed additive whether or not they are providing the same type of benefit. Subsequent studies and models attempted to address these limitations.

Recent Models of Net Economic Benefits

Since 1993, most approaches to estimating the pharmaceutical value of species preservation try to calculate the *net* value of biological material in the R&D process. In contrast to earlier efforts, these models account for the costs associated with new drug development, from sample acquisition to administration and marketing. Recent models also incorporate the effects of generic drug competition on the expected sales revenue profile of a new drug. Net revenues are discounted to the start of the R&D process to determine the net present value (NPV) of biological material to the pharmaceutical prospecting firm.

Essentially, the models by Aylward (1993), Mendelsohn and Balick (1995), and Artuso (1997) estimate the *average* value of the genetic material by dividing the NPV of a new drug by the number of species (or biotic samples) that need to be screened before the new drug source or sources are found. Simpson *et al.* (1996) estimate the *marginal* value of genetic material by calculating change in the value of a collection of species when one more species is added to the collection.

The models described below vary in terms of their data requirements. For comparison, the fixed parameters and data sources are summarized in a table for each model. The tables reveal that the models use one or more common sources of empirical data—specifically, the studies by Grabowski and Vernon (1990), and DiMasi *et al.* (1991). These frequently cited studies represent the most recent from a body of economic literature which focuses on empirical estimation of the R&D cost to the pharmaceutical industry of an approved "new chemical entity" (NCE). Grabowski and Vernon (1990) estimate the rates of return to R&D for 100 new drugs (or NCEs) introduced into the United States during the 1970s. The net present value of each NCE is calculated using sales data, estimates of promotion and production costs, R&D cost estimates based on Hansen (1979, 1980)7 , and opportunity cost of capital estimates based on a capital asset pricing model. The major finding of the study is that the rate of return on the average new drug is approximately 9%.

R&D estimation work by DiMasi *et al.* (1991) is based on a survey of 12 United States pharmaceutical firms. The firms provided R&D cost and timing data for 93 NCEs that entered the "clinical" R&D phase during the 197082 period. The R&D process is divided into one preclinical phase, three clinical phases, and two animal testing phases. The clinical and animal R&D costs associated with each NCE were obtained from the survey. However, the preclinical costs—those associated with collection, screening, isolation, synthesis, and modification—could not be disaggregated by NCE. To arrive at a preclinical cost of a NCE, the authors used aggregate cost data to derive a ratio of preclinical to total cost. This ratio was then applied to the individual NCE estimates of clinical costs to derive estimates of the respective preclinical costs. In the study's base case, the R&D cost per approved NCE was found to be US$114 million (1987 dollars). This estimate was capitalized at 9% (Grabowski and Vernon 1990) to the point of new drug approval, thereby increasing the average R&D cost to US$231 million per new drug.

Aylward (1993)

Aylward (1993) estimates the net returns to "pharmaceutical prospecting". Up to a point, the approach is essentially the same as that used in the Grabowski and Vernon (1990) study that analyzed empirical data to find the ratecontinue

of return to pharmaceutical R&D. In the Aylward study, the net present value of a hypothetical new drug is calculated using a potential sales profile, estimates of promotion and production costs, and R&D cost estimates based on DiMasi *et al.* (1991). At this stage, the approaches start to diverge. From the revenue stream, Aylward also deducts the cost of biotic samples to arrive at the net returns to pharmaceutical prospecting.[8]

Aylward's main contribution to the analysis of returns to pharmaceutical prospecting is in the apportionment of net returns across the factor inputs in the pharmaceutical prospecting process. These include: i) biodiversity protection; ii) biotic sample acquisition, including taxonomic identification; and, iii) research and development, including the activities from chemical extraction to application for regulatory approval.

Two slightly different models are developed to estimate expected net *private* returns, and the expected net *social* returns to the factor inputs. To calculate net private returns, the analysis excludes factor costs typically subsidized by the state (e.g., biodiversity protection and taxonomic identification). To calculate net social returns, all factor costs are included.

Calculation of the value of the individual species subjected to screening by a pharmaceutical firm proceeds essentially the same as in the above models; net returns are divided by the number of species required to find one successful new drug source (i.e., the success rate). The Aylward model is slightly different because pharmaceutical prospecting is separated into different activities. Specifically, net returns to an untested species are calculated by applying the success rate to the "net returns to biotic sample acquisition". Applying the success rate to the "net returns to biodiversity protection" yields the net returns attributable to the biodiversity protection of a given species.

Modeling Returns to Factors of Pharmaceutical Prospecting

Aylward (1993) presents a situation wherein genetic prospectors have access to a fully protected wildland area containing at least 10,000 different species of plants. Over the course of one year, 10,000 species are screened against one therapeutic target for pharmaceutical potential. Assuming a species success rate of 1:10,000, one new drug source is eventually identified.

The gross return of the resultant new drug is calculated as a revenue stream incorporating four phases of the product life: i) pre−patent; ii) on−patent before regulatory approval; iii) on−patent after approval; and, iv) post−patent when sales decay due to generic drug competition.

The gross return to pharmaceutical prospecting (GR^{PP}) is calculated by removing production and marketing costs from the projected revenue stream of the new drug. The net return to pharmaceutical prospecting (NR^{PP}) is calculated by removing the cost of pharmaceutical prospecting (C^{PP}):

$$NR^{PP} = GR^{PP} - C^{PP}$$

In the "private cost" version of the model, the private cost of pharmaceutical prospecting (PC^{PP}) equals the sum of the private cost of R&D ($PC^{R\&D}$) and the private cost of biotic samples (PC^{BS}). The net private return to pharmaceutical prospecting (NPR^{PP}) is:

$$NPR^{PP} = GR^{PP} - [PC^{R\&D} + PC^{BS}]$$

In the "social cost" version of the model, the cost of pharmaceutical prospecting (*C* PP) additionally includes the social cost of taxonomic information and the social cost of biodiversity protection.9 Hence, the *social* cost of pharmaceutical prospecting (*SC* PP) equals the sum of the social cost of biodiversity protection (*SC* BP), the social cost of R&D (*SC* R&D), and the social cost of biotic samples (*SC* BS , including the social cost of taxonomic information, *SC* TI). The net social return to pharmaceutical prospecting (*NSR* PP) is:

$$NSR^{PP} = GR^{PP} - [SC^{BP} + (SC^{BS} + SC^{TI}) + SC^{R\&D}]$$

To apportion the net return across the different factors of prospecting, in each model, the expected net return to each factor is assumed to be equal to its proportional share in the total cost of the prospecting process. Therefore, in the private cost model, the net private return to R&D (*NPR* R&D) and to biotic samples (*NPR* BS) are apportioned as follows:

$$NPR^{R\&D} = (PC^{R\&D} / PC^{PP}) \times NPR^{PP}$$
$$NPR^{BS} = (PC^{BS} / PC^{PP}) \times NPR^{PP}$$

In the social cost model, the net social returns to R&D (*NSR* R&D), to biotic samples (*NSR* BS), and to biodiversity protection (*NSR* BP) are calculated similarly.

Expected Net Returns Per Species or Per Biotic Sample

In the social cost model, the expected net return attributable to a species in the protected area is equal to the success rate multiplied by the net social return to biodiversity protection. Aylward (1993) assumes that there are 10,000 species in the protected area; all will be screened and one will provide a new drug source. Hence, the success rate is 1:10,000. In the private cost model, the expected net return attributable to a biotic sample subjected to the screening program is equal to the species success rate (1:10,000) multiplied by the net private return tocontinue

biotic samples (*NPR* BS), adjusted for the number of samples per species that are screened. Aylward assumes that two samples from each species enter the program. The success rate for biotic samples (as opposed to species) is therefore 1:20,000. The model parameters are shown in Table A.3 and results of the models are in Table A.4.

Net Returns from Prospecting Royalties

In addition to the cost−based models described above, Aylward (1993) also estimates a royalty−based model. For comparison with the cost−based models, both the net private and net social expected royalty on biotic samples are calculated.

In the royalty model, gross revenue consists of only sales up to patent expiration. Distribution costs, expressed as a percentage, are removed from gross sales to arrive at net sales (*NS*), on which royalties are calculated. Royalties received by the producer of biotic samples then depend on the expected rate of royalty (*r*). Adjusting for the species success rate (*P*) and the number of samples provided per species (*n*), the expected gross royalty on biotic samples (*Ry* BS) is:

$$RY^{BS} = P \times r \times NS / n$$

The private net royalty on biotic samples (*NPR* BS)is calculated by adding to *RY* BS the initial fees received bycontinue

Table A.3. Model parameters in Alyward (1993)

Model parameter	*Value*	*Source*
Sales: patent period mean sales for an average drug	US$69 million (model calculation)	Based on Grabowski and Vernon (1990) sales data adjusted to 1990 dollars using nominal growth rate for drug prices
Real price trends of pharmaceuticals	5%	Deflated nominal US pharmaceutical price trends for the period 1980 to 1991
Decay rate of post−patent sales	11%/yr	Grabowski and Vernon (1990)
Patent life	18	Based on Ballance *et al.* (1992) findings for 15 to 20 years in OECD countries
Rate of return for on−patent drugs	40% to 50%	Ballance *et al.* (1992)
Time to patenting	2 yrs	Assumption
Production and marketing costs	60% of sales	The Economist (1992); Merck & Co. (1992)
Pre−tax ROR and P&M	5% to 10%	Ballance *et al.* (1992)
Private costs of R&D	US$91 million (model calculation)	DiMasi *et al.* (1991)
Length of R&D period	12 yrs	DiMasi *et al.* (1991); US Pharmaceutical Manufacturers Association (1991)
Cost of capital in pharmaceutical industry	10%	Based on Grabowski and Vernon (1990) estimate of 9%, and others
Per biotic sample collection fee in developing countries	US$50	Based on interviews with collectors working in developing countries
Biotic samples per species	2 samples per species	Assumption
Species hit rate	1:10,000	Based on various studies ranging from 1:125 to 1:40,000
Social costs of taxonomic information	US$100	Based on case study of Costa Rica's National Biodiversity Institute (Aylward *et al.* 1993)
Cost of biodiversity protection	US$50 per species per year	Derived from estimates of direct and opportunity costs of production in Costa Rica
Royalty rate on biotic samples	2%	Industry sources suggest 1% to 3% range

Table A.4. Results of the models of Aylward (1993).

Model component	*Net return (US$)*
Private Cost Model	
Total to pharmaceutical prospecting (NPRPP)	39.13 million
Total to R&D (NPRR&D)	38.71 million
Total to biotic samples (NPRBS)	0.42 million
Per biotic sample	21.23
Social Cost Model	
Total to pharmaceutical prospecting (NSRPP)	33.24 million
Total to R&D (NSRR&D)	30.91 million
Total to biotic samples (NSRBS)	0.68 million
Per biotic sample	33.91
Total to biodiversity protection (NSRBP)	1.66 million
Per tested species	165.79

the collector (*F*) and netting out the private cost of biotic sample acquisition. The social net royalty (*NSR* BS) is calculated by also netting−out the social costs of taxonomic information and biodiversity protection. The results from this model are a royalty per biotic sample (*RY* BS) of US$233.12, a total net return to biotic samples (*NPR* BS) of US$4.91 million, and a total net return to biotic samples (*NSR* BS) of US$0.98 million.

Mendelsohn and Balick (1995, 1997)

Mendelsohn and Balick (1995) estimate the net present value of a new drug. They also estimate the number of new drug sources remaining to be discovered in tropical forests around the world. Given these two estimates—the NPV of a typical new drug and the number of new drugs yet to be discovered and developed—they arrive at a total worth of yet to be discovered drugs from tropical forests.

The model calculates the net revenue stream associated with the development, production and marketing of a new drug. The revenue profile reflects the pre−patent, on−patent and post−patent periods. It covers a 29 year period—the first 10 years are devoted to R&D, with sales of the new drug begin in year 11, reaching a peak in year 19. For the industry as a whole, sales level off after the peak year; for the firm holding the patent, revenue is quickly eroded in the post−period due to generic drug competition. The authors argue that if sales of the new drug are aggregated across all firms, the peak net revenue level would likely be maintained indefinitely. Using the data summarized in Table A.5, the authors arrive at a NPV of US$449 million per new drug.

To arrive at the number of drugs remaining to be discovered in the rainforests of the world, the authors rely on the following assumptions:break

Table A.5. Model parameters in Mendelsohn and Balick (1995).

Model parameter	*Value*	*Source*
Patent period average sales for an average drug	US$29 million	OTA (1993)
Decay rate of post−patent sales	20%	OTA (1993)
Patent life	20 yrs	not indicated
Production and marketing costs	60.6% of sales	OTA (1993)
Length of R&D period	10 yrs	Grabowski and Vernon (1990)
Present value of private R&D costs	US$125 million	OTA (1993)
Cost of capital in pharmaceutical industry	5%	OTA (1993)
Species hit rate	1:333	see text
Per biotic sample collection fee in developing countries	US$100	

One−half of the 250,000 known species of higher plants are found in rainforest ecosystems;

Each plant has six chemically distinct extracts that can be tested;

At any one time, the pharmaceutical industry as a whole tests sample extracts against 500 statistically independent screens (an individual company screens for about 50 to 75 different therapeutic uses); and,

Probability of success is one per one million tests, which implies that, on average, one new drug would be developed from every 333 plant species.10

From the above, there are approximately 375 plant−based drugs in the tropical forests.11 About 47 plant−based drugs have already been discovered, leaving 328 yet to be discovered.

Given the NPV estimate of US$449 million per new drug and the estimate of 328 new drugs yet to be discovered in the rainforest, the authors conclude that there is approximately US$147 billion (NPV) worth of new drugs in the rainforests around the world. Allocating this amount over the area of rainforest in the world provides a genetic resource value of US$48/ha. Allocating US$147 billion over the 125,000 rainforest plant species implies that any one species is worth $1.2 million.

Artuso (1997)

All of the above models to determine the average pharmaceutical value of an untested species use R&D cost estimates based on empirical research by others. The emphasis is on determining the expected net revenue associated with a new drug, rather than on the details of the R&D process itself. The empirical modeling efforts by DiMasi *et al.* (1991) or Grabowski and Vernon (1990), on the other hand, examine the R&D process in greater detail.

As discussed above, the empirical work on pharmaceutical R&D uses survey data at the individual firm level to develop costs for distinct phases of the R&D process. However, these studies do not provide valuations for genetic material inputs to the R&D process. Preclinical costs, which would include the input cost of genetic material, are estimated using aggregate data because firms are unable to allocate preclinical costs to specific new chemical entities (NCEs).

To value genetic material, Artuso (1997) borrows from the empirical models in that the approach breaks R&D into phases and estimates phase−specific (expected) costs. In the Artuso model, R&D is divided into nine phases from the "initial screening" of samples to "new drug approval". The model differs from the empirical ones because its ultimate goal is to arrive at a (maximum) value that a single prospecting firm would pay for genetic material at a single point in time; the firm is assumed to be a small player in a large industry. Phase−specific expected revenue is also estimated to arrive at the expected net present value of a prospecting program, which equals the total value of a collection of genetic extracts subjected to that program. In the base case, there are 15,000 extracts in the program; therefore, average value of an extract is simply the NPV of the program divided by 15,000.

The model estimates the pharmaceutical value of genetic inputs by incorporating a specific "rate of success" into each phase of the process. The expected cost of each phase is dependent upon the number of genetic samples under investigation *in that phase* . The number of samples under investigation in any particular phase will equal the number of samples that tested positively in the *preceding* phase. Therefore, the success rate of the preceding phase is the relevant rate for calculating costs in the current phase.

Model to Value a Set of Biological Extracts

We first summarize the calculation of expected R&D costs. The expected revenue and net present value calculations follow thereafter.

The expected total cost of pharmaceutical R&D is the summation of the expected costs associated with each phase of the process. The expected cost of each phase i (EC_i) equals the sum of its fixed costs (FC_i) and its variable costs. Variable costs depend on the cost per test of an extract (c_i), the number of extracts tested, and the number of therapeutic targets (M) against which the extracts are screened. The number of extracts tested in any phase depends upon the number of extracts originally entered into the screening process (N) and the success rates of all preceding phases (s_j). Hence, the expected cost of phase i is:

$$EC_i = FC_i + NMc_i \prod_{j=0}^{i-1} s_j$$

To arrive at the present value expected cost of phase i ($PVEC_i$), for the duration of the phase (d_i), the average annual cost of the phase (EC_i/d_i) is discounted by the specified rate (r) to the present. The period over which discounting occurs must account for D_i the total duration in years of all phases up to and including phase i .

$$PVEC_i = \frac{EC_i}{d_i} \sum_{t=0}^{d_i-1} \left(1+r\right)^{-(t+D_{i-1})}$$

The present value of the expected total cost ($PVETC$) of the R&D process is the summation of the present value of the expected cost of each phase of the process ($PVEC_i$) .continue

If there are *n* phases in the pharmaceutical R&D process, then:

$$PVETC = \sum_{i=1}^{n} PVEC_i$$

Table A.6 shows the phase data used to calculate *PVETC* .

For the calculation of revenue, the expected number of approved drugs (*A*) following from an R&D process is a function of the number of extracts screened (*N*), the number of screening targets (*M*), and the probability of any given compound advancing through all phases of the R&D process. The multiplicative product of the success rates of all the phases is:

$$A = NM \prod_{i=1}^{n} s_i$$

The number of new drugs receiving regulatory approval (*A*) multiplied by the discounted value of expected new drug revenue (R_t) yields the before−tax present value of expected *gross* revenue. Netting−out all non−R&D costs (production, equipment, marketing, and administration) yields the present value of expected *net* revenue ($PVENR_t$). The discounting period includes all *n* phases of the R&D process, plus *T* —the average commercial life (in years) of a new drug. Therefore:

$$PVENR = qA \sum_{t=1}^{Dn+T} (R_t - Z_t)(1+r)^{-t}$$

where *q* = average proportion of annual revenues after deducting all production and marketing costs; and,

Z_t = cost in year *t* of any initial capital and marketing costs not captured by *q* .

Table A.6. R&D phase data used by Artuso (1997) for baseline analysis. 15,000 extracts were tested for 10 therapeutic targets. Assumed real discount rate was 8.5%.

Phase	*Phase duration (yrs)*	*Success rate (%)*	*Mean number of successes*	*Costs per trial (thousand US$)*	*Expected phase costs (thousand US$)*	*Present value of expected phase costs (thousand US$)*
Initial screeninga	0.75	0.5	750	0.10	15,000	14,548
Secondary screeninga	0.10	40.0	300	1	750	732
Isolation and dereplicationa	0.50	10.0	30	20	6,000	5,712
Synthesis and modificationa	1.50	50.0	15	250	7,500	6,585
Preclinical trialsb	1.00	40.0	6	771	11,570	9,170
Clinical phase Ib	1.35	75.0	4.5	3,137	18,822	13,557

Clinical phase IIb	1.88	47.5	2.14	9,933	44,698	28,239
Clinical phase IIIb	2.49	70.0	1.50	18,817	40,222	21,282
NDA	3.00	90.0	1.35	1,000	1,496	633
Cumulative	**12.57**	**0.0009**	**1.35**	**33,930**	**146,058**	**100,457**

a Data based on various natural product screening programs.

b Data based on Burger (1990), DiMasi *et al.* (1991), and Hansen (1979).

Table A.7 shows the data and sources used in the *PVENR* calculation.

Accounting for the tax liability of a private firm (*r* in percent), the difference between the present values of expected net revenue and expected total cost of R&D yields the expected net present value of *N* biological extracts to the private firm (*ENPV* priv). That is to say:

$$ENPV_{priv} = (1-r)(PVENR - PVETC)$$

The expected net present value of *N* biological extracts to society (*ENPV* soc) is estimated by ignoring the tax liability and accounting for consumer surplus and additional societal benefits such as reduced contagion and increased productivity. A scalar (*m*) is used to increase *PVENR* to capture consumer surplus and any additional benefits:

$$ENPV_{soc} = m(PVENR) - PVETC$$

The results of the expected private NPV calculations are shown in Table A.8.

Sensitivity analyses were conducted by changing the assumptions regarding the discount rate, drug revenues, and the success rates of different phases of the R&D process. For example, decreasing the discount rate from 8.5% to 8%, the expected NPV of *N* extracts increased fromcontinue

Table A.7. Model parameters in Artuso (1997).

Model parameter	Value	Source
Sales revenues for new drug	Series	Grabowski and Vernon (1990), adjusted to 1994 prices
Sales decay	7.5%/yr in years 12 to 20	
Product life	20yrs	Vagelos (1991)
Global to US sales ratio	1.9	Grabowski and Vernon (1990); Joglekar and Patterson (1986)
Plant and equipment	50% of gross revenues in year 10; 67% occur in year 1; balance equally spread over years 2 to 10	Grabowski and Vernon (1990)
Administration and operating	40% of revenue	

costs		
Marketing	100% in year 1; 50% in year 2; 25% in year 3	
Tax rate	35%	
Discount rate	8.5%	Based on capital asset pricing model

US$7.3 million to US$18 million. Reducing the primary screening rate by 20% from 0.005 to 0.004 reduced the expected NPV of *N* extracts from US$7.3 million to US$2.9 million. If the preclinical success rate is reduced by 20% from 0.400 to 0.320, the expected NPV of the prospecting program becomes negative.

A Model Addressing Marginal Economic Value

Simpson et al. (1996)

Simpson and colleagues (including Simpson and Craft 1996; Simpson and Sedjo 1996ab) note that most of the existing valuations of biodiversity for genetic prospecting have estimated the *average* value of a species. Those reviewed above, for example, calculate the value of a new, plant−based commercial drug, net of all production, marketing and R&D. That net value represents the maximum amount a prospecting firm would pay for a collection of species to screen for new drug sources. The value of an individual species within the collection is estimated by multiplying the value of the collection (i.e., the net value of a new drug) by a probability that an untested species will yield a commercially viable new drug source (i.e., the success rate). The result is an average value for the individual species subjected to the screening program. From a policy planning perspective, however, some of the economic efficiency decisions made for a given site (e.g., a conservation area) would also require information relating to *marginal* values of species. Such valuations

Table A.8. Results of the expected private NPV calculations of Artuso (1997).

	Before tax (US$)	*After tax (US$)*
Total (15,000 Extracts)		
Expected net revenue	108.8 million	70 million
Expected R&D costs	100.5 million	65 million
Expected net value	7.3 million	5 million
Per Extract		
Expected net revenue	7,184	4,669
Expected R&D costs	6,697	4,353
Expected net value	487	316

generally take on a different analytical form. The Simpson *et al.* (1996) model estimates the value of a species by deriving its *incremental contribution* to the total value of the collection of species. For example, if a prospecting firm has a collection of 249,999 species of plants, the model calculates the additional value of screening a 250,000th species.

The rationale for a marginal valuation approach is based on the existence of "redundancy" among natural chemicals. Genetic resources may be relatively redundant for the following reasons:

If all individuals of a species produce the same compound, a viable population of the species is all that is needed to guarantee supply. Individuals in excess of the number required to maintain the population are redundant.break

In many cases, the same chemical compounds can be found in different species; hence, there will be redundant species for those particular compounds.

The discovery of a novel compound occurring in particular species may, in fact, only duplicate the therapeutic mechanisms already produced by an existing compound.

The possibility of redundancy is built into the Simpson *et al.* (1996) model so that the expected value associated with screening an additional species declines, due to the increasing probability of having hit upon a novel compound from samples already screened.

The authors derive a demand function for genetic resources in pharmaceutical research. In doing so, they demonstrate that if the collection of genetic resources to be screened is large, the expected value of the marginal species will be low because the probability of redundancy is positively related to the size of the collection. Furthermore, the higher the probability of success in finding a novel compound within the collection, the higher will be the probability of redundancy. This results in an even lower expected value of the marginal species.

Model to Value the Marginal Species

Each sampling is treated as an independent Bernoulli trial with equal probability of success. When a positive hit occurs, the sampling process is halted because further positive hits would be redundant. The value (V) of a collection of n samples to be screened is then:

$$V(n) = (pR - c)/p \times [1 - (1 - p)^n]$$

where p = probability with which any species sampled at random yields a success;

R = revenue generated by the new drug, net of production and marketing costs;

c = R&D costs only; and,

n = size of the collection.

The value of the marginal species denoted as $v(n)$ is the difference between V evaluated at n and V evaluated at $n+1$:

$$V(n+1) - V(n) = v(n) = (pR - c)(1 - p)^n$$

The equation for $v(n)$ is differentiated with respect to p to find p^*, the probability which maximizes the value of the marginal species. $v(n)$ is then evaluated at p^* to determine v^*, the maximum value of the marginal species, given the size of the collection, sales revenue and R&D costs. Hence:

$$p^* = (R + nc)/(n+1) \times R$$

$$v^* = v(n, p^*) = [(R-c)/n+1)] \times [(R-c)/R \times (n/(n+1))]^n$$

The model is adjusted to allow for the expected number of new drug approvals per year (*A*). The marginal value of a species is discounted at the rate *r* . Discounting takes places over an infinite time horizon, hence the marginal value equation is simply:

$$v(n) = (A/r)(pR - c)(1-p)^n$$

and the maximum expected present value of the marginal species (*EPVv* *) is:

$$EPVv^* = (A/r) \times [[(R-c)/(n+1)] \times [(R-c)/R \times (n/(n+1))]]^n$$

The model estimates a maximum potential value for the marginal species; data inputs and key results of a valuation exercise using the model are shown in Table A.9. Given the cost and revenue data, for a collection of 250,000 species, the probability that maximizes the value of the marginal species (*p* *) is 0.000012 (or 1:83,333). Success probabilities greater or lower than *p* * reduce the value of the marginal species. Evaluated at the maximizing probability *p* *, the maximum expected value of the marginal species is just under US$10,000.

Tests are run on the model to demonstrate the extreme sensitivity of the expected value to the probability of success and to the relative magnitudes of the revenue and cost variables. With costs and revenues constant, if the probability of success drops below 0.000008 (1:125,000), the value of the marginal species is negative. The lower success rate results in a loss in marginal value because the incremental revenue from testing the last available species has decreased. On the other hand, if the success rate increases to 0.00004 (1:25,000) the value of the marginal species declines to US$67. The loss in marginal value is because of the increased likelihood that the novel compound has already been found in another species.

Using the output of the model, the authors calculate the prices pharmaceutical companies would be willing to pay to preserve biodiversity−rich sites. Given the estimate of the marginal value of a higher plant species of approximately US$10,000, the authors estimate the value of the marginal hectare of endangered habitat. Using the theory of island biogeography, for 18 biodiversity "hot spots", a species−area curve is differentiated to determine the change in the number of species from a given change in the size of a particular forest area. Combining the results of these calculations with the marginal species value estimate, the authors derive land values ranging from US$0.74/ha in central Chile to US$20.63/ha in western Ecuador.break

Table A.9. Model parameters and results in Simpson *et al.* (1996).

Model parameter	*Value*	*Source*
Number of species	250,000	Myers (1988); Wilson (1992)
Expected number of new products development	10	US FDA average
Cost of single new product	US$300 million	

		DiMasi *et al.* (1991); OTA (1993)
Revenue to cost ratio	1.50	assumption
Discount rate	10%	assumption
Revenue	US$450 million	
Cost per sample (*c*)	US$3,600	
Maximizing probability (*p* *)	0.000012	
Probability of a hit in entire collection	0.9502	
Value of the marginal species	US$9,431.16	

A Look at the Frontiers of Valuation and Modeling

This annex has looked at the biodiversity valuation literature, with a view to considering the different methods that may be applicable to marine biodiversity valuation. Methods relating to direct and indirect uses and functions are among the best developed and techniques are readily transferred to coral reef systems. Methods relating to non−use values are also available, although they are complicated by methodological issues such as lexicographic preferences (Chapter 6).

Of greatest research interest, however, is the field of biological prospecting valuation (Chapter 7). Models for terrestrial systems have evolved considerably over the past decade, although none have yet been applied to marine systems. Also, bioprospecting model development in the literature has tended to be isolated in two distinct areas—agriculture and pharmaceuticals. While both have similar foundations in the modeling of the value of applied research (Evenson and Kislev 1976), distinct literatures have developed in agricultural and pharmaceutical modeling development. This has arisen because of different technical aspects of bioprospecting in these fields, as well as different policy concerns.

The bioprospecting valuation approaches we build on fall primarily into the realm of deterministic models relating to pharmaceutical development. These attempt to infer social values from intensely private behavior. The model developed in the Montego Bay pharmaceutical bioprospecting valuation research presented in Chapter 7, like its counterparts, provides no explicit empirical calculation of option values. It does, however, provide insights into issues of value related to marine environments, focusing on issues such as marine product success rates, institutional revenue sharing issues, and ecosystem yield. We encourage further research that looks into such issues in greater depth and extends models to bioprospecting for other marine products, such as mariculture. In that respect, future modeling efforts are likely to borrow more extensively from both the agricultural and the pharmaceutical literature.

We maintain, however, that no single terrestrial bioprospecting valuation model should be preferred over the others; each has different policy applications. In pharmaceutical bioprospecting, the early models of gross economic value had an important role to play for education and awareness policies, although they may be less useful for management and specific planning. The next generation of models, those relating to net economic values, taught us that we need to pay greater attention to the allocation and calculation of costs within the biological prospecting process. This has distributive implications, such as through the incidence of benefits and costs to the private sector versus society at large, as well as efficiency considerations, such as whether it in fact makes economic sense to undertake biological prospecting. In particular, the average cost models showed us how sensitive economic values can be to technical parameters, such as success rates, and to economic variables, such as royalty rates or R&D costs.

But even these models fail to tell the whole picture or answer all of the relevant economic policy questions. From a system planning perspective, we are constantlycontinue

reminded that we must pay attention to the complexity inherent in biological and ecological systems, as well as within the discovery process itself (Brown and Goldstein 1984; Polasky and Solow 1995; Solow *et al.* 1993). One manifestation of this is the potential for interdependence of probabilities within the discovery process; an example of this was illustrated by Simpson *et al.* (1996) in their treatment of "redundancy" to show that the value of the marginal species is in fact quite low when such complexities are considered. Another manifestation of this complexity arises at the policy planning stage when trying to transfer "$ per species" values to some tract of ecosystem such as rainforest. In such cases, the yield of species by the ecosystem is typically non−linear, and the first differential of this relationship must be estimated before allocative decisions about optimal levels of conservation can be made. Again, this issue was touched upon by Simpson *et al.* (1996), as well as by Artuso (1997), and their results illustrate the sensitivity of valuation results to assumptions relating to ecosystem yields.

As another example of the complexity and interdependence issue, none of the models have adequately grappled with differentiating among the *intended reasons* for bioprospecting. It is normally assumed that we are looking for new products and new discoveries that will somehow cure all of our worst maladies. In fact, some of the bioprospecting is oriented to looking for new, but cheaper, sources of existing materials. In that respect, bioprospecting is akin to mineral or oil exploration—we know what we are looking for and are simply looking for a cheaper source. This result is underlined by theoretical modeling work done by Evenson and Lemarié (1998). They show that, within an optimal search framework that distinguishes between different geographical regions, bioprospecting may shift towards species−rich (or trait−rich) regions where lower cost searches are available. In this case, redundancy is not an issue; indeed, redundancy may be a positive rather than a negative factor in valuation.

To date, no single model has provided all of the answers. At best, they provide some indication of value and what that value is sensitive to within a given policy context. There remain substantial limitations to valuation techniques. When designing a new model, or choosing among the existing ones, one must therefore pay attention to the particular policy issues or analytical issues one wishes to address. For marine products, these issues can be quite different than those related to terrestrial products. While any single valuation will generally be a useful policy input, it should normally be regarded as just one among many potential inputs to such a policy making exercise. It is no accident that wider reliance is also being made on multi−criteria analyses (MCA), with valuation as one component of that analysis. Adger *et al.* (1999) demonstrate how such MCA techniques can be of particular use in marine park planning applications where there are often a large number of stakeholders, having a wide variety of interests and objectives.break

Endnotes

1 The Canadian effort, maintained by Environment Canada, is available by subscription and is entitled "EVRI: Environmental Valuation Reference Inventory". At the end of 1998, it contained approximately 850 references, primarily relating to the valuation of water−related issues. It is located at: http://www.evri.ec.gc.ca/EVRI/ . The Australian effort, spearheaded by the New South Wales Government, is free of charge to use and is entitled ENVALUE. It relies on an extensive database developed by experts in the field of valuation, and addresses a wide range of pollution and environmental management issues. It is located at: http://www.epa.nsw.gov.au/envalue/StudyCnt.asp .

2 One such site is maintained at Oregon State University by Professor Stephen Polasky, who has done personal research work in genetic valuation and coauthored a bibliography on biodiversity conservation (Polasky *et al.* 1997). The internet site is located at: http://www.orst.edu/dept/ag resrcecon/biodiv/biblio.html.

3 The implicit price model is obtained by first estimating a market value model. The total cost of vacation packages is regressed on the attributes of those packages (i.e., type of accommodations, destinations, and duration). The estimated market value model is then differentiated with respect to days in the Galapagos to arrive at another relationship wherein price is a function of the days in the Galapagos and of total vacation expenditure. Survey data on days in the Galapagos and vacation cost was entered into the implicit price equation to obtain implicit price data, which would then be used in the estimation of a demand curve for a Galapagos vacation experience. From the demand curve so estimated, at the average per day implicit price (US$312), vacation days demanded would be 7.3, implying a total vacation cost of US$2,278.

4 Genetically modified (GM) products have been in the public eye more recently and have raised a number of policy issues which are likely to become interesting topics for valuation. Direct economic improvements from GM crops are becoming better documented. For example, it is estimated by the John Innes Center in the United Kingdom (M. Gale, Director, press release, 8 March 1999) that Roundup Ready soya, which was genetically engineered to resist Roundup herbicide, saved farmers some US$30/ha because of a 40% reduction in herbicide. But while the higher net incomes and the lower, as yet unmeasured, externalities of reduced pesticide use may be regarded as "benefits" from such modifications within any policy context, uncertainties associated with health concerns over GM crops, as asserted by anti−GM campaigners, would presumably constitute some disbenefit in any calculus of economic valuation. To date, however, such valuations have not been conducted.

5 An extensive series of CIMMYT discussion papers and related publications is documented on the CIMMYT web site located at: http://www.cimmyt.cgiar.org/ . Many of these relate to farm level studies and the role of institutional changes and policy interventions in improving incentives for farm level conservation of genetic resources. Saade (1996) describes impacts on farmers' incomes of high yield wheat varieties in Tunisia; a major conclusion was that large farmers and state farms were the primary beneficiaries of such introductions. Hartell *et al.* (1997) use econometric studies to investigate the relative contributions of various inputs to improved farm income in Pakistan; they conclude that in some areas the genetic improvement has made farmers better off, while in other areas (i.e., those with production constraints) the contributions of the genetic improvement are minimal and farm policy would be better targeted to production management.

6 Farnsworth and Soejarto (1985) list 40 flowering plants responsible for all plant−derived drugs sold in 1980.

7 The R&D cost studies by Hansen (1979, 1980) and DiMasi *et al.* (1991) are similar in their approaches in that both studies use NCE−specific survey data for a multi−phase R&D process.

8 Grabowski and Vernon (1990) may have implicitly deducted the cost of biotic samples because they used R&D cost estimates from Hansen (1979, 1980) that, according to DiMasi *et al.* (1991), included "discovery costs".

9 The social cost of taxonomic information reflects the costs to collect, curate and identify a specimen not already held in a local reference collection. The social cost of biodiversity protection is area specific and should include the direct, indirect, and opportunity costs of preservation. Aylward (1993) estimates the direct and opportunity

costs of preserving 600,000ha of Costa Rican parkland. Direct cost is based on park budget projections; opportunity cost is based on local land prices and an estimate of the net present value of neighboring agricultural land. Assuming a certain number of species residing in the parkland, a per species protection cost is then calculated.

10 Given that each plant has six distinct extracts, 333 plants would provide about 2,000 extracts. If each of these is subjected to 500 screens, then these 333 plants would provide 1 million tests, which would yield one success.

11 Assuming there are 125,000 plant species in the rainforest all yielding six extracts, there are then approximately 750,000 potential extracts which can each be subjected to 500 screens. At a success rate of one in one million, there would then be 375 potential drugs.break

Annex B—
Contingent Valuation As a Means of Valuing the Conservation of Coral Reefs:
An Assessment of the Method

Nick Hanley
Institute of Ecology and Resource Management, University of Edinburgh, Edinburgh, Scotland, United Kingdom

The contingent valuation method (CVM) is a means of assigning monetary values to resources and service flows that are unpriced or under−priced by the market. CVM is based on neo−classical welfare economics, where the value of an environmental resource to an individual is expressed either as their maximum willingness−to−pay (WTP) to acquire or safeguard it, or else the minimum monetary compensation they would accept to go without an increase in that good or tolerate a decrease (willingness−to−accept compensation; WTAC). Given that it is "missing markets" that result in such environmental resources as clean air, coral reefs or biodiversity being unpriced, CVM relies on a constructed, hypothetical market to produce monetary estimates of value. The researcher obtains peoples' bids (either WTP or WTAC) for a specified change in the environmental good of interest *contingent* on the description of this hypothetical market. Thus, an individual's WTP or WTAC can be expected to depend on:

The description of the contingent market;

What they know about the environmental good, which depends partly on what they are told about it as part of the CVM survey;

Their own preferences;

Their budget constraints; and,

The availability of substitutes and complements.

Empirically, it also turns out that stated WTP (throughout the rest of this annex, WTP will be used to refer to both itself and WTAC unless otherwise stated) also depends on the design of the constructed market and how responses are subsequently analyzed.

Historically, CVM developed through gradual acceptance and use by United States government agencies. An important milestone was the acceptance by the United States courts of the use of CVM in natural resource damage assessments under the 1980 Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). However, perhaps the most relevant event in the development of CVM was the case pursued by the State of Alaska and the federal government in the United States against Exxon as a result of the Exxon Valdez oil spill (Bateman and Willis 1999). This led to the establishment of the so−called Blue Ribbon Panel, out of which emerged National Oceanic and Atmospheric Administration (NOAA) guidelines on the use of CVM, especially regarding non−use values (Federal Register 1993, 1994). These guidelines are still the subject of some debate, but form the basis for the design elements presented in this annex.

Essentially, a CVM exercise consists of: i) describing the environmental change in question; ii) describing the contingent market; iii) establishing a bid vehicle and reason for payment; iv) seeking bids, either through an open−ended format, a bidding game, a payment card, or a single or double−bounded dichotomous choice mechanism; v) estimating mean or median WTP; iv) aggregating this average bid to a population total value; and, vii) carrying out reliability and validity tests of the CVM results.

Principal Problem Areas

The CVM method has been used to estimate the value of a wide variety of environmental resources, including air and water quality, outdoor recreation, and landscape and wildlife conservation. These applications have highlighted some general problems in CVM—namely, the concept of utilitarian values for environmental resources (Spash and Hanley 1995; Stevens *et al.* 1991); benefits transfer (Bergland *et al.* 1995); nesting and part−whole bias (Boyle *et al.* 1994); calibration and aggregation (Foster *et al.* 1998); and the concept of non−use values (Bishop and Welsh 1992). In addition, the ability of researchers usingcontinue

CVM to value the different characteristics that make up, say, a pleasant landscape, has been limited (e.g., Hanley and Ruffell 1993). This has turned attention to other stated preference approaches, notably choice experiments (Adamowicz *et al.* 1994).

Early work (summarized in Mitchell and Carson 1989) tended to concentrate on what might be termed "design bias" effects; these included the impact on WTP of changes in the starting point in bidding games and tests for strategic behavior. Later, much attention was, in contrast, given to large differences between WTP and WTAC measures of value, which were inconsistent with mainstream welfare economics predictions. These differences have now been attributed to endowment effects (Knetsch 1989) and/or to substitution effects (Hanemann 1991). Another recent trend has been the large number of articles concerned with optimal design and subsequent econometric analysis of dichotomous choice models. Other papers (e.g., Munro and Hanley 1999) have shown that changes in the information set provided to respondents in a CVM survey can significantly affect their WTP, but that this is a desirable characteristic of the method.

Perhaps the four main current worries within CVM are: i) part−whole bias; ii) lexicographic preferences; iii) non−use values; and, iv) aggregation. These problems are now briefly described, before tentative best practice guidelines are outlined.

Nesting and Part−Whole Effects

It is well known that in CVM a good will be valued higher when valued in isolation than when as part of a more inclusive bundle. This is to be expected if goods within the bundle are substitutes for each other, to a degree, in terms of the utility they generate (Carson *et al.* 1998). This phenomenon has variously become known in CVM as embedding, nesting and part−whole bias, and may well exist for private market goods as well as for non−market goods. One possible "cure" for this problem is to ask respondents to bid for the more inclusive good first, and then to apportion some amount of this total bid to the good being valued.

Willis *et al.* (1993), for example, used this approach in their study of English environmentally sensitive areas (ESAs). Respondents were first asked to state a WTP amount, in terms of additional income tax, to maintain the entire ESA program in England and Wales. Residents and visitors were then shown pictorial and textual representations of what the landscape in either ESA would look like with and without the ESA scheme in place. Respondents stated which landscape they preferred and were then asked to allocate an amount for that landscape from their already declared ESA "budget", having been told that money "spent" on one ESA could not be spent on another (in other words, that there was an opportunity cost).

From the CVM literature and from economic theory, we know that this procedure will elicit lower bids for an individual ESA than when that ESA is bid for alone. This procedure might be seen as desirable in the sense that it presents a direct opportunity cost for bidding for any individual ESA (less can be "spent" on the other nine) and, also, that it produces more conservative value estimates. However, this procedure suffers from one major problem. As has been noted above, respondents who are not familiar with the good being valued must be given enough accurate and unbiased information to permit them to make well informed choices. ESAs are, for most individuals, unfamiliar goods in terms of the benefits they generate. Providing "full" information on each ESA in this instance would be an impractical task. Thus, this method of dealing with nesting effects is flawed. Additionally, one might ask why respondents should not first be asked to allocate some total for all public environmental spending, then allocate some of this to the ESA program, and then allocate some of this to a specific ESA. But why stop there? On the same logic, respondents should surely first be asked about how much they are willing to pay in taxes for total government expenditure. Yet this seems beyond the original intention or capabilities of CVM, especially when one considers the information issue.

Lexicographic Preferences

Both Stevens *et al.* (1991) and Spash and Hanley (1995) have found evidence that when people are asked to participate in CVM surveys concerned with wildlife protection, a proportion of these respondents have preferences that are at odds with the utilitarian ethic and the demand model underlying cost−benefit analysis (CBA). In essence, such individuals (approximately 25% of the sample in each case) refuse the concept of trading off income changes for changes in the level of environmental quality. Spash and Hanley (1995) argue that such preferences may be characterized as "lexicographic", derived from an ethical system based on rights. The implication is that WTAC amounts for such individuals will be infinite, and WTP amounts will be either zero (i.e., the individual protests) or a positive amount that does not vary with the level of environmental change involved. Since the behavior of such individuals does not correspond to the model underlying CBA, they are effectively disenfranchised by the CBA process. Identifying such individuals is clearlycontinue

important, although what to do about them is much less clear. It also seems important to test, empirically, what determines such behavior and whether it is independent of the opportunity cost of, in this case, wildlife protection. The issue of lexicographic preferences in particular, and non−utilitarian ethics in general, within CBA is currently unresolved.

Non−Use Values and Obscure Resources

Non−use (passive use) values have long been a subject of some controversy in contingent valuation. Non−use values represent the utility derived from individuals from the existence of an environmental resource when they do not consume it *in situ* (e.g., by bird−watching or hunting). Arguments for and against the acceptability of non−use values can be found, for example, in Randall (1993) and Hausman (1993). An interesting finding in the CVM literature is that non−use values appear to exist for respondents who were not aware of the good before the survey took place. An example of this phenomenon is reported by Bishop and Welsh (1992) who note that the citizens of Wisconsin are apparently willing to pay US$12 million for preserving the striped shiner, a ". . . small minnow inhabiting the turbid depths of the Milwaukee River" of which few respondents were aware prior to the survey. Bishop and Welsh (1992, p.138) contend that these values are as real as non−use values for well−known resources such as the Grand Canyon: ". . . lack of knowledge cannot be taken as evidence that the existence of such resources lacks the ability to satisfy preferences . . . It could simply indicate the lack of past choice opportunities to motivate information gathering. In the case of the striped shiner, it is possible that people are concerned about the fate of endangered species, even obscure ones."

Thus, lack of *ex ante* knowledge is not a reason for a non−credible WTP value, especially as we have already argued that the CVM process is an information providing process that is *expected* to change preferences. Whether values for those in the sample who were ignorant of the resource prior to the survey can be used to say anything about the values of those outside the sample who have not so been informed is, however, a moot point.

Aggregation Problems

Some of the problems of aggregating benefit estimates in CVM studies are largely of a practical nature (e.g., estimating total visitors to a wilderness area). Estimates can, of course, be made. However, with regard to projects where the general public can be expected to benefit, two awkward questions arise. First, which population do we count as valid? Multiplying even very small per person values by national populations give rise to very large aggregate non−use values. Second, are the large aggregate values that arise credible? Bishop and Welsh (1992) refer to an "adding up" problem for non−use values whereby, possibly due to their symbolic value, individuals would give identical WTP values for *any* environmental good cause that they are made aware of, but their WTP for all of these projects added together would not be equal to the sum of these individual amounts.

For this reason, and also because of a worry that the very hypothetical nature of the CVM situation causes an inflation of stated values, economists have suggested "calibrating" CVM estimates when aggregated into smaller amounts (Foster *et al.* 1998; NOAA 1993). Foster *et al.* (1998) report ratios of stated to actual WTP for wildlife conservation in the United Kingdom in the range of 0.3 to 10.5 (with a mean of 2.93), although they also note that the methods adopted in the studies from which these numbers arise vary widely, making comparisons difficult. NOAA (1993) suggest a somewhat ad hoc calibration figure of 50% in the absence of an experimental study undertaken alongside any given CVM study, yet this neglects the probable range of calibration desirable in different contingent markets across the non−use/use and public/private good continuums.

Design Elements—A Best Practice Guide

In discussing current views on what constitutes "best" design in CVM, it is first necessary to describe the nature and evolution of United States government guidelines on the use of the technique, which seem likely to heavily influence the acceptability of CVM results in the United States. The wrecking of the oil tanker the Exxon Valdez off the coast of Alaska in 1989 was the somewhat unforeseen cause of a major spur to the development of CVM in terms of a legally acceptable method of valuing environmental damages in the United States. United States law had gradually seen the introduction of damage claims for environmental losses, principally under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) regulations of 1986 and the Oil Pollution Act of 1990. Following a famous judgment by the DC Court of Appeals (State of Ohio versus Department of the Interior), non−use (or more strictly, what has been termed "passive use" values, including the values derived from watching wildlife on TV, for example) were deemed relevant under this body of legislation in that persons could sue responsible parties for lost passivecontinue

use values. This clearly had an enormous implication for Exxon since many of the environmental damages resulting from the spill (i.e., damage to wildlife and a pristine, fragile ecosystem) were likely to be passive use values, as opposed to actual active use values, since actual active use of the area was relatively modest.

As a counter to the possibly large size of damage claims being made against Exxon, the company funded a series of studies that basically tried to discredit CVM as a method for valuing losses in passive use values (Cambridge Economics 1992). The government body responsible for issuing regulations on the assessment of damages from oil spills, the National Oceanic and Atmospheric Administration (NOAA), convened a panel of distinguished economists thought to have no vested interest in the CVM method to conduct hearings on the validity of the method in 1992. Members of the panel were Robert Solow, Kenneth Arrow, Edward Leamer, Paul Portney, Roy Radnor and Howard Schuman. The panel's report on their findings was published in January 1993 (Federal Register 15.1.93) and was basically a cautious acceptance of CVM for valuing environmental damages, including lost passive use values. These findings have recently been developed as a set of proposed guidelines for future legally admissible CVM studies, which seem bound to at least influence the future development of the method (Federal register 7.1.94). The principle recommendations were as follows:

1. A dichotomous choice format should be used;

2. A minimum response rate from the target sample of 70% should be achieved;

3. In−person interviews should be employed (not mail shots) with some role for telephone interviews in the piloting stages;

4. WTP, not WTAC, measures should be sought;

5. After excluding protest bids, a test should be made of whether WTP is sensitive to the level of environmental damage;

6. CVM results should be calibrated against experimental findings, otherwise a 50% calibration factor should be applied to CVM results;

7. Respondents should be reminded of their budget constraints; and,

8. Respondents should be given "adequate" information about the environmental change in question.

These measures are, at the very least, a rather strange mixture of theoretically based recommendation and crude "rules of thumb". Taken together, they make contingent valuation a very expensive exercise if implemented in full. It would be unfortunate if all CVM practitioners felt constrained to stick to these guidelines in future research, since the guidelines pose some awkward questions. These include:

Are all "protest" bids giving the same signals and how should these signals be interpreted and utilized in any case?

Can the 50% calibration factor be justified empirically?

How can the weaknesses of the dichotomous choice design format be overcome?

How Should a CVM Be Designed?

Credibility of Hypothetical Market

It is essential that the hypothetical market used be credible and, if possible, rely on routine or previously experienced behavior on the part of respondents. Such credibility can be tested for in focus groups (see below). Credibility as a concern extends to the bid vehicle used (thus respondents must be able to envisage that it could be collected); the bid vehicle should also be, as far as possible, uncontroversial.

Protest Bids

Protest bids (i.e., zero bids for reasons other than a true zero value being placed on the environmental change) should be identified, and reasons for them sought. CVM surveys that suffer from very high levels of protesting (e.g., more than 40% of all respondents) might be challenged as either having used a non−credible hypothetical market, having used a controversial bid vehicle, or having involved a radical change in implied property rights.

Information

Individuals need to be informed about all important aspects of the resource concerned and the nature of the change being considered. However, this information needs to be provided in a manner which ordinary people can comprehend (testing for comprehension is another function of focus groups). There is clearly a trade off between the amount of information provided and the extent to which people can assimilate and understand it within the normal time−span of a CVM survey. No firm guidelines can be provided here. Rather, the researcher must reach a common sense compromise. Focus groups can identify which aspects of the resource or resource change are deemed as most important by the individuals concerned.break

Careful Survey Instrument Development

The key feature of any CVM study is the questionnaire itself. A successful questionnaire design is now recognized to involve three primary steps: i) use of focus groups to find out how respondents identify with the resource in question, what language they use to describe it, and their understanding of draft survey materials; ii) use of verbal protocols, whereby respondents complete draft questionnaires in a "thinking aloud" mode, to enable researchers to understand how people will react to survey questions and how they will form their answers; and, iii) pilot surveys to pre−test aspects such as design of dichotomous choice bid levels.

Choice of Bid Collection Technique

As was mentioned above, CVM researchers can use open−ended, bidding game, payment card, or discrete choice (referendum type) designs. The question of which is preferable is still largely unresolved. Bidding games often suffer from starting point bias, while payment cards suffer from anchoring effects. Open−ended designs may be more difficult for respondents to complete and may encourage more strategic behavior. Since the NOAA study recommends dichotomous choice approaches, much recent attention has been focused on this method.

In a closed−ended referendum, a single payment is suggested to which respondents either agree or disagree (i.e., a yes or no reply). The calculation of mean or median WTP from such responses is more complex than the alternatives above, since all that is revealed to the researcher is whether the respondent is willing to pay a particular sum (known as the offer price). The researcher must then either make assumptions about the underlying distribution of true WTP, or else use non−parametric techniques. Double−bounded referendum models present those respondents who say "no" to the first amount with a lower amount and those respondents who say "yes" to the first amount with a higher amount, thus eliciting increased information (e.g., Carson *et al* . 1994). Finally, uncertainty over valuation can be allowed for in both open and closed−ended valuation methods (e.g., Ready *et al* . 1999).

Discrete choice approaches have consistently produced higher estimates of value than open−ended approaches due to the phenomena of "yea−saying" and preference uncertainty. In addition, they require larger sample sizes, while the calculation of mean WTP is influenced by the functional form of the logit equation, the extent of any truncation used, and the design of bid levels (number and amounts). Finally, there is some evidence that discrete choice approaches suffer from higher hypothetical market bias than open−ended approaches, although strategic behavior is likely to be greater in open−ended formats, which may also result in a greater degree of non−response.

Means of Sample Collection

CVM responses may be collected by mail shot, face−to−face surveys or telephone surveys. Of these three alternatives, telephone surveys are usually considered least desirable. Face−to−face surveys are recommended by the NOAA panel, but the context in which the survey is conducted is important (e.g., shopping malls versus people's homes). Such surveys are also relatively expensive. Mail shots are prone to low response rates and non−response bias, and the order in which the questions are answered is hard to control. However, mail shots can be very cost effective. Some surveys comparing mail shot with face−to−face questioning have found no significant differences in WTP, so long as high response rates can be achieved (i.e., greater than 40%).

Tests of Sensitivity to Scope

It is important to show that WTP is sensitive to the scale of the environmental change involved, where "scale" is defined in accordance with respondents' perceptions. Thus, WTP to protect one coral reef should be less than WTP to protect all coral reefs, although marginal WTP is expected to decline. The NOAA guidelines also recommend such tests of scope.

Tests for Reliability and Validity

Tests for reliability and validity should be incorporated in every CVM. These tests will involve some or all of the following:

Convergent validity test . Does CVM produce similar results for a given resource change as alternative valuation techniques?

Theoretical construct validity test . Can WTP responses be explained statistically to a satisfactory level and in a way in accordance with theoretical expectations? For example, does WTP increase with income? The alternative hypotheses here are that WTP measures are random numbers and/or are not in accord with economic theory.

Test−retest criterion . If the CVM survey is repeated on a different sample drawn from the same population, do statistically different results emerge?

Calibration . Can CVM results be related to actual payments for the resource in question?break

Debriefing . Have respondents understood the questions asked of them? Have they valued the same change in resource allocation that the researcher wished?

Special Features of CVM in Developing Country Applications

Many applications of CVM now exist in developing countries (for a survey, see Wasike 1996). These may be seen to have resulted from both academic interest in whether CVM could be transferred to a developing country context, and from policy and project needs on the part of agencies such as the World Bank and the United States Agency for International Development (USAID). Examples of developing country applications of CVM include Adger *et al* . (1994) on the value of Mexican forests, Navrud and Mungatana (1994) on the recreational value of wildlife viewing in Kenya, and Swallow and Wouldyalew (1994) on tsetse fly control in Ethiopia. In addition, many authors have applied CVM in developing countries to issues of drinking water supply. These include Briscoe (1990) for Brazil, Whittington *et al* . (1990) for Haiti, and McPhail (1994) for Tunisia.

Issues emerging from these applications include:

Low income levels on the part of respondents . Income is often strongly related to WTP in these surveys, yet income levels are often low. Some authors have experimented with WTP denominated in units other than money. Swallow and Woudyalew (1994) used willingness to contribute labor hours, while Shyamsundar and Kramer (1996) used rice as a means of payment.

Irregularity of income flows . In subsistence and other types of farming, income flows may be very irregular. Combined with imperfect markets for credit, this means that the temporal nature of payments in a CVM may be important (Wasike and Hanley 1998).

Contextual impacts . These include the presence of listeners during surveys and "prestige" effects. Whittington *et al* . (1993) found statistically significant effects on WTP of such contextual factors in Ghana.

Cultural views on environmental values . The western notion of CBA as a means of taking decisions, and of individual preferences as the measure of environmental values, may fit poorly with prevailing cultural views and values.

However, the consensus emerging from the growing number of CVM applications in developing countries is that, provided the analysis is sufficiently attuned to local circumstances, the method can be successfully applied.break

Annex C— Résultats des Recherches sur les Modèles de Soutien et Orientations Futures

Résumé rédigé par Kent Gustavson et Richard M Huber

Ce chapitre résume les résultats d'une recherche de cinq ans, financée par le Comité de recherche de la Banque mondiale et par des dons provenant des Pays−Bas, de la Suède et du Canada gérés par la Banque mondiale. La recherche a été réalisée sous la direction de Richard Huber (Banque mondiale). Les personnes suivantes y ont aussi participé; ce sont, par ordre alphabétique: RolfBak (Institut néerlandais de recherche maritime), Steve Dollar (Université d'Hawaï), Kent Gustavson (Bureau d'étude Gustavson pour les ressources écologiques), Erik Meesters (Institut néerlandais de recherche maritime), Frank Rijsberman (Analyse de ressources), Jack Ruitenbeek (Bureau d'étude HJ Ruitenbeek de ressources), Susie Westmacott (Analyse de ressources).

Les écosystèmes de récifs coralliens à travers le monde décroissent à un rythme inquiétant: ils sont autant menacés par le stress anthropique localisé que par des phénomènes régionaux et mondiaux, comme l'effet de serre (Bryant *et coll* . 1998; Jameson *et coll* . 1995; Hodgson 1999; Hoegh−Guldberg 1999; Wilkinson 1998). Certains facteurs semblent cependant encourageants: plusieurs récifs coralliens sont isolés, d'autres sont gérés de manière efficace, et ces écosystèmes ont la capacité potentielle de se rétablir (Wilkinson 1998). Mais il est évident que la gestion efficace de la zone côtière intégrée (ICZM en anglais) est nécessaire pour empêcher un appauvrissement important. Ce chapitre résume les résultats de la recherche sur la création de modèles de soutien aux décisions pour la gestion des récifs coralliens dans la région des tropiques en voie de développement. La stratégie de dissémination y est décrite, et des commentaires sont offerts pour les applications éventuelles et orientations futures de recherche.

ICZM dirige les activités d'au moins deux secteurs de planification, d'élaboration et d'application de projets. Plus formellement, il consiste en « . . . la planification et la gestion intégrées des ressources et de l'environnement côtiers par des moyens reposant sur les interconnections physiques, socio−économiques et politiques, au sein des systèmes dynamiques côtiers . . . » (Sorensen 1997). Ou encore, «ICZM est un processus d'administration, comprenant les structures légale et institutionnelle nécessaires pour assurer que les projets de développement et de gestion pour les zones côtières sont intégrés aux objectifs environnementaux (sociaux inclus), et sont élaborés de façon à faire participer les personnes concernées. Le but de ICZM est de tirer le plus grand parti des zones côtières, tout en minimisant les conflits et effets néfastes des activités sur ces mêmes zones, sur les ressources et sur l'environnement.» (Banque mondiale 1996, p. 2). Des lignes directrices et des procédures commencent à apparaître visant le développement d'ICZM (Bower *et coll* . 1994; Chua 1993; Clark 1995; Pernetta et Edler 1993; Sorensen 1997; Banque mondiale 1993a, 1996).

L'intégration est un élément clef dans ICZM—en particulier, l'intégration horizontale à travers divers secteurs économiques et agences de gestion dans la planification et l'application (Clark 1995; Sorensen 1997). Les activités côtières doivent être considérées conjointement, à cause de leur interdépendance et de leur impact prévu cumulatif et non−additif. Mais comment considérer ensemble plusieurs secteurs économiques et activités humaines? Comment intégrer un maintien des écosystèmes côtiers soutenant les activités économiques, directement et indirectement? Quelle devrait être le processus pour établir les activités devant être authorisées dans la zone côtière, comment devraient−elles être élaborées et mises en œuvre, et que doit être l'intensité de l'activité authorisée? Sur quelles bases les conflits éventuels entre les usagers de la zone côtière devraient−ils être réglés? Pour pouvoir répondre à ces questions, il faut considérer plusieurs paramètres, critères, et divers ensembles de valeurs.

Les modèles de soutien aux décisions économiques écologiques peuvent jouer un rôle important. Parmi eux, il y a ceux qui admettent la possibilité d'atteindre une solution de gestion efficace d'un point de vue économique, tout en considérant explicitement les limites qui doiventcontinue

être imposées sur le niveau et le genre d'activité économique, à cause des caractéristiques et de la capacité du milieu naturel. Pour ICZM, ces modèles de soutien doivent aussi s'adapter à l'information sur le contexte socioculturel de l'environnement de gestion, lequel joue un rôle capital dans la création de principes directeurs.

Quelles sont les caractéristiques d'un modèle de soutien aux décisions? Premièrement, il doit être capable de répondre aux questions spécifiques et pertinentes d'orientations. Pour faciliter l'élaboration et la création d'un tel modèle, il faudrait pouvoir compter sur une base existante de recherche déjà effectuée sur le sujet. Ruitenbeek *et coll* . (1999a, 1999b) ont remarqué que le manque d'informations sur l'écologie des récifs coralliens (c.−à−d. sur les relations et les liens fonctionnels) et les caractéristiques des économies qui ont un impact sur ces récifs ralentissent la création de módeles de soutien aux décisions économiques écologiques. La majorité de l'information disponible n'est pas directement «pertinente à la politique» et, dans ce contexte, ne facilite pas la tâche de prise de décision ou directement la création d'un modèle. Deuxièmement, un modèle doit être compris et utilisé directement par le groupe visé. La communication des données doit être relativement aisée, les essais faciles à faire, et les résultats faciles à interpréter. Troisièmement, on doit distinguer entre l'utilisation du modèle destiné surtout à la recherche scientifique et les modèles utilisés surtout comme information pour la prise de décision et les politiques—les modèles avec des constructions très expérimentales ne doivent pas être utilisés comme outils de soutien aux décisions. La théorie sur laquelle se basent les modèles de soutien aux décisions doit être relativement solide. Par exemple, en ce qui concerne l'utilisation de modèles écologiques destinés à être utilisés pour prendre des décisions, Friedland (1977) remarque que «l'objectif principal n'est pas la découverte de nouvelles vérités, mais la collecte et l'intégration de données existantes et leur présentation en une forme utile pour une prise de décision». Ceci a des conséquences directes sur le genre de modèle approprié.

Finalement, les modèles de soutien aux décisions doivent être flexibles aux changements des éléments des données, des relations spécifiées dans le modèle, et à la création de solutions de rechange ou de scénarios considérés par le modèle. Aussi, il est important que les besoins des usagers soient pris en considération. Un modèle qui utilise des données qui ne s'appliquent plus à un lieu particulier, dont les relations économiques écologiques sous−jacentes ne sont plus correctes, ou qui ne permet plus le changement de solutions de rechange de développement ou de scénario, ne sera pas utile à long terme.

Résultats des Projets de Modélisation

Le travail de recherche a commencé en 1995 selon deux grandes lignes concernant les récifs coralliens dans la région des tropiques en voie de développement: (i) la modélisation rentable d'interventions gestionnaires (c.−à−d. l'offre de la biodiversité en tant que bien économique); et (ii) la détermination de la valeur du système marin (c.−à−d., la demande pour la biodiversité). Essentiellement, la modélisation à moindre coût est recherché pour identifier la variation des prix pour les interventions, afin d'améliorer les conditions des récifs coralliens, où les effets de diverses politiques d'interventions et activités économiques sont liés à la santé des récifs et aux coûts associés aux améliorations (Brown *et coll* . 1996; Huber et Jameson 1998a; Huber *et coll* . 1994, 1996; Meesters 1995; Meesters et Westmacott 1996; Meesters *et coll* . 1995, 1996a, 1998; Ridgley et Dollar 1996; Ridgley *et coll* . 1995; Rijsberman 1995; Rijsberman et Westmacott 1996; Rijsberman *et coll* . 1995a; Ruitenbeek *et coll* . 1999a, 1999b; Westmacott 1996; Westmacott et Rijsberman 1997; Westmacott *et coll* . 1995). Le modèle de détermination de la valeur du système marin avait pour but d'identifier les bénéfices qui peuvent être réalisés en soutenant ou améliorant l'état des récifs (Gustavson 1998; Huber et Ruitenbeek 1997; Putterman 1998; Ruitenbeek et Cartier 1999; Spash *et coll* . 1998).

Les grandes lignes de la recherche consistaient à aider les décideurs dans la gestion et la protection des récifs coralliens (Huber et Ruitenbeek 1997; Huber *et coll* . 1994). L'établissement d'une méthodologie de coût−bénéfice appropriée à être utilisée sur les systèmes de récifs coralliens et les tropiques en voie de développement, et sur les systèmes marins en général, contribuera à des interventions politiques et institutionnelles adéquates pour faciliter une utilisation des récifs économiquement efficace, tout en considérant les impacts sur et le rôle des écosystèmes qui les soutiennent. Un tel groupe d'analyse de coût−bénéfice (ACB) est représenté par l'intégration des modèles de rentabilité et de détermination de valeur (Ruitenbeek et Cartier 1999). Trois sites ont été sélectionnés comme étude de cas pour tester la méthodologie: (i) Curaçao, les Antilles néerlandaises; (ii) les Maldives; et (iii) Montego Bay, Jamaïque.

Corail−Curaçao

Rijsberman et Westmacott (1996; cf. aussi Meesters 1995; Meesters *et coll* . 1996a; Rijsberman *et coll* . 1995a; Westmacott *et coll* . 1995) ont élaboré un modèle d'analyse de rentabilité pour la gestion des récifs coralliens et la protection de la côte sud de Curaçao. Le modèle decontinue

soutien aux décisions a été créer pour faciliter la communication entre les intéressés sur les orientations de développement et les stratégies de gestion environnementale ; l'analyse des impacts sur la santé des récifs coralliens des créations envisagées à travers les décharges des eaux résiduaires et des sédiments, intégrant ainsi l'utilisation de la terre, le tourisme et la planification de la conservation ; et l'analyse de la rentabilité des interventions gestionnaires ayant pour but de maintenir la santé des récifs coralliens. Le modèle utilise une interface structurée d'ordinateur.

Les résultats des trois scénarios (un scénario de création de référence statu quo et deux choix de scénario de croissance) indiquent qu'il est très probable que Curaçao connaîtra des réductions importantes dans la santé et l'abondance des récifs coralliens au cours des dix prochaines années. Néanmoins, la modélisation indique aussi que les interventions ayant trait aux stratégies de gestion environnementale peuvent freiner cette tendance et, dans certains cas, mener au rétablissement des récifs au−delà de leur état actuel. Les interventions suggérées incluent des combinaisons de traitement des eaux usées, une évacuation appropriée des déchets, et des réductions de la pollution des raffineries ; l'application de différents moyens pour préserver les plages et la réduction des déchets des industries et du transport maritime n'étaient pas efficaces (Rijsberman et Westmacott 1996). Par contre, Rijsberman et Westmacott ont aussi trouvé que les résultats de la modélistion peuvent êtres particuliers à l'échelle spatiale examinée, et que ces dernières interventions peuvent en effet être rentables et appropriées dans un contexte local plus petit.

Rijsberman et Westmacott (1996) soulignent que l'utilité d'un outil de modélisation ne peut être démontré qu'à travers un programme qui encourage une coopération étroite entre ceux qui sont concernés par la mise en œuvre du scénario et par la procédure de prise de décisions. Corail−Curaçao nous permet d'ordonner les mesures et d'explorer la formulation de diverses combinaisons de mesures afin d'atteindre un objectif spécifique pour la couverture et la diversité des récifs. Par exemple, pour atteindre une couverture de 14% et une diversité de 50% (comme indiqué par le modèle), il faudrait un investissement initial de 310 millions de NAF, avec un coût annuel opérationnel de 6 million de NAF (Rijsberman et Westmacott 1996).

Corail−Maldives

Westmacott et Rijsberman (1997 ; cf. aussi Brown *et coll* . 1996 ; Meesters et Westmacott 1996 ; Rijsberman 1995 ; Rijsberman et Westmacott 1996 ; Westmacott 1996 ; Westmacott et Rijsberman 1997) ont élaboré un modèle d'analyse de rentabilité pour la gestion et la protection des récifs coralliens au nord et au sud de Male, capitale des Maldives. En tant que modèle élaboré en même temps que celui de Corail−Curaçao, le but était d'examiner si un modèle adapté aux Maldives (Corail−Maldives) pourrait servir comme un outil utile de soutien aux décisions. Westmacott et Rijsberman (1997) décrivent le modèle et les résultats d'analyses préliminaires.

Ainsi qu'avec Corail−Curaçao, le modèle de Corail−Maldives était conçu pour permettre aux décideurs d'établir la rentabilité relative des diverses interventions de gestion environnementale pour diverses options de développement économique dans le cadre d'améliorations obtenues dans la santé des récifs (c.−à−d., utilisant des index de couverture et rugosité de récifs coralliens comme mesures provisoires). Les impacts des scénarios peuvent être des indicateurs économiques, sociaux et environnementaux qui sont sélectionnés dès le début des analyses par l'utilisateur du modèle. Les priorités des lignes directrices et les choix possibles de gestion ont été identifiés après des discussions avec des agences gouvernementales. Étant donné la nature des impacts sur les récifs coralliens dans les Maldives, les interventions de gestion ont pour objectif principal de minimiser les dégâts physiques (Westmacott et Rijsberman 1997). Westmacott et Rijsberman (1997) illustrent l'utilisation du modèle avec des exemples.

Westmacott et Rijsberman (1997) constatent qu'il existe un éventail d'indicateurs qui peuvent être utilisés pour décrire la réussite ou la défaite éventuelles d'une stratégie de gestion de zones côtières bien que le modèle soit quelque peu flexible, l'ensemble des indicateurs de gestion des zones côtières qui peuvent être sélectionnés et examinés par l'usager est limité par nécessité. De plus, l'utilisation de mesures rentables qui ne sont liées qu'aux variations de la santé des récifs coralliens peut omettre d'autres stratégies très importantes pour le succès d'un programme particulier d'ICZM (par ex., les problèmes de santé publique). Les résultats de scénarios de modélisation pour le soutien aux décisions pourraient être mis dans le contexte de buts et exigences sociaux dans la formulation de projets de création et de gestion. Ainsi qu'avec Corail−Curaçao, le modèle peut ne pas bien refléter les conditions locales à une échelle spatiale en−dessous de celle qui est incorporée dans les éléments du modèle.

La Détermination de la Valeur des Bénéfices des Récifs Coralliens

Pour arriver à une valeur économique totale (VET), les études d'évaluation économique des systèmes naturelscontinue

font souvent la distinction entre les valeurs d'utilisation et les valeurs de non−usage, ainsi qu'entre les valeurs d'utilisation directe et les valeurs d'utilisation indirecte. Ces distinctions reflètent souvent la méthode d'estimation. Lors de la spécification de la structure d'évaluation des récifs coralliens pour le Parc marin de Montego Bay, il était beaucoup plus utile de différencier trois classifications d'évaluation de biodiversité marine : (i) les méthodes d'évaluation de production orientées vers l'offre (c.−à−d., la contribution de fonctions de production des systèmes marins à la valeur économique) ; (ii) les méthodes d'évaluation d'utilité orientées vers la demande (c.−à−d., la contribution des systèmes marins sur l'utilité d'un individu ou de la société) ; et (iii) les méthodes d'évaluation de récupération de rente orientées vers le profit (c.−à−d., la contribution des systèmes marins à travers la distribution de valeur d'utilisation comme rente récupérée, profits, ou valeur ajoutée ; Huber et Ruitenbeek 1997 ; Ruitenbeek et Cartier 1999). Pour la dernière catégorie, la contribution potentielle de la biodiversité des récifs à travers la création d'une entreprise de bioprospection à été examinée.

Fonctions de Contribution de la Production Parc Marin de Montego Bay

Les valeurs d'utilisation locales furent estimées par Gustavson (1998) pour deux larges catégories d'utilisation—les pêcheries à proximité de la côte et le tourisme. Les valeurs d'utilisation indirecte associée à la protection côtière ont aussi été estimées. Ces utilisations locales des eaux du Parc marin de Montego Bay étaient non seulement plus importantes pendant l'application au dernier site d'étude, mais aussi identifiées comme une haute priorité pour la politique générale. Les valeurs rapportées par Gustavson montrent à quel point la contribution des productions provenant des récifs risque être perdu si les efforts de conservation ne sont pas adéquats.

Les services de tourisme de Montego Bay comprennent les hôtels, les services de la restauration, les divertissements (y compris les sports et attractions nautiques indépendants), le transport, les achats, et autres services divers. Les estimations de la valeur actuelle nette (VAN) associée au tourisme sont de l'ordre de 210 millions de dollars US (à un taux d'escompte de 15%) à 630 millions de dollars US (à un taux d'escompte de 5%) en 1996. Les estimations de VAN en 1998 associées avec la pêche sont de 1,66 million de dollars US à 7,49 millions de dollars US (monnaie de base : dollars de 1996 ; en utilisant les extrêmes, respectivement, de valeurs nettes annuelles et un taux d'escompte de 5% ; les valeurs d'escompte de 10% et 15% sont dans cette intervalle). La VAN du total des terres en danger d'érosion si la fonction protectrice des récifs est compromise, basé sur les 125 hectares vulnérables, est estimée à 65 millions de dollars US (en dollars constants de 1996). La valeur médiane de VAN de toutes les valeurs d'utilisation locale pour le Parc marin de Montego Bay est d'à peu près 381 millions de dollars US. En prenant une superficie totale de récif de 42,65 hectare comme référence, ceci revient à 8,63 millions/ha de dollars US ou 0,893 million ha1 année1 sur une base annuelle (avec un taux d'escompte de 10%).

Contributions à l'Utilité — Parc Marin de Montego Bay et Côte Sud de Curaçao

Spash *et coll* . (1998) ont utilisé la méthode des «enchères» (CVM) pour estimer les valeurs d'utilité associées à la biodiversité des récifs coralliens à Montego Bay en Jamaïque et le long de la côte sud du Curaçao. L'étude est particulièrement intéressante, parce qu'elle examine les valeurs d'utilité associées à une ressource environnementale marine (c.−à−d., la qualité des récifs coralliens), lesquelles avaient toujours été négligées dans le passé. De plus, la recherche a aussi contribué à déterminer les sources de parti pris quant aux préférences lexicographiques qui surgissent quand un répondant est réticent à accepter un arbitrage pour la perte d'un bien ou un service (c.−à−d., en refusant de faire des choix, ils n'agissent pas selon une théorie économique). Pour ces offres nulles, des distinctions ont été faites entre ceux qui manquent de moyens financiers, ceux qui considèrent les améliorations inutiles, ceux qui préfèrent dépenser l'argent sur d'autres biens ou services, ou ceux qui protestent d'avoir à faire un tel choix. Parmi ceux qui n'offraient aucune offre et donc faisaient preuve de parti pris, étaient inclus les resquilleurs: ils pensent que le paiement n'est pas une solution adéquate, n'ont pas confiance en l'institution proposée, ou rejettent le mécanisme de paiement. Le sondage a aussi exploré l'étendue de positions morales, basées sur le droit, qui seraient compatible avec les préférences lexicographiques. Pour faciliter la comparaison avec les résultats des études sur l'utilisation locale et les évaluations de bioprospection dans Montego Bay, la CVM a aussi été formulée pour séparer les valeurs d'utilisation directe et celle d'utilisation indirecte et de non−usage.

Les répondants étaient invités à contribuer à des fonds fiduciaires qui seraient gérés par un parc marin, afin d'augmenter la biodiversité à l'intérieur du parc. Le paiement serait fait une fois par an pendant cinq ans, et augmenterait le couvert de récif coralliens de 25%. L'analyse de la courbe d'offre (c.−à−d., l'analyse «tobit» et une estimation de maximum de vraisemblance) a four−soft

ni de l'information sur les variables qui déterminent la variation de la disposition à payer (DAP) et a perfectionné l'estimation des DAP. Pour les moyennes des échantillons, la DAP était de 2,08 $ US par personne à Curaçao, et 3,24 $ US par personne en Jamaïque (Spash *et coll* . 1998). La différence entre les deux est expliquée par le mélange de touristes et de résidents, les Jamaïcains étant disposés à payer presque deux fois plus que leurs homologues à Curaçao. En utilisant le profil d'un visiteur et d'une population locale typique et un taux d'escompte de 10%, ceci se traduit en une valeur approximative de DAP de 4,5 million $ US à Curaçao et 20 million $ US à Montego Bay (Spash *et coll* . 1998).

Contributions Éventuelles de Bioprospection—Parc Marin de Montego Bay

Le modèle pour estimer la bioprospection s'est concentré sur les revenus moyens net, utilisant les informations localisées des coûts pour la Jamaïque, ainsi que les valeurs de bénéfices et de taux de succès basées sur l'information propriétaire pour les produits marins dans les Caraïbes (Ruitenbeek et Cartier 1999). Les hypothèses du modèle paramétrique comprenaient la caractéristique des relations espèces/régions et la relation de partage de revenus entre les institutions (c.−à−d., un partage conditionnel du bénéfice net et un tarif d'échantillon à niveau fixe). L'analyse de sensibilité a exploré les effets des variations des paramètres du modèle sur la valeur estimée, y compris les variations dans la surface totale de substrat de récifs à couvert vivant disponible et la spécification des relations espèces/région comme co−déterminants du nombre attendu d'échantillons disponibles pour tester. D'autres options pour le modèle incluent un tarif de sondage fixe seulement, des parts de revenu mélangés, des coûts élevés de recherche−développement, des «taux de frappe» bas, et un programme de sondage raccourci. Une fonction d'avantage marginale qui reliait la valeur ou le «prix» de biodiversité marine à l'abondance de récif coralliens fut dérivé.

Une valeur de «cas de base» de 70 millions $ US a été calculée pour les récifs du Parc Marin de Montego Bay, de laquelle à peu près 7 millions $ US (c.−à−d., 10%) pourraient vraisemblablement être récupérés par la Jamaïque sous forme de redevances ou d'arrangements de rente (Ruitenbeek et Cartier 1999). La valeur marginale de bioprospection de récifs a été évaluée à 530 $ US/ha ou encore 225 000 $ US par pourcentage de variation de l'abondance de récifs coralliens (correspondant à un prix de planification local jamaïcain de 22 500 $ US par pourcentage de variation de l'abondance de récif corallien).

L'Identification d'Interventions à Moindre Coût—Parc Marin de Montego Bay

Comme pour les modèles de Corail−Curaçao et Corail−Maldives, Ruitenbeek *et coll* . (1999a ; cf. aussi Ridgley *et coll* . 1995 ; Ridgley et Dollar 1996 ; Ruitenbeek *et coll* . 1999b) ont appliqué une méthodologie de logique de l'incertain pour identifier les interventions à moindre coût qui mèneraient à une augmentation de l'abondance des récifs coralliens dans l'enceinte du Parc marin de Montego Bay. Les procédures de logique de l'incertain sont utilisées dans un modèle d'impact écologique sur les récifs coralliens pour générer une surface dose−réponse complexe qui émule la relation entre l'abondance des récifs coralliens et divers intrants dans le contexte de l'environnement marin abiotique. Ceci est relié à un modèle économique non linéaire qui décrit les activités économiques actuelles et futures dans huit secteurs, dans les interventions de politique et technique, et dans les frais de pollution à Montego Bay. L'optimisation nous donne des aperçus sur les moyens les plus rentables pour protéger les récifs coralliens pour divers niveaux recherchés de qualités de récifs.

Á Montego Bay en Jamaïque, une augmentation de jusqu'à 20% de l'abondance de récifs coralliens peut être atteinte avec l'utilisation de mesures appropriées à un coût réel de 153 millions $ US sur 25 ans (Ruitenbeek *et coll* . 1999a). Les mesures spécifiques de politiques considérées incluaient l'installation d'un piège de sédimentation sur la Rivière de Montego, la plantation d'arbres sur la crête élevée, l'installation d'un système d'aération de déchets, celle d'un centre de traitement à grande échelle, la vulgarisation agricole pour fournir des technologies qui réduisent les déchets, l'installation d'un émissaire d'évacuation et d'une station de pompage, l'amélioration de la récupération des ordures ménagères, et l'application d'une taxe hôtelière. Certaines interventions étaient relativement rentables. Par exemple, la récupération d'ordures ménagères, l'installation d'un émissaire d'évacuation et l'utilisation d'un piège de sédimentation sur la Rivière Montego imposeraient un coût actuel de 12 millions $ US et auraient pour conséquence d'améliorer le couvert de récif corallien par plus de 10% (Ruitenbeek *et coll* . 1999a).

Une démonstration clé de la recherche était que les méthodologies conventionnelles pour mesurer la rentabilité peuvent aboutir à des solutions qui ne sont pas optimales quand les politiques sont appliquées à des systèmes complexes. En effet, les analyses de rentabilité ont tendance à supposer que les interventions individuelles sont distinctes et indépendantes, et que les bénéfices peuvent être séparés des coûts (souvent quand lescontinue

bénéfices ne peuvent pas être définis). Quand il s'agit de systèmes très complexes tels que les récifs coralliens, les synergies, les rétroactions et autres interdépendances entre les interventions individuelles et le niveau de santé qui en résulte des récifs coralliens peuvent invalider les recommandations des interventions d'une politique évaluée individuellement qui serait appliquée d'une manière séquentielle. Par exemple, le reboisement était l'une des interventions optimales pour une amélioration des récifs coralliens de l'ordre de 14% et 20%, mais ne figurait pas parmi les mesures optimales pour une amélioration de 15% ou 16% (Ruitenbeek *et coll* . 1999a). Ruitenbeek *et coll* . (1999a) ont remarqué que cela signifie que les objectifs de santé de récifs coralliens, en ce qui concerne les bénéfices secondaires, doivent être établis avant d'appliquer des politiques d'intervention.

Intégration des Résultats de Montego Bay pour un Niveau d'Intervention Efficace

La synthèse des diverses études d'évaluation de récifs coralliens pour le Parc marin de Montego Bay permet d'obtenir une fonction de valeur totale et de bénéfice marginal (ou prix) (Ruitenbeek et Cartier 1999). Pour obtenir la fonction de bénéfice marginal, reliant les prix aux variations d'abondance de récif corallien, il fallait ajouter d'autres hypothèses ayant trait au lien entre les catégories de valeur et l'abondance ou la qualité de récifs coralliens. En particulier, on présume qu'il existe une relation linéaire entre la qualité des récifs et les valeurs d'utilisation locale et les valeurs d'utilité de non−usage. Il est très probable que cela ne soit pas justifié, mais présumer une relation moins compliqué n'est pas non plus justifiable avec les données actuelles. Seuls les résultat du modèle d'évaluation de bioprospection (Ruitenbeek et Cartier 1999) permettaient la spécification d'une forme fonctionnelle différente. Les valeurs marginales nettes, comme le notent Ruitenbeek et Cartier (1999), seront probablement surestimées dans certains cas et sous−estimées dans d'autres.

Le bénéfice total attribué aux récifs coralliens du Parc marin de Montego Bay est évalué à 470 millions $ US ; chaque variation de 1% génère à peu près un bénéfice marginal de 10 millions $ US, ou encore le prix marginal des récifs coralliens est d'à peu près 23 million $ US /ha (Ruitenbeek et Cartier 1999). La majorité de la valeur est attribuée au tourisme. La protection côtière et les bénéfices d'utilité de non−usage contribuent aussi, mais à un moindre degré. Les pêcheries existantes et l'élaboration éventuelle d'un programme de bioprospection ont un effet négligeable sur les valeurs marginales (Ruitenbeek et Cartier 1999).

Il est possible d'atteindre une optimisation globale en utilisant la fonction de coût marginal élaborée dans l'étude de l'intervention à moindre coût pour le Parc marin de Montego Bay (Ruitenbeek *et coll* . 1999a), conjointement avec les approximations de bénéfice marginal. Une amélioration d'abondance des récifs coralliens de 13% est suggérée par Ruitenbeek et Cartier (1999 ; c.−à−d., d'un couvert approximatif de 29% évalué à partir des conditions d'équilibre du modèle cf. Ruitenbeek *et coll* . 1999a à un couvert de 42%), nécessitant des dépenses nettes de 27 millions $ US. Les interventions nécessaires entraîneraient l'installation de pièges de sédimentation, l'aération des déchets, l'installation d'évacuation de déchets, l'application d'une récupération améliorée de déchets solides, et l'application de stimulants économiques pour améliorer la gestion des déchets dans l'industrie hôtelière.

Une analyse de sensibilité suggère que cette optimisation est assez résistante aux variations d'approximations des bénéfices économiques nets—les bénéfices devraient être augmentés de 275 millions $ US, ou diminués de 300 millions $ US, pour que l'amélioration visée de la qualité de récifs coralliens augmente de plus de 20% (Ruitenbeek et Cartier 1999).

La Valeur Humaine de l'Utilisation des Récifs Coralliens

En plus de l'application de l'analyse de rentabilité, l'évaluation de ressources ou CBA, il est important que les décideurs considèrent d'une manière compréhensive et systématique le contexte social, culturel et économique de création de politiques et de changement écologique. Un tel contexte ou information sur la «structure humaine» ne font pas traditionnellement partie d'une telle analyse, dans laquelle des indicateurs ou mesures monétaires quantitatives sont souvent appliqués dans un environnement de prise de décision à «évaluation automatique», réduisant ainsi l'interprétation approfondie du niveau approprié ou optimal, et des types d'interventions et de politiques nécessaires.

Les méthodologies d'évaluation économique appliquées dans ces projets étaient destinées à énumérer les bénéfices totaux reçus actuellement des récifs coralliens, à travers les contributions de fonction de production et d'utilité humaine (ainsi que de rentes ou redevances éventuelles provenant de la création d'entreprises de bioprospections marines). En théorie, de tels bénéfices monétaires refléteront l'ensemble local de valeurs. Néanmoins, réduire l'information sociale, culturelle et économique en une seule valeur métrique résulte en une grande perte. Cette perte a été démontrée par la mise au point et l'application d'une méthodologie d'évaluationcontinue

socio−économique rapide pour fournir une explication sur les groupes utilisant les récifs coralliens dans le cadre d'étude du site à Montego Bay (Bunce et Gustavson 1998a; Bunce *et coll.* 1999). Une telle information faciliterait l'adaptation de stratégies de gestion selon les profils d'utilisation des groupes, les priorités gestionnaires, et les ressources disponibles. En gros, l'information sur la «structure humaine» aide à identifier une solution économiquement rentable, aussi viable d'un point de vue social que culturel. Cette information a démontré une utilité dans l'élaboration de politiques et programmes efficaces pour le Parc marin de Montego Bay (Bunce *et coll.* 1999; cf. aussi Huber et Jameson 1998c).

Contexte d'Orientation et Conseils

Étude de Cas — La Récupération de Rente Provenant de l'Utilisation des Récifs Coralliens de Montego Bay

La récupération d'au moins une partie de la rente, provenant d'utilisations directes, pour payer la gestion nécessaire et l'amélioration éventuelle de la ressource est un aspect particulièrement intéressant pour les autorités du Parc marin de Montego Bay, et pour toute autorité de systèmes marins côtiers. En d'autres termes, il existe des coûts sociaux associés à la conservation et la gestion de la ressource qui doivent être payés par les usagers.

En tant que composante de l'étude d'évaluation d'utilisation locale (Gustavson 1998), les frais gouvernementaux actuels, qui récupèrent peut−être une partie de la rente, ont été étudiés. Imposer des frais d'usage ne fait pas actuellement partie de la politique du Parc marin de Montego Bay (un mécanisme reconnu pour la récupération de la rente), bien qu'elle soit présente dans les étapes initiales. D'autres frais gouvernementaux, liés spécifiquement au tourisme ou aux activités liés aux pêcheries, peuvent récupérer une portion du surplus du consommateur ou du producteur, mais ne sont pas forcément destinés à ce but. Sont inclus les frais de permis d'affaires, de permis de pêcheries, de plage, et les taxes de départ de touristes.

En principe, les frais de permis sont perçus pour payer les coûts de régulation et d'administration des activités ou des affaires du gouvernement. Aucune information n'est disponible sur le coût actuel pour réguler les activités relatives aux récifs, mais il est très probable que ces coûts ne soient pas perçus selon le barème des frais en vigueur. En effet, les frais de plage en place étaient généralement bas et, bien qu'ils varient plus ou moins avec le genre d'utilisation, ne sont pas liés au niveau de surplus de producteurs. Aucun de ces fonds n'est explicitement destiné à financer la gestion du Parc marin de Montego Bay. Il n'existe pas d'autres frais gouvernementaux ou d'agence gestionnaire qui sont liés explicitement aux activités de tourisme ou de pêcherie dans la région. Les impôts de bénéfices des sociétés, ou l'impôt sur les bénéfices particuliers dans le cas de pêcheurs ou bénéfices distribués individuellement des entreprises de tourisme, peuvent aussi récupérer une partie de la rente. Néanmoins, les taxes sont payées à la perception générale du gouvernement et par conséquent ne sont pas disponibles pour l'utilisation dans la gestion du parc marin. Il est important d'encourager la tendance actuelle du Parc Marin de Montego Bay à instaurer des frais d'utilisation.

Étude de Cas — Conseil pour les Institutions sur l'Orientation de la Bioprospection en Jamaïque

Putterman (1998) donne des recommandations particulières sur la politique et le renforcement institutionnel en ce qui concerne l'incorporation de l'utilisation de ressources génétiques dans ICZM en Jamaïque, un outil potentiellement puissant pour la conservation et le développement économique. La diversité génétique ou moléculaire, une mesure de diversité biologique dans une espèce, peut engendrer de nouveaux produits pharmaceutiques et industriels, et de nouvelles variétés agricoles. Plusieurs stratégies pour la collaboration de recherche peuvent être employés en tant que stratégie réduisant le risque pour optimiser la capacité de découvrir de nouveaux produits chimiques ou gènes prometteurs; de même, plusieurs mécanismes existent pour partager les bénéfices et options pour la compensation (cf. Putterman 1998). Actuellement, il n'existe pas de politique jamaïcaine pour contrôler l'accès aux ressources génétiques, comme le remarque Putterman (1998). Une révision des institutions et politiques jamaïcaines aboutit aux recommandations suivantes:

Pour élaborer un ensemble d'options de politiques pour les ressources, il faut incorporer les obligations dans la Convention sur la diversité biologique et la Convention des Nations Unies sur la Loi de la mer; il faut aussi tenir compte de l'effet de l'élaboration de politiques sur les activités du secteur privé;

Réglementer à l'avance l'accès aux ressources génétique par le biais de permis et de contrats qui définiraient les droits à ces ressources avant qu'il n'y ait prélèvement ou exportation d'échantillons;

Établir des lois de *suis generis* (originelle) pour les propriétés tangibles et savoir traditionnel, afin de définir qui a le droit de participer aux négociations de contrats de transfert de ressources génétiques ou savoir traditionnel, et d'en tirer parti;

Développer a priori des procédures de consentement, afin de donner aux doyens légaux de droits sur les ressources génétiques et savoir traditionnel un moyen de contrôler l'utilisation de ces ressources; et,break

Créer une formule de partage national pour convertir une partie du revenu monétaire du développement d'un nouveau bien aux biens publics, afin d'assurer un partage juste et équitable des bénéfices créés par l'utilisation de ressources génétiques.

Les valeurs actuelles nettes d'une bioprospection éventuelle sont petites par rapport aux valeurs d'usage local associées au tourisme et à la protection des côtes (Gustavson 1998; Ruitenbeek et Cartier 1999) et, comme mentionné ci−dessus, elles auront un effet négligeable sur les valeurs marginales de récifs coralliens. Néanmoins, Ruitenbeek et Cartier (1999) remarquent que les impacts des coûts institutionnels associés au déroulement du programme national de bioprospection en Jamaïque recommandé par Putterman (1998) sont minimes. C'est la volonté de la direction locale et des concernés locaux du Parc marin de Montego Bay de s'engager dans une telle entreprise qui est maintenant remise en question.

Résultats de Modélisation et Conseil sur la Politique pour l'Utilisation de Modèle de Soutien aux Décisions

En général, au−delà des questions particulières sur la politique et les institutions qui se posent quand on considère l'élaboration éventuelle d'un programme de bioprospection à Montego Bay, des questions de politique surgissent des résultats de la modélisation d'intervention à moindre coût et du bénéfice de récifs coralliens. Ruitenbeek et Cartier (1999) remarquent que, si l'efficacité économique est le but, les coûts et les bénéfices doivent être considérés dans le cadre de la recherche quant aux systèmes complexes non linéaires comme les récifs coralliens. Une analyse de coût−efficacité ne suffirait pas. Ruitenbeek et Cartier suggèrent aussi une plus grande attention au niveau local sur les dimensions socio−économiques et gestionnaires d'usages directes, y compris l'encouragement de régimes de gestion locale pratiques qui considèrent et incluent les personnes concernées. Cette suggestion est aussi soulignée par Bunce et Gustavson (1998a).

Dissémination

Les approches d'intervention et évaluation à moindre coût de cette recherche de modélisation sont un outil utile de soutien aux décisions, de politique et de formation pour les directeurs de récifs coralliens et pour les décideurs gouvernementaux qui font face à des problèmes majeurs de gestion de récifs coralliens. La stratégie de dissémination jointe pour les projets comporte les aspects suivants:

Le lancement d'une exposition itinérante pour disséminer les résultats, qui inclurait un CD−ROM du COCOMO Modèle de Soutien aux décisions du Récif Corallien de Montego Bay;

La prolongation des séminaires financés par la Gestion des Connaissances de la Banque mondiale, aux niveaux local et national, avec pour objectif de recevoir une rétroinformation sur les découvertes de la modélisation de recherche appliquée, identifier les régions prioritaires pour des recherches futures, et identifier des moyens éventuels pour renforcer la capacité locale et régionale pour gérer les ressources côtières;

La création de programmes pour les usagers sur les sites Internet de la Gestion de Connaissances de la Banque mondiale (BIONODE et Ressources d'Eau) et autres sites Internet; et,

L'aide aux fonds fiduciaires du Parc marin de Montego Bay pour la préparation d'un projet dénommé ReefFix qui peut être reproduit sur une échelle régionale (Jameson et Huber 1999).

Les parties concernées participant aux études de cas ont exprimé leur désir et intérêt pour une compréhension plus complète des activités de développement en cours et planifiées en ce qui concerne la zone côtière. Qu'ils soient des pêcheurs locaux, des organisateurs de sports nautiques, des hôteliers, des entrepreneurs et promoteurs locaux, des habitants locaux ou des touristes, il est important de répondre à ces demandes d'information pour avoir une gestion efficace de la zone côtière. La stratégie de dissémination est nécessaire pour augmenter la participation des divers groupes concernés dans l'évaluation des variations dans l'environnement marin, et dans l'atténuation ou la prévention des impacts négatifs sur les récifs coralliens. La création d'un réseau de décideurs et de rechercheurs—une «communauté de mise en pratique»—pour faciliter le partage d'expériences internationales sur la restauration des récifs coralliens et pour promouvoir la recherche conjointe est aussi important.

COCOMO

COCOMO est un modèle de soutien aux décisions pour la gestion de la zone côtière de Montego Bay qui illustre les problèmes côtiers et qui évalue les effets des activités humaines. C'est aussi un bon outil pour élaborer les politiques et renforcer la capacité dans la gestion des zones côtières intégrées (ICZM). Le site d'étude de cas de Montego Bay a été sélectionné pour le projet de modélisation interactif à cause des besoins critiques pour un tel outil. Le centre urbain croît rapidement, avec un développement souvent ad hoc et non planifié. Plusieurs changements physiques ont été effectués sur la zone côtière, y compris le remplissage de la côte, la destruction de mangroves et la sédimentation, en plus d'enrichissementcontinue

nutritif côtier, pressions intensives de pêche, et utilisation extensive par les sports nautiques, plongeons, et industries de tourisme. Ces changement ont engendré une baisse de la qualité de l'eau et des ressources côtières, et ont eu des impacts sur l'écosystème précieux de récifs coralliens.

En particulier, la recherche de modélisation appliquée de COCOMO aide les fonds fiduciaires du Parc marin de Montego Bay avec un programme cohérent et compréhensif qui:

 Sensibilise et encourage l'unanimité de la part des parties concernées en ce qui concerne les priorités environnementales à Montego Bay;

 Identifie les exigences qui existent pour combattre les problèmes de gestion de zone côtière à Montego Bay à long et à court termes avec les diverses organisations gouvernementales et non gouvernementales (ONG) concernées;

 Identifie les investissements environnementaux réalisables, les solutions à coût relativement bas; et,

 Établit un dialogue avec les parties concernées.

L'interface conviviale du modèle est créée pour les décideurs, les spécialistes, et ceux qui sont intéressés par les problèmes côtiers de Montego Bay. Elle utilise un grand nombre de graphique pour donner une vue d'ensemble rapide aux usagers sur les problèmes côtiers et comment le développement, les pêcheries, le tourisme, l'agriculture, l'industrie, et les ménages affectent la côte et les récifs coralliens de Montego Bay. L'information sur la contribution des récifs coralliens à Montego Bay à travers les pêcheries, le tourisme et la protection côtière est incorporée dans le modèle. Plusieurs décisions peuvent être prises sur l'interface de l'usager pour protéger la zone côtière et les récifs coralliens, certaines étant plus rentables que d'autres. COCOMO prédit l'ensemble d'intervention à moindre coût pour réaliser une abondance spécifiée de récifs coralliens. Par conséquent, les impacts des activités de développement peuvent être explorés, et des priorités peuvent être établies pour des décisions futures de gestion de côtes. En utilisant ce modèle, l'usager acquiert une conscience unique de la façon dont les relation entre les activités et les communications côtières parmi les parties concernées sont améliorées.

ReefFix

Un projet de restauration ICZM de récif corallien, gestion de crête et de démonstration de renforcement de capacité—ReefFix—est en train d'être élaboré à travers le Parc marin de Montego Bay. ReefFix représente la phase d'application des résultats de la modélisation de soutien aux décisions. Le but du programme est de mettre au point et d'appliquer un projet de restauration et de gestion de crête à moindre coût, et ensuite transférer l'information et la technologie à d'autres pays tropicaux américains qui ont des problèmes semblables. Une caractéristique importante du projet ReefFix est qu'il prend une direction guidée par des besoins spécifiques de politiques pour la gestion des récifs coralliens qui souffrent d'impacts considérables. L'élément de renforcement de capacité comprend le renforcement de capacités humaines et institutionnelles pour la gestion intégrée, la science, la formation et l'éducation. Il est important de ne pas seulement transférer l'information dans le contexte du pays en voie de développement, mais aussi d'encourager l'échange d'expérience et de créer une expertise locale sur la gestion de récifs coralliens. Le programme s'est fixé les objectifs suivant:

 Utiliser l'outil de modèle de soutien aux décisions développé pour le Parc Marin de Montego Bay (COCOMO) pour fournir l'information à la direction et aux décideurs locaux;

Mettre au point et appliquer un plan d'action pour la gestion des crêtes pour le Parc marin de Montego Bay, afin d'améliorer la qualité de l'eau marine et d'accroître l'abondance de récifs coralliens;

Mettre au point et appliquer un plan d'action pour la gestion des pêcheries pour le Parc marin de Montego Bay, afin d'accroître l'abondance de poissons, d'améliorer les conditions économiques pour les pêcheurs, et contribuer à rendre le Parc marin de Montego Bay autonome; et,

Appliquer un plan d'action pour la démonstration aux Amériques tropicales qui améliorera la capacité ICZM pour la restauration des écosystèmes de récifs coralliens dans d'autres pays. Le plan peut inclure l'application d'un format de modèle de soutien aux décisions à moindre coût de ICZM qui peut être adapter à d'autres localités.

Applications de Procédures et de Politiques

Une optimisation économique rationnelle, qui considère seulement les coûts d'interventions gestionnaires conjointement avec l'évaluation des bénéfices économiques totaux reçus (cf. solution pour Montego Bay donnée dans Ruitenbeek et Cartier 1999), peut réduire le rôle des concernés et des agences gouvernementales en ce qui concerne l'établissement de buts et l'expression de groupes divers de valeurs représentées par divers groupes d'usagers. En effet, c'était l'approche générale de Rijsberman et Westmacott (1996) et Westmacott et Rijsberman (1997) dans la mise au point et l'applicationcontinue

des modèles de soutien aux décisions de Corail−Curaçao et Corail−Maldives afin de se concentrer sur la capacité des décideurs d'analyser, à travers plusieurs scénarios définis par les usagers, la rentabilité de différentes interventions et les conditions économiques, sociales et environnementales évidentes dans plusieurs indicateurs. Leur approche initiale n'aboutissait pas un «optimum global», mais se concentrait plutôt sur la création de moyens avec lesquels les décideurs (et toute personne avec un simple intérêt) pourraient explorer les possibilités de gestion.

Définir une solution optimale à travers un modèle de soutien aux décisions ne nécessite pas forcément la négation de la participation des parties concernées dans la décision gestionnaire, mais ceci n'est pas conseillé. La participation des parties concernées et des agences de gestion ne doit pas être oubliée. Les recommandations dérivées du modèle de solution normative peuvent ne pas être adéquates ou réalisables étant donné le contexte social et institutionnel particulier. En effet, le succès de tout programme de gestion de récifs coralliens sera affecté par l'environnement social et la procédure même de prise de décision. Il est important que les parties concernées participent à autant d'étapes que possible de mise au point du programme, même si cette participation est réduite à un partage d'information. Il devient de plus en plus évident dans les procédures de gestion environnementale que c'est le processus lui−même qui aboutit à un programme de gestion réussi. Sans une procédure ouverte et participatoire, des barrières importantes peuvent surgir quant à une gestion efficace.

La modélisation de soutien aux décisions doit être appliquée dans un contexte particulier de politique. Ceci est particulièrement vrai pour les éléments d'évaluation, car le choix d'une des techniques d'évaluation disponibles, comme l'ont remarqué Ruitenbeek et Cartier (1999), doit être poussé par des questions de politique particulières ou par des problèmes analytiques qui doivent être résolus. Les questions de politique définissent les données et les analyses qui sont nécessaires. La structure et l'utilisation des modèles de soutien aux décisions devrait êtres flexibles.

Bien que les scénarios aient défini les recommandations spécifiques quant aux genres d'interventions nécessaires et au niveau de santé des récifs coralliens atteints par les études de site, il est toujours prématuré, dans la création et l'utilisation de ces modèles, de recommander et d'élaborer des programmes de ICZM. Le développement d'interventions spécifiques nécessitera vraisemblablement des raffinements après une considération plus approfondie des conditions sociales et institutionnelles à travers une procédure participatoire. De plus, bien que les résultats annoncés dans ce rapport soient dérivés de modèles très avancés d'un point de vue technologique, il existe des lacunes sérieuses dans la quantité et la qualité de données économiques et écologiques disponibles, et des lacunes dans le développement de la science derrière la construction du modèle. En résumé, il n'est pas conseillé d'utiliser les modèles pour dicter les directions de la gestion des récifs coralliens, mais plutôt il faut les utiliser pour soutenir de telles décisions.

Directions Futures de Modèles de Soutien aux Décisions

Un défi important pour l'étude de systèmes complexes non linéaires, tels que les écosystèmes de récifs coralliens, est la fourniture d'une décision adéquate de la composition, relations fonctionnelles, et comportement du système en question. Ruitenbeek et Cartier (1999) et Ruitenbeek *et coll.* (1999a, 1999b) ont noté que la recherche doit se concentrer plus sur l'analyse des écosystèmes, avec une emphase particulière sur les liens et relations fonctionnelles. La création de modèles de soutien de décisions écologiques économiques est rendu difficile par un manque de compréhension du comportement des écosystèmes; l'incertitude sur les écosystèmes peut empêcher une analyse économique rationnelle utile.

Les techniques complexes de modélisation, comme la logique de l'incertain, peuvent s'avérer plus utiles. L'élément d'intervention à moindre coût des modèles de soutien aux décisions, tel que résumé ici, démontre l'utilité d'incorporer un environnement de modélisation à logique floue quand il s'agit d'examiner le comportement de l'écosystème d'un récif corallien qui répond à un stress et une intervention anthropique. Des recherches approfondies sur l'utilisation d'ensembles flous dans des applications similaires sont nécessaires (Smith 1994). Néanmoins, il est possible qu'une combinaison de plusieurs techniques soit nécessaire pour explorer les comportements et interactions entre les systèmes écologiques et économiques, que ce soit des modèles linéaires déterministes, des modèles de simulation complexes, des modèles de logique floue ou des réseaux neuraux.

Lier des systèmes différents dans un environnement de modélisation est un défi continuel rencontré par le domaine d'économie écologique, ainsi que d'autres domaines de recherche interdisciplinaires. Les domaines de biologie et d'économie de conservation ont souffert séparément d'une incapacité à fournir des liens exploratoires adéquats entre les activités économiques et la diminution d'espèce ou d'écosystème. En général, il estcontinue

nécessaire de fournir une description ou caractérisation complexe, afin de faciliter la prise de décision dans la direction. Des indicateurs, comme les approximations de variables ou simplifications d'une réalité complexe, remplissent souvent cette fonction.

Dans les efforts de modélisation présentés ci−dessus, l'indicateur principal utilisé pour la santé du récif corallien était la couverture spatiale (c.−à−d., le pourcentage de substrat total disponible couvert par du corail vivant). Cet indicateur fournit un «lien» descriptif simple entre les activités économiques et les écosystèmes de récifs coralliens affectés. De plus, l'indicateur a formé la base pour les décisions concernant les «meilleures» interventions gestionnaires pour recevoir une rentabilité maximale de bénéfice, et concernant le degré d'intervention nécessaire pour atteindre un résultat économiquement efficace. Une question évidente se pose: cet indicateur de santé de récif corallien est−il adéquat, et devrait−on inclure d'autres indicateurs dans la modélisation?

Les propriétés d'un bon indicateur utilisé dans une prise de décision et dans l'élaboration d'une politique peut être décrit comme suit:

La création de l'indicateur correspond au but et à l'application sélectionnés;

La valeur de base derrière l'indicateur est explicite;

L'indicateur fournit une simplification ou abstraction simple des caractéristiques visées du système;

La théorie derrière la création de l'indicateur est assez solide;

La sensibilité de l'indicateur aux changements de paramètre du système a été suffisamment étudiée et définie, et l'indicateur est assez sensible pour atteindre le but du développement; et,

L'information fournie par l'indicateur peut être comprise et appliquée par l'usager.

La plupart des indicateurs ne peuvent pas remplir les critères ci−dessus; néanmoins, le but de la création d'indicateurs est toujours de satisfaire autant de critères que possible étant donné les déficits du niveau de connaissance scientifique disponible et les restrictions sur la recherche. La couverture de récif corallien est un indicateur raisonnable de santé de récif corallien avec ses carences, mais des développements futurs de ces modèles de soutien aux décisions nécessiteront un perfectionnement ou une modification des indicateurs utilisés. L'idée de création d'indicateurs d'écosystèmes pour être utilisés dans la prise de décision et dans l'élaboration de politique est encore relativement récente, bien que du progrès ait été fait (e.g., Jameson *et coll.* 1999). Dans quelle mesure l'indicateur peut former le «lien» entre les éléments écologiques et économiques de modèles de systèmes complexes, et faciliter la conscience et la compréhension . . . cela doit être exploré.

Un dernier point quant à la mise au point et à l'amélioration future de modèles de soutien aux décisions écologiques économiques pour ICZM: toute analyse doit être capable d'explorer les variations possibles dans les résultats et les recommandations qui s'en suivent. Il est impératif que la modélisation de soutien aux décisions comprenne une analyse de sensibilité ou un moyen pour évaluer le risque ou erreur possible associés à un scénario particulier. Par exemple, la modélisation d'évaluation de la bioprospection montrait que les approximations de rendement d'écosystème dépendait beaucoup des relations supposées des espèces/surface (Ruitenbeek et Cartier 1999). Des variations relativement petites dans de telles relations non linéaires qui sont inhérents dans un modèle peuvent entraîner des variations importantes dans le résultat. Les recommandations de politique optimale doivent considérer ces variations. La précaution est nécessaire jusqu'à ce que la science des modèles de soutien aux décisions et leur application soit perfectionnées de manière à avoir un plus grande confiance aux résultats.

Comme dernier message avant de conclure, le travail de modélisation de soutien aux décisions économiques écologiques sera utile pour l'élaboration de programmes ICZM efficaces dans les tropiques en voie de développement. Des recherches approfondies et des perfectionnements des modèles, ainsi qu'une attention plus grande au processus de prise de décision, doivent être considérés comme un défi nécessaire, et non comme un obstacle. Étant donné de nouvelles preuves indiquant que nous faisons face à une crise mondiale d'appauvrissement des récifs coralliens, la gestion doit aller de l'avant avec le meilleur ensemble d'outils de soutien aux décisions disponibles actuellement.break

Annex D—
Modelos de Apoyo a las Decisiones Ecológico−Económicas para la Gestión Integral de los Arrecifes de Coral en los Trópicos en Vías de Desarrollo—Resultados de Investigaciones y Orientaciones para el Futuro

Resumen preparado por Kent Gustavson y Richard M Huber

Este capitulo es un resumen de los resultados de una investigación realizada durante los últimos cinco años con el apoyo del Comité de Investigaciones del Banco Mundial y de los Fondos Fiduciarios de Holanda, Suecia y Canadá, administrados por el Banco Mundial. La investigación fue llevada a cabo bajo la dirección de Richard M Huber, líder del equipo (Banco Mundial), con la contribución de varios investigadores, como los mencionados a lo largo de este capitulo. Las principales contribuciones provinieron de (en orden alfabético) RolfBak (Instituto Holandés de Investigaciones Marinas), Steve Dollar (Universidad de Hawaii), Kent Gustavson (Gustavson Ecological Resource Consulting), Erik Meesters (Instituto Holandés de Investigaciones Marinas), Frank Rijsberman (Resources Analysis), Jack Ruitenbeek (HJ Ruitenbeek Resources Consulting), y Susie Westmacott (Resources Analysis).

Los ecosistemas de arrecifes de coral a nivel mundial están enfrentando una severa disminución, estando amenazados por presiones antrópicas localizadas así como también por causa de fenómenos regionales y globales naturales como el calentamiento global (Bryant *et al.* 1998; Hodgson 1999; Hoegh−Guldberg 1999; Jameson *et al.* 1995; Wilkinson 1998). Todavía puede haber alguna causa para ser optimista dada la remota ubicación geográfica de muchos arrecifes de coral, la gestión efectiva de algunos, y la capacidad potencial de recuperación de estos ecosistemas (Wilkinson 1998), aunque ya es claro que la gestión integral efectiva de las zonas costeras (GIZC) es necesaria para ayudar a prevenir su agotamiento y deterioro posterior. Este capitulo es un resumen de los resultados obtenidos durante la investigación con relación a modelos para apoyar la toma de decisiones para la gestión de los arrecifes de coral en las zonas tropicales en vías de desarrollo. Se expone la estrategia de diseminación y se ofrecen comentarios en cuanto a las aplicaciones potenciales de política y la dirección de futuras investigaciones.

GIZC presta una orientación integral a las actividades de dos o más sectores en la planificación, desarrollo, e implementación de proyectos. De una manera más formal, es ". . . la planeación y la gestión integral de recursos y ambientes costeros en una forma que está basada en las interconexiones físicas, socioeconómicas y políticas dentro y entre los sistemas dinámicos de las zonas costeras . . ." (Sorensen 1997). Similarmente, "la GIZC es un proceso de gobierno y consiste de un marco legal e institucional necesario para asegurar que los planes de desarrollo y de gestión para las zonas costeras sean integrados con metas ambientales y sociales, y sean elaborados con la participación de aquellos afectados. El propósito de la GIZC es maximizar los beneficios proporcionados por la zona costera y minimizar los conflictos y efectos dañinos entre las diversas actividades, sobre los recursos naturales y el medio ambiente" (World Bank 1996, p. 2). Han comenzado a surgir lineamientos y procedimientos para el desarrollo de la GIZC (e.g., Bower *et al.* 1994; Chua 1993; Clark 1995; Pernetta y Elder 1993; Sorensen 1997; World Bank 1993a, 1996).

Un elemento esencial de la GIZC es la *integración* —particularmente, la integración horizontal a lo largo de sectores económicos y agencias de gestión en la planeación e implementación (e.g., Clark 1995; Sorensen 1997). Las actividades costeras deben ser consideradas en conjunto dada su interdependencia e impactos acumulados no aditivos (impactos independientes) esperados. Pero ¿de qué manera los múltiples sectores económicos o actividades humanas van a ser considerados conjuntamente? ¿De qué manera la preocupación para el mantenimientocontinue

de los ecosistemas costeros—los cuales apoyan directa o indirectamente las actividades económicas—va a ser incorporada en la toma de decisiones? ¿Cuál debería ser el marco para la toma de decisiones con el fin de determinar que actividades deberían ser permitidas dentro de la zona costera?, ¿Cómo deberían esas actividades ser desarrolladas y operadas? ¿Qué nivel de actividad debería ser permitido? ¿Sobre que base los conflictos entre diferentes usuarios de recursos costeros deberían ser resueltos? Dar respuesta a tales preguntas necesariamente implica la consideración conjunta de parámetros de sistemas múltiples, criterios múltiples, y distintos valores.

Los modelos para apoyar la toma de decisiones ecológico−económicas pueden jugar un papel fundamental. La familia de modelos ecológico−económicos incluye aquellos que reconocen la validez de alcanzar una solución económicamente eficiente para la gestión, aunque simultánea y explícitamente considera las limitaciones necesariamente impuestas sobre la escala y el tipo de actividades económicas debido a las características y a la capacidad del ambiente natural. Los modelos de apoyo a las decisiones ecológico−económicas para la GIZC también deberían permitir acomodar información relacionada con el contexto socio−cultural en el que se efectúa la gestión, el cual tiene un papel esencial que jugar en el desarrollo de políticas.

¿Cuáles son las características de un modelo útil de apoyo al proceso de toma de decisiones? Primeramente, un modelo útil de apoyo a la toma de decisiones debe poder responder preguntas específicas y relevantes asociadas con el diseño de política. Para ayudar en el diseño y creación de tal modelo, uno debe poder avanzar en su construcción a partir del conjunto existente de investigaciones relevantes en el área del la formulación e implementación de políticas. Como ha señalado Ruitenbeek *et al.* (1999a, 1999b), la falta de información respecto a la ecología de los arrecifes de coral (i.e., nexos funcionales y relaciones) y las características de las economías que los afectan actualmente dificultan el desarrollo de modelos efectivos de apoyo en toma de decisiones ecológico−económicas. Gran parte de la información científica existente no es directamente "relevante para el diseño de política" y, en este contexto, es de poca ayuda a los tomadores de decisiones; o directamente en la creación de un modelo de apoyo a la toma de decisiones. Segundo, un modelo debe ser capaz de ser entendido y utilizado directamente por un grupo meta de clientes. Los insumos deben ser relativamente fáciles a proveer, las pruebas fáciles de conducir, y los resultados fáciles de interpretar. Tercero, se debería distinguir entre el uso de modelos previstos mayormente para investigaciones científicas y aquellos dirigidos para informar procesos de toma de decisiones y diseño de políticas—se debería evitar el uso de modelos altamente experimentales como herramientas de apoyo en la toma de decisiones. La teoría en la cual se basan los modelos de apoyo a la toma de decisiones debería ser relativamente robusta. Por ejemplo, respecto al uso de modelos ecológicos previstos para su uso en toma de decisiones, Friedland (1977) observa que "El objetivo básico no es el descubrimiento de verdades previamente desconocidas sino la recolección e integración del conocimiento existente y su presentación en una forma útil en el proceso de diseño de políticas." Esto tiene ramificaciones directas sobre cual tipo de modelo es el más apropiado. Finalmente, los modelos de apoyo en el proceso de toma de decisiones deberían ser susceptibles a la modificación y revisión de sus componentes de información; de las relaciones especificadas dentro del modelo; y de las alternativas de desarrollo o escenarios considerados por el modelo. Nuevamente, es imperativo mantener en mente las necesidades de los usuarios. Un modelo basado en información que ya no es válida para una zona particular, cuyas relaciones ecológicas y económicas subyacentes ya no son más precisas, o que no es lo suficientemente flexible para soportar modificaciones o alteraciones de los escenarios o alternativas de desarrollo especificados, será de poco uso en el largo plazo.

Resultados de los Proyectos con Modelos

En 1995, con fondos del Comité de Investigaciones del Banco Mundial, se inició el trabajo en dos áreas de investigación con relación a los arrecifes de coral en zonas tropicales en vías de desarrollo: (i) uso de modelos costoefectivos para intervenir en la gestión (i.e. la "oferta" de la biodiversidad como activo económico); y (ii) valoración de sistemas marinos (i.e., la "demanda" por biodiversidad). Esencialmente, el uso de modelos costoefectivos buscó identificar la curva de costos para aquellas intervenciones dirigidas a mejorar las condiciones de los arrecifes de coral; en donde los efectos de las diferentes intervenciones de política y actividades económicas están vinculados a la salud general del arrecife de coral y a los costos asociados con efectuar las mejoras (Brown *et al.* 1996; Huber y Jameson 1998; Huber *et al.* 1994, 1996; Meesters 1995; Meesters y Westmacott 1996; Meesters *et al.* 1995, 1996, 1998; Ridgley y Dollar 1996; Ridgley *et al.* 1995; Rijsberman 1995; Rijsberman y Westmacott 1996; Rijsberman *et al.* 1995a; Ruitenbeek *et al.* 1999a, 1999b; Westmacott 1996; Westmacott y Rijsberman 1997; Westmacott *et al.* 1995). El modelo de valoración delcontinue

sistema marino intentó identificar los beneficios que pueden ser obtenidos a partir de mejorar o sostener las condiciones del arrecife de coral.

El objetivo amplio de las investigación fue ayudar a los diseñadores de política en el manejo y protección de los arrecifes de coral (Huber y Ruitenbeek 1997; Huber *et al.* 1994). El establecimiento de una metodología costo−beneficio apropiada, a ser usada en los sistemas de arrecifes de coral en los trópicos en desarrollo y en sistemas marinos en general, ayudará a la identificación de intervenciones institucionales y de política más convenientes; y así ayudará a lograr usos económicamente eficientes de los arrecifes de coral, y que a la vez toman en cuenta los impactos sobre y el papel del ecosistema que sustenta la vida en los arrecifes de coral. Este tipo de "paquete" basado en el análisis costo−beneficio (ACB) está representado por la integración de los modelos de costo−efectividad y de valoración (Ruitenbeek y Cartier 1999). Se escogieron tres lugares para estudios de caso en donde probar las metodologías: (i) Curaçao, en las Antillas Holandesas; (ii) la República de las Islas Maldivas; y, (iii) la Bahía de Montego en Jamaica.

Coral−Curaçao

Rijsberman y Westmacott (1996; también ver Meeseters 1995; Meesters *et al.* 1996a; Rijsberman *et al.* 1995a; Westmacott *et al.* 1995) desarrollaron un modelo de análisis costo−efectividad para la gestión y protección del arrecife de coral en la costa sur de Curaçao. El modelo de apoyo en la toma de decisiones fue diseñado para facilitar la comunicación entre los grupos de interés involucrados con respecto a las orientaciones del desarrollo y las estrategias de gestión ambiental; y el análisis de los impactos sobre la salud del arrecife producidos por los desarrollos planificados—a través de la descarga de aguas residuales y sedimentos—de tal manera que se integrase la planificación del uso del suelo, el turismo y la conservación; y, el análisis costo−efectividad de las intervenciones en la gestión diseñadas para mantener la salud del arrecife de coral. El modelo utiliza una estructura computarizada basada en la interacción.

Los resultados de los tres escenarios modelados (un escenario de desarrollo representativo del *status quo* y dos escenarios de crecimiento alternativos) indican que Curaçao es muy probable que experimente disminuciones significativas en la salud del arrecife de coral y abundancia durante los próximos 10 años. Sin embargo, el modelo también indica que las intervenciones que involucran estrategias de protección ambiental pueden detener esta tendencia y, en algún caso, conducir a la recuperación del arrecife por encima de su actual nivel de salud. Las intervenciones recomendadas incluyen combinaciones de tratamientos de desagües, disposición apropiada de desechos sólidos, y reducciones en la contaminación de las refinerías. Medidas alternativas para el mantenimiento de las playas y la reducción de desechos generados por la industria manufacturera y el transporte marítimo no fueron encontradas como medidas efectivas. Sin embargo, Rijsberman y Westmacott (1996) también reconocen que los resultados de los modelos pueden ser específicos a la escala espacial examinada y que estas últimas intervenciones ciertamente pueden ser costo−efectivas y apropiadas en un contexto local más reducido.

Rijsberman y Westmacott (1996) destacan que la utilidad del modelo solamente puede ser demostrada mediante una aplicación que íntimamente involucre a los grupos de interés en la construcción del escenario y en el proceso de toma de decisiones. Coral−Curaçao le permite a uno ordenar y priorizar las medidas y explorar la formulación de diferentes combinaciones para obtener una meta específica en términos de la extensión y diversidad del arrecife. Por ejemplo, para lograr una meta promedio del 14% con respecto a la cubierta de coral en el arrecife y del 50% con respecto a la diversidad (indexado de acuerdo al modelo), se requiere una inversión inicial de 310 millones NAF, con un costo anual de operación y de mantenimiento de 6 millones NAF (Rijsberman y Westmacott 1996).

Coral−Maldivas

Westmacott y Rijsberman (1996; también ver Brown *et al.* 1996; Meesters y Westmacott 1996; Rijsberman 1995; Rijsberman y Westmacott 1996; Westmacott 1996; Westmacott y Rijsberman 1997) desarrollaron un modelo de análisis costo−efectividad para la gestión y protección del arrecife de coral en el North y South Male en la República de las Maldivas. Como fue un modelo desarrollado paralelamente con Coral−Curaçao, el objetivo fue investigar si un modelo adaptado para las Maldivas (Coral−Maldivas) proporcionaría una herramienta útil para la toma de decisiones. Westmacott y Rijsberman (1997) describen el modelo y los resultados del análisis inicial.

Como con el modelo Coral−Curaçao, el modelo Coral−Maldivas fue diseñado para que las autoridades encargadas pudiesen determinar el costo−efectividad relativo de diferentes intervenciones de gestión ambiental para variadas opciones de desarrollo económico en términos de las mejorías en la salud del arrecife de coral que son obtenidas (i.e., utilizando índices de la cubierta del arrecife de coralcontinue

y de la rugosidad como medidas aproximadas). Además, los impactos de los escenarios pueden ser vistos en términos de indicadores económicos, sociales, y ambientales elegidos por el usuario del modelo desde el inicio del análisis. Las prioridades de política y las alternativas de gestión viables fueron identificadas mediante discusiones con agencias gubernamentales. Dada la naturaleza de los impactos en los arrecifes de coral en la República de las Maldivas, las intervenciones de gestión se enfocan en minimizar el daño fisico (Westmacott y Rijsberman 1997). Westmacott y Rijsberman (1997) ilustran el uso del modelo mediante la presentación de casos.

Westmacott y Rijsberman (1997) señalan que hay un gran número de indicadores que pueden ser utilizados para describir el potencial de éxito o fracaso de una estrategia de gestión de la zona costera—y, aunque el modelo es algo flexible, el grupo de indicadores de gestión en zonas costeras que puede ser seleccionado y examinado por el usuario es limitado. Además, en tanto las intervenciones y medidas costo−efectivas se relacionan solamente con los cambios en la salud del arrecife de coral, ellas pueden ignorar otras estrategias críticas para el éxito de un programa particular para la gestión integral de la zona costera (GIZC) (e.g., aspectos de salud pública). Se sugiere que los resultados de los escenarios en los modelos para apoyar la toma de decisiones, en la formulación de planes de desarrollo o de gestión, sean ubicados dentro del contexto de metas y requerimientos sociales. Así como con Coral−Curaçao, el modelo puede no reflejar adecuadamente las condiciones locales a una escala espacial menor a la incorporada en los componentes del modelo.

La Valoración de los Beneficios de los Arrecifes de Coral

En el proceso para llegar a una medida del valor económico total (VET), los estudios de valoración económica de sistemas naturales mayormente distinguen los valores de uso de los valores que no implican un uso, y valores de uso directo de valores de uso indirecto. Estas distinciones mayormente reflejan el método de estimación. Durante la especificación del diseño de la valoración de arrecifes de coral para el Parque Marino de la Bahía de Montego, fue definitivamente más útil distinguir entre tres clasificaciones para la valoración de la biodiversidad marina: (i) métodos de valoración de la producción "orientados a la oferta" (i.e., contribuciones de los sistemas marinos a la utilidad de un individuo o la sociedad); (ii) métodos de valoración de la utilidad "orientados a la "demanda" (i.e., contribuciones de sistemas marinos a la utilidad de un individuo o la sociedad); y, (iii) métodos de valoración de la renta capturada orientados a la ganancia (i.e., contribuciones de sistemas marinos a través de la distribución de valores del uso tales como la renta capturada, ganancias o valor agregado; Huber y Ruitenbeek 1997; Ruitenbeek y Cartier 1999). En la última categoría, se analizó la contribución potencial de la biodiversidad de los arrecifes de coral a través del desarrollo de una iniciativa de bioprospección.

Contribuciones de las Funciones de Producción — Parque Marino de la Bahía de Montego

Los valores locales de uso directo fueron estimados por Gustavson (1998) para dos categorías generales de uso—pesca cerca de la costa y turismo. Los valores de uso indirecto asociados con la protección costera también fueron estimados. Estos usos locales de las aguas del Parque Marino de la Bahía de Montego fueron identificados como los más significativos durante la aplicación final del estudio en el sitio, así como los más prioritarios al nivel del diseño de política. Los valores reportados por Gustavson (1998) representan la magnitud de las contribuciones en la producción derivada del arrecife, en riesgo de perderse si los esfuerzos de conservación prueban ser inadecuados.

Los servicios turísticos en la Bahía de Montego incluyen alojamiento, comida, bebida, entretenimiento (incluyendo deportes y atracciones acuáticas), transporte y tiendas, y otros servicios diversos. Estimaciones del valor presente neto (VPN) asociadas con el turismo se ubican en un rango que va desde US$ 210 millones (usando una tasa de descuento del 15%) hasta US$ 630 millones (usando una tasa de descuento del 5%) en 1996.

Las estimaciones del VPN en 1998 asociadas con la pesca se calculan entre US$ 1.66 millones y US$ 7.49 millones (dólares constantes de 1996; utilizando estimados inferiores y superiores, respectivamente, de los valores netos anuales y a una tasa de descuento del 5%; los estimados hechos a tasas de descuento del 10% y 15% caen dentro de este rango). Si es que la función de protección desempeñada por los arrecifes de coral fuera comprometida, sobre la base de que aproximadamente 250 acres son vulnerables, luego el VPN del volumen total de tierra en riesgo de erosión es estimado en US$ 65 millones (en dólares constantes de 1996). La mediana del VPN tomando en cuenta todos los valores de los usos locales para el Parque Marino de la Bahía de Montego fue estimada en US$ 381 millones. Asumiendo una área total de arrecifes de 42.65 hectáreas como un caso de referencia, esto se traduce en US$ 8.93 millones/hectárea o US$ 0.893 millones de ha1 año1 sobre una base anualizada (asumiendo una tasa de descuento del 10%).break

Contribuciones a la Utilidad — Parque Marino de la Bahía de Montego y la Costa Sur de Curaçao

Spash *et al.* (1998) utilizó el método de valoración contingente (MVC) para evaluar los valores de la utilidad asociados con la biodiversidad de los arrecifes de coral en la Bahía de Montego, en Jamaica, y a lo largo de la costa sur de Curaçao. El estudio es particularmente notable por haber examinado los valores de la utilidad asociados con un recurso ambiental marino (i.e., la calidad del arrecife de coral), lo cual había sido negado por investigaciones previas. Adicionalmente, la investigación logró avances para abordar de manera explícita fuentes de sesgo debido a las preferencias lexicográficas que surgen cuando la persona entrevistada no desea aceptar ningún "trade−off" por la pérdida de un bien o servicio (i.e., al rechazar un "trade−off", la persona entrevistada no se comporta de acuerdo a lo señalado por la teoría económica). Para precios iniciales iguales a cero, se efectuaron distinciones entre aquellos que carecen de ingresos, aquellos que consideran las mejorías como de menor importancia, aquellos que prefieren gastar su dinero en otros bienes o servicios, o aquellos que protestaron por tener que ejercer tal elección. Entre aquellos que protestaron con los precios iniciales, proporcionando así una fuente de sesgo, estuvieron aquellos "polizones" (free riders), aquellos que sienten que el pago no es una solución adecuada, aquellos que han perdido la fe en la institución propuesta, o aquellos que rechazan el mecanismo de pago. La encuesta también exploró el grado de las opiniones correctamente sustentadas en consideraciones éticas que serían compatibles con las preferencias lexicográficas. El MVC fue diseñado para facilitar la comparación con los resultados de los estudios de valoración de los usos locales y de la bioprospección en la Bahía de Montego. El MVC también fue diseñado para permitir la separación de los valores de uso directo de los indirectos y de los valores no asociados con uso alguno (non−use values).

Se les pidió a los participantes en la encuesta una contribución para un fondo fiduciario que podría ser administrado por un parque marino para incrementar la biodiversidad dentro de las fronteras del parque. El pago tendría que ser donado anualmente por un periodo de cinco años y lograría un crecimiento del 25% en la cobertura del arrecife de coral. El análisis de la curva de precios (i.e. un análisis "tobit" en combinación con una estimación de máxima probabilidad) proporcionó información adicional respecto a las variables que determinan las variaciones en la "disposición a pagar" (DAP) y refinó los estimados de la "disposición a pagar" (DAP). En el promedio, la DAP fue estimada en US$ 2.08 por persona en Curaçao y US$ 3.24 por persona en Jamaica (Spash *et al.* 1998). La diferencia fue explicada por la combinación de turistas y residentes locales, con los jamaiquinos dispuestos a pagar casi el doble que sus contrapartes en Curaçao. Utilizando perfiles típicos de visitantes y la población local y a una tasa de descuento del 10%, se calcula una DAP estimada en aproximadamente US$ 4.5 millones en Curaçao y US$ 20 millones en la Bahía de Montego, Jamaica (Spash *et al.* 1998).

Contribuciones Potenciales de la Bioprospección — Parque Marino de la Bahía de Montego

El modelo para la bioprospección en la Bahía de Montego se enfocó en los rendimientos netos sociales promedios, basándose en información local sobre costos y en valores de beneficios, y en tasas de descuento exitosas basadas en información de los propietarios para los productos marinos en el Caribe. (Ruitenbeek y Cartier 1999). Los supuestos del modelo respecto a los parámetros incluyeron la especificación de la relación entre especies y área y la relación de participación institucional de los ingresos fiscales (i.e., un reparto de las ganancias netas contingentes y una tarifa fija para muestreo). El análisis de sensibilidad exploró los efectos que las variaciones en los parámetros del modelo tenían sobre el estimado del valor, incluyendo variaciones en el área total del sustrato disponible en el arrecife con una cobertura biológicamente viva y la especificación de la relación entre especies y área como codeterminantes del número esperado de muestras disponibles para pruebas. Otros escenarios del modelo incluyeron una tarifa fija en el muestreo, un enfoque combinado con participación de ingresos fiscales, costos altos de investigación y desarrollo, tasas muy bajas, y un programa de muestreo más corto. Una función de beneficios marginales fue derivada la cual relacionó el valor o el "precio" de la biodiversidad marina con la abundancia del arrecife de coral.

Para un "caso base" se estimó un valor de US$ 70 millones para los arrecifes del Parque Marino de la Bahía de Montego, de los cuales aproximadamente US$ 7 millones (i.e., 10%) realistamente podrían ser captados por Jamaica bajo arreglos típicos de regalías o rentas (Ruiteenbeek y Cartier 1999). El valor marginal del arrecife para bioprospección se estimó en US$ 530,000/ha o US$ 225,000 por el cambio porcentual en la abundancia del arrecife de coral (correspondiente a un precio de planificación local jamaiquino de US$ 22,500 por el cambio porcentual en la abundancia del arrecife de coral).break

La Identificación de Intervenciones de Menor Costo Parque Marino de la Bahía de Montego

De manera muy similar a los modelos Coral−Curaçao y Coral−Maldivas, Ruiteenbeek *et al.* (1999a; también ver Ridgley y Dollar 1996; Ridgley *et al.* 1995; Ruitenbeek *et al.* 1999b) aplicó una metodología lógica probabilística para identificar las intervenciones de menor costo que conducirían a un incremento en la abundancia del arrecife de coral dentro del Parque Marino de la Bahía de Montego. Los procedimientos lógicos probabilísticos son utilizados dentro de un modelo ecológico de impacto en el arrecife para generar una compleja configuración dosis−respuesta que modela la relación entre la abundancia del arrecife de coral y varios insumos dentro del contexto de un medio marino abiótico marino. Esto está vinculado a un modelo económico no lineal que describe las actividades económicas actuales y futuras dentro de ocho sectores, las intervenciones técnicas y de política, y las cargas de contaminantes en la Bahía de Montego. La optimización proporciona pistas acerca de los medios más costo−efectivos para la protección de los arrecifes de coral bajo diferentes metas de calidad del arrecife.

En la Bahía de Montego, Jamaica, se puede lograr hasta un incremento del 20% en la abundancia de coral mediante el uso de medidas apropiadas de política con un costo en valor presente de US$ 153 millones para un periodo de 25 años (Ruitenbeek *et al.* 1999a). Las medidas de política específicas consideradas incluyen la instalación de una trampa de sedimentos en el río Montego, el sembrío de árboles en las cuencas altas, la instalación de un sistema de ventilación de desechos, la instalación de una planta de tratamiento centralizada de gran escala, la extensión agrícola para proporcionar tecnologías que reducen desperdicios, la instalación de un emisor submarino y una estación de bombeo, mejoras en la recolección de desechos sólidos domésticos, y la implementación de un impuesto a los hoteles. Se encontró que algunas intervenciones eran relativamente costo−efectivas. Por ejemplo, la recolección de desechos sólidos domésticos, la instalación de un emisor, y el uso de una trampa de sedimento en el Río Montego impondrían un costo en valor presente de US$ 12 millones y resultaría en una mejoría en la cobertura del arrecife de coral de más del 10% (Ruitenbeek *et al.* 1999).

Una demostración clave de la investigación fue que las metodologías convencionales para medir el costo−efectividad pueden resultar en soluciones subóptimas de política cuando son aplicadas a sistemas complejos. Esto se debe el análisis costo−efectividad tiende a asumir que la separación e independencia de intervenciones individuales y la posibilidad de tratar separadamente los beneficios de los costos (por lo general cuando los beneficios no pueden ser definidos). Cuando se trata de sistemas altamente complejos tales como los arrecifes de coral, las sinergías, retroalimentaciones y otras interdependencias entre intervenciones individuales y el nivel resultante de salud del arrecife de coral pueden invalidar las recomendaciones que provienen de intervenciones de política individualmente evaluadas, las cuales se asume es posible aplicarlas en una forma secuencial, por etapas. Por ejemplo, se encontró que la reforestación formaba parte del conjunto de intervenciones óptimas para metas consistentes con mejoras del arrecife de coral de 14% y 20%, pero no formaba parte del conjunto de intervenciones óptimas para mejoras del 15% o 16% (Ruitenbeek *et al.* 1999). Como han señalado Ruitenbeek *et al.* (1999), esto significa que las metas fijadas para la salud del arrecife de coral, en referencia al grado de los beneficios derivados, deben ser establecidas antes de que se persigan las intervenciones de política.

Integrando los Resultados Obtenidos para la Bahía de Montego Hacia un Nivel Eficiente de Intervención

Una síntesis de los diferentes estudios de valoración de los arrecifes de coral para el Parque Marino de la Bahía de Montego nos permite llegar a una función de beneficios (o precios) marginales netos (Ruitenbeek y Cartier 1999). Para poder llegar a una función de beneficios marginales, relacionando el precio con cambios en la abundancia del arrecife de coral, supuestos adicionales fueron requeridos respecto a la relación entre las categorías de valores y la abundancia o calidad del arrecife de coral. Específicamente, se asume una relación lineal entre la calidad del arrecife y los valores de uso local y los valores utilitarios no asociados con el uso. Probablemente este no es el caso, pero asumir una relación menos simplificada no puede ser justificado dado nuestro actual conocimiento. Solo los resultados del modelo de valoración de la bioprospección (Ruitenbeek y Cartier 1999) permitieron la especificación de una forma funcional diferente. Como han señalado Ruitenbeek y Cartier (1999), los valores marginales netos totales probablemente serán sobrestimados en algunas instancias y subestimados en otras.

El beneficio total atribuido a los arrecifes de coral del Parque Nacional de la Bahía de Montego ha sido estimado en US$ 470 millones, cada cambio en 1% en la abundancia es probable que genere un beneficio marginal de US$ 10 millones o, alternativamente, el precio marginal del arrecife de coral es de US$ 23 millones/ha (Ruitenbeek y Cartier 1999). La mayor parte de estecontinue

valor se atribuye al turismo. La protección costera y los beneficios utilitarios no asociados con el uso también contribuyen, pero en una proporción mucho menor. Las pesquerías existentes y el desarrollo potencial de un programa de bioprospección tienen un efecto mínimo en los valores marginales (Ruitenbeek y Cartier 1999).

Utilizando la función de costos marginales presentada en el estudio de intervenciones de menor costo para el Parque Marino de la Bahía de Montego (Ruitenbeek *et al.* 1999a), conjuntamente con los estimados de beneficios marginales, permite llegar a una optimización global. De acuerdo a lo reportado por Ruitenbeek y Cartier (1999), se sugiere una mejora óptima de la abundancia del arrecife de coral del 13% (i.e., de aproximadamente 29% de cobertura biológica estimado a partir de las condiciones de equilibrio del modelo—véase Ruitenbeek *et al.* 1999a — a aproximadamente 42% de cobertura biológica), requiriendo gastos netos de US$ 27 millones. Las intervenciones requeridas involucrarían la instalación de una trampa de sedimentos, la ventilación de desechos, la instalación de un emisor para desagües, la implementación de un sistema mejora o de recolección de desechos sólidos domésticos, y la implementación de incentivos económicos para mejorar la gestión de desechos por parte de la industria hotelera. El análisis de sensibilidad sugiere que esta optimización es bastante robusta a cambios en los estimados de los beneficios económicos netos—los beneficios necesitarían ser aumentados en US$ 275 millones o disminuidos en US$ 300 millones para que la meta propuesta respecto a mejora en la calidad del arrecife de coral cambie en más del 2% (Ruitenbeek y Cartier 1999).

El Contexto Humano del Uso del Arrecife de Coral

Además de la aplicación del análisis costo−efectividad, la valoración de recursos o el análisis costo−beneficio (ACB), es clave que los tomadores de decisiones consideren de manera integral y sistemática el contexto social, cultural y económico asociado con el desarrollo políticas y el cambio ecológico. Dicho contexto o información con "enfoque humano" tradicionalmente no forma parte de tales análisis, en los cuales los indicadores o medidas monetarias cuantitativas frecuentemente han sido aplicados dentro de un ambiente caracterizado por la "evaluación automática" de la toma de decisiones, limitando la posterior interpretación de los niveles óptimos o apropiados y los tipos de intervenciones y políticas necesarias.

Las metodologías de valoración económica aplicadas en estos proyectos fueron diseñadas para enumerar los beneficios totales recibidos de los arrecifes de coral, a través de contribuciones de la función de producción y de la utilidad humana (así como también los beneficios potenciales por regalías o rentas obtenidos por el desarrollo de iniciativas de bioprospección). Tales beneficios monetarios reflejarán, en teoría, el conjunto local de valores. Sin embargo, se pierde mucho cuando se reduce la información social, cultural y económica a un valor métrico singular. Esto fue demostrado mediante el desarrollo y aplicación de la metodología de evaluación socio−económica rápida para proporcionar un entendimiento de los diferentes grupos de usuarios de los arrecifes de coral en el lugar del estudio de caso de la Bahía de Montego (Bunce y Gustavson 1998a; Bunce *et al.* 1999). Este tipo de información facilitará una mejor adaptación de las estrategias de gestión a los patrones de uso de los grupos de usuarios, así como a sus prioridades de gestión y a sus recursos disponibles. En esencia, la información con "enfoque humano" ayuda a identificar un resultado económicamente eficiente que también es social y culturalmente viable. Esta información ha demostrado su utilidad en el desarrollo de políticas y programas efectivas para el Parque Marino de la Bahía de Montego (Bunce *et al.* 1999; véase también Huber y Jameson 1998c).

Contexto y Recomendaciones de Política

Estudio de Caso—La Captura de Rentas Generadas por el Uso de los Arrecifes de Coral en la Bahía de Montego

De gran interés para las autoridades responsables de la gestión del Parque Marino en la Bahía de Montego, así como también para los administradores de cualquier sistema marino costero, es poder captar al menos una proporción de la renta generada por los usos directos con el fin de poder financiar la gestión necesaria del recurso, incluyendo posibles mejoras al mismo. En otras palabras, hay costos sociales asociados con la conservación y la gestión del recurso que deberían ser pagados por los usuarios.

Como un componente del estudio de valoración de los usos locales (Gustavson 1998), los cobros efectuados actualmente por el gobierno, los cuales pueden capturar una proporción de la renta, fueron explotados. Actualmente, no es parte de la política del Parque Marino de la Bahía de Montego cobrar tarifas (un mecanismo explícitamente reconocido para capturar la renta) a sus usuarios, aunque se está en las etapas iniciales del comienzo de tal programa. Otros cobros del gobierno, que están específicamente vinculados ya sean a las actividades relacionadas con el turismo o con las pesquerías, pueden capturar una proporcion del excedente del productor o del consumidor, pero no son explícitas ni necesariamente diseñadoscontinue

con esa finalidad. Estos incluyen los derechos de licencias para los negocios, licencias para pesca, derechos uso de playa, e impuestos turísticos a salida de los visitantes.

En principio, los derechos por licencias son recolectados para pagar los costos incurridos por el gobierno en la administración y regulación de un negocio o actividad. No hubo información disponible sobre los costos reales asociados con la regulación de las actividades Ilevadas a cabo en los arrecifes de coral, aunque es muy posible que en todos estos casos estos costos no sean recuperados a partir de los programas de tarifas existentes. Se encontró que los derechos de uso de playa son actualmente mínimos y, aunque varían de acuerdo con el tipo de uso, no están vinculados a los diferentes niveles del excedente del productor. Ninguno de estos fondos está explícitamente orientados a pagar los costos asociados con la gestión del Parque Marino de la Bahía de Montego. Ninguna otra tarifa o cargo del gobierno o agencia responsable de la gestión está específicamente ligada ya sea a actividades relacionadas al turismo o la pesca en el área. Impuestos a las ganancias corporativas, o impuestos al ingreso personal en el caso de los pescadores o de las ganancias individualmente distribuidas en los negocios relacionados al turismo—también pueden captar una porción de la renta. Sin embargo, los impuestos son pagados al organismo gubernamental recaudador de impuestos, y de esa manera no están disponibles para ser utilizados en la gestión del parque marino. El interés actual del Parque Marino en la Bahía Montego para implementar derechos de uso debería ser apoyado.

Estudio de Caso—Instituciones y Recomendaciones de Política para la Bioprospección en Jamaica

Putterman (1998) ofrece recomendaciones específicas para el fortalecimiento institucional y de política con respecto a la incorporación del aprovechamiento de recursos genéticos dentro de la GIZC (gestión integral de la zona costera) en Jamaica como una herramienta potencialmente poderosa para la conservación y el desarrollo económico. La diversidad genetica o molecular, una medida de la diversidad biológica entre especies, puede ser la fuente de nuevos productos farmacéuticos, productos industriales y variedades agrícolas. Muchas estrategias para la colaboración en la investigación—como una estrategia que reduce riesgos para maximizar la posibilidad de descubrir nuevos químicos o genes—pueden ser empleadas. Así también, existen muchos mecanismos de reparto de beneficios y opciones de compensación (ver Putterman 1998). De acuerdo a Putterman (1998), actualmente no existe ninguna política en Jamaica que regule el acceso a recursos genéticos. Una revisión de las instituciones y políticas jamaiquinas conduce a las siguientes recomendaciones (Putterman 1998):

En el diseño de un conjunto de opciones de política sobre recursos naturales, se deben incorporar las obligaciones de la Convención sobre Diversidad Biológica y de la Convención de las Naciones Unidas sobre la Ley del Mar, así como también se le debe tomar en cuenta el efecto que el diseño de políticas tendrá en las actividades del sector privado;

Regular el acceso a los recursos genéticos desde un principio por medio de permisos y contratos para definir los derechos a estos recursos antes de que sus muestras sean recolectadas o exportadas;

Establecer derechos (novedosos) *sui generis* sobre la propiedad tangible y el conocimiento tradicional para así definir quien tiene derecho de participar y beneficiarse en la negociación de contratos que implican la transferencia de recursos genéticos o del conocimiento tradicional;

Desarrollar procedimientos de consentimiento previamente informados con el fin de dar a los propietarios legales de los derechos a los recursos genéticos y al conocimiento tradicional un medio de controlar el uso de estos recursos; y,

Crear una formula nacional para el reparto de beneficios con la finalidad de convertir una proporción del ingreso monetario derivado del desarrollo de nuevos productos en bienes públicos; para asegurar un reparto justo y equitativo de los beneficios por la utilización de los recursos genéticos.

Los valores presentes netos potenciales por la bioprospección son pequeños en comparación a los valores de los usos locales actuales asociados con el turismo y la protección costera (Gustavson 1998; Ruitenbeek y Cartier 1999) y, como se señalo anteriormente, se anticipa que estos tendrán un efecto insignificante sobre el valor marginal de los arrecifes de coral. Sin embargo, Ruitenbeek y Cartier (1999) señalan que los impactos de los costos institucionales asociados con la operación de un programa de bioprospección nacional en Jamaica, de acuerdo a lo recomendado por Putterman (1998), son mínimos. La implementación de un programa de bioprospección puede estar garantizada. La pregunta es si existe la voluntad de los administradores locales y de las partes interesadas en el Parque Marino de la Bahía de Montego para involucrarse en este tipo de iniciativas.

Modelando Resultados y Recomendaciones de Política para el Uso de Modelos de Apoyo a la Tomas de Decisiones

Generalmente, más allá de preguntas especificas sobre politicas e institucionales que surgen cuando uno considera el desarrollo potencial de un programa de bioprospeccióncontinue en la Bahía de Montego, surgen cuestiones de política asociadas con las intervenciones de menor costo y con los resultados de la modelación de los beneficios del arrecife de coral. Ruitenbeek y Cartier (1999) notan que si la eficiencia económica es la meta, tanto los costos y los beneficios deben ser considerados en la investigación cuando una trata con sistemas complejos no lineales tales como los arrecifes de coral. El análisis costo−efectividad por si solo no puede ser adecuado. Ruitenbeek and Cartier (1999) también llaman la atención sobre la necesidad de poner un mayor énfasis a nivel local sobre las dimensiones socioeconómicas y relativas a la gestión asociadas con los usos directos, incluyendo la promoción de regímenes locales prácticos para la gestión que consideran e involucran a todas las partes afectadas. Este punto también es destacado por Bunce y Gustavson (1998a).

Diseminación

Las aproximaciones de estas investigaciones—basadas en la intervención de menor costo y en la valoración—sobre los modelos presentados son herramientas de apoyo a la toma de decisiones, para el diseño de política y para la capacitación de los administradores de los arrecifes de coral y tomadores de decisiones en el gobierno que se ven enfrentados a asuntos significativos respecto a la gestión de los arrecifes de coral. La estrategia consolidada de diseminación para los proyectos ha tenido las siguientes fases:

El lanzamiento de una "gira" para diseminar los resultados lo que incluye un CD−ROM del COCOMO—el modelo de apoyo a las decisiones—cuyas siglas significan arrecifes COsteros en la COsta de la bahía de MOntego;

La continuación de talleres apoyados por la unidad de Gestión del Conocimiento del Banco Mundial, local y nacionalmente, con las metas consistentes en obtener retroalimentación en cuanto a los hallazgos de investigaciones aplicadas con modelos, identificación de áreas prioritarias para investigaciones futuras, e identificación de posibilidades potenciales para fortalecer la capacidad regional y local en la gestión de recursos costeros;

La creación de programas propiciados por los usuarios en la página web de la unidad de Gestión del Conocimiento del Banco Mundial (BIONODE y Recursos Acuáticos) y en otras páginas web; y

Apoyo al Fondo del Parque Marino de la Bahía de Montego en la preparación de un proyecto replicable regionalmente, conocido como ReefFix (Jameson y Huber 1999).

Las partes interesadas involucradas en los estudios de caso expresaron la necesidad y su interés en lograr un entendimiento más completo en cuanto a las actividades de desarrollo y conservación, en marcha y programadas, que involucran a la zona costera. Ya sea que se trate de pescadores locales, operadores de deportes acuáticos, hoteleros, empresarios locales, residentes locales o turistas, es clave satisfacer estos requerimientos de información para lograr una gestión efectiva de la zona costera. La estrategia de diseminación es necesaria para incrementar la participación de los diversos grupos de interés en la evaluación de los cambios en el medio marino y en la mitigación o prevención de impactos negativos sobre los arrecifes de coral. El desarrollo de una red de tomadores de decisiones e investigadores—"una comunidad de practicantes"—para así poder compartir experiencias internacionales en la restauración del arrecife de coral y donde se fomenten esfuerzos de colaboración para la investigación es un aspecto clave.

COCOMO

COCOMO es un modelo de apoyo a la toma de decisiones en la gestión de la zona costera de la Bahía de Montego que ilustra los problemas costeros y estima los efectos de las actividades humanas. También sirve como una herramienta para el desarrollo de políticas y construcción de capacidades para la gestión integrada de zonas costeras (GIZC). El estudio de caso en la Bahía de Montego fue seleccionado para el proyecto de modelación interactivo debido a las necesidades críticas que existen por este tipo de herramienta. El centro urbano se está experimentando un rápido, con un desarrollo por lo general *ad hoc* y sin planificación. Han ocurrido muchas alteraciones físicas en la zona costera, incluyendo rellenos sanitarios en el litoral, destrucción de manglares, y sedimentación; además de un enriquecimiento de nutrientes en el litoral, presiones intensivas sobre las pesquerías, y un uso extensivo por los deportes acuáticos, buceo, e industrias de turismo. Esto ha resultado en la degradación de la calidad del agua y de los recursos costeros, y ha causado impactos significativos al valioso ecosistema de arrecifes de coral.

Específicamente, la investigación aplicada a partir de la utilización del modelo COCOMO está brindando asistencia al Fondo Marino de la Bahía de Montego con un programa integral y coherente que:

Aumenta la conciencia y promueve la construcción de consenso por parte de los grupos de interés con respecto a las prioridades ambientales en la Bahía de Montego;

Identifica los desafíos para abordar los asuntos relativos a la gestión de la zona costera en la Bahía de Montego, en e corto y largo plazo, con la ayuda de las diferentescontinue

organizaciones gubernamentales y no gubernamentales involucradas (ONGs).

Identifica inversiones ambientales específicas con soluciones factibles y de bajo costo; y,

Inicia un proceso de diálogo entre los grupos de interés.

La conexión a la computadora del modelo, de fácil uso para los usuarios, ha sido desarrollada para diseñadores de política, especialistas, y todos aquellos interesados en asuntos costeros en la Bahía de Montego. El mecanismo de conexión hace uso intensivo de gráficos para proporcionar a los usuarios una breve visión general de asuntos costeros y como la urbanización, pesca, turismo, agricultura, industria y los hogares impactan en la zona costera y en los arrecifes de coral de la Bahía de Montego. La información sobre el ecosistema de arrecifes de coral y la vida marina asociada se encuentra almacenada dentro del modelo, así como también la información sobre la contribución del arrecife a la Bahía de Montego a través de las pesquerías, el turismo, y la protección costera. A través de la conexión del usuario, diferentes acciones pueden ser adoptadas para la protección de la zona costera y de los arrecifes de coral, algunas siendo más costo efectivas que otras. COCOMO predice el grupo de intervenciones de menor costo para alcanzar una abundancia especificada en el arrecife de coral. De tal manera que, los impactos vinculados a desarrollos (e.g., urbanización) pueden ser explorados y se pueden establecer prioridades para futuras acciones para la gestión costeras. En el proceso de utilizar el modelo, el usuario obtiene una conciencia única de las relaciones entre las actividades costeras. Asimismo, la comunicación entre las partes involucradas es mejorada.

ReefFix

Un proyecto demostrativo consistente en la restauración de los arrecifes de coral en el contexto de la GIZC, la gestión de cuencas y la construcción de capacidades—ReefFix—está siendo implementado en el Parque Marino de la Bahía de Montego (Jameson y Huber 1999). ReefFix es la fase de implementación de los resultados del modelo de apoyo a la toma de decisiones. La meta del programa es diseñar e implementar un proyecto de restauración de los arrecifes de coral y manejo de cuencas de menor costo y luego transferir la información y la tecnología a otros países tropicales de América que estén enfrentando desafíos similares. Una característica clave de ReefFix es que éste adopta un enfoque impulsado por necesidades específicas de política relacionadas a la gestión de los arrecifes de coral que experimentan impactos significativos. El componente dirigido a la construcción de capacidades incluye el fortalecimiento de las capacidades humanas e institucionales para la gestión integral, la ciencia, la capacitación y la educación. Se reconoce que no sólo es importante transferir información a los países en desarrollo, sino también fomentar el intercambio de lecciones aprendizaje con base a experiencias y construir el conocimiento local (*el expertise*)para la gestión de los arrecifes de coral.

El programa tiene los siguientes objetivos:

Utilizar el modelo de apoyo a la toma de decisiones para del Parque Marino de la Bahía Montego (COCOMO) para proporcionar información a los administradores y tomadores de decisiones locales;

Desarrollar e implementar un plan de acción para la gestión de cuencas para el Parque Marino de la Bahía de Montego para mejorar la calidad del agua marina e incrementar la abundancia biológica de los arrecifes de coral;

Desarrollar e implementar un plan de acción para la gestión de pesquerías en el Parque Marino en la Bahía de Montego para incrementar la abundancia de peces, mejorar las condiciones económicas de los pescadores, y ayudar al Parque Marino de la Bahía de Montego para que sea autosostenido desde el punto de vista financiero;

Implementar un plan de acción demostrativo para las Américas tropicales el cual mejorará la capacidad de la GIZC para la restauración de ecosistemas de arrecife de coral en otros países. Esto puede incluir la aplicación de un modelo GIZC de menor costo para apoyar la toma de decisiones que pueda ser adaptado de acuerdo a las necesidades locales.

Proceso y Aplicaciones de Política

Una optimización económica racional, considerando exclusivamente los costos de las intervenciones de gestión conjuntamente con la valoración de los beneficios económicos totales recibidos, (e.g., véase la solución para la Bahía de Montego proporcionada en Ruitenbeek y Cartier 1999), puede que aparentemente reduzca el rol de las partes interesadas y de las agencias de gestión en el proceso de fijación de metas y en la manifestación de diversos valores representados por los diferentes grupos de usuarios. En efecto, el enfoque general de Rijsberman y Westmacott (1996) y de Westmacott y Rijsberman (1997)—en el desarrollo e implementación de los modelos de apoyo a la toma de decisiones Coral−Curaçao y Coral−Maldivas—fue concentrarse en la capacidad de las autoridades (tomadores de decisiones) para analizar, a través de diferentes escenarios definidos por el usuario, el costo−efectividad de intervenciones alternativas y lascontinue

condiciones económicas, sociales y ambientales resultantes de acuerdo a lo reflejado por varios indicadores. La aproximación inicial del modelo no Ilega tan lejos como para derivar óptimo global, pero se enfoca en proveer un medio por el cual los tomadores de decisiones (y aquellas personas interesadas) puedan explorar alternativas de gestión.

La definición de una solución óptima mediante un modelo de apoyo a la toma de decisiones no necesariamente impide la participación de las partes interesadas localmente en las decisiones de gestión, sin embargo, se deben tomar las precauciones necesarias para que esto no ocurra. La participación de las partes interesadas y las agencias responsables de la gestión no debe ser olvidada. Las recomendaciones generadas por la solución de un modelo normativo puede que no sea adecuada o factible dado el contexto institucional y social específico. En efecto, el éxito de cualquier programa de gestión de arrecifes de coral será grandemente afectado por el entorno social y por el proceso mismo de toma de decisiones. Es crítico que las partes interesadas estén involucradas en el mayor número de etapas del desarrollo de un programa de gestión en tanto sea práctico, aún si es simplemente a través de un ejercicio para compartir información. Como ha llegado a ser crecientemente evidente en todos los procesos de gestión ambiental, es el *proceso* en sí mismo el que frecuentemente juega el papel clave para un programa de gestión exitoso. Sin un proceso abierto y participativo, es de esperarse que surjan barreras significativas a la gestión efectiva.

Los modelos de apoyo a la toma de decisiones deberían ser implementados dentro de un contexto específico de política. Esto es especialmente cierto respecto a los componentes de la valoración, como ha sido señalado por Ruitenbeek y Cartier (1999). La selección de una técnica de entre un número de técnicas de valoración debería ser dirigida por preguntas específicas de política a la mano o por los aspectos analíticos que necesitan ser abordados. Las preguntas políticas definen la información que se necesita y el análisis que es requerido. El diseño y utilización de los modelos de apoyo a la toma de decisiones deben estar sujetos a mejoras.

Aunque los escenarios—resultantes del desarrollo de los modelos de apoyo a las decisiones ecologico−económicas como los reportados en este artículo—hayan definido recomendaciones específicas de política en cuanto a los tipos de intervenciones requeridas y el nivel de salud del arrecife de coral que debería alcanzarse en los lugares estudiados, todavía es demasiado temprano el desarrollo y uso de dichos modelos como para poder recomendar que las inversiones requeridas ya sean efectuadas. Se requieren investigaciones adicionales que involucren a las partes interesadas y a las agencias de gestión presentes en el lugar donde se lleva a cabo el estudio de caso, tal como se describe anteriormente en la estrategia de diseminación, para refinar las recomendaciones y desarrollar programas de gestión integral en zonas costeras. El diseño de intervenciones específicas podría requerir un refinamiento basado en una consideración más profunda de las condiciones locales sociales e institucionales a través de un proceso más participativo. Adicionalmente, aunque los resultados presentados aquí se derivan de modelos basados en "el estado del arte", se reconoce que existieron deficiencias notables en la cantidad y calidad de la información ecológica y económica disponible, así como importantes deficiencias en el desarrollo de la ciencia que subyace a la construcción del modelo. En resumen, los modelos no deberían ser utilizados para dictar las orientaciones de la gestión de los arrecifes de coral, pero son para ayudar a *sustentar* tales decisiones.

Futuras Orientaciones para los Modelos de Apoyo a la Toma de Decisiones

Un desafío significativo en el estudio de sistemas complejos no lineales, tales como los ecosistemas de arrecife de coral, está en proporcionar una descripción adecuada de la composición, relaciones funcionales y comportamiento del sistema en cuestión. Ruitenbeek y Cartier (1999) y Ruitenbeek *et al* . (1999a, 1999b) señalan que la investigación mostrar un mayor énfasis en el análisis de ecosistemas, con un enfoque en encadenamientos y relaciones funcionales. El desarrollo de modelos de apoyo a la toma de decisiones ecológico−económicas está siendo obstruido por la falta de entendimiento respecto al comportamiento de ecosistemas; la incertidumbre sobre el funcionamiento del ecosistema puede impedir el análisis económico racional útil.

Las técnicas de modelación de sistemas complejos tales como las técnicas lógicas probabilísticas pueden ser más útiles. El componente de intervenciones de menor costo de los modelos de apoyo a la toma de decisiones, de acuerdo a lo resumido aquí, demuestra la utilidad de incorporar un entorno de modelación lógico y probabilístico cuando se examina el comportamiento de un ecosistema de arrecife de coral en respuesta a intervenciones o presiones antrópicas. La investigación posterior acerca del uso de técnicas probabilísticas en aplicaciones similares está garantizada (Smith 1994). Aunque pueda ser que tal vez se requiera una combinación de diferente técnicas—tales como modelos lineales determinísticos, modelos de simulaciones complejas, modelos lógicos probabilísticos o redes neurálgicas—paracontinue

la exploración del comportamiento y de las interacciones entre sistemas ecológicos y económicos.

La vinculación de sistemas dispares dentro de un entorno de modelación es un desafío continuo al cual se enfrenta el campo de la economía ecológica, así como también otras áreas interdisciplinarias. Areas tales como la biología de la conservación y la economía han luchado por separado con una incapacidad de proporcionar vínculos adecuados entre las actividades económicas y el declive de especies o ecosistemas. Generalmente, una descripción o caracterización concreta de un ambiente ecológico económico complejo es requerida sencillamente para facilitar la toma de decisiones en la gestión. Los indicadores, como variables aproximadas o simplificaciones de una realidad compleja, muchas veces cumplen esta función.

En los esfuerzos de modelación presentados aquí, el indicador principal utilizado para la salud del arrecife de coral fue la cobertura espacial (i.e., el porcentaje del sustrato total disponible cubierto por arrecifes de coral vivos). Este indicador proporcionó un "vinculo" descriptivo sencillo entre las actividades económicas y el ecosistema de arrecife de coral afectado. Además, este indicador formó la base para decisiones respecto a las "mejores" intervenciones en la gestión con el fin de recibir el mayor rendimiento en beneficios y respecto al grado de las intervenciones garantizadas para obtener un resultado económicamente eficiente. Esto genera una pregunta obvia—¿es este indicador de la salud del arrecife de coral adecuado, o acaso deberían otros indicadores ser incluidos en el modelo?

Las propiedades de un "buen" indicador a ser usado en el proceso de toma de decisiones y en el desarrollo de políticas podrían ser descritas como sigue:

El diseño del indicador corresponde al propósito y aplicación escogidos;

La base de valor subyacente al diseño del indicador es explícita;

El indicador proporciona una simplificación o abstracción suficiente de las características del sistema "meta";

La teoría detrás del diseño del indicador es relativamente sólida;

La sensibilidad del indicador a los cambios en los parámetros del sistema ha sido suficientemente explorada y definida, y el indicador es suficientemente sensible para satisfacer el propósito de su diseño; y,

La información proporcionada por el indicador puede ser entendida y aplicada por el usuario.

No se puede esperar que la mayoría de los indicadores satisfagan todos los criterios mencionados anteriormente; sin embargo, permanece como meta principal en el desarrollo de indicadores satisfacer tantos como sea posible dada las limitaciones del nivel de conocimiento científico disponible y las restricciones en la investigación. Se afirma que la cobertura de los arrecifes de coral es un indicador razonable de la salud del arrecife de coral dadas estas limitaciones, pero el futuro desarrollo de estos modelos de apoyo a la toma de decisiones puede necesita refinar o modificar los indicadores utilizados. El desarrollo de indicadores ecosistémicos para ser usados en la toma de decisiones y en el desarrollo de políticas está en su infancia, aunque progresos están siendo hechos (e.g., Jameson *et al* . 1999). Cómo es que tales indicadores pueden formar el "nexo" entre los componentes ecológicos y económicos de modelos de sistemas complejos, y a la vez facilitar la conciencia y entendimiento—es una pregunta que todavía necesita ser investigada.

Como un punto final relacionado a un posterior desarrollo y perfeccionamiento de modelos de apoyo a la toma de decisiones ecológico−económicas para una GIZC, cualquier análisis debe ser capaz de explorar las posibles variaciones en los resultados y en las subsiguientes recomendaciones. Es indispensable que los modelos de apoyo a la toma de decisiones incluyan un análisis de sensibilidad o algún medio con el cual medir el riesgo o los posibles errores asociados con cualquiera de los escenarios. Por ejemplo, el modelo de valoración de la bioprospección mostró que los estimados de la productividad del ecosistema fueron altamente dependientes de relación especie−área asumida (Ruitenbeek y Cartier 1999). Relativamente pequeñas variaciones en este tipo de relaciones no lineales intrínsecas al modelo pueden conducir a grandes variaciones en el resultado. Las recomendaciones relacionadas a la política óptima deben tener esto en cuenta. La cautela es prudente hasta que la ciencia de modelos de apoyo a la toma de decisiones y sus aplicaciones se hayan desarrollado hasta un punto que garantice gran confianza en los resultados.

Como un mensaje final, se cree que el trabajo con modelos de apoyo a la toma de decisiones ecológico−económicas probará ser útil en el desarrollo de programas efectivos para la GIZC en los trópicos en vías de desarrollo. Investigaciones y perfeccionamientos posteriores de los modelos, junto con una mayor atención a los procesos de toma de decisiones, deberían ser vistos como un desafío necesario, y no como un impedimento. Dada la evidencia emergente que indica que estamos enfrentando una crisis ecológica a nivel mundial con la desaparición de los arrecifes de coral, la gestión debe avanzar dada el mejor paquete de herramientas actualmente disponible para apoyar la toma de decisiones.break

REFERENCES

Background and Related Working Papers

Brown B, Bythell J, Clark S, Edwards A, Meesters E, Westmacott S (1996) Cost−effectiveness analysis of coral reef management and protection: a case study for the Maldives, formulation of the ecological response model. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Bunce LL, Gustavson KR (1998) Coral reef valuation: a rapid socioeconomic assessment of fishing, watersports, and hotel operations in the Montego Bay Marine Park, Jamaica and an analysis of reef management implications. Report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC

Cartier CM, Ruitenbeek HJ (1998) Preliminary review of studies and models for marine biodiversity valuation. Internal working paper prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC

Gustavson K (1998) Values associated with the local use of the Montego Bay Marine Park. Report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC

Hanley N (1996) Contingent valuation as a means of valuing the conservation of coral reefs in Jamaica: a state−of−the−art assessment of the method. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Huber RM, Dollar S, Mathur SC, Ruitenbeek HJ (1994) Cost−effectiveness analysis in integrated coastal zone management: a least cost model for coral reef environments in the developing tropics. Report to the World Bank Research Committee, World Bank, Washington, DC

Huber RM, Dollar S, Mathur SC, Ridgley M, Rijsberman F, Ruitenbeek HJ (1996) Cost−effectiveness analysis in integrated coastal zone management: a least cost model for coral reef environments in the developing tropics. Phase I: a prototype model. Report to the World Bank Research Committee, World Bank, Washington, DC

Huber RM, Ruitenbeek HJ (eds) (1997) Marine system valuation: an application to coral reef systems in the developing tropics. Interim Report to World Bank Research Committee, Project #RPO 68105, World Bank, Washington, DC

Meesters EH (1995) Cost−effectiveness analysis of coral reef management and protection: a case study of Curaçao: I. Coral reef data collection and analysis. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Meesters EH, Bak RPM, Westmacott S (1995) A fuzzy logic model to predict coral reef development under nutrient and sediment stress. Report prepared for Resource Analysis and the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Meesters EH, Bak RPM, Westmacott S (1995) A fuzzy logic model to predict coral reef development under nutrient and sediment stress in Curaçao. Phase 3 report, ecological model definition. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Meesters EH, Westmacott S (1996) Cost−effectiveness analysis of coral reef management and protection. a case study of the Maldives. Formulation of the ecological response model. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Putterman DM (1997) Review of marine genetic resource R&D issues (Annex 6). In: Huber RM, Ruitenbeek HJ (eds) Marine system valuation: an application to coral reef systems in the developing tropics. Interim Report to World Bank Research Committee, Project #RPO 68105, World Bank, Washington, DC

Putterman DM (1998) Access to marine genetic resources in Jamaica: incorporating genetic resources utilization into integrated coastal zone management. A study of policies and institutions. Report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DCbreak

Ridgley M, Dollar S (1996) A coral−reef impact−assessment model using fuzzy rule−based logic, Phase II Interim Report. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Ridgley M, Dollar S, Bailey K (1995) Overview of the development of a prototype model to estimate future pollution−induced coral reef impacts. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Rijsberman F (1995) Cost−effectiveness analysis of coral reef management and protection: a case study of the Maldives. First visit report. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Rijsberman F, Westmacott S (1996) Cost−effectiveness analysis of coral reef management and protection: a case study for Curaçao. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Rijsberman FR, Westmacott S, Hirsch D (1995) Cost−effectiveness analysis of coral reef management and protection, a case study of Curaçao: phase 1 report. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Ruitenbeek HJ, Cartier CM with contributions from Bunce L, Gustavson K, Putterman D, Spash CL, van der Werff ten Bosch JD, Westmacott S, Huber R (1999) Issues in applied coral reef biodiversity valuation: results for Montego Bay, Jamaica. World Bank Research Committee Project RPO#68222 Final Report, World Bank, Washington, DC

Ruitenbeek HJ, Ridgley M, Dollar S, Huber R (1999) Optimization of economic policies and investment projects using a fuzzy logic based cost−effectiveness model of coral reef quality: empirical results for Montego Bay, Jamaica A least cost model for coral reef management and protection. World Bank Research Committee Project

RPO#68008 Final Report, World Bank, Washington, DC

Spash CL, van der Werff ten Bosch JD, Westmacott S, Ruitenbeek HJ (1998) Lexicographic preferences and the contingent valuation of coral reef biodiversity in Curaçao and Jamaica. Report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC

Westmacott S (1996) Cost−effectiveness analysis of coral reef management and protection, a case study of the Maldives: phase 2 report model definition and data collection. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Westmacott S, Klinckhamers P, Fernandes L, Rijsberman F (1995) Cost−effectiveness analysis of coral reef management and protection, a case study of Curaçao: Phase 2: field visit project report. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Westmacott S, Rijsberman F (1997) Cost−effectiveness analysis of coral reef management and protection: CORAL, a coral reef management model for the Republic of the Maldives. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Papers Arising from the Research

Bunce L, Gustavson K (1998) Coral reef valuation a rapid socioeconomic impact assessment of primary users of the Montego Bay Marine Park, Jamaica. Paper presented to Coastal Zone Canada 98, 30 August−3 September 1998, Victoria, BC

Bunce L, Gustavson K, Miller M, Williams J (1999). The human side of management: a case study analysis of the socioeconomic framework of Montego Bay Marine Park. Coral Reefs (in press).

Gustavson K, Williams J (1999) Local use valuation as information towards the creation of effective marine park management in the developing tropics. Paper presented to Coastal Zone 99, 2430 July 1999, San Diego, CA

Huber RM, Jameson SC (1998a) CORAL: A least cost management decision support model for coral reef ecosystems. Intercoast Network 32 (Fall), Narragansett, RI

Huber RM, Jameson SC (1998b) Integrated coastal zone management decision support modeling for coral reef ecosystems. Proceedings Ocean Community Conference 98, Baltimore, MD

Huber RM, Jameson SC (1998c) Montego Bay, Jamaica: a case study in public−private partnerships for pollution prevention and management of a valuable coral reef ecosystem. Tropical Coasts (Manila, Philippines) 5(2) 6(1) (December, 1998 January, 1999)break

Jameson SC, Huber RM (1999) Restoration of a valuable coral reef ecosystem: ReefFix Montego Bay, Jamaica. Proceedings of the NCRI Conference on Scientific Aspects of Coral Reef Assessment, Monitoring, and Restoration, Ft. Lauderdale, FL

Meesters EH, Bak RPM, Westmacott S (1996) A fuzzy logic model to predict coral reef dynamics. 8th International Coral Reef Symposium, Panama, Abstracts, p 131

Meesters EH, Bak RPM, Westmacott S, Ridgley M, Dollar S (1998) A fuzzy logic model to predict coral reef development under nutrient and sediment stress. Conservation Biology 12(5):957965

Rijsberman FR, Westmacott S (1997) Use of decision support tools for coastal zone management in Curaçao and Jamaica. Paper presented at the Seminar on Integrated Coastal Zone Management for the Caribbean, Caribbean Council for Science and Technology, 2427 June, Trinidad

Ruitenbeek HJ, Ridgley M, Dollar S, Huber RM (1996) Use of fuzzy logic in a coral reef management model: preliminary results for Montego Bay, Jamaica. Fourth Biennial Meeting International Society for Ecological Economics, Boston University, Boston, MA

Ruitenbeek HJ, Ridgley M, Dollar S, Huber R (1999) Optimization of economic policies and investment projects using a fuzzy logic based cost−effectiveness model of coral reef quality: empirical results for Montego Bay, Jamaica. Coral Reefs (in press)

Spash CL (1998a) Environmental values, attitudes and ethics: non−compensatory choices in a developing country context. Paper presented at 25th Anniversary of Doctoral Program, 17 April, University of Wyoming

Spash CL (1998b) Informing and forming preferences in contingent valuation: a case study. Paper presented to the World Congress of Environmental and Resource Economists, 2527 June, Venice, Italy

Consolidated Bibliography

Adamowicz W, Louviere J, Williams M (1994) Combining revealed and stated preference methods for valuing environmental amenities. Journal of Environmental Economics and Management 26(3):271292

Adger N, Brown K, Cervigni R, Moran D (1994) Towards estimating total economic value for forests in Mexico. Working Paper GEC−9421, CSERGE

Adger WN, Brown K, Tompkins E, Bacon P, Shim D, Young K (1999) Evaluating trade−offs between uses of marine protected areas in the Caribbean. In: Kirkpatrick C, Lee N (eds) Integrated appraisal and sustainable development in a developing world. Edward Elgar, Cheltenham

Ajzen I, Brown TC, Rosenthal LH (1996) Information bias in contingent valuation: effects of personal relevance, quality of information and motivational orientation. Journal of Environmental Economics and Management 30(1):4357

Artuso A (1997) Drugs of natural origin: economic and policy aspects of discovery, development and marketing. Haworth Press, Binghamton, NY

Artuso A (1998) Creating linkages between valuation, conservation and sustainable development of genetic resources (Chapter 14). In: Evenson RE, Gollin D, Santaniello V (eds) Agricultural values of plant genetic resources, CAB International Publishing, Wallingford, Oxon

Association of University Technology Managers (AUTM) (1995) Uniform biological material transfer agreement. AUTM, Norwalk, CT

Atkinson MJ, Smith SV (1983) C:N:P ratios of benthic marine plants. Limnology and Oceanography 28(3):568574

Aylward BA (1993) The economic value of pharmaceutical prospecting and its role in biodiversity conservation. Discussion Paper 9305. International Institute for Environment and Development, London

Aylward BA, Echeverría J, Fendt L, Barbier E (1993) The economic value of species information and its role in biodiversity conservation: case studies of Costa Rica's National Biodiversity Institute and pharmaceutical prospecting. Report to Swedish International Development Authority. LEEC, London and INBIO, San José

Ayyub B, McCuen R (1987) Quality and uncertainty assessment of wildlife habitat with fuzzy sets. Journal of Water Resources Planning and Management 113(1):95109

Baarse G, Rijsberman FR (1986) Ecology and tourism: protecting the coast of the Dutch island of Texel. Project Appraisal 1(2):7587

Baarse G, Rijsberman FR (1987) A policy analysis approach to the problem of sea level rise. In: Wind HQ (ed), Impacts of sea level rise on society. Balkema Publishers, Rotterdam, pp 2176break

Bak RPM, Nieuwland G (1995) Long−term change in coral communities along depth gradients over leeward reefs in the Netherlands Antilles. Bulletin of Marine Science 56:609619

Balarin J (1998) Participatory aquatic resource management. Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmbH, Eschborn

Ballance R, Pogany J, Forstner H (1992) The world's pharmaceutical industries: an international perspective on innovation, competition and policy. Elgar, Aldershot

Barbier EB, Acreman M, Knowler D (1997) Economic valuation of wetlands: a guide for policy makers and planners. RAMSAR Library, Gland

Barbier EB, Aylward BA (1996) Capturing the pharmaceutical value of biodiversity in a developing country. Environmental and Resource Economics 8:157181

Barbier EB, Burgess JC, Folke C (1994) Paradise lost: the ecological economics of biodiversity. Earthscan, London

Bardossy A, Duckstein L (1995) Fuzzy rule−based modeling with applications to geophysical, biological, and engineering systems. CRC Press, Boca Raton, FL

Baron J, Maxwell NP (1996) Cost of public−goods affects willingness−to−pay for them. Journal of Behavioural Decision Making 9(3):173183

Barton DN (1994a) Economic factors and valuation of tropical coastal resources. SMR Report. Centre for Studies of Environment and Resources, University of Bergen, Bergen

Barton JH (1994b) Ethnobotany and intellectual property rights. In: Ethnobotany and the search for new drugs. Ciba Foundation Symposium 185. Wiley & Sons, Chichester

Barton JH, Siebeck WE (1994) Material transfer agreements in genetic resources exchange the case of the International Agricultural Research Centres. Issues in Genetic Resources 1. International Plant Genetic Resources Institute, Rome

Bateman IJ, Munro A, Rhodes B, Starmer C, Sugden R (1997) Does part−whole bias exist?: an experimental investigation. Economic Journal 107(441):322332

Bateman I, Willis KJ (1999) Contingent valuation of environmental preferences: assessing theory and practice in the USA, Europe, and developing countries. Oxford University Press

Bell FW (1989) Application of wetland valuation theory to Florida fisheries. Florida Sea Grant College and Department of Economics, Florida State University

Bennett JW (1984) Using direct questioning to value the existence benefits of preserved natural areas. Australian Journal of Agricultural Economics 28:136−152

Bergland O, Magnussen K, Navrud S (1995) Benefits transfer: testing for accuracy and reliability. Discussion Paper 9503, Department of Economics, Agricultural University of Norway

Bernard HR (1989) Research methods in cultural anthropology. Sage Publications, London

Biodiversity Conservation Network (BCN) (1997) Annual report: evaluating an enterprise−oriented approach to community−based conservation in the Asia/Pacific region. World Wildlife Fund, Washington, DC

Birkeland C (1997) Status of coral reefs in the Marianas. In: Grigg RW, Birkeland C (eds) 1997 Status of coral reefs in the Pacific. Sea Grant College Program, School of Ocean and Earth Science and Technology, University of Hawaii, pp 89100

Bishop R, Walsh M (1992) Existence values in benefit−cost analysis and damage assessment. Land Economics 68:405414

Blamey RK, Hundloe TJ (1993) Characteristics of recreational boat fishing in the Great Barrier Reef Region. Report to the Great Barrier Reef Marine Park Authority, Townsville

Bockstael NE, McConnell KE (1980) Calculating equivalent and compensating variation for natural resource facilities. Land Economics 65:5763

Bower BT, Ehler CN, Basta DJ (1994) A framework for planning for integrated coastal zone management. National Ocean Service, National Oceanic and Atmospheric Administration (NOAA−ORCA), Washington, DC

Boyle K, Desvouges W, Johnson F, Dunsford R, Hudson S (1994) An investigation of part−whole biases in contingent valuation. Journal of Environmental Economics and Management 27(1):6483

Brevoort P (1996) The US botanical market an overview. HerbalGram 36:4957break

Brown B, Bythell J, Clark S, Edwards A, Meesters E, Westmacott S (1996) Cost−effectiveness analysis of coral reef management and protection: a case study for the Maldives, formulation of the ecological response model. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Brown B, Dawson Shephard A, Weir I, Edwards A (1990) Effects of the degradation of the environment on local reef fisheries in the Maldives. Final report to ODA. University of Newcastle Upon Tyne, Newcastle

Brown GM Jr, Goldstein JH (1984) A model for valuing endangered species. Journal of Environmental Economics and Management 11:3039

Bryant D, Burke L, McManus J, Spalding M (1998) Reefs at risk: a map−based indicator of potential threats to the world's coral reefs. World Resources Institute, Washington, DC

Buddemeier RW (1999) Is it time to give up? Plenary Abstracts, International Conference on Scientific Aspects of Coral Reef Assessment, Monitoring and Restoration, April 1416, 1999, Ft. Lauderdale, FL, p 40

Bunce LL, Gustavson KR (1998a) Coral reef valuation: a rapid socioeconomic assessment of fishing, watersports, and hotel operations in the Montego Bay Marine Park, Jamaica and an analysis of reef management implications. Report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC

Bunce L, Gustavson K (1998b) Coral reef valuation a rapid socioeconomic impact assessment of primary users of the Montego Bay Marine Park, Jamaica. Paper presented to Coastal Zone Canada 98, 30 August−3 September 1998, Victoria, BC

Bunce LL, Gustavson KR, Miller M, Williams J (1999) The human side of reef management: a case study analysis of the socioeconomic framework of Montego Bay Marine Park. Coral Reefs (in press)

Burrill GS, Lee KB (1993) Biotech 94', long−term value, short−term hurdles: the industry annual report. Ernst & Young, San Francisco, CA

Buzzard S (1990) Surveys: avoiding the common problems. In: Finsterbusch K, Ingersoll J, Llewelly L (eds) Methods for social analysis in developing countries. Westview Press, Boulder, CO

Cambridge Economics (1992) Contingent valuation: a critical assessment. Cambridge, MA

Carson R, Flores N, Hanemann M (1998) Sequencing and valuing public goods. Journal of Environmental Economics and Management 36(3):314323

Carson RT, Mitchell RC (1993) The issue of scope in contingent valuation studies. American Journal of Agricultural Economics 75(5):12631267

Carson RT, Mitchell RC (1995) Sequencing and nesting in contingent valuation surveys. Journal of Environmental Economics and Management 28(2):155173

Carson RT, Mitchell RC, Hanemann WM, Kopp RJ, Presser S, Ruud PA (1992) A contingent valuation study of lost passive use values resulting from the Exxon Valdez oil spill. Report to the Attorney General of the State of Alaska

Carson R, Wilks L, Imber D (1994) Valuing the preservation of Australia's Kakadu Conservation Zone. Oxford Economic Papers 46:727749

Cartier CM, Ruitenbeek HJ (1998) Preliminary review of studies and models for marine biodiversity valuation. Internal working paper prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC

Cartier CM, Ruitenbeek HJ (1999) Review of the biodiversity valuation literature (Chapter 3). In: Ruitenbeek HJ, Cartier CM with contributions from Bunce L, Gustavson K, Putterman D, Spash CL, van der Werff ten Bosch JD, Westmacott S, Huber R. Issues in applied coral reef biodiversity valuation: results for Montego Bay, Jamaica. World Bank Research Committee Project RPO#68222 Final Report, World Bank, Washington, DC

Cernea M (ed) (1985) Putting people first: sociological variables in rural development. Oxford University Press, Oxford

Cesar H (1996) Economic analysis of Indonesian coral reefs. World Bank Environment Department, Washington, DC

Cesar H (1998) Indonesian coral reefs: a precious but threatened resourcee. In: Hatziolos ME, Hooten AJ, Fodor M (eds) Coral reefs: challenges and opportunities for sustainable management. Proceedings of an Associated Event of the Fifth Annual World Bank Conference on Environmentally and Socially Sustainable Development. World Bank, Washington, DC, pp 163171break

Chambers R (1994) The origins and practice of participatory rural appraisal. World Development 22(7):953969

Chua TE (1993) Essential elements of integrated coastal management. Ocean and Coastal Management 21(13):81108

Clark CW (1976) Mathematical bioeconomics: the optimal management of renewable resources. John Wiley and Sons, New York

Clark JR (1995) Coastal zone management handbook. CRC Press Inc, Boca Raton, FL

Colin P (1998) Marine pharmaceuticals from the reef: a view from the field. In: Hatziolos ME, Hooten AJ, Fodor M (eds) Coral reefs: challenges and opportunities for sustainable management. World Bank, Washington, DC, pp 7678

Cummings RG, Brookshire DS, Schulze WD (eds) (1986) Valuing environmental goods: an assessment of the contingent valuation method. Rowman and Allanheld, Totowa

D'Auria MV, Paloma LG, Minale L, Riccio R, Zampella A, Debitus C (1993) Metabolites of the New Caledonian sponge *Cladocroce incurvata* . Journal of Natural Products 56(3):418423

Dahuri R (1996) Preliminary approaches to economic valuation of coastal resources in Indonesia. Paper presented to the 7th Biannual Workshop on Economy and Environment in South−East Asia, Singapore

Danielson LE, Leitch J A (1986) Private versus public economics of prairie wetland allocation. Journal of Environmental Economics and Management 13(1): 8192

Davis WS, Simon TP (1995) Biological assessment & criteria: tools for water resource planning and decision making. CRC Press, Boca Raton, FL

de Groot RS (1992) Functions of nature: evaluation of nature in environmental planning, management and decision making. Wolters−Noordhoff

D'Elia CF, Buddemeier RW, Smith SV (eds) (1991) Workshop on coral bleaching, coral reef ecosystems and global change: report on proceedings. Maryland Sea Grant College. 1721 June 1991, Brickell Point Sheraton, Miami, FL

D'Elia CF, Webb KL, Porter JW (1981) Nitrate−rich groundwater inputs to Discovery Bay, Jamaica: a significant source of N to local reefs? Bulletin of Marine Science 31:903910

Desvouges WH, Johnson FR, Dunford RW, Boyle KJ, Hudson SP, Wilson KN (1993) Measuring natural resource damages with contingent valuation: tests of validity and reliability. In: Hausman JA (ed) Contingent valuation: a critical assessment. North−Holland, Amsterdam

Dexter LA (1970) Elite and specialized interviewing. Northwestern University Press, Evanston

DiMasi JA, Hansen RW, Grabowski HG, Lasagna L (1991) Cost of innovation in the pharmaceutical industry. Journal of Health Economics 10:107142

Dixon JA (1992) Meeting ecological and economic goals: the case of marine parks in the Caribbean. Paper presented to the Second Meeting of the International Society for Ecological Economics, 36 August 1992, Stockholm

Dixon JA (1993) Economic benefits of marine protected areas. Oceanus (fall):3540

Dixon JA, Scura L, van't Hof T (1993) Meeting ecological and economic goals: marine parks in the Caribbean. Ambio 22(23):117125

Downes D, Laird SA, Klein C, Carney BK (1993) Biodiversity prospecting contract. In: Reid WV, Laird SA, Meyer CA, Gámez R, Sittenfeld A, Janzen DH, Gollin MA, Juma C (eds) Biodiversity prospecting: using genetic resources for sustainable development. World Resources Institute, Washington, DC, pp 255287

Driml SM (1994) Protection from profit: economic and financial values of the Great Barrier Reef World Heritage Area and other protected areas. Research Publication 34, Great Barrier Reef Marine Park Authority, Townsville

Driml SM (1997) Bringing ecological economics out of the wilderness. Ecological Economics 23:145153

Driml SM (1999) Dollar values and trends of major direct uses of the Great Barrier Reef Marine Park. Research Publication 56. Great Barrier Reef Marine Park Authority, Townsville

Driml SM, Hundloe TJ, Blamey RK (1997) Understanding Great Barrier Reef economics. Proceedings 1: The Great Barrier Reef, Science, Use and Management, A National Conference. James Cook University, Townsville

Eakin CM, McManus JW, Spalding MD, Jameson SC (1997) Coral reef status around the world: where are we and where do we go from here? Proceedings of the 8th International Coral Reef Symposium 1:277282

Economist (1992) A modern smokestack industry. 14 November:110break

Edwards SF (1991) The demand for Galapagos vacations: estimation and application to wilderness preservation. Coastal Management 19:155169

Eskeland G (1992) Demand management in environmental protection: fuel taxes and air pollution in Mexico City. Country Economics Department, World Bank, Washington, DC

Espeut P (1992) Fishing for finfish in Belize and the south coast of Jamaica: a socio−economic analysis. Research Report 3. ICOD/ UWI/ Jamaica/ Belize Reef Fisheries Management Planning Project 19891992. Centre for Marine Science Research, University of the West Indies at Mona, Kingston, Jamaica

Espeut P, Grant S (1990) An economic and social analysis of small−scale fisheries in Jamaica. Prepared for the FAO. Institute of Social and Economic Research, University of the West Indies at Mona, Kingston, Jamaica

Evenson RE, Gollin D, Santaniello V (eds) (1998) Agricultural values of plant genetic resources, CAB International Publishing, Wallingford, Oxon

Evenson RE, Kislev Y (1976) A stochastic model of applied research. Journal of Political Economy 84(2):265281

Evenson RE, Lemarié S (1998) Optimal collection and search for crop genetic resources. In: Smale M (ed) Farmers, gene banks and crop breeding: economic analyses of diversity in wheat, maize and rice. Kluwer, Boston, pp. 7992

Farnsworth NR, Akerele O, Bingel AS, Soejarto DD, Guo Z−G (1985) Medicinal plants in therapy. Bulletin of the World Health Organization 63:96581

Farnsworth NR, Soejarto DD (1985) Potential consequences of plant extinction in the United States on the current and future availability of prescription drugs. Economic Botany 39(3):231240

Federal Register (1993) Natural resource damage assessments under the Oil Pollution Act of 1990. Federal Register 15.1.93, pp. 46014614

Federal Register (1994) Natural resource damage assessments: proposed rules. Federal Register 7.1.94, pp. 11391184

Fenical W (1993) Chemical studies of marine bacteria: developing a new resource. Chemical Reviews 93(5):16731683

Flam F (1994) Chemical prospectors scour the seas for promising drugs. Science 266:13245

Floudas C, Pardalos P (eds) (1992) Recent advances in global optimization. Princeton University Press, Princeton, NJ

Foster V, Bateman I, Harley D (1998) Real and hypothetical willingness to pay for environmental preservation: a non−experimental comparison. In: Acutt M, Mason P (eds) Environmental valuation, economic policy and sustainability. Edward Elgar, Cheltenham

Friedland EI (1977) Values and environmental modeling. In: Hall CAS, Day JW Jr. (eds) Ecosystem modeling in theory and practice: an introduction with case histories. John Wiley and Sons, New York, pp 115131

Gibbons A (1992) Researchers fret over neglect of 600 million patients. Science 256:1135

Ginsburg RN (comp) (1994) Proceedings of the colloquium on global aspects of coral reefs: health, hazards and history, 1993. Rosenstiel School of Marine and Atmospheric Science, University of Miami, FL

Gill PE, Murray W, Wright MH (1981) Practical optimization. Academic Press, London

Gollin D, Smale M (1998) Search modeling for traits (Chapter 2). In: Evenson RE, Gollin D, Santaniello V (eds) Agricultural values of plant genetic resources. CAB International Publishing, Wallingford, Oxon

Gollin M (1995) Biological materials transfer agreements. Bio/Technology 13:243

Gorman M (1995) Tanga Coastal Zone Conservation and Development Programme report on socio−economic study/ participatory rural appraisal

Grabowski HG, Vernon JM (1990) A new look at the returns and risks to pharmaceutical R&D. Management Science 36(7):804821

Greater Montego Bay Redevelopment Corporation (GMRC) (1996) Greater Montego Bay Area Plan 2014. Draft Technical Report. Commissioned by the Greater Montego Bay Redevelopment Company. Prepared by Planning and Design Quorum Inc, 4 Queens Drive, Montego Bay, Jamaica

Gregory R (1986) Interpreting measures of economic−loss: evidence from contingent valuation and experimental studies. Journal of Environmental Economics and Management 13(4):325337

Gren I−M (1995) The value of investing in wetlands for nitrogen abatement. European Review of Agricultural Economics 22:157172break

Grigg RW (1997) Hawaii's coral reefs: status and health in 1997, the International Year of the Reef. In: Grigg RW and Birkeland C (eds) Status of coral reefs in the Pacific. Sea Grant College Program, School of Ocean and Earth Science and Technology, University of Hawaii, HI

Gustavson K (1998) Values associated with the local use of the Montego Bay Marine Park. Report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC

Gustavson K (1999) Economic production from the coral reef fisheries of Jamaica and captured ecosystem values. PhD Dissertation. University of Victoria, Victoria, BC

Gustavson K, Williams J (1999) Local use valuation as information towards the creation of effective marine park management in the developing tropics. Paper presented to Coastal Zone 99, 2430 July 1999, San Diego, CA

Gutierrez B, Pearce DW (1992) Estimating the environmental benefits of the Amazon forest: an intertemporal valuation exercise. GEC Working Paper 9244. Centre for Social and Economic Research on the Global Environment, London

Hammack J, Brown G (1974) Waterfowl and wetlands: towards bioeconomic analysis. Johns Hopkins Press, Baltimore, MA

Han SP (1977) A globally convergent method for nonlinear programming. Journal of Optimization Theory and Applications 22:297

Hanemann WM (1991) Willingness to pay and willingness to accept: how much can they differ. American Economic Review 81(3):635647

Hanemann WM (1994) Valuing the environment through contingent valuation. Journal of Economic Perspectives 8(4):1943

Hanley N (1996) Contingent valuation as a means of valuing the conservation of coral reefs in Jamaica: a state−of−the−art assessment of the method. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Hanley N, Craig S (1991) Wilderness development decisions and the Krutilla−Fisher model: the case of Scotland's Flow Country. Ecological Economics 4:14564

Hanley N, Ruffell R (1993) The contingent valuation of forest characteristics: two experiments. Journal of Agricultural Economics (May)

Hanley N, Spash CL (1993) Cost−benefit analysis and the environment. Edward Elgar, Aldershot

Hansen RW (1979) The pharmaceutical development process: estimates of current development costs and times and the effect of regulatory changes. In: Chien RI (ed) Issues in pharmaceutical economics. Lexington Books, Lexington, MA

Hansen RW (1980) Pharmaceutical development costs by therapeutic categories. University of Rochester Graduate School of Management Working Paper GPB−806. University of Rochester

Hartell J, Smale M, Heisey PW, Senauer B (1997) The contribution of genetic resources and diversity to wheat productivity: a case from the Punjab of Pakistan. Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) Economics Working Paper 9701. CIMMYT, Mexico

Harvard Business School (1992) INBio/Merck Agreement: pioneers in sustainable development. NI−593015. Harvard Business School, Boston, MA

Hatziolos ME, Hooten AJ, Fodor M (eds) (1998) Coral reefs: challenges and opportunities for sustainable management. World Bank, Washington, DC

Hausman J (1993) Contingent valuation: a critical assessment. North Holland, Amsterdam

Henkel J (1998) Drugs of the deep: treasures of the sea yield some medical answers and hint at others. FDA Consumer (January/February)

Hitchman NDS (1997) Eutrophication: the death angel covering coral reefs in Montego Bay, Jamaica. BA Honors Thesis. Environmental Science and Public Policy, Harvard−Radcliffe Colleges, Cambridge, MA

Hodgson G (1997) Reef Check core methods. http://www.ust.hk/~webrc/ReefCheck/methods.html

Hodgson G (1998) Reef Check and sustainable managment of coral reefs. In: Wilkinson CR (ed) Status of coral reefs of the world: 1998. Global Coral Reef Monitoring Network, AIMS, Queensland, pp.165168

Hodgson G (1999) A global coral reef assessment. Marine Pollution Bulletin 38(5):345355

Hodgson G, Dixon JA (1988) Logging versus fisheries and tourism in Palawan. Occasional Paper 7. East−West Environment and Policy Institute, Honolulu, HIbreak

Hoegh−Guldberg O (1999) Climate change, coral bleaching and the future of the world's coral reefs. Marine and Freshwater Research (in press)

Hoehn JP, Randall A (1987) A satisfactory benefit cost indicator from contingent valuation. Journal of Environmental Economics and Management 14(3):226247

Holder JS (1991) Managing the Caribbean Environment as Tourism's Resource. Paper presented at the seminar on Tourism, Health and the Environment. PAHO, 31 October 3 November 1991, Tobago

Huber RM, Dollar S, Mathur SC, Ruitenbeek HJ (1994) Cost−effectiveness analysis in integrated coastal zone management: a least cost model for coral reef environments in the developing tropics. Report to the World Bank Research Committee, World Bank, Washington, DC

Huber RM, Dollar S, Mathur SC, Ridgley M, Rijsberman F, Ruitenbeek HJ (1996) Cost−effectiveness analysis in integrated coastal zone management: a least cost model for coral reef environments in the developing tropics. Phase I: a prototype model. Report to the World Bank Research Committee, World Bank, Washington, DC

Huber RM, Jameson SC (1998a) CORAL: A least cost management decision support model for coral reef ecosystems. Intercoast Network 32 (Fall), Narragansett, RI

Huber RM, Jameson SC (1998b) Integrated coastal zone management decision support modeling for coral reef ecosystems. Proceedings Ocean Community Conference 98, Baltimore, MD

Huber RM, Jameson SC (1998c) Montego Bay, Jamaica: a case study in public−private partnerships for pollution prevention and management of a valuable coral reef ecosystem. Tropical Coasts (Manila, Philippines) Volume 5, No.2 Volume 6, No.1 (December, 1998 January, 1999)

Huber RM, Ruitenbeek HJ (eds) (1997) Marine system valuation: an application to coral reef systems in the developing tropics. Interim Report to World Bank Research Committee, Project #RPO 68105, World Bank, Washington, DC

Hughes TP (1994) Catastrophes, phase shifts, and large scale degradation of a Caribbean coral reef. Science 265:15471551

Hundloe T (1990) Measuring the value of the Great Barrier Reef. Journal of the Royal Australian Institute of Parks and Recreation 26(3):1115

Hundloe T, Vanclay F, Carter M (1987) Economic and socio economic impacts of crown of thorns starfish on the Great Barrier Reef. Report to the Great Barrier Reef Marine Park Authority, Townsville

Imber G, Stevenson G, Wilks L (1991) A contingent valuation survey of the Kakadu Conservation Zone. Resource Assessment Commission Research Paper 3. Australian Government Publishing Service, Canberra

International Crops Research Institute for the Semi−Arid Tropics (ICRISAT) (1990) ICRISAT's contribution to pearl millet production. ICRISAT, Cereals Program, Andhra Pradesh

Interorganizational Committee on Guidelines and Principles for Social Impact Assessment (ICGPSIA) (1994) Guidelines and principles for social impact assessment. US Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Washington, DC

IUCN (1993) Reefs at risk: a program for action. Rue Mauverney 28, CH−1196, Gland

Iwu MM (1994) African medicinal plants and the search for new drugs based on ethnobotanical leads. In: Ethnobotany and the search for new drugs. Ciba Foundation Symposium 185. John Wiley & Sons, Chichester

Jabbour A (1983) Folklore protection and national patrimony: developments and dilemmas in the legal protection of folklore. Copyright Bulletin 17:1014

Jacob M (1996) Marine organisms yield new cytotoxic agents, nutrients. Genetic Engineering News 16(3):19

Jameson SC (1997) Analysis of Louis Berger water quality data with respect to coral reef ecosystem health and eutrophication. Memo to Richard M Huber, The World Bank, Washington, DC

Jameson SC, Erdmann MV, Gibson Jr GR, Potts KW (1998) Development of biological criteria for coral reef ecosystem assessment. Atoll Research Bulletin No. 450 (September 1998), Smithsonian Institution, Washington, DC, http://www.epa.gov/owow/oceans/coral

Jameson SC, Erdmann MV, Gibson GR Jr., Potts KP (1999) Charting a course towards predictive monitoring: Coral reef bioindicators where are we? And where do we go from here? Bulletin of Marine Science (in press)

Jameson SC, Huber RM (1999) Restoration of a valuable coral reef ecosystem: ReefFix Montego Bay, Jamaica. Proceedings of the NCRI Conference on Scientific Aspects of Coral Reef Assessment, Monitoring, and Restoration, Ft. Lauderdale, FLbreak

Jameson SC, McManus JW, Spalding MD (1995) State of the reefs: regional and global perspectives. International Coral Reef Initiative, US Department of State, Washington, DC

Joglekar P, Paterson ML (1986) A closer look at the returns and risks of pharmaceutical R&D. Journal of Health Economics 5:153177

Johannes RE (1975) A comparison of nutrient−limited productivity in *Sargassum natans* from neritic versus oceanic waters of the Western North Atlantic Ocean. Limnology and Oceanography 40:625633

Johannes R (1981) Words of the lagoon. University of California Press

Johnson J (1998) Tourism in Jamaica: an economic analysis of 1997. Prepared for the Jamaica Tourist Board, Pacific Analysis Inc, Victoria, BC

Kahneman D, Knetsch JL (1992) Valuing public goods: the purchase of moral satisfaction. Journal of Environmental Economics and Management 22(1):5770

Kainuma M, Nakamori Y, Morita T (1991) Development of an intelligent decision support system for environmental modeling and planning. Research Report 128. National Institute for Environmental Studies, Japan

Karr JR (1991). Biological integrity: a long−neglected aspect of water resource management. Ecological Applications 1:6684

Karr JR, Chu EW (1999) Restoring life in running waters: better biological monitoring. Island Press, Washington, DC

Karr JR, Fausch KD, Angermeier PL, Yant PR, Schlosser IJ (1986) Assessing biological integrity in running waters: a method and its rationale. Illinois Natural History Survey, Special Publication 5

Kerans BL, Karr JR (1994) A benthic index of biotic integrity (B−IBI) for rivers of the Tennessee Valley. Ecological Applications 4:768785

Kleypas JA, Buddemeier RW, Archer D, Gattuso J, Langdon C, Opdyke BN (1999) Geochemical consequences of increased atmospheric carbon dioxide on coral reefs. Science 284:118120

Knetsch JL (1989) The endowment effect and evidence of non−reversible indifference curves. American Economic Review 79(5):12771284

Knetsch JL (1994) Environmental valuation: some problems of wrong questions and misleading answers. Environmental Values 3(4):351368

Knetsch JL, Sinden JA (1984) Willingness to pay and compensation demanded: experimental evidence of an unexpected disparity in measures of value. Quarterly Journal of Economics 99(3):507521

Kosko B (1992) Neural networks and fuzzy systems: a dynamical systems approach to machine intelligence. Prentice−Hall, Englewood Cliffs

Kosko B (1993) Fuzzy thinking. Hyperion, New York

Lang C, L'Eplattenier G, Reymond O (1989) Water quality in rivers of western Switzerland: application of an adaptable index based on benthic invertebrates. Aquatic Science 51:224234

Lapointe BE (1999) From the President's desk. Reef Line 11(2):2 and 15 (The Quarterly Journal of ReefRelief), Key West, FL

Lapointe BE, Littler MM, Littler DS (1997) Macroalgal overgrowth of fringing coral reefs at Discovery Bay, Jamaica: bottom−up versus top−down control. Proceedings of the 8th International Coral Reef Symposium 1: 927932

Leeworthy VR (1991) Recreational use value for John Pennekamp Coral Reef State Park and Key Largo National Marine Sanctuary. Strategic Assessment Branch, Ocean Assessments Division, National Oceanic and Atmospheric Administration (NOAA), Rockville, MD

Lenat DR (1988) Water quality assessment of streams using a qualitative collection method for benthic macroinvertebrates. Journal of the North American Benthological Society 7:222233

Maddala GS (1983) Limited−dependent and qualitative variables in econometrics. Cambridge University Press, Cambridge

Maher WA, Norris RH (1990) Water quality assessment programs in Australia: deciding what to measure and how and where to use bioindicators. Environmental Monitoring and Assessment 14:115130

Malinvaud E (1972) Lectures on microeconomic theory. North−Holland, Amsterdam

Mansfield E (1995) Intellectual property protection, direct investment, and technology transfer. IFC Discussion Paper 27. IFC, Washington, DCbreak

Marshall C, Rossman G (1993) Designing qualitative research. Sage Publications, Newbury Park

Mathworks (1998) MATLABTM : The language of technical computing, version 5.2. Mathworks, Natick, MA

McAllister DE (1988) Environmental, economic and social costs of coral reef destruction in the Philippines. Galaxea 7:161178

McAllister DE (1991a) Estimating the pharmaceutical values of forests, Canadian and tropical. Canadian Biodiversity 1(3): 1625

McAllister DE (1991b) What is a coral reef worth? Sea Wind 5(1):2124

McClanahan TR (1995) A coral reef ecosystem−fisheries model: impact of fishing intensity and catch selection on reef structure and processes. Ecological Modelling 80:119

McManus JW, Ablan MC (eds) (1997) ReefBase: a global database on coral reefs and their resources. User's guide version 2.0. International Center for Living Aquatic Resources Management (ICLARM), Makati City

McManus JW, Ablan MC, Vergara SG, Menez LA, Reyes KP, Gorospe ML, Halmarick L (1997) Reefbase aquanaut survey manual. International Center for Living Aquatic Resources Management (ICLARM) Educational Series 18, ICLARM, Manila

McNeill D, Freiberger P (1993) Fuzzy logic. Simon & Schuster, New York

McPhaill AA (1994) Why don't households connect to the piped water system? Observations from Tunisia. Land Economics 70(2):189196

Meesters EH (1995) Cost−effectiveness analysis of coral reef management and protection: a case study of Curaçao: I. Coral reef data collection and analysis. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Meesters EH, Bak RPM, Westmacott S (1995) A fuzzy logic model to predict coral reef development under nutrient and sediment stress. Report prepared for Resource Analysis and the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Meesters EH, Bak RPM, Westmacott S (1996a) A fuzzy logic model to predict coral reef development under nutrient and sediment stress in Curaçao. Phase 3 report, ecological model definition. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Meesters EH, Bak RPM, Westmacott S (1996b) A fuzzy logic model to predict coral reef dynamics. 8th International Coral Reef Symposium, Panama, Abstracts, p 131

Meesters EH, Bak RPM, Westmacott S, Ridgley M, Dollar S (1998) A fuzzy logic model to predict coral reef development under nutrient and sediment stress. Conservation Biology 12(5):957965

Meesters EH, Bos A, Gast GJ (1992) Effects of sedimentation and lesion position on coral tissue regeneration. Proceedings of the 7th International Coral Reef Symposium 2:681688

Meesters EH, Westmacott S (1996) Cost−effectiveness analysis of coral reef management and protection, a case study of the Maldives. Formulation of the ecological response model. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Mendelsohn R, Balick MJ (1995) The value of undiscovered pharmaceuticals in tropical forests. Economic Botany 49(2):223228

Mendelsohn R, Balick MJ (1997) Notes on economic plants. Economic Botany 51(3):328

Mestel M (1999) Drugs from the sea. Discover 20(3):7075

Miller FR, Kebede Y (1984) Genetic contributions to yield gains in sorghum, 1950 to 1980. In: Fehr WR (ed) Genetic contributions to yield gains of five major crop plants. Crop Science Society of America Special Publication 7. American Society of Agronomy, Madison, WI

Mitchell R, Carson R (1989) Using surveys to value public goods: the contingent valuation method. Resources for the Future, Washington, DC

Moffat AS (1993) New chemicals seek to outwit insect pests. Science 261:5501

Moore KS, Wehrli S, Roder H, Rogers M, Forrest JN, McCrimmon D, Zasloff M (1993) Squalamine: an aminosterol antibiotic from the shark. Proceedings of the National Academy of Science 90:13541358

Munasinghe M, McNeely J (1994) Protected area economics and policy: linking conservation and sustainable development. World Bank, Washington, DCbreak

Munda G (1995) Multicriterion evaluation in a fuzzy environment: theory and applications in ecological economics. Physica−Verlag, Heidelberg

Munro A, Hanley N (1999) Information, uncertainty and contingent valuation. In: Bateman IJ, Willis KG (eds) Contingent valuation of environmental preferences: assessing theory and practice in the USA, Europe, and developing countries. Oxford University Press

Munro JL (1983) Jamaican fisheries trends. International Center for Living Aquatic Resources Management (ICLARM) Stud Rev 7:1. ICLARM, Manila

Myers N (1988) Threatened biotas: 'hot spots' in tropical forests. Environmentalist 8:187208

Narain U, Fisher A (1994) Modeling the value of biodiversity using a production function approach. In: Perrings C, Maler K−G, Folke C, Jansson B−O, Rolling CS (eds) Biodiversity conservation: policy issues and options. Kluwer Academic Publishers, Dordrecht

National Cancer Institute (NCI) (1995) Letter of Collection. NCI, Office of Technology Development, Bethesda

National Oceanic and Atmospheric Administration (NOAA) (1993) Report of the NOAA panel on contingent valuation. Federal Register 58(10):46014614

Natural Resources Conservation Authority (NRCA) (1997) Towards a beach policy for Jamaica (a policy for the use of the foreshore and the floor of the sea). Green Paper 2/97. Natural Resources Conservation Authority, Ministry of Environment and Housing, Kingston, Jamaica

Navrud S, Munagtana (1994) Environmental valuation in developing countries: the recreational value of wildlife viewing. Ecological Economics 11:135151

New York Times (1993) Strange oases in sea depths offer map to riches. William J. Broad, 16 November

Newman D (1995) Marine bioprospecting. In: Hooten AJ, Hatziolos ME (eds) Sustainable financing for coral reef conservation: proceedings of a workshop. Environmentally Sustainable Development Proceedings Series 9, World Bank, Washington, DC, pp 3842

Nicholson WE (1994) A project for the assessment of the Montego Bay Marine Park's impact on the local fishing industry. An ICOD/CCA/NRCA Fisheries Project. Montego Bay Marine Park, Montego Bay, Jamaica

Niebling K (1996) Biotech and drug firms claim territory in cosmeceutics. Genetic Engineering News 16(7): 127

Norse EA (1993a) Chapter 3: Marine and terrestrial conservation. In: Global marine biological diversity: a strategy for building conservation into decision making. Island Press, Washington, DC

Norse EA (ed) (1993b) Global marine biological diversity, a strategy for building conservation into decision making. Island Press, Washington, DC

O'Callaghan Consulting Services Limited (1992) Environment study report. Greater Montego Bay Redevelopment Corporation, Montego Bay, Jamaica

Ogden J, Alcolado P, Alleng G, Bonair K, Laydoo R, Bone D, Klein E, Penchaszadeh P, Buchan K, Walker S, Bush P, Cortes J, DeMeyer K, Garcia J, Garzon−Ferreira J, Gayle P, Guzman H, Gerace D, Geraldes F, Jordan−Dahlgre E, Ruiz−Renteria F, Kjerfve B, Koltes K, Parker C, Oxenford H, Patt A, Azueta J, McField M, Peralta R, Pors L, Ramirez J, Rojas−Galaviz J, Ryan J, Singh J, Smith S, Tschirky J, Varela R, Woodley J, Linton D, Wiebe W, Zieman J (1997) Caribbean Coastal Marine Productivity (CARICOMP): A research and monitoring network of marine laboratories, parks, and reserves. Proc 8th International Coral Reef Symosium 1: 641646

Oppenheim AN (1992) Questionnaire design, interviewing and attitude measurement. Pinter Publishers, New York

Orbach MK, Johnson JC (1989) The transformation of fishing communities: a public policy perspective. In: Thomas JS, Maril L, Durrenberger EP (eds) Marine resource utilization: a conference in social science issues. University of South Alabama Publication Services, Mobile, AL

Organization of American States (OAS) (1994) Economic analysis of tourism in Jamaica. Technical Report of the OAS National Program of Technical Cooperation with the Jamaica Tourist Board and the Ministry of Industry, Tourism, and Commerce. OAS, Washington, DC

Office of Technological Assessment (OTA) (1987) Technologies to maintain biological diversity. OTA −F−330. US Government Printing Office, Washington, DC

Office of Technological Assessment (OTA) (1993) Pharmaceutical R&D: costs, risks, and rewards. US Government Printing Office, Washington, DCbreak

Paleroni NJ (1994) Some reflections on bacterial diversity. ASM News 60(10):537540

Pardey PG, Skovmand B, Taba S, Van Dusen ME, Wright BD (1998) The cost of conserving maize and wheat genetic resources *ex situ* . In: Smale M (ed) Farmers, gene banks and crop breeding: economic analyses of diversity in wheat, maize and rice. Kluwer, Boston, MA, pp 3553

Patton MQ (1990) Qualitative evaluation and research methods. Sage Publications, Newbury Park

Pearce DW, Moran D (1994) The economic value of biodiversity. IUCN/Earthscan, London

Pearce DW, Puroshothaman S (1992a) Protecting biological diversity: the economic value of pharmaceutical plants. Discussion Paper 9227. Centre for Social and Economic Research on the Global Environment, London

Pearce DW, Puroshothaman S (1992b) The economic value of plant−based pharmaceuticals. In: Swanson T (ed) Intellectual property rights and biodiversity conservation. Cambridge University Press, Cambridge

Pendleton LH (1995) Valuing coral reef protection. Ocean and Coastal Management 26(2): 119131

Perez P (1995) Environmental biotechnology business opportunities for the next five years. Ninth International Biotechnology Meeting and Exhibition. Biotechnology Industry Organization, San Francisco, CA

Pernetta J, Elder D (1993) Cross−sectoral, integrated coastal area planning: guidelines and principles for coastal area development. International Union for the Conservation of Nature and Natural Resources (IUCN) and World Wildlife, Gland

Perrings C, Walker BW (1995) Biodiversity loss and the economics of discontinuous change in semiarid rangelands. In: Perrings C, Maler K−G, Folke C, Holling CS, Jansson B−O (eds) Biodiversity loss: economic and ecological issues. Cambridge University Press, Cambridge, pp 190210

Phillips DJH (1980) Quantitative aquatic biological indicators. Applied Science Publishers Ltd, London

Pido MD (1995) The application of rapid rural appraisal techniques in coastal resources planning: experience in Malampaya Sound, Philippines. Ocean and Coastal Management 26(1):5772

Pido MD, Chua TE (1992) A framework for rapid appraisal of coastal environments. In: Chua TE, Scura LF (eds) Integrative framework and methods for coastal area management. International Center for Living Aquatic Resources Management (ICLARM) Conference Proceedings 37, ICLARM, Manila, pp 135148

Pido MD, Pomeroy RS, Carlos MB, Garces LR (1996) A handbook for rapid appraisal of fisheries management systems. International Center for Living Aquatic Resources Management (ICLARM), Manila

Pigott JD, Land LS (1986) Interstitial water chemistry of Jamaica reef sediment: sulfate reduction and submarine cementation. Marine Chemistry 19:355378

Pigou AC (1920) The economics of welfare. Macmillan, London

Plan Development Team (PDT) (1990) The potential of marine fisheries reserves for reef management in the US South Atlantic. National Oceanic and Atmospheric Administration (NOAA), Technical Memorandum NMFS−SEFC−261 Contribution No. CRD/8990/04

Polasky S, Pavich S, Jaspin M (1997) Bibliography on the conservation of biological diversity: biological/ecological, economic and policy issues. Department of Agricultural and Resource Economics, Oregon State University, OR

Polasky S, Solow A (1995) On the value of a collection of species. Journal of Environmental Economics and Management 29:298303

Pollnac RB (1998) Rapid assessment of management parameters for coral reefs. Coastal Resources Center, University of Rhode Island Press, RI

Pollnac RB, Sondita F, Crawford B, Mantjoro E, Rotinsulu, Siahainenia (1997) Socioeconomic aspects of resource use in Bentenan and Tumbak. CRC/URI CRMP, Jakarta, pp 79, http://www.indomarine.or.id/pesisir/

Posey DA (1996) Traditional resource rights: international instruments for protection and compensation for indigenous peoples and local communities. IUCN, Gland/Cambridge

Powell MJD (1978) The convergence of variable metric methods for nonlinearly constrained optimization calculations. In: Mangasarian OL, Meyer RR, Robinson SM (eds) Nonlinear programming 3. Academic Press, London

Prescott−Allen R, Prescott−Allen C (1988) Genes from the wild: using wild genetic resources for food and raw materials. Earthscan, Londonbreak

Principe P (1989a) The economic significance of plants and their constituents as drugs. In: Wagner H, Hikino H, Farnsworth N (eds) Economic and medicinal plant research 3. Academic Press, London, pp 655656

Principe P (1989b) The economic value of biological diversity among medicinal plants. OECD, Paris

Putterman DM (1996) Model material transfer agreements for equitable biodiversity prospecting. Colorado Journal of International Environmental Law and Policy 7(1):145173

Putterman DM (1997) Review of marine genetic resource R&D issues (Annex 6). In: Huber RM, Ruitenbeek HJ (eds) Marine system valuation: an application to coral reef systems in the developing tropics. Interim Report to World Bank Research Committee, Project #RPO 68105, World Bank, Washington, DC

Putterman DM (1998) Access to marine genetic resources in Jamaica: incorporating genetic resources utilization into integrated coastal zone management. A study of policies and institutions. Report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC

Quammen D (1996) The song of the dodo: island biogeography in an age of extinctions. Simon & Schuster, New York

Randall A (1986) The possibility of satisfactory benefit estimation with contingent markets. In: Cummings RG, Brookshire DS, Schulze WD (eds) Valuing environmental goods: an assessment of the contingent valuation method. Rowman & Allanheld, Totowa

Randall A (1993) Passive use values and contingent valuation. Choices 8(2):1215

Randall A, Stoll J (1980) Consumers' surplus in commodity space. American Economic Review 70(3):449455

Ready R, Navrud S, Duborg R (1999) How do respondents with uncertain willingness to pay answer contingent valuation questions? Paper presented to EAERE conference, June, Oslo

Reaka−Kudla ML (1997) The global biodiversity of coral reefs: a comparison with rain forests. In: Reaka−Kudla ML, Wilson DE, Wilson EO (eds) Biodiversity II: understanding and protecting our biological resources. Joseph Henry Press, Washington, DC, pp 83108

Reaka−Kudla ML, Wilson DE, Wilson EO (eds) (1997) Biodiversity II: understanding and protecting our biological resources. Joseph Henry Press, Washington, DC

Reef Check (1997) Reef Check 97 Press Conference Background Material, 16 October 16. Institute for Environment and Sustainable Development, Hong Kong University of Science and Technology, http://www.ust.hk/~webrc/ReefCheck/reef.html

Reid WV, Laird SA, Gámez R, Sittenfeld A, Janzen DH, Gollin MA, Juma C (1993a) A new lease on life. In: Reid WV, Laird SA, Meyer CA, Gámez R, Sittenfeld A, Janzen DH, Gollin MA, Juma C (eds) Biodiversity prospecting: using genetic resources for sustainable development. World Resources Institute, Washington, DC, pp 152

Reid WV, Laird SA, Meyer CA, Gámez R, Sittenfeld A, Janzen DH, Gollin MA, Juma C (1993b) Biodiversity prospecting: using genetic resources for sustainable development. World Resources Institute, Washington, DC

Renard Y (1991) Institutional challenges for community−based management in the Caribbean. Nature and Resources 27(4):49

Resource Analysis and Coastal Zone Management (CZM) Centre (1994) COastal zone Simulation MOdel (COSMO): manual. Resource Analysis and Coastal Zone Management Centre, National Institute for Coastal and Marine Management, The Hague

Resource Analysis and Delft Hydraulics (1993) How to account for impacts of climate change in integrated coastal zone management: concepts and tools for approach and analysis. World Coast Conference 1993, 15 November 1993, Noordwijk, The Netherlands

Rhoades RE (1991) The world's food supply at risk. National Geographic 179(4):74103

Richmond RH (ed) (1993) Proceedings of the Seventh International Coral Reef Symposium. 2227 June 1992, University of Guam Marine Lab, Mangilao, Guam

Ridgley M, Dollar S (1996) A coral−reef impact−assessment model using fuzzy rule−based logic, Phase II Interim Report. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Ridgley M, Dollar S, Bailey K (1995) Overview of the development of a prototype model to estimate future pollution−induced coral reef impacts. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DCbreak

Ridgley M, Rijsberman FR (1992) Multicriteria evaluation in a policy analysis of a Rhine estuary. Water Resources Bulletin 28(6):10951109

Rijsberman F (1995) Cost−effectiveness analysis of coral reef management and protection: a case study of the Maldives. First visit report. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Rijsberman FR, Koudstaal R (1989) Development and application of a framework for analysis for integrated coastal resources management in an international context. In Magoon OT (ed), Coastal Zone 1989. ASCE, New York, pp 5871

Rijsberman F, Westmacott S (1996) Cost−effectiveness analysis of coral reef management and protection: a case study for Curaçao. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Rijsberman FR, Westmacott S, Hirsch D (1995a) Cost−effectiveness analysis of coral reef management and protection, a case study of Curaçao: phase 1 report. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Rijsberman FR, Westmacott S, Waardenburg D (1995b) CORONA: coastal resources management roleplay. Trainers' manual. Resource Analysis, Delft, and CZM Centre, National Institute for Coastal and Marine Management, the Hague

Risk MJ (1992) Musings on monitoring. Reef Encounter 12:79

Rosenberg DM, Resh VH (1993) Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York

Rowe R, d'Arge R, Brookshire D (1980) An experiment on the economic value of visibility. Journal of Environmental Economics and Management 7:119

Rubin SM, Fish SC (1994) Biodiversity prospecting: using innovative contractual provisions to foster ethnobotanical knowledge, technology and conservation. Colorado Journal of International Environmental Law and Policy 5:2358

Ruitenbeek HJ (1989) Social cost−benefit analysis of the Korup project, Cameroon. WWF, Godalming

Ruitenbeek HJ (1992) The rainforest supply price: a tool for evaluating rainforest conservation expenditures. Ecological Economics 6(1):5778

Ruitenbeek HJ (1996) Distribution of ecological entitlements: implications for security and population movement. Ecological Economics 17:4964

Ruitenbeek HJ, Cartier CM with contributions from Bunce L, Gustavson K, Putterman D, Spash CL, van der Werff ten Bosch JD, Westmacott S, Huber R (1999) Issues in applied coral reef biodiversity valuation: results for Montego Bay, Jamaica. World Bank Research Committee Project RPO#68222 Final Report, World Bank, Washington, DC

Ruitenbeek HJ, Ridgley M, Dollar S, Huber RM (1996) Use of fuzzy logic in a coral reef management model: preliminary results for Montego Bay, Jamaica. Fourth Biennial Meeting International Society for Ecological Economics, Boston University, Boston, MA

Ruitenbeek HJ, Ridgley M, Dollar S, Huber R (1999a) Optimization of economic policies and investment projects using a fuzzy logic based cost−effectiveness model of coral reef quality: empirical results for Montego Bay, Jamaica A least cost model for coral reef management and protection. World Bank Research Committee Project RPO#68008 Final Report, World Bank, Washington, DC

Ruitenbeek HJ, Ridgley M, Dollar S, Huber R (1999b) Optimization of economic policies and investment projects using a fuzzy logic based cost−effectiveness model of coral reef quality: empirical results for Montego Bay, Jamaica. Coral Reefs (in press)

Saade ME (1996) Adoption and impact of high yield wheat varieties in northern Tunisia. CIMMYT Economics Working Paper 9603. CIMMYT, Mexico

Sagoff M (1988) The economy of the earth. In: MacLean D (ed) Cambridge studies in philosophy and public policy. Cambridge University Press, Cambridge

Sagoff M (1996) On the value of endangered and other species. Environmental Management 20(6):897911

Sahney AK (1982) Sample survey of the fishing industry in Jamaica 1981. Presented at the WECAF Conference, FAO, 1721 May 1982. Data Collection and Statistics Branch, Data Bank and Evaluation Division, Ministry of Agriculture, Kingston, Jamaica

Samples KC, Dixon JA, Gowen MM (1986) Information disclosure and endangered species valuation. Land Economics 62(3):306312break

Sawyer DA (1992) Taka Bone Rate: management, development and resource valuation of an Indonesian atoll. Masters Thesis. Dalhousie University, Halifax, NS

Scanlan PM (1988) The dolphins are back: a successful quality model for healing the environment. Productivity Press, Portland, OR

Scheuer PJ (1990) Some marine ecological phenomena: chemical basis and biomedical potential. Science 248:1737

Schonhuth M, Kievelitz U (1994) Participatory learning approaches. Rapid rural appraisal/ participatory appraisal. An introductory guide. Schriftenreihe der GTZ, No. 248

Scrip Newsletter, January 1996, p 37

Sen A (1988) The standard of living. Cambridge University Press, Cambridge

Shyamsundar P, Kramer RA (1996) Tropical forest protection: an empirical analysis of the costs borne by local people. Journal of Environmental Economics and Management 31(2):129144

Simberloff DS, Abele LG (1976) Island biogeography theory and conservation practice. Science 191:285286

Simpson RD, Craft AB (1996) The social value of using biodiversity in new pharmaceutical research. Discussion Paper 9633. Resources for the Future, Washington, DC

Simpson RD, Sedjo RA (1996a) Investments in biodiversity prospecting and incentives for conservation. Discussion Paper 9614. Resources for the Future, Washington, DC

Simpson RD, Sedjo RA (1996b) Valuation of biodiversity for use in new product research in a model of sequential search. Discussion Paper 9627. Resources for the Future, Washington, DC

Simpson RD, Sedjo RA, Reid JW (1996) Valuing biodiversity for use in pharmaceutical research. Journal of Political Economy 104(1):163184

Singh GN (1996) Community Intellectual Rights Act. In: Egziabher TBG (ed) A case for community rights. Third World Network, Penang

Smale M (1995) "Maize is life": Malawi's delayed green revolution. World Development 23(5):819831

Smale M (ed) (1998) Farmers, gene banks and crop breeding: economic analyses of diversity in wheat, maize and rice. Kluwer, Boston, MA

Smale M, Heisey PW, Leathers HD (1995) Maize of the ancestors and modern varieties: the microeconomics of high yielding variety adoption in Malawi. Economic Development and Cultural Change 43(2):351368

Smith PN (1994) Application of fuzzy sets in the environmental evaluation of projects. Journal of Environmental Management 42:365388

Solow A, Polasky S, Broadus J (1993) On the measurement of biological diversity. Journal of Environmental Economics and Management 24:6068

Sorensen J (1997) National and international efforts at integrated coastal zone management: definitions, achievements, and lessons. Coastal Management 25:341

Soule DF (1988) Marine organisms as indicators: reality or wishful thinking? In: Soule DF, Kleppel GS (eds) Marine organisms as indicators. Springer−Verlag, New York, pp 111

Spash CL (1993a) Economics, ethics, and long−term environmental damages. Environmental Ethics 15(2):117132

Spash CL (1993b) Estimating the importance of inviolable rights: the case of long−term damages and future generations. Scottish Economic Society

Spash CL (1994) Double CO2 and beyond: benefits, costs and compensation. Ecological Economics 10(1):2736

Spash CL (1997) Ethics and environmental attitudes with implications for economic valuation. Journal of Environmental Management 50(4):403416

Spash CL (1998a) Environmental values, attitudes and ethics: non−compensatory choices in a developing country context. Paper presented at the 25th Anniversary of Doctoral Program, 17 April 1998, University of Wyoming, WY

Spash CL (1998b) Informing and forming preferences in contingent valuation: a case study. Paper presented to the World Congress of Environmental and Resource Economists, 2527 June 1998, Venice, Italy

Spash CL (1998c) Investigating individual motives for environmental action: lexicographic preferences, beliefs and attitudes. In: Lemons J, Westra L, Goodland R (eds) Ecological sustainability and integrity: concepts and approaches. Kluwer Academic Publishers, Dordrechtbreak

Spash CL, Hanley N (1995) Preferences, information and biodiversity preservation. Ecological Economics 12(3):191208

Spash CL, van der Werff ten Bosch JD, Westmacott S, Ruitenbeek HJ (1998) Lexicographic preferences and the contingent valuation of coral reef biodiversity in Curaçao and Jamaica. Report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC

Specht JE, Williams JH (1984) Contributions of genetic technology to soybean productivity retrospect prospect. In: Fehr WR (ed) Genetic contributions to yield gains of five major crop plants. Crop Science Society of America Special Publication 7. American Society of Agronomy, Madison, WI

Spencer Davies P, Brown BE (1992) Identification of a coral reef management strategy in developing countries. I: Main report and recommendations. Report to the Commission of the European Communities

Spurgeon J (1992) The economic valuation of coral reefs. Marine Pollution Bulletin 24(11):529536

Stevens TH, Echeverria J, Glass RJ, Hager T, More TA (1991) Measuring the existence value of wildlife: what do CVM estimates really show? Land Economics 67(4):390400

Stroh WH (1998) Industrial enzymes market: growth experienced from new products and movement into global market. Genetic Engineering News 5(1):11

Sullivan K, Chiappone M (1994) Montego Bay Marine Park, Jamaica: rapid ecological assessment. Conservation Data Centre, Nature Conservancy, and Natural Resources Conservation Authority, Arlington, VA

Swallow BM, Woudyalew M (1994) Evaluating willingness to contribute to a local public good: application of contingent valuation to tsetse control in Ethiopia. Ecological Economics 11:153161

Swaminathan MS (ed) (1996) Agrobiodiversity and farmers' rights: proceedings of a technical consultation on an implementation framework for farmers' rights. MS Swaminathan Research Foundation, Madras

Swanson TM (1996) The reliance of northern economies on southern biodiversity: biodiversity as information. Ecological Economics 17(1):18

Taylor FF (1993) To hell with paradise: a history of the Jamaican tourist industry. University of Pittsburgh Press, Pittsburgh, PA

Tomascik T (1993) Coral reef ecosystems: environmental management guidelines. Environmental Management Development in Indonesia Project (EMDI) Environmental Reports 35. School for Resource and Environmental Studies, Dalhousie University, Halifax, NS

Tomascik T, Sander F (1985) Effects of eutrophication on reef building corals: I. Growth rate of the reef building coral *Montastrea annularis* . Marine Biology 87:143155

Tomascik T, Sander F (1987) Effects of eutrophication on reef building corals: III. Reproduction of the reef building coral *Porites porites* . Marine Biology 94:7794

Townsley P (1993) A manual on rapid appraisal methods for coastal communities. Bay of Bengal Programme, Madras, India

United States Agency for International Development (USAID) (1996) Montego Bay Environmental Monitoring Program. Final report. Prepared by Hay B, Louis Berger International Inc, Needham, MA

United States Department of Commerce (USDOC) (1994) Florida Keys National Marine Sanctuary draft management plan/environmental impact statement. Volumes 13. USDOC, Office of Ocean and Coastal Resource Management, Silver Spring, MD

United States Environmental Protection Agency (USEPA) (1990a) Biological criteria: national program guidance for surface waters. EPA−440/590004, USEPA, Office of Water, Office of Regulations and Standards, Criteria and Standards Division, Washington, DC

United States Environmental Protection Agency (USEPA) (1990b) Near coastal program plan for 1990: estuaries, November 1990. EPA−600490/033, USEPA, Washington, DC

Vagelos PR (1991) Are prescription drug prices too high? Science 252:10801084

Van Gaasbeek AF, Heijbroak AMA, Baandrager P, Boers GJ (1994) The world seed market: developments and strategy. Rabobank Nederland Agribusiness Research, Utrecht

Veghel MLJ (1994) Polymorphism in the Caribbean reef building coral *Montastrea Annularis* . Ph.D. Disseration, University of Amsterdam

von Altrock C (1995) Fuzzy logic and neurofuzzy applications explained. Prentice−Hall, Englewood Cliffs

Walgate R (1990) Miracle or menace: biotechnology and the Third World. Panos Dossier (3). Panos Institute, Londonbreak

Wasike W (1996) Contingent valuation of river pollution control and domestic water supply in Kenya. PhD Dissertation, University of Stirling, Stirling, Scotland

Wasike W, Hanley N (1998) The pricing of domestic water services in developing countries: a contingent valuation application to Kenya. International Journal of Water Resources Development 14(1):4154

Weber J, Saunders L (1996) Managing a coral reef ecosystem in Indonesia. Paper presented to the 4th Biennial Meeting of the International Society for Ecological Economics, Boston, MA

Werners S (1998) Development of the user−friendly computer model COCOMO for coastal conservation in Montego Bay. Status report prepared for the Environmentally and Socially Sustainable Development Sector Department, Latin America and the Caribbean Region (LCSES) of the World Bank, Washington, DC. Mimeo

Westmacott S (1995) Decision support in coastal zone management. International Institute for Hydraulic and Environmental Engineering (IHE) and Resource Analysis, Delft

Westmacott S (1996) Cost−effectiveness analysis of coral reef management and protection, a case study of the Maldives: phase 2 report model definition and data collection. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Westmacott S, Klinckhamers P, Fernandes L, Rijsberman F (1995) Cost−effectiveness analysis of coral reef management and protection, a case study of Curaçao: Phase 2: field visit project report. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

Westmacott S, Rijsberman F (1995) CORAL, a coastal management model for the sustainable development of coral reef areas. Physics and Chemistry of the Earth 20(34):245250

Westmacott S, Rijsberman F (1997) Cost−effectiveness analysis of coral reef management and protection: CORAL, a coral reef management model for the Republic of the Maldives. Report prepared for the Latin America and Caribbean Environment and Urban Development Division (LA3EU) of the World Bank, Washington, DC

White AT (1989) Two community−based marine reserves: lessons for coastal management. In: Chua TE, Pauly D (eds), Coastal area management in Southeast Asia: policies, management strategies and case studies. ICLARM

Conference Proceedings 19. International Center for Living Aquatic Resources Management (ICLARM), Manila

White AT, Hale LZ, Renard Y, Cortesi L (1994) Collaborative and community−based management of coral reefs: lessons from experience. Kumarian Press, West Hartford, CT

Whittington D, Brisco J, Mu X, Barron W (1990) Estimating willingness to pay for water services in developing countries. Economic Development and Cultural Change 38(4):293311

Whittington D, Lauria D, Wright A, Choe K, Hughes J, Swarna V (1993) Household demand for improved sanitation services in Ghana. Water Resources Research 29(6):15391560

Wilkinson CR (ed) (1998) Status of coral reefs of the world: 1998. Global Coral Reef Monitoring Network, AIMS, Queensland

Williams ID, Polunin NVC (1999) Large scale correlations of macroalgal cover and fish abundance on Caribbean reefs. Manuscript.

Willig RD (1976) Consumer's surplus without apology. American Economic Review 66(4):587597

Willis K, Garrod G, Saunders C (1993) Valuation of the South Downs and Somerset Levels Environmentally Sensitive Areas. Centre for Rural Economy, University of Newcastle on Tyne, Newcastle

Wilson EO (1992) The diversity of life. Harvard University Press, Cambridge

Wilson JG, Jeffrey DW (1994) Benthic biological pollution indices in estuaries. In: Kramer KJ (ed) Biomonitoring of coastal waters and estuaries.. CRC Press, Boca Raton, FL, pp 311324

Witt S (1985) Biotechnology and genetic diversity. California Agricultural Lands Project, San Francisco, CA

Woodley JD (1995) Tropical Americas regional report on the issues and activities associated with coral reefs and related ecosystems. International Coral Reef Initiative, US Department of State, Washington, DC

Woodley JD (1999) Sea−urchins exert top−down control of marcoalgae on Jamaican coral reefs (1). Coral Reefs 18:192

Woodley JD, Gayle PMH, Judd N (1999) Sea−urchins exert top−down control of marcoalgae on Jamaican coral reefs (2). Coral Reefs 18:193

World Bank (1991) Agricultural biotechnology, the next "Green Revolution"? Technical Paper 133. World Bank, Washington, DCbreak

World Bank (1993a) Nordwijk guidelines for integrated coastal zone management. World Bank, Washington, DC

World Bank (1993b) World development report: investing in health. World Bank, Washington, DC

World Bank (1996) Guidelines for integrated coastal zone management. Environmentally Sustainable Development Studies and Monographs Series 9. World Bank, Washington, DC

World Conservation Monitoring Centre (WCMC) (1992) Global biodiversity: status of the earth's living resources. Chapman and Hall, London

World Conservation Monitoring Centre (WCMC) (1994a) Case study: biodiversity and the pharmaceutical industry. World Conservation Monitoring Centre, Cambridge

World Conservation Monitoring Centre (WCMC) (1994b) Case study: the use of plant genetic resources in agriculture. World Conservation Monitoring Centre, Cambridge

Wright A, McCarthy PJ (1994) Drugs from the sea at Harbor Branch. Sea Technology 35(8):1018

Wright MG (1995) An economic analysis of coral reef protection in Negril, Jamaica. Working Paper 11. Centre for Environment and Development, University of the West Indies at Mona, Kingston, Jamaica

Yuan R, Hsu M (1996) Herbal medicines, part 1. Genetic Engineering News 16(2):2932

Zadeh L (1965) Fuzzy sets. Information and Control 8(3):338353

Zilberman D, Yarkin C, Heiman A (1998) Institutional change and biotechnology in agriculture: implications for developing countries. In: Smale M (ed) Farmers, gene banks and crop breeding: economic analyses of diversity in wheat, maize and rice. Kluwer, Boston, MA, pp 191204

Zilinskas RA, Colwell RR, Lipton DW, Hill RT (1995) The global challenge of marine biotechnology: a status report on the United States, Japan, Australia and Norway. Maryland Sea Grant Publication, College Park MDbreak

LIST OF CONTRIBUTORS

Leah Bunce
International Program Office
National Ocean Service, NOAA
1305 East−West Highway
SSMC−IV/13th Floor
Silver Spring, MD 20910
USA
Tel: +1 301 713 3078, ext.129
Fax: +1 301 713 4263
E−mail: L Bunce@ocean.nos.noaa.gov

Cynthia Cartier
HJ Ruitenbeek Resource Consulting Ltd
RR#2, Site 52, C21
Gabriola, BC V0R 1X0
Canada
Tel: +1 250 247 8436
Fax: +1 250 247 8492
E−mail: ccartier@island.net

Steve Dollar
School of Ocean & Earth Science & Technology
University of Hawaii at Manoa
1000 Pope Road

Honolulu, Hawaii 96822
USA
Tel: +1 808 956 7631
Fax: +1 808 956 3014
E−mail: sdollar@soest.hawaii.edu

Kent Gustavson
Gustavson Ecological Resource Consulting
PO Box 115
Gabriola, BC V0R 1X0
Canada
Tel: +1 250 247 9734
Fax: +1 250 247 9735
E−mail: gustecol@netcom.ca

Nick Hanley
Institute of Ecology and Resource Management
Kings Building
University of Edinburgh
Edinburgh, Scotland EH9 3JG
United Kingdom
Tel: +44 131 5354111
Fax: +44 131 6672601
E−mail: N.D.Hanley@ed.ac.uk

Bernward Hay
Louis Berger and Associates, Inc
75 Second Avenue, Suite 700
Needham, MA 02494
USA
Tel: +1 781 444 3330, ext.282
Fax: +1 781 444 0099
E−Mail: hay@lberger.com

Richard M Huber
The World Bank, Rm 16025
Environmentally and Socially Sustainable Development
Sector Management Unit
Latin America and the Caribbean Region (LCSES)
1818 H Street NW
Washington, DC 20433
United States of America
Tel: +1 202 473 8581
Fax: +1 202 522 3540
E−mail: RHuber 1@worldbank.org

Stephen C Jameson
Coral Seas Inc −
Integrated Coastal Zone Management
4254 Hungry Run Road
The Plains, VA 201981715

United States of America
Tel: +1 703 754 8690
Fax: +1 703 754 9139
E−Mail:sjameson@coralseas.com

Christiane Klöditz
Resource Analysis
Zuiderstraat 110
2611 SJ Delft
The Netherlands
Tel: +31 015 2191507
Fax: +31 015 2124892
E−mail: Christiane.Kloditz@resource.nl

Daniel Putterman
Genetic Resources Consulting
1828 L Street NW, Suite 1000
Washington, DC 20036
USA
Tel: +1 202 463 8450
Fax: +1 202 293 4598
E−mail: dputterman@igc.apc.orgbreak

Mark Ridgley
Department of Geography
University of Hawaii at Manoa
2424 Maile Way
Honolulu, Hawaii 96822
USA
Tel: +1 808 956 7030
Fax: +1 808 956 3512
E−mail: ridgley@hawaii.edu

Frank Rijsberman
Resource Analysis
Zuiderstraat 110
2611 SJ Delft
The Netherlands
Tel: +31 015 2191507
Fax: +31 015 2124892
E−mail: Frank.Rijsberman@resource.nl

Jack Ruitenbeek
HJ Ruitenbeek Resource Consulting Ltd
RR#2, Site 52, C21
Gabriola, BC V0R 1X0
Canada
Tel: +1 250 247 8436
Fax: +1 250 247 8492
E−mail: hjruiten#web.net

Clive L Spash
Department of Land Economy
University of Cambridge
19 Silver Street
Cambridge CB3 9EP
United Kingdom
Tel: +44 1223 339773
Fax: +44 1223 337130
E−mail: cls27@cam.ac.uk

Jasper D van der Werff ten Bosch
Resource Analysis
Zuiderstraat 110
2611 SJ Delft
The Netherlands
Tel: +31 015 2191507
Fax: +31 015 2124892
E−mail: Jasper.v.d.Werff@resource.nl

Saskia Werners
Resource Analysis
Zuiderstraat 110
2611 SJ Delft
The Netherlands
Tel: +31 015 2191507
Fax: +31 015 2124892
E−mail: Saskia.Werners@resource.nl

Susie Westmacott
33 Old Priory Close, Hamble
Southampton, S031 4QP
United Kingdom
Tel: +44 1703 457 950
Fax: +44 1703 457 950
E−mail: susie@infobonaire.com

Jill Williams
Executive Director
The Montego Bay Marine Park Trust
Pier 1, Howard Cooke Blvd.
Montego Bay
Jamaica
Tel: +1 876 952 5619
Fax: +1 876 940 0659
E−mail: mbmp@n5.com.jm