Reefs at Risk in the Caribbean

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CONTRIBUTING INSTITUTIONS

The Reefs at Risk in the Caribbean project was developed and implemented by the World Resources Institute (WRI) in collaboration with many partner organizations.

Research Institutions and Universities

- Atlantic and Gulf Rapid Reef Assessment (AGRRA)
- Caribbean Coastal Marine Productivity Program (CARICOMP)
- Centre For Marine Sciences, the University of the West Indies at Mona, Jamaica (CMS-UWI)
- Florida International University (FIU)
- Gulf and Caribbean Fisheries Institute (GCFI)
- National Center for Caribbean Coral Reef Research (NCORE)
- University of Miami (UM)
- University of South Florida (USF)
- University of the West Indies (UWI)

Nongovernmental Organizations

- Caribbean Conservation Association (CCA)
- Corporación para el desarrollo sostenible del Archipiélago de San Andrés, Providencia y Santa Catalina (CORALINA)
- Environmental Defense
- Fondation pour la Protection de la Biodiversité Marine (FoProBiM)
- Island Resources Foundation (IRF)
- The Nature Conservancy (TNC)
- Reef Environmental Education Foundation (REEF)
- Reef Check
- World Wildlife Fund (WWF)

Government Agencies and International Organizations

- Global Coral Reef Monitoring Network (GCRMN)
- International Coral Reef Action Network (ICRAN)
- United Nations Environment Programme - Caribbean Environment Programme (UNEP-CEP)
- United Nations Environment Programme - World Conservation Monitoring Centre (UNEP-WCMC)
- U.S. National Aeronautics and Space Administration (NASA)
- U.S. National Oceanographic and Atmospheric Administration (NOAA)
- World Bank / GEF Mesoamerican Barrier Reef System (MBRS) Project
- The World Fish Center

Financial Support

- The Curtis and Edith Munson Foundation
- The Henry Foundation
- Netherlands Ministry of Foreign Affairs
- Swedish International Development Cooperation Agency (SIDA)
- United Nations Foundation (UNF)
- U.S. Agency for International Development (USAID)

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WASHINGTON, DC

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Cover Photo
French Anglefish by Wolcott Henry©

Inside Front Cover Photo
Staghorn Coral by Toni Parras

Report Series Design
Lomangino Studio Inc.

Layout of *Reefs at Risk in the Caribbean*
Maggie Powell

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ISBN 1-56973-567-0
Library of Congress Control Number: 2004113031
Printed in the United States of America on chlorine-free paper with recycled content of 50%, 30% of which is post-consumer.

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Foreword

The Caribbean region is endowed with a wealth of coastal and marine resources, including a wonderful multitude of unique plants and animals. Most Caribbean countries depend on the sea for the goods and services it provides. Reef fisheries are a vital source of protein for millions of people in the region and a source of employment for hundreds of thousands of full- and part-time fishers. Over 116 million people live within 100 km of the Caribbean coast and over 25 million tourists a year visit the Caribbean, almost all of whom spend the majority of their time in coastal areas. Tourism revenue alone brings in over US$25 billion a year to the region.

There is growing concern, however, that the accelerating degradation and loss of these resources would result in significant hardship for coastal populations, nations, and economies. This report identifies nearly two-thirds of the region's reefs to be directly threatened by human activities, and estimates future economic losses from diminished coral reef fisheries, dive tourism and shoreline protection services at between US$350 – US$870 million per year. Coral reefs are extremely important to the economies of Caribbean countries today, and they are the capital stock for future economic and political security.

Ensuring the vitality of coral reefs and their ability to continue providing benefits to society and economies is critically important, but there is much we do not know about these resources. Until now, a comprehensive assessment of Caribbean coral reefs, including their location and threats, has never been undertaken. *Reefs at Risk in the Caribbean* seeks to analyze the full range of threats to these unique ecosystems as well as to orient the region's policy-makers toward potential opportunities for capturing greater benefit from their sustainable use.

Because coral reefs do not conform to national boundaries, protecting and restoring them can only be achieved through collaboration among nations and organizations. In fact, this report would not have been possible without the many partners, organizations, and individuals in the region who came together with the sole purpose of making sure that this analysis was accurate and represented the needs and priorities of the region. We deeply appreciate their support and that of those agencies that kindly provided funds for this analysis.

Reefs at Risk in the Caribbean is an integral part of the work of the World Resources Institute, the International Coral Reef Action Network (ICRAN), and the UNEP Caribbean Environment Programme (CEP) in the Wider Caribbean. We hope that the report will serve as a valuable tool for governments and environmental organizations in the region to better understand the growing threats affecting the marine environment of the Caribbean and to identify priorities and sites for immediate action.

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World Resources Institute

KRISTIAN TELEKI
Executive Director
International Coral Reef Action Network

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Coordinator
UNEP Caribbean Environment Programme

Preface

Since the age of seven, when my father threw me overboard, I have been observing coral reefs through a dive mask. I have marveled at the beauty, biological diversity, and productivity of coral reefs and have seen how important they are to the local people who depend on them for food, income, recreation, and spiritual enrichment. I have also seen how human activity has undermined the health and vitality of reefs. The coral reefs I observed in the 1940s are totally different today. Sadly, none has changed for the better.

When I think of coral reef ecology, the concepts of *connection and interdependence* come to mind. Corals have their symbiotic algal partners, while "cleaner fish" have their clients. Landscape management relates directly to sediment and nutrient delivery and to reef health, while energy use and carbon dioxide emissions link to global warming and coral bleaching. The historical over-harvesting of large animals has impaired reef vitality. Public awareness is essential for sustainable reef management. These are just some of the examples that underscore the vital connections in time and space that affect coral reefs. The tragic decline in reef health is due to human insult, and their restoration likewise depends on human action.

PHOTO: WOLCOTT HENRY ©

I am pleased to see that *Reefs at Risk in the Caribbean* addresses these connections and calls attention to the importance of people in the equation of reef health and restoration. The involvement of multiple partner organizations ensures that this report reflects the many facets of reef assessment and management, and will be widely used. Predictably, I totally concur with the need for greater public awareness. It is my view that without public support, rational and sustainable management will not occur. I am often told that our television shows were instrumental in inspiring many of our present ocean experts to pursue a career in ocean sciences. Of course, awareness is not action. *Reefs at Risk in the Caribbean* clearly outlines the critical steps required for building capacity and improving management. The focus on socioeconomic issues is crucial to ensuring that future generations will continue to benefit from coral reefs.

Ultimately, our challenge is not to manage reefs: it is to manage ourselves. I applaud the World Resources Institute for its admirable work to protect coral reefs, a priceless natural treasure.

JEAN-MICHEL COUSTEAU | Ocean Futures Society

Acknowledgments

The Reefs at Risk in the Caribbean project would not have been possible without the encouragement and financial support provided by the United Nations Foundation, the U.S. Agency for International Development, the United Nations Environment Programme - Caribbean Environment Programme, the U.S. National Oceanographic and Atmospheric Administration, the Swedish International Development Cooperation Agency, the Netherlands Ministry of Foreign Affairs, the Curtis and Edith Munson Foundation, the Henry Foundation, the World Bank / GEF Mesoamerican Barrier Reef System Project, the National Center for Caribbean Coral Reef Research, the Nature Conservancy, Environmental Defense, and the World Fish Center. The Reefs at Risk project is part of the International Coral Reef Action Network, a collaboration developed to reverse the decline of the world's coral reefs. (See inside back cover.)

The World Resources Institute gratefully acknowledges the many partners and colleagues who contributed to this project. (*See inside front cover for full institutional names.*) We thank Philip Kramer (TNC) and Robert Ginsburg (AGRRA) for the provision of AGRRA data and guidance with the threat analysis; Mark Spalding (University of Cambridge) for sharing his knowledge of Caribbean coral reefs; Hillary Nobles (IRF) for compiling information on coral reef condition; Serge Andréfouët (Institut de Recherche pour le Développement) and Christine Kranenburg (USF) for coral reef maps; Jennifer Gebelein (FIU), Steve Rohmann and Aurelie Shapiro (NOAA) for land cover classifications; Ed Green, Corinna Ravilious, Emily Corcoran, Michelle Taylor, and Ed McManus (UNEP-WCMC) for providing maps of coral reefs and marine protected areas; Al Strong, William Skirving, Scott Baron and Andrew Barton (NOAA) for information on warming seas; Melanie McField (WWF) for reviewing the watershed model; Johnathan Kool (NCORE), Steven Menard, and Janet Nackoney (WRI) for support on GIS; John McManus, Cara Dickman, and NCORE staff, Marilyn Brandt, Wade Cooper, and Aletta Yniguez for organizing the project workshop; Ian Gillett (Belize Coastal Zone Management Institute), Julie Robinson (NASA), and Kathleen Sullivan Seeley (UM) for satellite images and coral reef maps; Bruce Potter (IRF) for sharing information throughout the Caribbean community; Rich Iovanna (U.S. Environmental Protection Agency) for assisting with validation of the threat model; Mahfuz Ahmed and Chiew Kieok Chong (World Fish), Suzanne Garrett (UM), Bob Leeworthy (NOAA), Suzie Greenhalgh and Siet Meijer (WRI), and Herman Cesar (Cesar Environmental Economics Consulting) for data, ideas, guidance, and review of the economic valuation; Dulce Linton and George Warner (UWI) for coral data and expert review; Clive Wilkinson (GCRMN) for providing links to the network; Uwe Deichmann (World Bank) for plume module implementation; Gregor Hodgson and Craig Shuman (Reef Check) for their data; Alessandra Vanzella-Khouri, Luc St-Pierre, Malden Miller, Nelson Andrade (UNEP-CEP), and Kristian Teleki and Alison Glass (ICRAN) for their guidance and support; and Barbara Best, Laura Cornwell (USAID), and Angel Braestrup (Munson Foundation) for their steadfast encouragement.

In addition to many of those already mentioned, the following people provided valuable input through participation in the Reefs at Risk threat analysis workshop (October 2002 in Miami): Oscar Alvarez (ICRAN-MAR Project), Billy Causey (Florida Keys National Marine Sanctuary), Richard Curry (Biscayne National Park), Jaime Garzon-Ferreira (Instituto de Investigaciones Marinas y Costeras), Hector Guzmann (Smithsonian Tropical Research Institute), Milton Haughton (CARICOM Fisheries Unit), Noel Jacobs (MBRS), Michelle Libby (TNC), Brian Luckhurst (Bermuda Fisheries), Liana McManus (RSMAS), Peter Murray (OECS Natural Resources Management Unit), Jamie Oliver (World Fish), Hazel Oxenford (UWI), Caroline Rogers (USGS), Luc St. Pierre (UNEP/CEP), Elizabeth Taylor (CORALINA), and Ernesto Weil (University of Puerto Rico).

Many people provided input on the analysis of overfishing including: Richard Appledorn (University of Puerto Rico), Julio Baisre (Ministry of the Fishing Industry of

Cuba), Daniel Matos-Caraballo (Fisheries Research Laboratory, Puerto Rico DNER), Bob Glazer (Florida Fish & Wildlife Conservation Commission), Paul Hoetjes (Dept. of Public Health and Environment, Netherlands Antilles), Barbara Kojis (Division of Fish and Wildlife, USVI DPNR), Craig Lilyestrom (Marine Resources Division, Puerto Rico DNER), Ken Lindeman (ED), Robin Mahon (Independent), John Munro (World Fish), Richard Nemeth (University of the Virgin Islands), Christy Pattengill-Semmens (REEF), Juan Posada (Universidad Simón Bolívar), Lionel Reynal (Institut Français de Recherche pour l'Exploitation de la Mer), and Mike Smith (Conservation International).

Invaluable assistance with data and review of information on marine protected areas was provided by Carola Borja (Conservation International), Julia Brownlee (NOAA), Phillippe Bush (Dept. of Environment, Cayman Islands), Reinaldo Estrada (Centro Nacional de Areas Protegidas, Cuba), Jose L. Gerhartz (UWI Center for Environment and Development), Mike Mascia (USEPA), Jeannette Mateo (TNC), Kalli de Meyer (Coral Resource Management), and Kim Thurlow (TNC).

We would like to thank the following formal reviewers of the report who provided valuable comments on the manuscript and maps: Jorge Cortés (Universidad de Costa Rica), George Warner (UWI), Herman Cesar (Cesar Environmental Economics Consulting), Georgina Bustamante (Independent), Kristian Teleki (ICRAN), John McManus (NCORE), and Philip Kramer (TNC). Internal reviewers from WRI include Marta Miranda, Yumiko Kura, Suzie Greenhalgh, Jonathan Pershing, Steve Cox, and AnnMarie DeRose. Special thanks to Dan Tunstall and David Jhirad for their many reviews of the draft and steady encouragement, and to Gayle Coolidge for her skillful management of the review process.

The following people reviewed specific parts of the text, provided data or general support: Richard Murphy (Ocean Futures Society); Bente Christensen (InterAmerican Development Bank); Pedro Alcolado (Institute of Oceanology, Cuba); Arthur Paterson, Roger Griffis, and Andy Bruckner (NOAA); Marea Hatziolos (World Bank); Daniel Prager (WRI); Marc Rammelare (National Environment and Planning Agency, Jamaica); Mercedes Silva (Caribbean Tourism Organization); Toby Gardner (University of East Anglia); Gillian Cambers (University of Puerto Rico); Steve Schill, Annette Huggins, and Tony Chatwin (TNC); Douglas Beard and Dan Phillips (USGS); Dan Zimble (ESRI); Ken Kassem (Independent); Anita Daley (Independent); Tom Laughlin, Nancy Daves, and Elizabeth McLanahan (NOAA); and Dick Wilbur (Department of State).

Many other staff at WRI contributed to this project through publication, financial management, and outreach assistance including Adlai Amor, Beth Bahs-Ahern, Hyacinth Billings, Peter Denton, Chris Elias, Paul Mackie, Greg Mock, Georgia Moyka, and Elsie Vélez-Whited. Special thanks to Camila Bonifaz for cheerful support throughout the project.

The report was edited by Kathleen Lynch and Karen Holmes. Many thanks for the valuable proofreading by Jo Tunstall and Elizabeth Selig. The report was embellished through the layout by Maggie Powell and the beautiful photographs provided by Wolcott Henry, Toni Parras, Krishna Desai, Mark Spalding, Andy Bruckner, and Ed Green.

LB / JM

PHOTO: WOLCOTT HENRY©

Executive Summary

Coral reefs are an integral part of the Caribbean fabric, threading along thousands of kilometers of coastline. Teeming with fish and invertebrate life, these ecosystems provide food for millions of people. Buffering shorelines, they protect the land from the worst ravages of storms. Coral reefs form the foundation of the thriving Caribbean tourism industry, the region's most important economic sector. The reefs supply much of the sand for the region's beautiful beaches and lure divers and snorkelers from far and wide to come and explore the reefs' colorful and mysterious depths. The dazzling array of species living on coral reefs has also attracted the attention of the pharmaceutical industry as a potential source of new drugs and life-saving medical treatments.

Unfortunately, these valuable ecosystems are degrading rapidly under the mounting pressure of many human activities. Coastal development, land clearance, and intensive agriculture all contribute damaging sediment and pollution to coastal waters, while overfishing is changing the ecological balance of coral reef environments. In addition, rising sea temperatures have prompted dramatic "coral bleaching" events in recent years, weakening and killing corals in many areas. At the same time, poorly understood coral diseases have spread rapidly across the region, devastating some of the main reef-building corals. Coral reef degradation and mortality will significantly impact the region's economy through reduced habitat for fish and shellfish, diminished appeal for tourists, and a lessened capacity to protect the shoreline.

Understanding the nature and extent of these threats and their likely economic impacts on the future productivity of Caribbean coral reefs as sources of food, recreation, employment, and biopharmaceuticals is of central importance to conservation and planning efforts. Numerous studies are underway to monitor and assess reef conditions at particular locations in the Caribbean, but data gaps persist and, for the majority of reefs, little information is available. Many such efforts fail to combine ecosystem studies with monitoring of socioeconomic and environmental conditions, making it difficult to link changes in coral condition to specific causes.

PURPOSE AND GOAL OF REEFS AT RISK IN THE CARIBBEAN

The Reefs at Risk in the Caribbean project was launched to help protect and restore these valuable, threatened ecosystems by providing decision-makers and the public with information and tools to manage coastal habitats more effectively. The project focuses on compiling, integrating, and disseminating critical information on these precious resources for the entire Caribbean region. This information is intended both to raise awareness about the threats to and value of Caribbean reefs and to encourage greater protection and restoration efforts.

Conducted by the World Resources Institute in cooperation with over 20 organizations working in the region, the project represents a unique, region-wide look at the threats facing Caribbean coral reefs. The collaborative process of data gathering and analysis has produced the first regionally consistent, detailed mapping of these threats. The project provides decision-makers and the public with important insights on links between human activities that stress and damage reef organisms and where degradation of reefs could be expected to occur, or may have already occurred. The maps created by the Reefs at Risk project will assist regional and national organizations in setting priorities for conservation and natural resource management. The analytical tools and threat indicators will also allow managers to assess, for the first time, the source and scale of threats affecting those many reef areas for which more detailed monitoring information is unavailable.

PHOTO: TONI PARRAS

Coral reefs — a dazzling array of life.

METHODS AND LIMITATIONS

Reefs at Risk project collaborators worked to gather and compile data from many sources on Caribbean coral reefs, their condition, the surrounding physical environment, and the social and economic factors associated with human pressure on reef ecosystems. These data were consolidated within a geographic information system (GIS) that includes information on coral reef locations, pressures (i.e., pollution and other observed threats and physical impacts), changes in reef condition, and information on management of reef resources.

Using these data, the project team developed regionally consistent indicators of coral reef condition and threats in four broad categories representing the key stresses to reefs in the Caribbean: coastal development (i.e., pressures from sewage discharge, urban runoff, construction, and tourism development), watershed-based sediment and pollution (i.e., pressures related to soil erosion and runoff of fertilizers and pesticides from farmlands), marine-based pollution and damage (i.e., pressures from shipping and boating, including dumping of garbage, oil spills, discharge of ballast, and physical damage caused by groundings and anchors), and overfishing (i.e., pressure from unsustainable levels of fishing). The reef area considered by this analysis totaled 26,000 square kilometers (sq km), which was divided into 25-hectare units (500 m on a side). For ease of interpretation, each coral reef unit was rated at low, medium, or high threat for each of the four individual threat categories. In medium-threat areas, pressure on reefs is considered sufficiently high to result in degradation within the next 5 to 10 years. In high-threat areas, degradation is likely to occur sooner and potentially be more severe. Substantial input from scientists across the region guided the selection of thresholds for categorizing a given threat level as low, medium, or high. These threat indicators were further calibrated against available data on observed impacts on coral reefs.

The four indicators were then combined into a single, integrated index of overall human pressure on Caribbean reefs. This integrated Reefs at Risk Threat Index reflects the highest threat level (i.e., low, medium, or high) achieved by any of the four individual threats in a given 25-hectare reef unit. To capture the impact of cumulative threats in a single location, units in which three or four of the individual threats were rated as high were categorized as very high in the integrated Reefs at Risk Threat Index. Similarly, for units in which at least three threats were rated as medium, the integrated index was rated as high.

The geographic data sets and threat indicators assembled under this project have also been used in an economic valuation of some of the key goods and services related to coral reefs (fisheries, tourism, and shoreline protection) and the losses that are likely to result from degradation across the Caribbean.

The analysis carried out by the Reefs at Risk project relies on available data and predicted relationships but, like other analytical models, presents a simplified picture of human activities and complex natural processes. The model does not capture all pressures on coral reefs, owing both to limitations of the model and inaccuracies in the geographic data sets used. In addition, two major, region-wide threats to Caribbean coral reefs are not incorporated into the Reefs at Risk analysis: coral diseases and coral bleaching. Because of scientific uncertainty as well as lack of spatial detail in the relevant data sets, it is not currently possible to produce accurate models of the present and future distribution of threats from diseases and bleaching. Existing information, however, suggests that the threats are widespread, potentially affecting coral reefs across the region.

Data sources used in the analysis are listed in Appendix B. Details of the analysis method are available online at

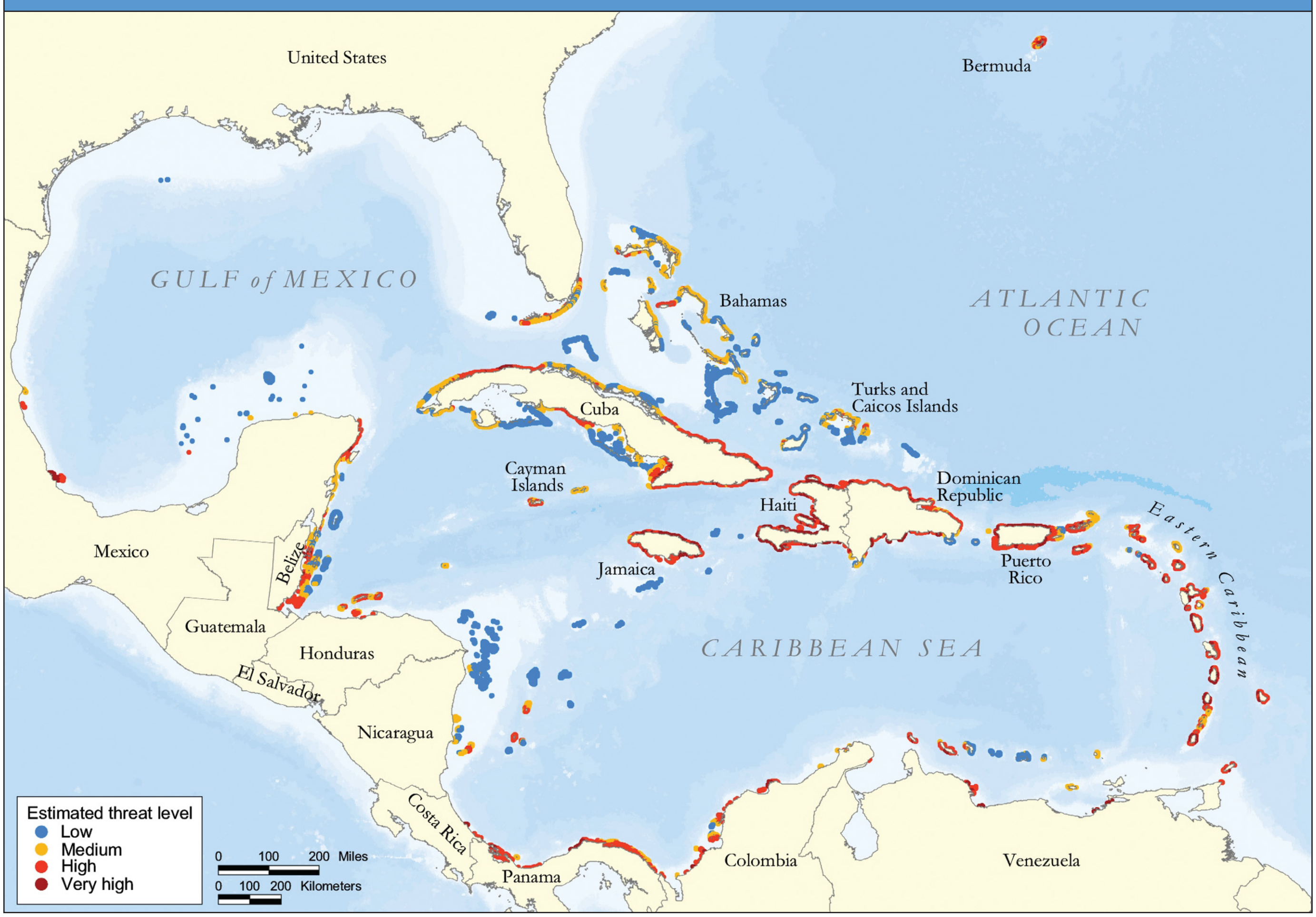
http://reefsatrisk.wri.org

KEY FINDINGS

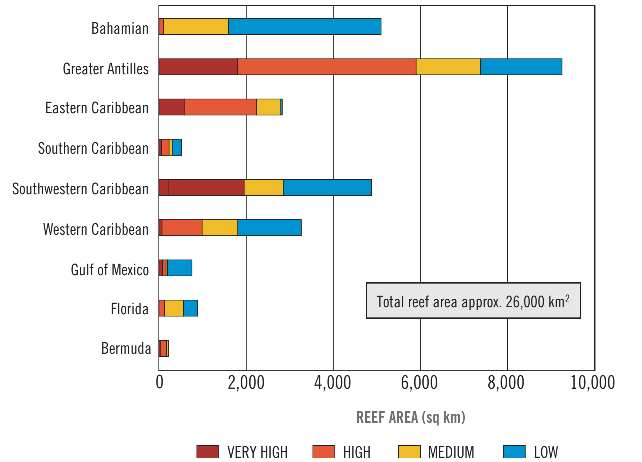
- **The Reefs at Risk Threat Index indicates that nearly two-thirds of coral reefs in the Caribbean are threatened by human activities.** Integrating threat levels from all sources considered in this analysis (coastal development, watershed-based sediment and pollution, marine-based threats, and overfishing), the Reefs at Risk Threat Index identified about one-tenth of Caribbean coral reefs at very high levels of threat, one-third at high threat, one-fifth at medium threat, and one-third at low threat. Areas with high threat levels include the Eastern Caribbean, most of the Southern Caribbean, Greater Antilles, Florida Keys, Yucatan, and the nearshore portions of the Western and Southwestern Caribbean. In these areas, degradation of coral—including reduced live coral cover, increased algal cover, or reduced species diversity—has already occurred or is likely to occur within the next 5 to 10 years. Extensive tracts of reef in the Bahamas, Turks and Caicos Islands, archipelagos off Colombia and Nicaragua, and some reefs off Belize, Cuba, and Mexico were rated as subject to low threats from human activities.

- **An estimated one-third of Caribbean coral reefs are threatened by coastal development.** Our indicator of coastal development threat identified about one-third of the region's reefs as threatened by pressures associated with coastal development, including sewage discharge, urban runoff, construction, and tourist development. Slightly over 15 percent were rated at high threat and a similar percentage at medium threat. Coastal development pressures were significant along the coastlines of most of the Greater Antilles, Eastern Caribbean, the Bay Islands in Honduras, along parts of the Florida Keys, the Yucatan, and the Southern Caribbean.

REEFS THREATENED BY HUMAN ACTIVITIES — THE REEFS AT RISK THREAT INDEX



REEF AREA BY SUB-REGION CLASSIFIED BY THE REEFS AT RISK THREAT INDEX

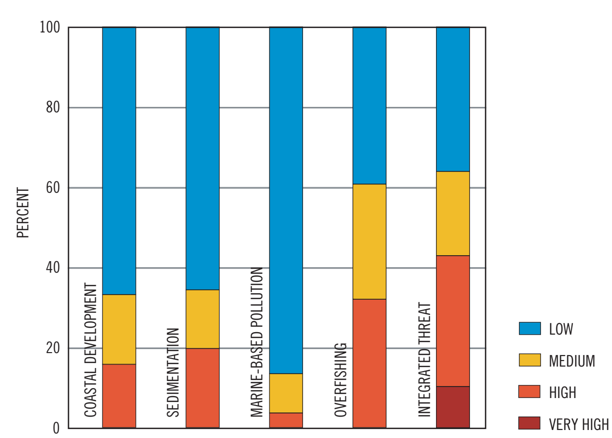


- **Sediment and pollution from inland sources threaten about one-third of Caribbean coral reefs.** Analysis of more than 3,000 watersheds across the region identified 20 percent of coral reefs at high threat and about 15 percent at medium threat from damage caused by increased sediment and pollution from agricultural lands and other land modification. Erosion of agricultural soils, particularly on steep slopes, can produce sediments that block light needed for photosynthesis and eventually smother coral reefs, while pollution from agricultural chemicals such as fertilizers and pesticides can impede coral growth or kill coral. Areas with a large proportion of reefs threatened by watershed-based sediments and pollution were found off Jamaica, Hispaniola, Puerto Rico, the high islands of the Eastern Caribbean, Belize, Costa Rica, and Panama.

- **Marine-based threats to coral reefs are widespread across the Caribbean.** Our indicator of marine-based damage and pollution identified about 15 percent of Caribbean reefs as threatened by discharge of wastewater from cruise ships, tankers and yachts, leaks or spills from oil infrastructure, and damage from ship groundings and anchors. Threat was relatively high in many of the Eastern Caribbean islands, Bermuda, Puerto Rico, Jamaica, Panama, Aruba, and the Netherlands Antilles.

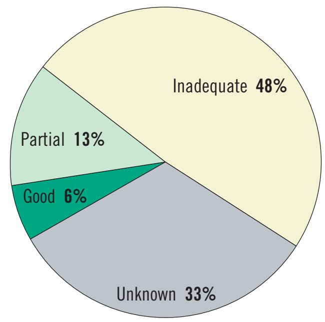
- **Overfishing threatens over 60 percent of Caribbean coral reefs.** Fishing above sustainable levels affects coral reefs by altering the ecological balance of the reef. The removal of herbivorous fish, which consume algae, facilitates algal overgrowth of corals. Declines in coral cover and increases in algal cover have been observed across the region. This analysis identified about one-third of Caribbean reefs at high threat from overfishing pressure and about 30 percent at medium threat. The threat was rated as high on almost all narrow coastal shelves close to human population centers. Fishing pressure was lower in the Bahamas, where the human population is small, and in the Western and Southwestern Caribbean and Cuba, where many reefs are far from the mainland.

REEFS AT RISK BY CATEGORY OF THREAT



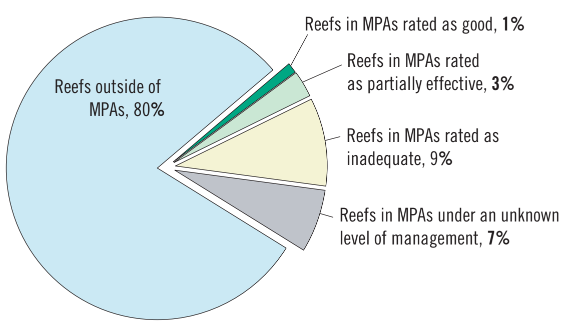
MANAGEMENT EFFECTIVENESS OF MARINE PROTECTED AREAS (MPAs) AND PROTECTION OF CORAL REEFS

Management Effectiveness of Caribbean MPAs



Number of MPAs in the region is approximately 285.

Protection of the Caribbean's Coral Reefs



Area of reefs in the region is approximately 26,000 sq km.

- **Diseases and rising sea temperatures threaten to damage coral reefs across the Caribbean region.** Although not quantitatively assessed in this project, diseases and warming sea surface temperatures present further, and growing, region-wide threats to Caribbean coral reefs. Diseases have caused profound changes in Caribbean coral reefs in the past 30 years, with very few areas unscathed by disease, even reefs far removed from human influence. One of the region's major reef-building corals has already been devastated by disease. In addition, coral bleaching episodes—the most direct evidence of stress from global climate change on Caribbean marine biodiversity—are on the rise. The complex, synergistic interactions between disease, climatic change, and other human-induced stresses may heighten the overall level of threat described above.

- **Ineffective management of protected areas further threatens Caribbean coral reefs.** With the growth of tourism, fisheries, and other development in coral reef areas, marine protected areas (MPAs) are an important tool for safeguarding coral reefs. At present, over 285 MPAs have been declared across the Caribbean, but the level of protection afforded by MPAs varies considerably. The Reefs at Risk Project found only 6 percent of MPAs to be rated as effectively managed and 13 percent as having partially effective management. An estimated 20 percent of coral reefs are located inside MPAs, but only 4 percent are located in MPAs rated as effectively managed. MPAs are but one tool available to reduce stress on coastal resources, but are by no means a shelter from all threats. This analysis of MPAs as a management tool is an indicator of the inadequacy of current efforts to manage coastal resources and protect coral reefs.

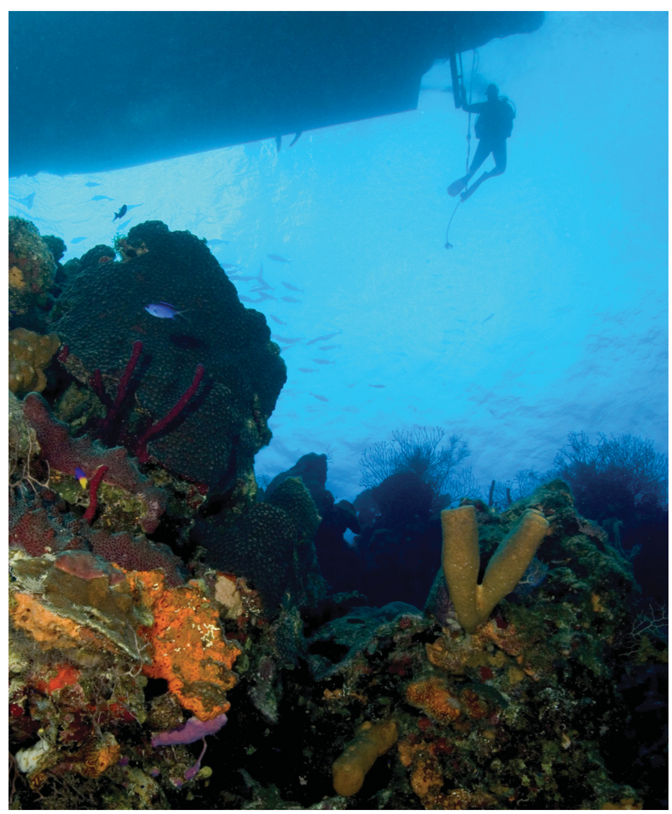


PHOTO: WOLCOTT HENRY ©

The diver entry fee at Bonaire Marine Park helps to support one of the best managed MPAs in the region.

- **The coastal communities and national economies of the Caribbean region are poised to sustain substantial economic losses if current trends in coral reef degradation continue.** Coral reefs provide valuable goods and services to support local and national economies, and degradation of coral reefs can lead to significant economic losses, particularly in the coastal areas of developing countries, through loss of fishing livelihoods, malnutrition due to lack of protein, loss of tourism revenues, and increased coastal erosion. Analyses carried out by the Reefs at Risk project indicate that Caribbean coral reefs provide goods and services with an annual net economic value in 2000 estimated at between US$3.1 billion and US$4.6 billion from fisheries, dive tourism, and shoreline protection services.

  - o Coral reef-associated fisheries in the Caribbean region provide net annual revenues valued at an estimated US$310 million. *Degradation of the region's coral reefs could reduce these net annual revenues by an estimated US$95 million to US$140 million per year by 2015.*

  - o Net benefits from dive tourism total an estimated US$2.1 billion per year in 2000. Dive tourism is high-value tourism, with divers typically spending 60–80 percent more than other tourists. *By 2015, coral reef degradation could result in annual losses of US$100 million to US$300 million to the Caribbean tourism industry.* Losses to particular areas within the Caribbean could be proportionately greater, as tourism shifts away from areas where coral reefs have become degraded and toward areas of remaining intact reefs.

  - o Coral reefs protect coastal shorelines by dissipating wave and storm energy. The estimated value of shoreline protection services provided by Caribbean reefs is between US$700 million and US$2.2 billion per year. *Within the next 50 years, coral degradation and death could lead to losses totaling US$140 million to US$420 million annually.*

CONCLUSIONS AND RECOMMENDATIONS

The coral reefs of the Caribbean, a mainstay of the region's economic and social health, are beset by a wide range of threats resulting from human activities. Degradation of coral reefs damages not only the integrity of these important ecosystems but also the health, safety, and livelihoods of the human societies that depend on them. Although the potential human and economic losses are great, actions to reverse the threats to Caribbean coral reefs can often be undertaken at very low cost, with very high financial and societal returns, even in the short term.

Actions are required across a range of scales—from local to national and international. Such actions include the establishment of better management practices to encourage sustainable fisheries, to protect reefs from direct damage, and to integrate the sometimes conflicting approaches to management in the watersheds and adjacent waters around coral reefs. Fundamental to supporting these actions is wider involvement of the public and stakeholders in the management process, as well as an improved level of understanding of the importance of coral reefs. Better understanding of the economic value of coastal ecosystems and of the linkages between human activities and changes in coral reef condition will further support and underpin the necessary changes in management and will strengthen political and societal support for these changes.

To these ends, we recommend the following specific actions:

Create the Will for Change

- **Raise awareness of the importance, value, and fragility of coral reefs through targeted education campaigns.** Many residents and visitors to the Caribbean fail to realize and understand the connections between their own activities and the health of coral reefs. Educators, universities, nongovernmental organizations (NGOs), and others should help change behavior and build political will for policy change by developing and disseminating educational materials aimed at key audiences, such as community groups, fishers, workers in the tourist industry, tourists, developers, politicians, and students.

- **Factor the economic value of coral reef goods and services into development planning, policies, and projects.** Incorporating information on the economic value of the goods and services provided by coral reefs can help bolster arguments for strengthening and expanding reef protection and management programs. Researchers should undertake additional, regionally consistent economic valuation studies of Caribbean coral reefs, and decision-makers should use the results of these studies to debate the true costs of development options and select development that minimizes damage to reef ecosystems.

Build Capacity for Change

- **Develop local and national expertise for better management of coral reef ecosystems through training of resource managers and decision-makers.** Financial resources, educational levels, and availability of training vary widely across the region, and the small size of many countries undermines their ability to sustain full scientific and administrative capacities. National governments, international organizations, NGOs, and others should support and implement expanded provision of training to coastal resource managers and decision-makers across the region.

PHOTO: KELVIN GUERRERO

Sharing ideas, knowledge, and success stories is fundamental to developing management capacity.

- **Encourage free flow and exchange of information and experience about management and protection of coral reef resources.** Across the Caribbean, there are examples of excellence in management, training programs, government and community involvement, research, and monitoring. International NGOs and intergovernmental agencies should facilitate increased sharing of information and expertise among countries, among government agencies, and among scientists and management agencies.

- **Facilitate stakeholder participation in decision-making about management and protection of coral reef resources.** The absence of community inclusion and participation has played a key role in the failure of many reef management efforts. National governments and resource managers need to apply collaborative and cooperative approaches to coral reef management, making sure to involve all stakeholder groups.

- **Create the systems of governance required for effective management of coral reefs.** In many cases, the activities of different groups, agencies, or even international bodies concerned with management of marine resources overlap and even conflict. National governments can facilitate good governance of the coastal zone by carrying out national assessments of the institutional and legal framework for executing policy and updating institutional and legal frameworks where necessary.

- **Integrate socioeconomic and environmental monitoring to increase understanding of coastal habitats.** Good management requires continued access to information about natural resources and how they change over time and in response to natural and human influences. The scientific community and resource managers should move toward monitoring programs that integrate human, physical, and ecological data.

- **Use the Reefs at Risk indicators and apply the analytical methodology at finer resolutions to support decision-making on coral reef management.** The analysis and tools developed under this project provide a valuable and low-cost means of understanding potential pressures on coral reefs. National, provincial, and local resource agencies should contribute to the development of similar indicators at a finer scale to help increase confidence in and support for wise management decisions.

Improve Management

- **Develop sustainable fisheries through education, stakeholder involvement, and reduced intensity of fishing practices.** Fishing is exceeding sustainable levels in most Caribbean countries. National governments should work with resource users and other stakeholder groups to implement sustainable fishing policies and practices. Licensing, incentives for sustainable practices, and penalties for illegal fishing can help reduce the intensity of fishing practices. The establishment of "no take areas" or "marine fishery reserves" can be adopted, in part, as a strategy to replenish depleted fish stocks. Critical to the success of such reserves will be involving and educating stakeholders and providing alternative income generation.

- **Apply holistic approaches to coastal zone management.** Successful management of coral reef ecosystems entails dealing effectively with multiple influences and threats, many of which can be traced to activities taking place at considerable distances from the reefs themselves. National governments need to provide incentives for agencies with disparate mandates and conflicting agendas to share information and work together effectively.

- **Expand Marine Protected Areas and improve their management effectiveness in safeguarding coral reef ecosystems.** Marine Protected Areas (MPAs) are an important component of comprehensive coastal-area management; however, only a small percentage of coral reefs are located within designated MPAs and only a small percentage of MPAs are rated as fully or partially effective. National governments, donors, NGOs, and the private sector need to support expansion of MPAs to cover additional coral reefs and to provide assistance to strengthen the management effectiveness of many existing MPAs.

- **Develop tourism sustainably to ensure long-term benefits.** Tourism is vital to the Caribbean region, but unplanned, unrestricted development can severely damage coral reefs. Decision-makers should take steps to limit such damage, including education of tourists and development of certification schemes, accreditation, and awards for good environmental practices as incentives for environmentally sensible development.

- **Implement good marine practices to restrict dumping of waste at sea and the clearing of ballast waters.** Regional bodies, national governments, NGOs, and the private sector should work together to develop best practices (for example, in the cruise industry). Ports, harbors, and marinas need to offer pump-out and waste treatment facilities for vessels of all sizes.

International Action

- **Ratify and implement international agreements.** International agreements are an important tool for setting targets and achieving collective goals. National governments should not only sign but also implement important international agreements addressing the threats evaluated in this study, including the Cartagena Convention (addressing land-based sources of pollution, oil spills, and protected areas and wildlife), the United Nations (UN) Convention on the Law of the Sea (on ocean governance), MARPOL (on marine pollution), and the UN Framework Convention on Climate Change.

- **Promote international cooperation and exchange.** Even in the absence of international legal instruments, regional collaboration on issues such as fisheries and watershed management could greatly reduce some threats. International NGOs, intergovernmental agencies, and funding organizations can actively support cooperation and exchange to promote synergy and foster partnerships to protect Caribbean coral reefs.

Chapter 1. INTRODUCTION

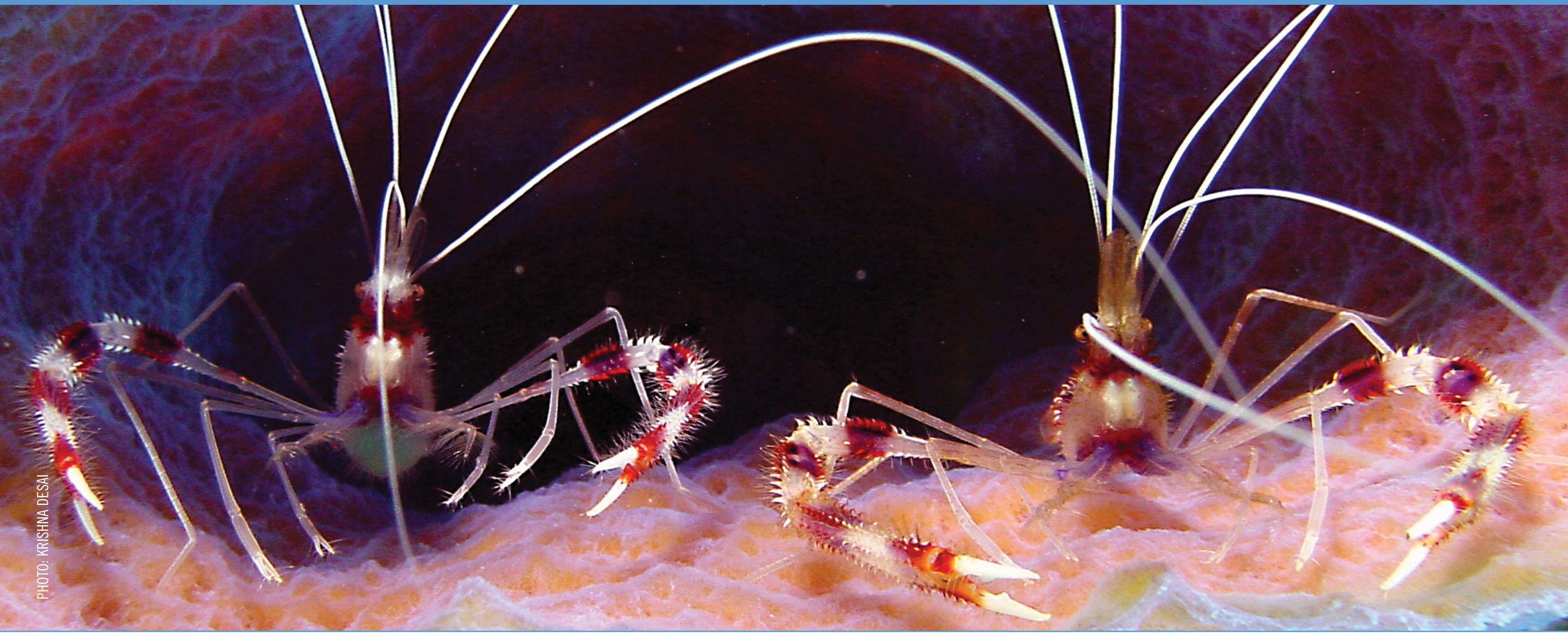


PHOTO: KRISHNA DESAI

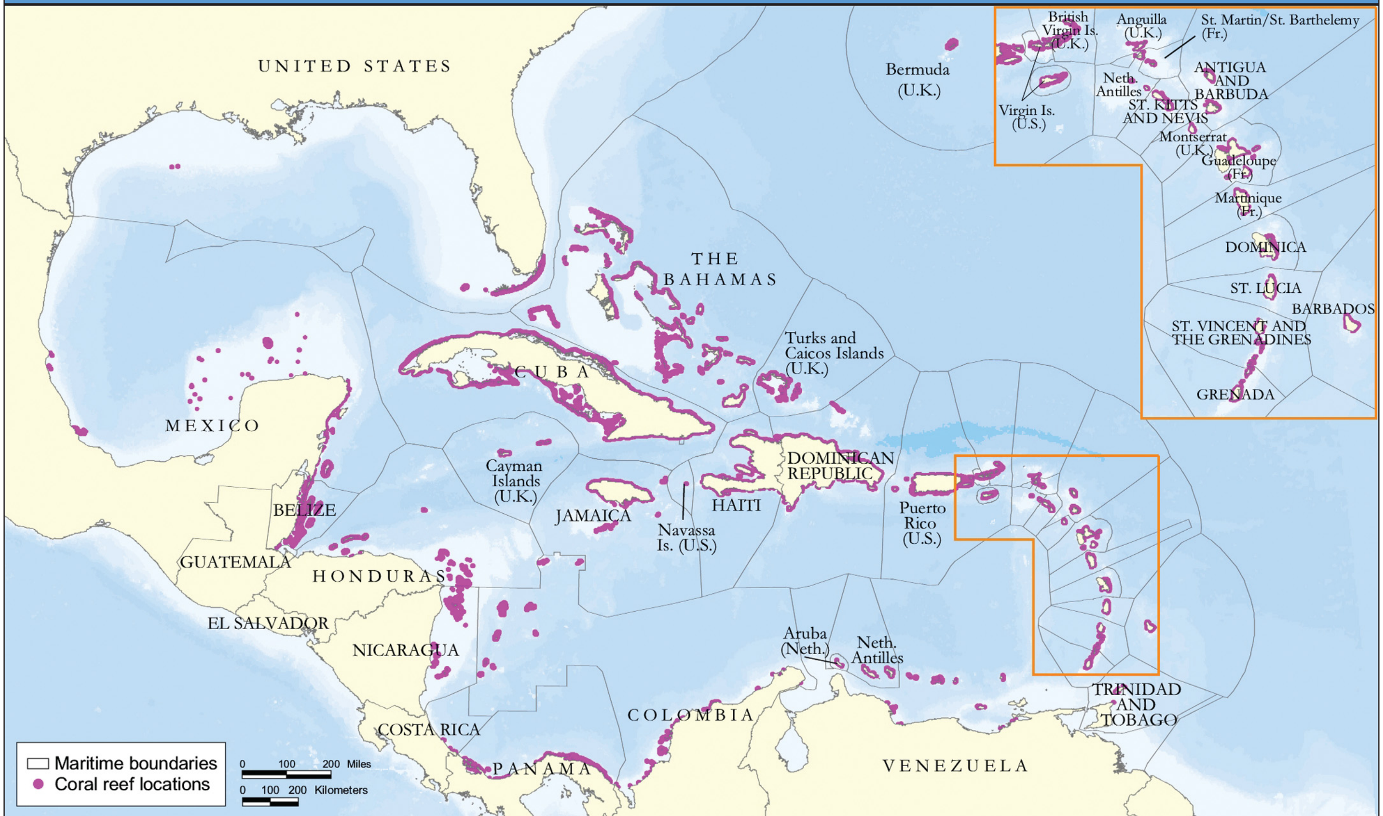
The Wider Caribbean (hereafter called the Caribbean) is a large marine realm encompassing the Caribbean Sea, the Gulf of Mexico, and part of the northwestern Atlantic Ocean extending out to the tiny island of Bermuda. *(See Map 1.)* Richly endowed with biological treasures, it is also a region of tremendous cultural and political diversity shaped by a vivid history. The wide coastal shelves and warm tropical waters create ideal conditions for the formation of an estimated 26,000 square kilometers (sq km) of coral reefs.[1] Separated from other coral reefs, these have evolved in isolation, and remarkably few of the many thousands of species in these waters are found anywhere else in the world.[2]

More than 116 million people live within 100 km of the Caribbean coast *(see Appendix A, Table A3),* and many livelihoods depend strongly on the marine environment. Coral reefs contribute significantly to nutrition and employment, particularly in rural areas and among island communities, where there may be few employment alternatives. The reefs are also a major draw for tourists to the region. Coral reefs provide shoreline protection, notably during storms and hurricanes, and generate white sand for many beaches. The biodiversity of coral reef ecosystems has enormous value as a provider of potentially life-saving pharmaceuticals.

Despite their value, coral reefs in the Caribbean are under threat.[3] Growing coastal populations and rising tourist numbers exert increasing pressure. Land-based activities, including construction, deforestation, and poor agricultural practices, are depositing an increasing load of sediment and nutrients in coastal waters, smothering some corals and contributing to overgrowth by algae. Current levels of fishing pressure are unsustainable in most areas and have already led to species loss and the collapse and closure of fisheries in some countries.[4] Increasing pressures are undermining the resilience of reefs to threats from global climate change.[5] In addition, extensive areas of corals have succumbed to diseases in recent years. The origins of these diseases remain poorly understood, but corals across the region are susceptible.[6]

Understanding the effects of human activities on specific reefs, including the economic consequences of these disturbances, is key to future conservation and planning efforts. Within the region numerous studies are underway to assess and monitor particular coral reefs *(see Appendix C for details)*. In a few places, such as Jamaica and the Florida Keys, changes in coral condition are well documented, but in most other places, the availability of detailed information is limited, inhibiting effective management.

MAP 1. THE CARIBBEAN REGION



The Caribbean region, as defined by this analysis, encompasses 35 countries and territories bordering the Gulf of Mexico and Caribbean Sea,[a] including the oceanic island of Bermuda (*see Map 1*). Politically, and socioeconomically, these countries are highly diverse, from the world's richest nation to some of the poorest; from long-established democracies to totalitarian systems; and from industrialized countries with intensive agricultural systems to countries with little industry and largely natural landscapes.

The nearly 7.8 million sq km of land that drains into the Caribbean [b] stretches from the Upper Mississippi Basin in southern Canada to the Orinoco Basin of Colombia and Venezuela. The total population within this drainage area was estimated at 290 million in 2000,[c] of whom some 41 million people lived within 10 km of the coastline.[d] Average population density within this coastal strip increased by 14 percent between 1990 and 2000. (*See Appendix A, Tables A2 and A3 for detailed physical and population statistics.*)

Over the last three decades, tourism has surpassed fishing as the most important economic activity for many coastal localities. In 2000, more than 40 million people visited the region (excluding the United States), generating over US$25 billion in revenue.[e] Between 1990 and 2000, tourist (stay-over) arrivals grew at an average annual rate of 4.7 percent.[f] Cruise-based tourism grew even faster, at an average of 6.5 percent per annum between 1990 and 2000.[g] (*See Appendix A, Table A4, for detailed economic statistics.*)

Notes:

a. Within the Caribbean region, there are 35 distinct political units, including 24 sovereign nations (14 island nations and 10 continental), five overseas territories of the United Kingdom, two overseas departments of France, two self-governing units of the Netherlands, one territory of the United States, and the U.S.-associated commonwealth of Puerto Rico.
b. Caribbean drainage area was calculated at WRI using watersheds developed from USGS HYDRO1K and NASA SRTM elevation data.
c. Population in Caribbean drainage areas was calculated at WRI using population data from the Center for International Earth Science Information Network (CIESIN), *Gridded Population of the World, Version 3* (Palisades, NY: CIESIN, Columbia University, 2003).
d. Caribbean coastline is based on World Vector Shoreline. For continental countries, Pacific coastlines were excluded. Population data are from CIESIN (2003).
e. See Appendix A, Table A4.
f. CTO (2002), p. 21.
g. Ibid, p. 21.

Map Sources:

Maritime boundaries: Derived at WRI using data from the Global Maritime Boundaries Database (Veridian - MRJ Technology Solutions, 2002). Reef locations: See Appendix B. Bathymetry: Developed at WRI from depth point data from the Danish Hydrologic Institute's (DHI) C-MAP data product, interpolated at 1-km resolution.

ABOUT THE PROJECT

The Reefs at Risk in the Caribbean project was initiated to improve coral reef management by giving resource managers and policymakers specific information and tools to help manage coastal habitats more effectively. The project is designed to raise awareness about the nature and extent of the threats facing the region's coral reefs and to draw attention to the considerable value of these resources.

Achieving these aims by building up new information from surveys and monitoring would be prohibitively expensive. Rather, the project focuses on compiling existing information from a broad range of sources and putting this information together in a standardized, regionally consistent format. Some of this information relates directly to coral reefs, such as the locations of the reefs themselves. However, the project also entails gathering information on other natural and human features that can be developed into proxy measures, or indicators, of human threats to reefs. In addition, the project brings together social and economic data on the region, supporting an analysis of the economic value of the region's coral reefs and underpinning a series of policy and management recommendations.

The indicators developed by the Reefs at Risk in the Caribbean project enable detailed comparative analyses of threats to coral reefs on many scales. The Reefs at Risk indicators are a simplification of human activities and complex natural processes. The approach and methodology used to create the indicators, and their limitations, are described in Chapter 2. In Chapter 3, we examine in detail the main categories of threat to coral reefs, discuss the effects of these threats, and suggest remedies for mitigating threats. Chapter 4 explores reef status and threats in nine sub-regions of the

PHOTO: KRISHNA DESAI

Coral polyps filter feeding at night.

BOX 1. CARIBBEAN CORAL REEFS

A coral reef is both a physical structure and a highly productive ecosystem. The physical structure is built over centuries by the piling up of skeletons deposited by reef-building corals, which are colonies of tiny animals. Each animal within the colony is known as a polyp and has a simple tubular body with a ring of stinging tentacles around a central mouth. Within these polyps are even smaller single-celled plants (*zooxanthellae*). Corals filter food from the water using their tentacles, but they also rely heavily on their zooxanthellae, which use the sun's energy to synthesize sugars, some of which are taken up and used by the polyps. These corals, then, must have sunlight to grow, reproduce, and build their limestone (calcium carbonate) skeletons. Of the roughly 800 species of reef-building (*Scleractinian* or stony) corals that have been described worldwide, about 65 are found in the Caribbean.[a] Although these species are the great architects of the coral reef, their numbers are dwarfed by a great diversity of other life forms—turtles, fish, crustaceans, mollusks, urchins, sponges, and others—which make coral reef ecosystems the most diverse on Earth.

The Caribbean region possesses about 26,000 sq km of shallow coral reefs,[b] about 7 percent of the global total.[c] Reefs dominate shallow marine habitats over wide areas of the Caribbean, especially around islands. They are more sparsely distributed through the Gulf of Mexico. Far out in the Atlantic, the coral reefs of Bermuda are the most northerly in the world.

Notes:

a. Spalding et al. (2001).
b. Although estimates of coral reef area will change with advances in mapping, the best data currently available support this estimate. See Appendix B for sources used for this estimate, and Appendix A, Table A1 for comparison of different estimates of reef area by country.
c. G. Paulay, "Diversity and Distribution of Reef Organisms," in *Life and Death of Coral Reefs*. C. Birkeland, ed. (New York: Chapman & Hall, 1997), p. 303; Spalding et al. (2001).

Caribbean. Chapter 5 offers an estimation of the economic value of three key goods and services provided by Caribbean coral reefs—fish catch from reef fisheries, dive tourism, and shoreline protection services—and presents an evaluation of economic losses that could result as coral reefs degrade. Finally, Chapter 6 formulates broad management and policy recommendations based on the findings of the analysis.

Reefs at Risk in the Caribbean is part of a series that began with a global analysis, *Reefs at Risk: A Map-Based Indicator of Threats to the World's Coral Reefs,* released in 1998.[7] Subsequently, region-specific projects have refined the original model, have incorporated a much higher-resolution analysis, and have provided an improved tool for analyzing the impacts of human activities on reefs. The first in the regional analysis series, *Reefs at Risk in Southeast Asia,* was released in 2002. The Reefs at Risk in the Caribbean project, a two-year collaborative effort involving more than 20 partner institutions, has compiled and integrated far more information than can be presented in this report. More detailed information, including all maps and statistics, country-level results, and details of the analytic methods are available at http://reefsatrisk.wri.org/ and on the accompanying *Reefs at Risk in the Caribbean* data CD.


PHOTO: ED GREEN

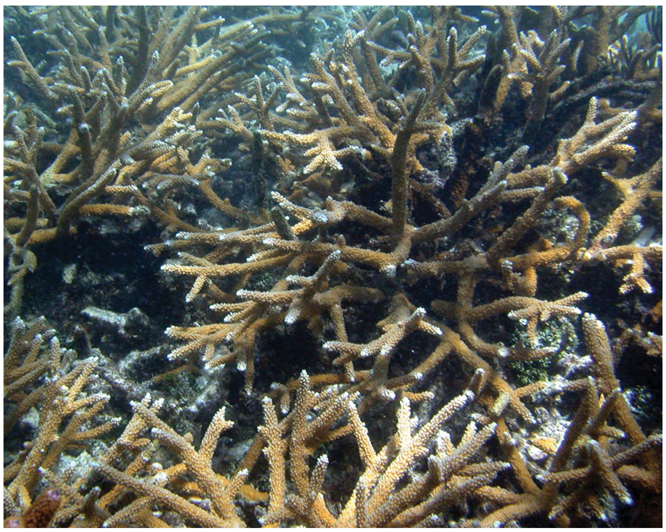


PHOTO: ANDY BRUCKNER


PHOTO: TONI PARRAS

About 65 species of reef-building coral are found in the Caribbean. The major reef building species, which are typically large (>25 cm diameter) and fast growing, are Elkhorn (*Acropora palmata*), Staghorn (*Acropora cervicornis*) and Star Coral (*Montastraea* spp.). Coral reefs are a valuable asset to coastal communities — offering a source of food, popular locations for tourism and recreation and a potential source of bioactive compounds for new medicines.

Chapter 2. PROJECT APPROACH AND METHODOLOGY


PHOTO: KRISHNA DESAI

Reefs at Risk in the Caribbean brings together information on the region's coral reefs and on their socioeconomic and physical environment as a basis for a region-wide analysis. The information is consolidated within a geographic information system (GIS) that includes data on coral reef locations (maps), pressures on coral reefs (observed threats, pollution, physical impacts), changes in reef condition, observations of coral bleaching and disease, and information on coral reef management. More than 30 physical and socioeconomic data sources were assembled in support of the analysis—including data on elevation, land cover, bathymetry, population distribution and growth rates, and location of cities, ports, and other infrastructure.

Using these data, the Reefs at Risk project has developed maps showing the distribution of human pressure on coral reefs. These are classed into four broad categories of threat: coastal development, sediment and pollution from inland sources, marine-based sources of threat, and overfishing. These threats are also integrated into a single index of relative human pressure. By utilizing only regional datasets, the Reefs at Risk project ensures consistency in its findings, allowing direct comparison of results across the region. The clear and open model structure also makes it possible to query the findings to establish driving mechanisms.

Both the individual threat indicators and the overarching index of human pressure serve as a basic guide to present and future coral reef conditions across the Caribbean region. Some areas rated as threatened may have already suffered considerable degradation, while all are likely to experience degradation—including reduced live coral cover, increased algal cover, or reduced species diversity—within 10 years.

Two broad areas of threat could not be included in the model—disease pathogens and abnormally high sea surface temperatures. Both of these issues are extremely important and, indeed, have already had major impacts on wide areas of Caribbean coral reefs. However, because of uncertainty about some of the factors contributing to coral vulnerability, as well as a lack of spatial detail in the data sets required for such an analysis, we were not able to develop quantitative indicators and maps to predict future threats. Although these threats are not included in the model, Chapter 3 presents current knowledge and projections on the extent of climate-related threats (including coral bleaching) and disease in the context of the other pressures on Caribbean coral reefs.

TABLE 1. REEFS AT RISK ANALYSIS METHOD

Threat	Analysis Approach	Limitations
Coastal Development	• Threats to reefs evaluated based on distance from cities, ports, airports, and dive tourism centers. Cities and ports stratified by size. • Coastal population density (2000), coastal population growth (1990–2000), and annual tourism growth combined into indicator of "population pressure" treated as an additional stressor. • Thresholds selected for each stressor based on guidance from project collaborators and observations of local damage from coastal development (including sewage discharge). Stressors aggregated into single map layer. • Management effectiveness included as mitigating factor for threats to reefs inside marine protected areas (MPAs).	• Provides a good indicator of relative threat across the region, but is likely to miss some site-specific threats. • Data sets used are the best available, but limitations regarding accuracy and completeness are inevitable. • In particular, rapid growth of tourism sector makes it difficult to capture the most recent developments.
Sediment and Pollution from Inland Sources	• Watershed-based analysis links land-based sources of threat with point of discharge to the sea. • Analysis of sediment and pollution threat to coral reefs implemented for more than 3,000 watersheds discharging to the Caribbean. • Relative erosion rates estimated across the landscape, based on slope, land cover type, precipitation (during the month of maximum rainfall), and soil type.[a] • Erosion rates summarized by watershed (adjusting for watershed size) to estimate resulting sediment delivery at river mouths. • Sediment plume dispersion estimated using a function in which sediment diminishes as distance from the river mouth increases. Estimated sediment plumes calibrated against observed sediment impacts on selected coral reefs.[b]	• Nutrient delivery to coastal waters probably underestimated due to lack of spatial data on crop cultivation and fertilizer application and resulting use of a proxy (sediment delivery) for indirect estimation.[c] • Sediment and nutrient delivery from flat agricultural lands probably underestimated because slope is a very influential variable in estimating relative erosion rates.
Marine-Based Sources of Threat	• Threats to coral reefs from marine-based sources evaluated based on distance to ports, stratified by size; intensity of cruise ship visitation; and distance to oil and gas infrastructure, processing, and pipelines.	• Estimates focus on ships in or near port. Threat associated with marine travel lanes probably underestimated due to lack of sufficiently detailed database on Caribbean shipping lanes.
Overfishing	• Threats to coral reefs evaluated based on coastal population density and shelf area (up to 30 m depth) within 30 km of reef. Analysis calibrated using survey observations of coral reef fish abundance. • Management effectiveness included as mitigating factor for threats to reefs inside marine protected areas (MPAs). • Destructive fishing practices not evaluated, as these are rare in the Caribbean region.	• Local overfishing pressure captured in proxy indicator (based on human population per unit of coastal shelf area), due to lack of spatially-specific data on numbers of fishers, landing sites, fishing method/effort, or fish catch from reef fisheries. • Indicator reflects fishing within 30 km of shore. Impacts of larger-scale commercial fishing pressure, illegal fishing, or movement of fleets not included in analysis.

NOTES:

a. "Relative Erosion Potential" was estimated at WRI using a simplified version of the *Revised Universal Soil Loss Equation*, United States Department of Agriculture (USDA) Agricultural Research Service (Washington, DC: USDA, 1989).

b. Data from Reef Check surveys and expert opinion from the Reefs at Risk workshop were used to calibrate the estimate of threat from inland sources. Data on percent live coral cover and algal cover from Atlantic and Gulf Rapid Reef Assessment (AGRRA) surveys were used to evaluate results.

c. Although phosphorus is often attached to soil particles, nitrogen is highly soluble and moves more independently of soil particles.

THREAT ANALYSIS METHOD

The project's modeling approach involves identifying sources of stress that can be mapped for each threat category. These "stressors" include simple population and infrastructure features, such as population density and location and size of cities, ports, and tourism centers, as well as more complex modeled estimates of riverine inputs. Model rules were developed to build proxy indicators of threat level for these stressors. This involved the development of distance-based rules by which the threat declines as distance from the stressor increases. For ease of interpretation, these threats are simply subdivided into "low," "medium," and "high" categories. Substantial input from scientists in the region contributed to the selection of the stressors and threat rules (thresholds) developed, while the threat indicators were further calibrated against available information on observed impacts on coral reefs.

Table 1 provides a summary of the threat analysis method and limitations for each threat category. Results of the threat analysis are presented in Chapter 3. Appendix B provides a list of the data sources used in the analysis and details of model validation. The full technical notes for the analysis are available online at http://reefsatrisk.wri.org/.

Integrating Threats: The Reefs at Risk Threat Index

The four threats described in Table 1 were integrated into a single index—the Reefs at Risk Threat Index. For each reef unit (a 25-hectare square measuring 500 m on each side), the index is set to the highest threat value ("low," "medium," or "high") recorded for any individual threat. To capture cumulative threat in a given location, the integrated index is designated as "very high" in areas where three or four individual threats were rated as "high." In areas where at least three threats were rated as "medium," the integrated index is set to "high."

The Reefs at Risk Threat Index was used to analyze the economic value of key goods and services provided by Caribbean coral reefs. The methods used for this analysis are described in Chapter 5 and online at http://reefsatrisk.wri.org.

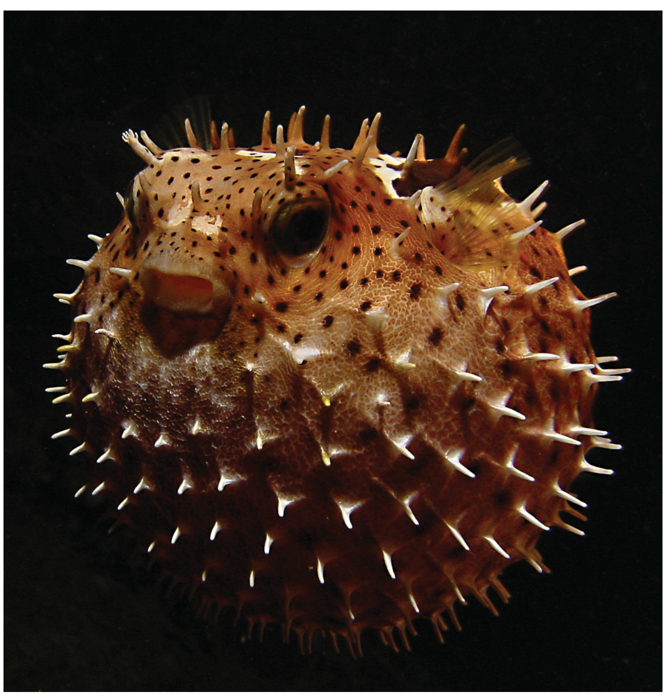


PHOTO: KRISHNA DESAI

Nature is complex and sometimes unpredictable.

LIMITATIONS OF THE ANALYSIS

The Reefs at Risk analysis approach is a simplification of human activities and complex natural processes. The model relies on available data and predicted relationships but cannot capture all aspects of the dynamic interactions between people and coral reefs. The threat indicators gauge current and potential risks associated with human activities. A strength of the analysis lies in its use of regionally consistent data sets to develop regionally consistent indicators of human pressure on coral reefs. However, the model is not perfect, and omissions and other errors in the data sets are inevitable.

Fairly limited data are available to calibrate the individual threat layers and validate the overall model results. *(See Appendix B.)* The thresholds chosen to distinguish low, medium, and high threat relied heavily on the knowledge of project collaborators. Their review of model results also served as our most comprehensive validation of results.

Lack of spatial detail in the region-wide physical and oceanographic data sets and some other information gaps, such as causes of coral diseases, prevented us from including the threats of climate change, coral bleaching, and coral disease in the model. Hence, these overarching threats are not accounted for in this analysis. The Reefs at Risk model results should be regarded as our best attempt to evaluate human pressure on Caribbean coral reefs, using currently available sources. These are indicators of current human pressure that, in some areas, has already led to reef degradation and in all areas provides an indication of threat to future condition.

Chapter 3. THREATS TO CORAL REEFS


PHOTO: WOLCOTT HENRY©

Rising population densities and associated coastal development as well as increased fishing, agricultural, and industrial activities are the major causes of pressures on Caribbean coral reefs. These sources have changed little in recent decades, but they have intensified dramatically.[8] Over millennia, reef communities have adapted to many natural pressures, such as hurricanes, where damage was followed by recovery, but now, a great range of direct and indirect human pressures have been added. Acting alone or in combination, these pressures can lead to acute or chronic ecosystem stress, which results in the breakdown and loss of coral communities, or to more subtle changes in ecosystem structure, such as the flourishing growth of algae on reefs. Changes to reefs can be gradual or rapid, but ultimately these changes diminish the value of goods and services derived from reefs by, for example, reducing coral reef habitat available for fisheries or reducing the shoreline protection afforded by reefs.

Coral reefs vary considerably in their ability to withstand pressures and to recover from damage or disturbances. This may be partly driven by ecological factors, including the species composition of the reef itself and its connectivity to other reefs. In addition, the physical setting of a reef (distance from land, reef depth, and the rate of water flow in the area) influences its vulnerability. Characterizing the pressures acting on any reef is complex, as there are multiple sources of stress operating over several spatial and temporal scales.[9]

This chapter examines the four region-wide threats included in the Reefs at Risk Caribbean model: coastal development, sedimentation and pollution from inland sources, marine-based threats, and overfishing. In addition, the issues of climate change (including coral bleaching) and coral diseases are discussed. Remedies applicable across the Caribbean region are suggested to address each of these threats. The chapter concludes with the integration of these four threats into the Reefs at Risk Threat Index, which attempts to represent the cumulative threat to coral reefs from these four key categories. In the following chapter, Chapter 4, these region-wide projections of threat are linked with observed changes in coral reefs and management responses in nine Caribbean sub-regions.

COASTAL DEVELOPMENT

The estimated number of people living within 10 km of the Caribbean coast grew from 36 million in 1990 to 41 million in 2000.[10] Some 36 percent of Caribbean coral reefs are located within 2 km of inhabited land and are thus highly susceptible to pressures arising from coastal populations.[11] Extensive construction and development for housing, roads, ports, and other development has been required to support both the residential and tourist populations.

Poorly managed coastal development puts stress on coral reefs through direct damage from dredging, land reclamation, and sand and limestone mining for construction as well as through less direct pressures such as runoff from construction sites and removal of coastal habitat. The loss of mangroves and seagrass, which filter sediment and nutrients coming from the land, has been widespread in the Caribbean[12] and adds to the pressure. Increased sediment in coastal waters reduces the amount of light reaching the corals and hinders the ability of their symbiotic algae *(zooxanthellae)* to photosynthesize.[13]

In addition, the widespread discharge of untreated sewage is a major source of nutrients entering coastal waters. Coral reefs flourish in waters nearly devoid of nutrients, and increased nutrient concentrations promote algal growth at the expense of corals.[14] Although information is incomplete, data suggest that less than 20 percent of sewage generated within the Caribbean region is properly treated.[15]

MAP 2. REEFS THREATENED BY COASTAL DEVELOPMENT

Threats to reefs from coastal development were estimated based on distance from cities, ports, airports, and dive tourism centers, as well as population density, population growth, and tourism growth in the area. For reefs inside marine protected areas (MPAs), management effectiveness was included as a factor mitigating threat. (*See Box 3 in Chapter 4 and Table A5 in Appendix A.*)

Source: WRI, *Reefs at Risk in the Caribbean*, 2004 (*see Appendix B*).

Sewage discharge is a common problem in developing countries, but it is also a problem in the Florida Keys, where seepage from cesspools and discharge of secondary-treated sewage at ocean outfalls add to nutrient build-up.[16]

Another source of diminished water quality is runoff of motor oil and other waste from roads. Industrial pollution from oil refineries, sugar processing, distilleries, breweries, food processing, and the paper and chemical industries are also a concern.[17]

In recent years, the Caribbean region has undergone massive growth in tourism, a sector of major importance to the regional economy. Well-planned tourism development can have minimal impact, or even a net positive impact, on coral reefs, but rarely is this the case. Unplanned or poorly regulated tourism can kill reefs. Tourism activities can produce both direct physical impacts (such as diver and anchor damage) and indirect impacts from resort development and operation (pollution from untreated sewage). The development of tourism infrastructure (construction of ports, airports, and hotels) also takes its toll on coral reefs. Many of these disturbances are similar to those caused by coastal development more generally, but tourism is a particular problem because it frequently moves into new, undeveloped areas, away from existing urban developments.

Modeling results. The model's indicator of coastal development threat—incorporating estimated pressure from sewage discharge, urban runoff, construction, and tourism development—identified about one-third of the region's reefs as threatened (slightly over 15 percent each at medium and at high threat). Coastal development pressure was identified as significant along the coastlines of most of the Greater Antilles, Eastern Caribbean, the Bay Islands in Honduras, and along parts of the Florida Keys, the Yucatan, and the Southern Caribbean. Areas identified at lowest threat from coastal development were the Bahamas, the Turks and Caicos Islands, and Cuba *(see Map 2)*.

Remedies. Impacts of coastal development on coral reefs can be minimized in many ways. Better planning can ensure protection for important habitats and prevent dredging or building near sensitive and valuable habitats (such as wetlands, mangroves, and seagrass). Guidelines for construction and engineering activities can also help reduce threats. Investment in building and maintaining sewage treatment systems in towns and tourist areas can reduce sewage discharge to the sea. Innovative legal measures that ensure accountability and payment for waste disposal and treatment, or demand "no net loss" of sensitive ecosystems, can help modify building design and promote environmentally sustainable infrastructure development.

Where coastal development is implemented and how it is managed profoundly influence the degree of impact to coral reefs.

Tourism takes many forms (mass tourism, small hotels, eco-resorts) and can bring a variety of benefits to the local population.[18] Ownership of a resort, sources of food and beverage (local or imported), and taxation rules all affect how much a local community benefits from tourism. In addition, the design and development of the resort, energy sources and use, and degree of sewage treatment affect the resort's environmental impact. Determining the carrying capacity of the area and the reef itself as part of the development planning process can help ensure that tourism development brings maximum benefit to local communities while minimizing damaging environmental impacts. Certification schemes, accreditation, and awards based on actual achievement (not just statement of intent) of good environmental practices by hotels and dive and tour operators provide incentives for environmentally sensible development. Education of tourists, especially teaching divers and snorkelers not to damage reefs, is essential to reducing impacts. Tourists can contribute financially to recovery and management efforts through park entrance fees or donations.

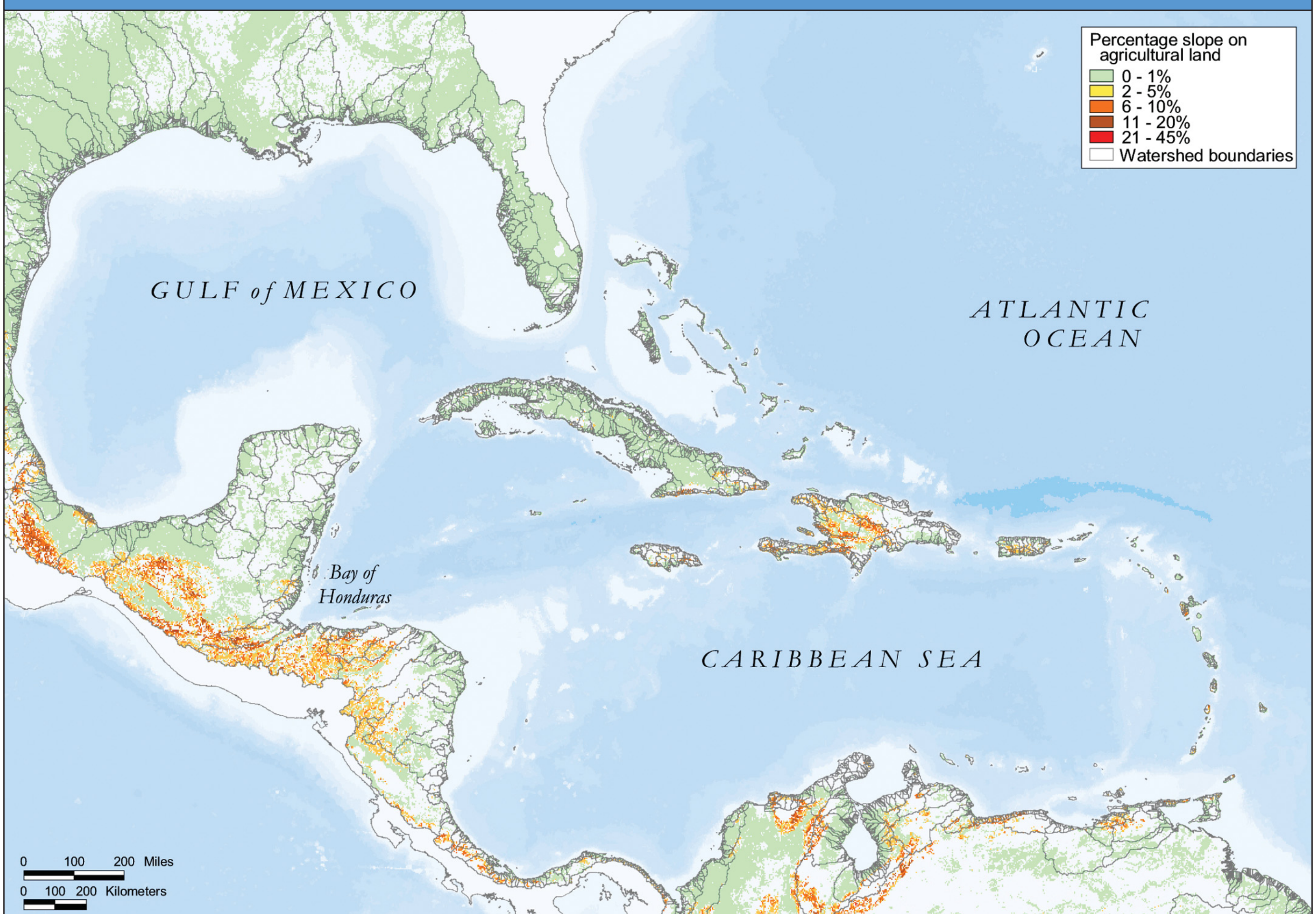
SEDIMENTATION AND POLLUTION FROM INLAND SOURCES

Agriculture, though important to economic development and food security, is a source of increased sediment, nutrient, and pesticide runoff. Conversion of land to agriculture increases soil erosion and sediment delivery to coastal waters. In areas where agriculture coincides with steep slopes and heavy precipitation, soil erosion can be extreme. This analysis classified nearly a quarter of the land area draining into the Caribbean as agricultural land cover.[19] Map 3 shows agricultural lands by slope category. Several watersheds were identified as areas of particularly high erosion risk: in Mexico (discharging to the Gulf of Mexico); in Guatemala and Honduras (discharging to the Bay of Honduras); and Colombia, Eastern Jamaica, Haiti, and Puerto Rico (discharging into the Caribbean Sea).

Increased sediment delivery to coastal waters is a key stress on coastal ecosystems. It screens out light needed for photosynthesis, jeopardizes survival of juvenile coral due to loss of suitable substrate, and, in extreme cases, can lead to complete smothering of corals. Coral reef damage from siltation has been documented on the coasts of Panama, Costa Rica, and Nicaragua, among other locations.[20]

Runoff of fertilizer and livestock manure from agricultural lands is a significant source of nutrients (especially nitrogen and phosphorus) entering coastal waters. Some of the major crops in the region—sugarcane, citrus, bananas,

MAP 3. AGRICULTURAL LANDS BY SLOPE CATEGORY



Sources: Watershed boundaries derived at WRI. Percentage slope on agricultural land derived at WRI from Global Land Cover Characteristics Database (U.S. Geological Survey (USGS), 2000) at 1-km resolution and HYDRO1K Digital Elevation Model (USGS, 2000) at 1-km resolution.

grains, and coffee—require large inputs of fertilizer and pesticides.[21] For example, the average fertilizer application rate for cultivation of bananas is 479 kilograms per hectare per growing season.[22] The discharge of nutrients into coastal waters is a major cause of eutrophication, especially in low-flow areas, and can cause algal blooms, changes in the aquatic community structure, and decreased biological diversity. The presence of algae on substrate can inhibit colonization by larval recruits, thereby initiating a decrease in live coral cover and an increase in algal or other vegetative cover. In extreme cases, high levels of nutrients produce "dead zones" because of massive oxygen depletion in the nutrient-rich waters. Such zones occur regularly off the Mississippi Delta, and smaller events have been recorded along much of the Florida coastline.[23] Where such events meet coral reefs, the results can be devastating. An isolated event in Venezuela in 1996 led to the death of almost all reef organisms over several square kilometers.[24]

Accumulation of toxic pesticides in coastal organisms is another aspect of threat from agricultural runoff. Negative impacts include damage to seagrass beds from herbicides and changes in reef community structure, such as loss of live coral cover and increases in algae and sponges.[25] The environmental effects of pesticide runoff depend on the chemicals used, amounts applied, farm layout (including vegetation cover, slope, and drainage), and the presence of riparian buffer zones along rivers and streams.

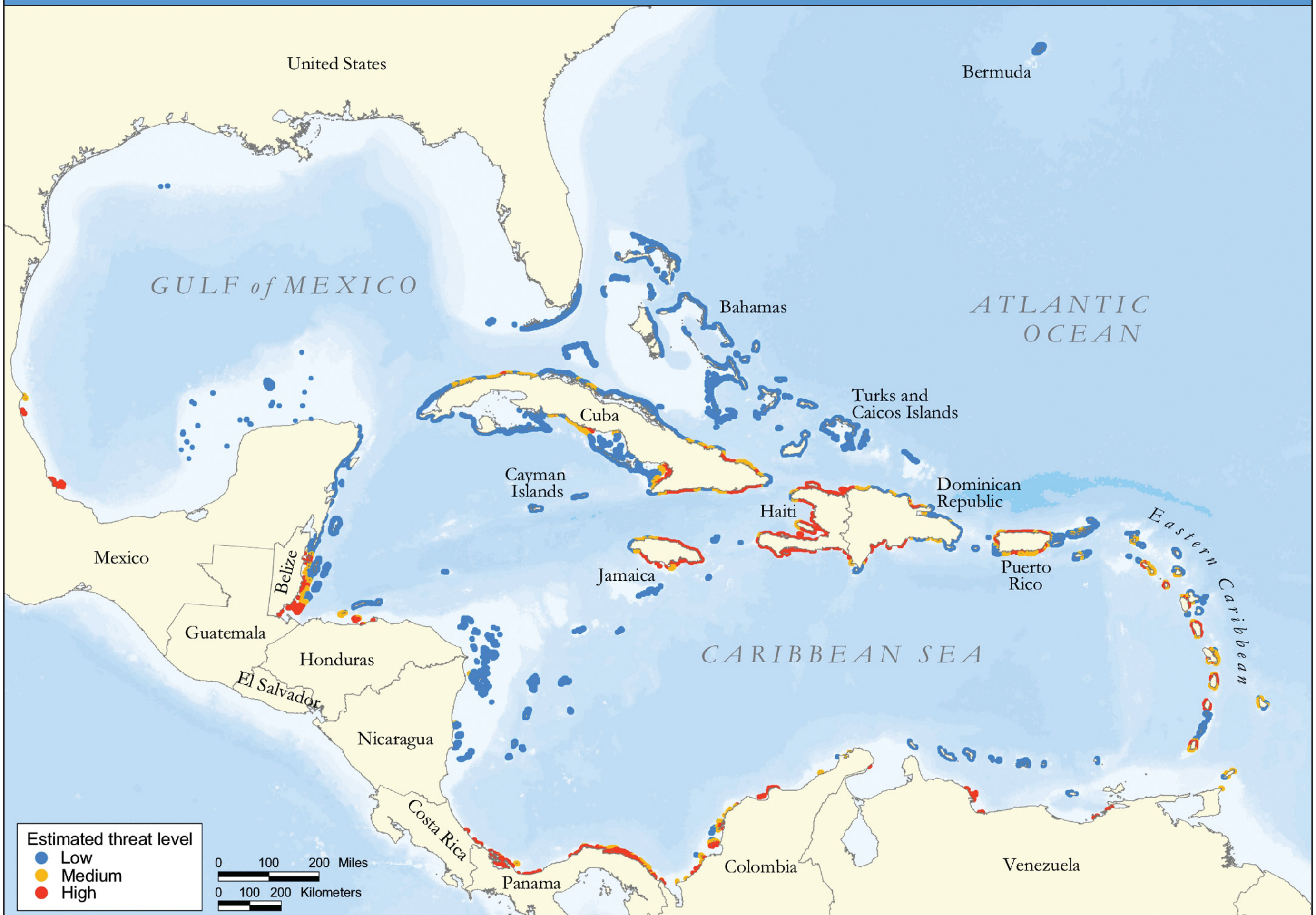
Modeling results. Analysis of more than 3,000 watersheds across the region[26] identified coastal waters likely to experience increased sediment and pollutant delivery related to land-use activities. Approximately 9,000 sq km of coral reefs (about one-third of the regional total) were identified as threatened (about 15 percent at medium threat and 20 percent at high threat). Areas with a large proportion of threatened reefs were identified off Jamaica, Hispaniola, Puerto Rico, Panama, Costa Rica, and Colombia. Some reefs in eastern Cuba were identified as threatened, as were the near-shore reefs in Belize, Venezuela, and reefs near the high islands of the Eastern Caribbean *(see Map 4)*.

Remedies. Sustainable agricultural planning and management encourages soil and water conservation practices that protect coral reefs by controlling cropland erosion and surface water runoff. Terracing helps avoid excessive runoff from farming on steep slopes. Optimal practices in tillage, fertilizer application, and harvesting will further reduce loss of both soil and nutrients, while reforestation near streams helps to reduce erosion. Fertilizers and pesticides can be used in ways that minimize leaching and transport to coastal areas.

Construction of roads and housing in steep areas can result in enormous erosion during severe rainfall events.

In sensitive areas where there are particularly important coastal resources, stronger regulation of agricultural practices may help to protect coral reefs and the livelihoods of coastal populations. Elsewhere, adding pollution taxes to the cost of agrichemicals at the point of sale can reduce wasteful or extravagant use. Assuring retention of coastal wetlands, mangroves, and seagrasses near river mouths would mitigate harmful impacts by filtering sediment and nutrients from the water before they reach coral reefs.

MAP 4. REEFS THREATENED BY SEDIMENTATION AND POLLUTION FROM INLAND SOURCES



Threats to reefs from sedimentation and pollution from inland sources were modeled for over 3,000 watersheds discharging into the Caribbean. The model incorporates estimates of relative erosion rates across the landscape (based on slope, land cover type, precipitation during the month of maximum rainfall, and soil type) summarized by watershed to estimate resulting sediment delivery at river mouths. Sediment plume dispersion was estimated as a function of distance from the river mouth and calibrated against observed impacts of sediment on coral reefs.

Source: WRI, *Reefs at Risk in the Caribbean*, 2004 (*see Appendix B*).

MARINE-BASED SOURCES OF THREAT

Within the Caribbean region, marine-based sources of pollution cause great concern. Activities giving rise to this pollution include oil discharge and spills, sewage, ballast and bilge discharge, and dumping of garbage and other human waste from ships. Direct physical damage is caused by groundings and anchors, particularly in high-visitation areas. Anchors can devastate coral reefs. The chain and anchor of a large cruise ship can weigh 4.5 metric tons (mt). Even in calm seas, reckless anchoring can damage up to 200 square meters of ocean bottom.[27]

Most small vessels, including fishing vessels, dive boats, and private recreational boats, remain in coastal waters, but many others, including commercial transport, oil transport, and cruise vessels, crisscross the Caribbean in an intricate network. The Caribbean is also an important oil-producing area, with most of this oil shipped within the region. The areas most vulnerable to spills or accidents are in the vicinity of ports or channels reserved for tanker traffic. Accidental

MAP 5. REEFS THREATENED BY MARINE-BASED SOURCES

Threats to coral reefs from marine-based sources were evaluated based on distance to ports (stratified by size), intensity of cruise ship visitation, and distance to oil and gas infrastructure, processing, and pipelines.

Source: WRI, *Reefs at Risk in the Caribbean,* 2004 (*see Appendix B*).

releases of oil are a relatively minor source of pollution, however, compared to the amount of oil that enters the environment from disposal of tanker bilge water, washing of tanks, and routine maintenance of oil drilling rigs and pipelines.[28] Oil damages coral reproductive tissues, harms zooxanthellae, inhibits juvenile recruitment, and reduces resilience of reefs to other stresses.[29] Discharge of bilge and ballast water from ships releases a toxic mix of oil, nutrients, exotic marine species, and other pollutants. Tides and currents dissipate much of this pollution over time and space, but pollution often lingers in enclosed areas and quiet waters with less circulation and exchange.

Cruise ships are also a significant source of pollution in the Caribbean. A typical cruise ship generates an average of 8 mt (2,228 gallons) of oily bilge water[30] and 1 mt of garbage[31] each day. The volume of cruise-ship tourism has roughly quadrupled in the last 20 years[32] and the Caribbean cruise industry accounts for about 58 percent of the world's cruise ship passengers.[33] According to recent estimates by the Ocean Conservancy, 25 million passenger bed-days on cruise ships in the Caribbean generated an estimated 90,000 mt of waste in 2000.[34]

Ship-generated wastes are a major source of solid waste in coastal areas.[35] During the Ocean Conservancy's Coastal Cleanup for 2003, more than 55,000 people participated in the Caribbean. This effort documented and removed more than 1,200 mt of waste along 2,100 km of coastline.[36]

Sewage discharge from both cruise ships and increasingly numerous yachts causes concern in heavily visited areas. Large ships have sewage-holding tanks and are prohibited from discharging untreated sewage within 7 km of the nearest land, according to Annex IV of MARPOL.[37] Coastal cargo vessels and recreational boats are less likely to have holding tanks. Due to the lack of port reception facilities for sewage wastes in most Caribbean countries, these smaller vessels are more likely than large ships to discharge their wastewaters in marinas and near-shore waters.[38] In the case of recreational vessels, these discharges may take place very close to coral reefs.

Modeling results. Many of the region's small islands were identified as under high threat from shipping and marine-based sources of pollution. Threat was estimated as high in St. Lucia, Montserrat, St. Kitts and Nevis, the Netherlands Antilles (including Aruba), the Virgin Islands, and Bermuda. In addition, Puerto Rico, the Dominican Republic, Jamaica, and Panama were identified as having many threatened reefs *(see Map 5)*. Overall, the analysis identified about 15 percent of the region's reefs as threatened by marine-based sources (about 10 percent at medium and about 5 percent at high threat).

Remedies. The development of a regulatory framework can prompt establishment of facilities to receive and manage ship-generated wastes in ports. This is essential for cruise ships, which contribute an estimated 77 percent of all ship-type waste, compared with 20 percent from cargo ships.[39] Development of legislation to incorporate the international conventions on the prevention of pollution from ships (MARPOL, London Dumping, OPRC, CLC, and FUND)[40] will greatly help reduce the threat. Pollution from small vessels such as yachts can also be addressed through regulations and guidelines, while education of vessel owners helps enforce compliance. In addition, a phase-out of the use of anchors in all coral reef and seagrass areas is crucial, with a clear priority on areas where current boat traffic is high. The use of mooring buoys or anchorage zones can be promoted as an alternative.

OVERFISHING

In the Caribbean region, fisheries have long been the mainstay of coastal communities, particularly in the island nations. Coral reef fisheries—predominantly artisanal, small-scale, subsistence fisheries—are an inexpensive source of protein and provide employment where few alternatives exist. In tourist areas, many fish are sold directly to local restaurants. For countries such as Belize and the Bahamas, the export market in snapper, grouper, and reef-associated lobster and conch generates millions of dollars for the national economy, supplying demand far away from these tropical sources.[41]

The open access of reef fisheries, typically with few regulations, makes reef fish particularly susceptible to overexploitation. Because most reefs are close inshore and geographically contained, fish distribution is highly predictable in space and time.[42] Portable fish traps, the most widely used fishing gear in the Caribbean, are cheap and effective.[43] Unfortunately, such traps can also be destructive and wasteful—destructive when fishers drop them directly onto the reef, breaking up the corals, and wasteful when they are lost underwater because the traps continue to catch fish for many months or years, a process known as ghost fishing. The life cycle of reef fish also makes them vulnerable to fishing pressure. Fishers selectively remove larger organisms because of their greater value, and one typical sign of overfishing is a decline in average size of target species. Because the largest individuals have the greatest reproductive output, removing them from the population reduces replenishment of the stock.[44]

Another particularly damaging form of overfishing in the Caribbean has been the targeting of spawning aggregations. Several of the larger grouper and snapper species, from areas spanning several hundred square kilometers, congregate at known localities once or twice a year to spawn in vast numbers. Where fishers know the location of such spawning aggregations, they can remove the entire population of a species over the course of just a few nights.

In heavily fished reef systems, the large, valuable fish—such as groupers and snappers—become so scarce that people fish for lower-valued species[45] (termed "fishing down the food web"). For example, in Bermuda herbivorous reef fish (e.g., parrotfish, surgeonfish, and triggerfish) increased from less than 1 percent of the catch in the 1960s to 31 percent in the 1990s. The shift led to a ban on fish traps in 1990 that is still enforced.[46]

Overfishing not only affects the size of harvestable stocks but can lead to major shifts, direct and indirect, in community structure, both of fish species and reef communities as a whole.[47] In the competition for space between corals and algae, herbivorous fish help to control algae, thus favoring the growth and recruitment of corals.[48] When the herbivores are removed, algae can flourish and coral cover is reduced. This effect is evident in the sequence of events that led to the dramatic decline of Jamaica's reefs *(see Box 2)*. Overfishing can lead to short-term losses in biodiversity, the loss of species with critical roles in the ecosystem, and may also lower the resilience of the reef to other threats.

Modeling results. The Reefs at Risk indicator for the overfishing threat identified highly populated areas and areas where coastal shelves are narrow (such as in the Eastern Caribbean) as being under high threat, based on the large numbers of fishers and relatively small fishing area *(see Map 6)*. The analysis estimated that fishing pressure is lower in the Bahamas, where the human population is small. In the western Caribbean and Cuba, where many reefs are far from the mainland, the analysis also rated the threat as low.

It should be noted that this indicator does not capture fishing pressure from more remote locations or illegal fishing *(see Chapter 2 - "Limitations of the Analysis" and Table 1)*. In the region as a whole, the study identified about 60 percent of reefs as threatened by overfishing (with about 30 percent each under medium and high threat). Destructive fishing practices (e.g., use of dynamite or cyanide) were not evaluated for the Caribbean, as they are rarely practiced in the region. The destructive impact of trap fishing and of lost fishing nets entangling reefs should be noted. To a broad approximation, these are likely to follow the patterns of fishing pressure as a whole.

Remedies. Effective management of coastal resources is crucial, especially along densely populated coastlines. Less intensive fishing will allow the fisheries resource to build up to the point where the harvest is balanced with the natural replenishment of the population.[49] Financial and other incentives can encourage sustainable fishing practices, while fines and penalties discourage illegal fishing and other breaches of sustainable practices. Licensing new fishers helps limit access to fisheries currently vulnerable to overfishing. Legal systems can also be put in place to restrict the catch of species subject to severe overfishing, such as the bans on all takings of selected conch species instituted in several

BOX 2. JAMAICA'S REEFS – BACK FROM THE BRINK?

Overfishing in Jamaican waters can be traced back over 100 years, with the capture of not only the large predators but also of most of the herbivorous, algal-grazing fish. This reduced the resilience of the reef ecosystem, and it became highly dependent on a single species, the long-spined sea urchin, to keep algal levels down. The reefs were smashed by Hurricane Allen in 1980, but began slowly to recover, with the grazing urchins playing a critical role in keeping down the algae so new corals could settle. Then in 1983 the urchins were all killed by a disease. With overfishing still rampant, there were no major grazers left. The already-established corals could survive, but algal levels began to rise. In 1988 Hurricane Gilbert struck the island, once again devastating the corals. At this point, the algae flourished, perhaps helped by the high levels of nutrient pollution in the water, and clearly benefiting from the lack of any grazers. A "phase shift" occurred in which the coral reefs were largely replaced by algal ecosystems. Between 1977 and 1993, live coral cover declined from 52 percent to 3 percent, and fleshy algae cover increased from 4 percent to 92 percent. The reasons for the change are complex and multiple: overfishing, disease, and two hurricanes, perhaps exacerbated by nutrient pollution.[a] But, recent monitoring provides some signs of hope – return of sea urchins, decreased algal cover and increasing coral cover in a few locations.[b] Increased coastal management efforts and resilience in the system are likely contributing to this modest recovery.

Notes:

a. T.P. Hughes et al. (2003).

b. J. Mendes, J.D. Woodley, and C. Henry, "Changes in Reef Community Structure on Lime Cay, Jamaica, 1989–1999: The Story Before Protection." Paper presented at the International Conference on Scientific Aspects of Coral Reef Assessment, Monitoring, and Restoration, Fort Lauderdale, Florida, 14–16 April 1999; L. Cho and J. Woodley, "Recovery of Reefs at Discovery Bay, Jamaica and the Role of *Diadema antillarum*." Paper presented at the 9th International Coral Reef Symposium, Bali, Indonesia, 23–27 October 2000.

MAP 6. REEFS THREATENED BY OVERFISHING

Threats to coral reefs from overfishing were evaluated based on coastal population density adjusted by the shelf area (up to 30 m depth) within 30 km of the reef. The management effectiveness of marine protected areas (MPAs) was included as a factor mitigating threat to reefs inside their boundaries. The analysis was calibrated using survey observations of coral reef fish abundance. (*See Box 3 in Chapter 4 and Table A5 in Appendix A.*)

Source: WRI, *Reefs at Risk in the Caribbean*, 2004 (*see Appendix B*).

Caribbean countries. Other controls limit the numbers caught, the size of individuals that may be taken (to ensure that individuals can reach breeding age), or the fishing gear used (for example, several countries now require the use of biodegradable panels in fish traps to avoid "ghost fishing" by lost traps). Seasonal restrictions can be used to protect species as they spawn. One of the most important tools, increasingly recognized and put into practice across the Caribbean, is the total closure of areas to fishing. Such "no-take zones" provide fish with a refuge, allowing spawning stocks to build up and adults to spill over into the surrounding waters. These zones have been shown to greatly increase overall catch levels from wider reef ecosystems.[50]

CLIMATE CHANGE

The rapid buildup of greenhouse gases (GHGs) in the atmosphere during the past century has already altered the global climate. GHG concentrations have grown by more than a third since pre-industrial times and, without significant policy intervention, are expected to reach double pre-industrial levels by the end of the twenty-first century.[51] The average temperature of the Earth has risen by 0.6°C to

0.8ºC in the last 100 years, and the global average sea level has risen some 18 centimeters (cm).[52] The impacts of these basic changes have not been fully determined, but could alter patterns of surface currents and upwellings, the location and intensity of extreme climatic events, and chemical processes in the oceans (associated with elevated levels of dissolved carbon dioxide).[53] The following sections describe some of the ongoing and projected impacts of climate change on coral reefs in the Caribbean.

Coral bleaching

The most direct evidence of the impact of climate warming on Caribbean marine biodiversity has been widespread "bleaching" of its reef-building corals. Currently, scientific uncertainties preclude incorporation of climate change or coral bleaching into the Reefs at Risk model. These phenomena must, however, be recognized as important threats to coral reefs in the Caribbean.

Bleaching refers to the loss of a coral's natural color (often hues of green and brown) caused by the expulsion of symbiotic algae *(zooxanthellae)*, leaving the coral very pale to brilliant white in appearance. Bleaching can be a response to many different stresses, including salinity changes, excessive light, toxins, and microbial infection, but increases in sea surface temperature (SST) are the most common cause of bleaching over wide areas.[54] Coral bleaching in the Caribbean is usually triggered by an increase of at least 1.0ºC in SST above the normal summertime maximums with a duration of at least 2 to 3 days.[55]

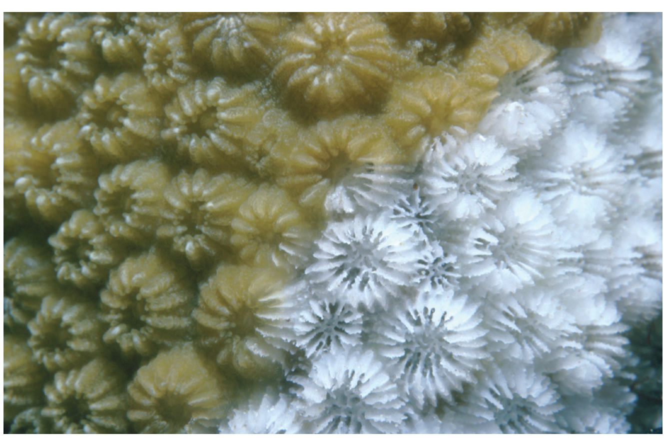
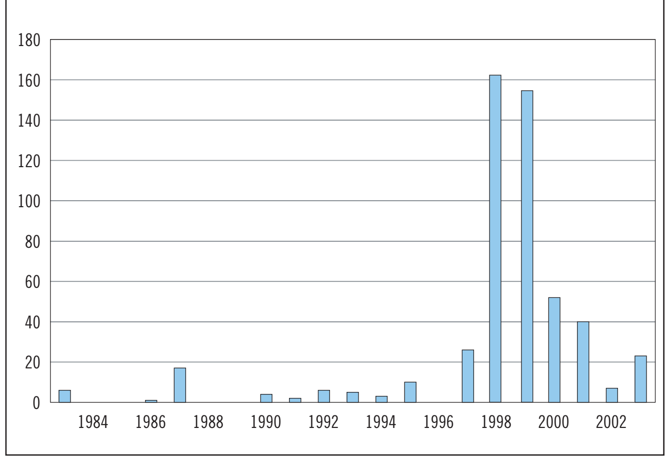


PHOTO: ED GREEN

In response to stress, corals expel their symbiotic algae (*zooxanthellae*) leaving them bleached in appearance. Bleached corals can recover and regain their color, but in more severe cases many die.

FIGURE 1. NUMBER OF REPORTED BLEACHING OBSERVATIONS BY YEAR



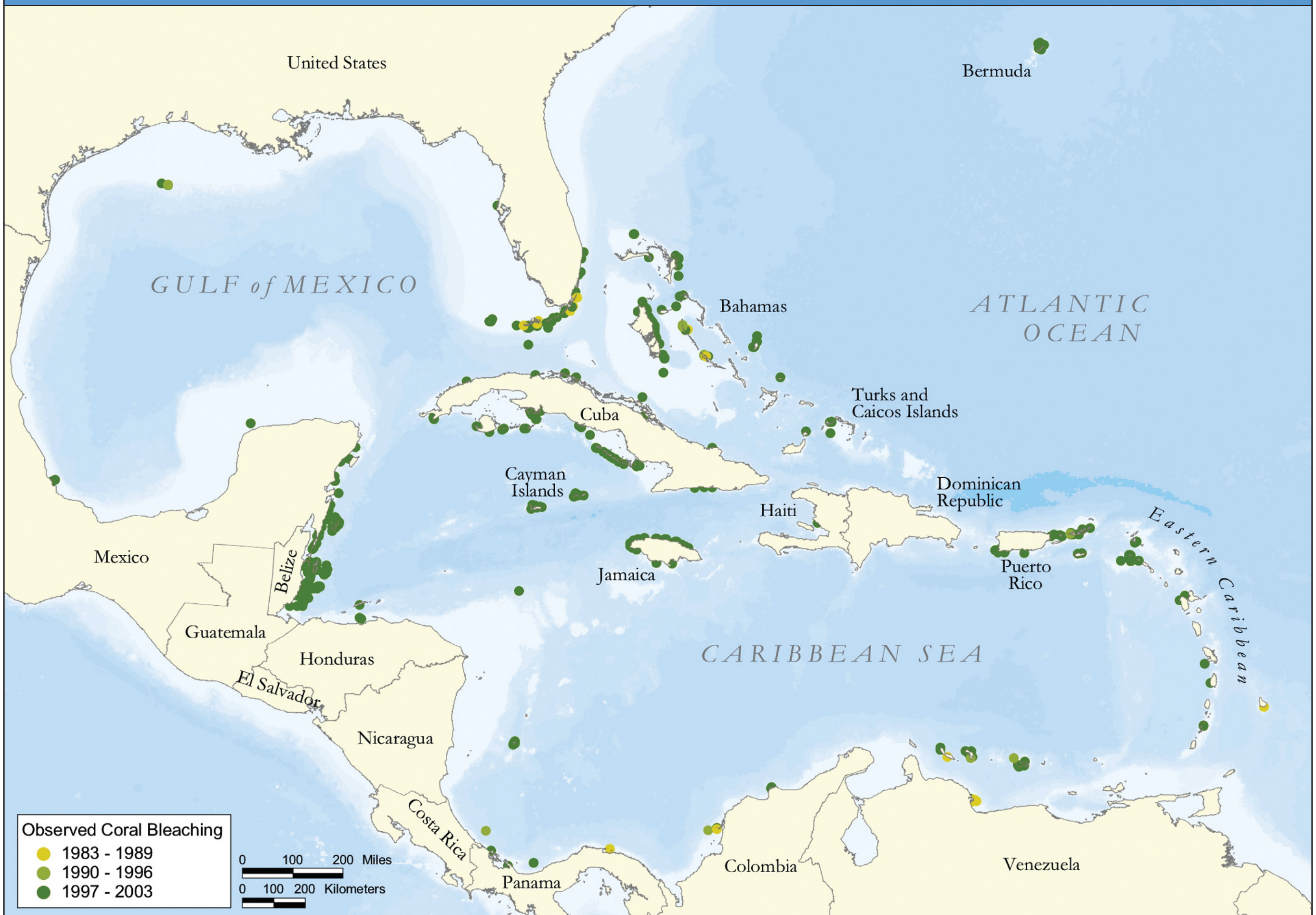
In mild events, bleaching is transient, and corals regain their color (algae) within months with little apparent mortality. In more severe cases, many of the corals die. Post-bleaching surveys have shown that some coral species have higher rates of mortality than others.[56] Repeated bleaching events in the Caribbean over the past decades have caused widespread damage to reef-building corals and contributed to the overall decline in reef condition.[57]

No incidents of mass coral bleaching were formally reported in the Caribbean before 1983.[58] Since the early 1980s, however, more than 500 observations have been reported *(see Map 7 and Figure 1)*.[59] One of the earliest incidences was during the 1982–83 El Niño Southern Oscillation (ENSO), while another major bleaching event occurred in 1987, during an ENSO.[60] Further bleaching incidents were recorded at various locations through the 1990s. In 1998, the highest average maximum SSTs on record in the Caribbean/Atlantic coincided with a large ENSO[61] and extensive areas of the Caribbean experienced bleaching at this time, with particularly severe occurrences in the Bahamas and Western Caribbean.[62]

Predicting Future Bleaching Threat

The conditions under which coral reefs have thrived in the Caribbean for millennia are rapidly changing. Global climate models predict that, by 2070, atmospheric temperatures in the Caribbean region will rise between 2°C and 4ºC, with large changes in the northern Caribbean and

MAP 7. CORAL BLEACHING OBSERVATIONS



Observations of coral bleaching in the Caribbean are widespread. Of the over 500 observations in recent decades, 24 were during the 1980s, over 350 during the 1990s, and over 100 since 2000. The increase in recorded incidents reflects both rising sea surface temperatures and greater awareness and communication of coral bleaching events.

Source: Reefbase, "Coral Beaching Dataset," download from http://www.reefbase.org on 10 August 2004.

around the continental margins.[63] Because current SST levels are near the upper temperature thresholds for survival of corals, bleaching is predicted to become an annual event in the Caribbean by 2020.[64] The long-term survival of shallow-water corals may depend on their ability to adapt to changing temperatures, and research suggests that some corals take on more heat-tolerant algae after bleaching, allowing them to be more resistant to future thermal stress.[65] Also, ocean circulation might allow coral species with higher temperature tolerances to migrate into warming areas.[66]

During the major bleaching events to date, localized areas with less incidence of bleaching have been observed, notably areas of deeper water as well as areas of greater water circulation. Scientists cannot currently predict specific patterns of ecosystem tolerance or cross-regional variation in temperature changes. Widespread monitoring and sharing of information on both patterns of bleaching and recovery are essential to improving our understanding of this very important, overarching threat to Caribbean coral reefs.

Hurricanes and Tropical Storms

Most of the Caribbean lies within the hurricane belt. High-intensity tropical storms develop over areas of warm sea water during the summer months and can sweep across the region, with devastating consequences on land and sea. The largest such storms can drive up waves over 16 meters in height, pounding coastal waters and smashing many shallow reefs to rubble. The high rainfall associated with storms often results in increased sedimentation around reefs close to shore or near river mouths. These are natural events from which coral reefs can recover, though recovery of the most severely damaged reefs may take a decade or two after the fiercest storms.

From 1995 to 2000, the Caribbean region experienced the highest level of hurricane activity in the reliable record. However, this followed a period of lower-than-average storm activity.[67] Climate models cannot yet accurately project how the frequency and intensity of hurricanes will change.[68] If, as models are refined, they point to the likelihood of increasing storm intensity, this should be cause for concern, particularly when added to the mounting pressures on coral reefs from marine and terrestrial pollution and coral disease.

Sea-Level Rise

Over the next century, mean global sea level is predicted to rise about 3 to 10 cm per decade.[69] The Intergovernmental Panel on Climate Change (IPCC) has concluded that such rates of sea-level rise would not pose a major threat to coral reefs.[70] Healthy reef ecosystems have the potential to respond to a rising sea through reef accretion, that is, the upward growth of the reef as corals lay down their calcium skeletons.[71] However, the situation is less clear for reefs already degraded by or under stress from other threats, as well as for associated seagrass and mangroves growing in low-lying coastal zones.[72]

Reduced Calcification Potential

Rising levels of atmospheric carbon dioxide (CO_2) are beginning to alter the chemistry of the shallow ocean.[73] Higher concentrations of dissolved CO_2 increase the acidity of this surface water, in turn affecting the solubility of other compounds. One such compound, known as aragonite, is used by the corals in reef building. Aragonite levels are currently falling, and reductions in the ability of corals to build reefs by laying down their limestone skeletons are becoming evident. This points to a slowdown or reversal of reef building and loss of reef in the future.[74]

Outlook for Reefs under a Changing Climate

Most scientists agree that corals' ability to adapt to shifting environmental conditions resulting from climate change depends on the severity of other human stresses, such as overfishing, coastal development, and land-based sources of pollution. Reef areas not subject to these other threats are likely to be more resilient than those that are heavily stressed. Management efforts can be directed toward reducing localized stress. A key management tool will be the siting of marine protected areas (MPAs). Ideal areas for prospective MPAs include those that might be resistant to coral bleaching (because of depth, greater water circulation, or shading) or areas with good potential for recovery (downstream from a coral larvae source). International efforts under agreements such as the Convention on Biological Diversity and the Framework Convention on Climate Change can leverage political and financial responses to the problems.[75] At the same time, curbing excessive CO_2 emissions is essential to reducing the long-term threat.

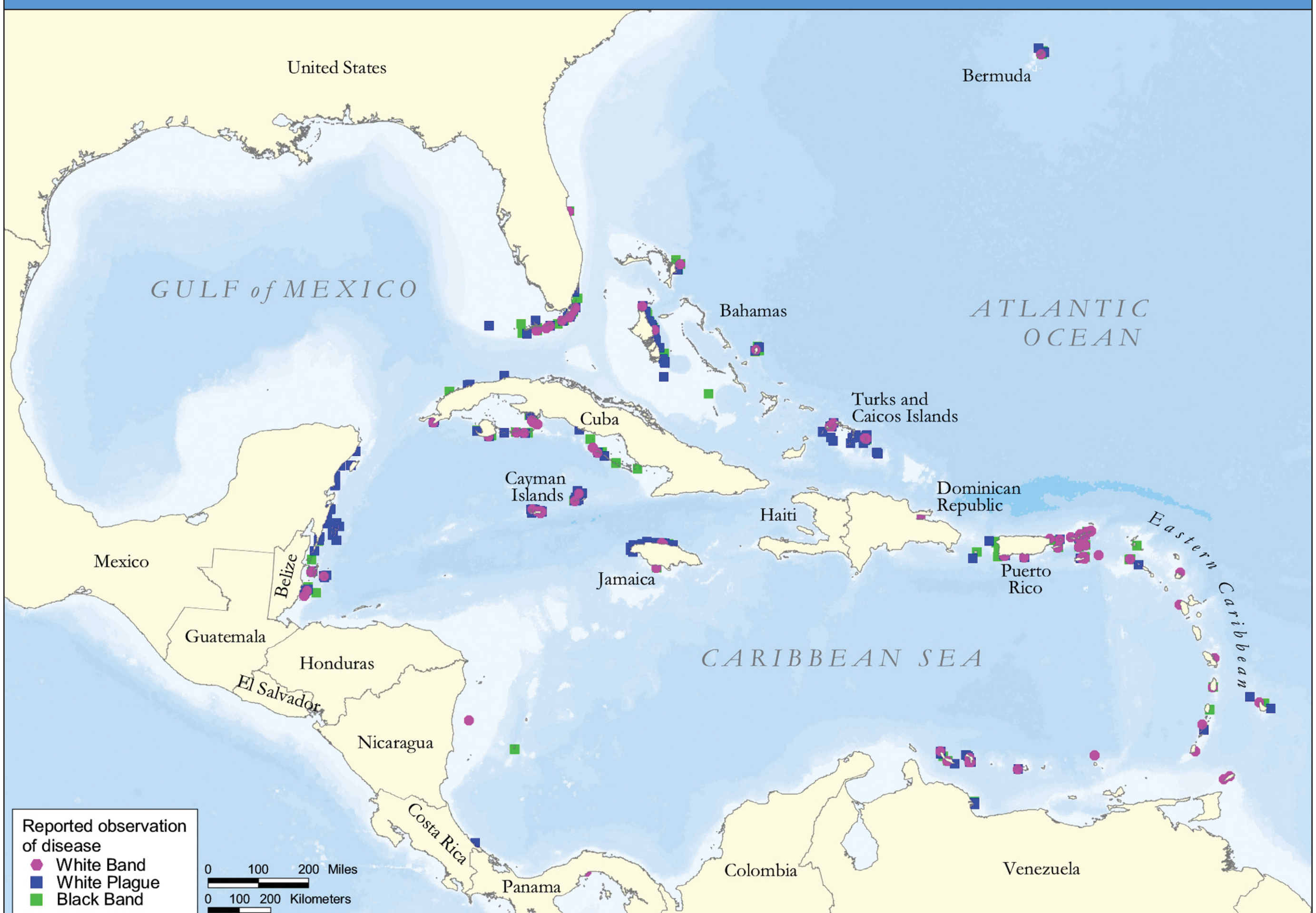
DISEASE

Perhaps the most profound and widespread changes in Caribbean coral reefs in the past 30 years have been caused by diseases of corals and other organisms. In recent decades, an unprecedented array of new diseases has emerged, severely affecting coral reefs. Most observations of coral reef disease reported across the globe have come from the Caribbean region.[76] Prominent among these reports have been the Caribbean-wide die-off of the long-spined black sea urchin *Diadema antillarum*;[77] widespread losses of major reef-building corals (staghorn and elkhorn) due to white band disease;[78] the current widespread occurrence of aspergillosis, a fungal disease that attacks some species of gorgonians (sea fans);[79] and numerous outbreaks of white plague.[80]

The Global Coral Disease Database[81] includes 23 differently named diseases and syndromes affecting corals alone in the Caribbean. Three of these diseases—black band disease, white band disease, and white plague—account for two-thirds of the reports in the database and affect at least 38 species of corals across the Caribbean (*see Map 8*). The impact of coral disease varies according to a variety of factors; a disease can cause different levels of mortality in different years at the same location.

The reasons for this sudden emergence and rapid spread of reef diseases throughout the Caribbean are not well understood. Diseases have been observed all across the Caribbean, even on the most remote coral reefs, far from human stresses.[82] Almost nothing is known about the causal agents; indeed, pathogens have been identified for only three of the 23 diseases observed in the region.[83] Linkages to other sources of stress to reefs (e.g., sedimentation or pollution) are poorly understood and the role of human activities in bringing these diseases into the region is also unclear. At least one pathogen seems related to desertification in Africa, blown with dust across the Atlantic,[84] while the pathogen responsible for the die-off of the long-spined sea urchin may have been transported into the region via the Panama Canal in ballast water from ships.[85] More research and integrated environmental monitoring are needed to better understand and help predict this major, widespread threat to coral reefs.

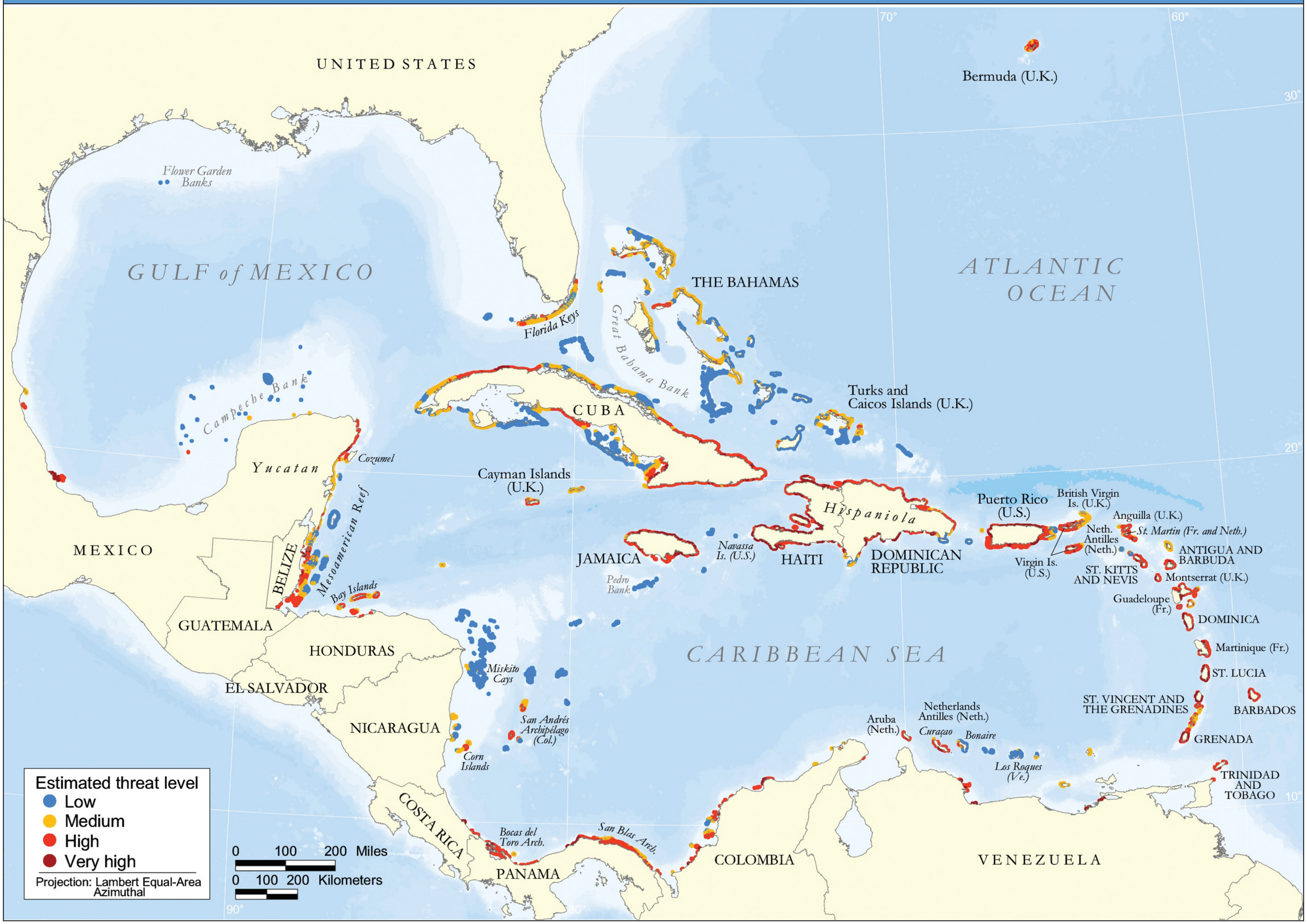
MAP 8. CORAL DISEASE OBSERVATIONS



Most reported observations of coral disease worldwide have been in the Caribbean. Three diseases occurring widely in Caribbean coral are black band, white band, and white plague. Reporting of disease occurrences is limited by the distribution of monitoring activities in the region.

Source: Global Coral Disease Database, United Nations Environment Programme - World Conservation Monitoring Centre, 2001.

MAP 9. INTEGRATED THREAT — THE REEFS AT RISK THREAT INDEX



Source: WRI, *Reefs at Risk in the Caribbean*, 2004 (*see Appendix B*).

TABLE 2. REEFS THREATENED BY HUMAN ACTIVITIES

Country/Territory	Reef Area (km^2)	Reef Area as % of Total in Region	Reefs at Risk Threat Index[a] (%)				Individual Threats[b]: Coastal Development (%)			Sediment and Pollution from Inland Sources (%)			Marine–Based Sources of Pollution (%)			Fishing Pressure (%)		
			Low	Medium	High	Very High	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Anguilla	70	< 1	0	11	89	0	33	33	34	99	1	0	100	0	0	0	11	89
Antigua and Barbuda	180	< 1	0	39	51	11	29	55	16	71	29	0	71	18	11	0	39	61
Aruba	25	< 1	0	0	85	15	0	28	72	100	0	0	26	48	26	0	0	100
Bahamas	3,580	14	75	24	2	0	95	5	0	100	0	0	99	1	0	78	21	1
Barbados	90	< 1	0	0	86	14	0	20	80	40	60	0	85	15	0	0	6	94
Belize	1,420	5	37	29	32	2	89	11	0	51	20	29	92	8	0	63	30	7
Bermuda	210	< 1	0	20	61	19	51	20	29	100	0	0	38	34	28	0	25	75
British Virgin Islands	380	1	3	62	25	10	54	29	18	83	17	0	76	16	7	4	77	19
Cayman Islands	130	< 1	17	57	26	0	35	43	22	100	0	0	99	0	0	17	63	20
Colombia	2,060	8	56	24	19	1	86	7	7	76	16	8	97	3	0	61	25	14
Costa Rica	30	< 1	0	0	77	23	14	62	24	0	0	100	77	0	23	0	77	23
Cuba	3,290	13	32	32	33	3	78	14	7	71	20	8	92	7	1	32	35	33
Dominica	70	< 1	0	0	63	37	4	49	47	0	25	75	86	10	4	0	0	100
Dominican Republic	1,350	5	18	8	63	10	41	22	37	55	24	21	90	6	4	21	11	68
Grenada	160	< 1	0	20	41	40	15	22	63	43	27	30	76	14	9	0	37	63
Guadeloupe[c]	400	2	0	15	66	18	15	33	52	55	31	13	73	23	4	1	28	71
Guatemala	0	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Haiti	1,260	5	0	0	45	55	8	33	59	1	8	91	92	7	0	0	0	100
Honduras	1,120	4	66	13	21	0	75	11	14	90	7	3	94	5	1	70	24	5
Jamaica	1,010	4	32	2	34	32	45	24	32	39	19	42	69	24	7	32	2	67
Martinique	260	1	0	0	65	35	9	43	48	2	79	19	62	31	8	0	0	100
Mexico	1,220	5	50	20	20	10	70	15	15	86	2	12	83	10	7	51	29	20
Montserrat	25	< 1	0	0	71	29	8	81	11	0	30	70	24	47	29	0	100	0
Netherlands Antilles North[d]	40	< 1	48	21	31	0	59	41	0	76	24	0	65	9	26	72	27	1
Netherlands Antilles South[e]	210	< 1	37	15	39	9	57	27	15	100	0	0	55	19	26	64	4	32
Nicaragua	870	3	86	11	2	0	96	2	2	99	1	0	99	1	0	86	14	0
Panama	1,600	6	0	16	75	10	80	12	8	0	18	82	64	28	8	0	98	2
Puerto Rico	1,610	6	7	8	59	25	46	30	24	37	32	31	72	20	8	9	8	84
St. Kitts and Nevis	160	< 1	0	0	77	23	5	67	28	0	81	19	74	15	11	0	3	97
St. Lucia	90	< 1	0	0	39	61	1	32	67	0	51	49	60	29	11	0	2	98
St. Vincent and the Grenadines	140	< 1	0	38	48	14	36	29	35	84	0	16	71	19	10	0	59	41
Trinidad and Tobago	40	< 1	0	0	99	1	1	46	52	13	87	0	99	1	0	0	31	69
Turks and Caicos Islands	1,190	5	50	46	4	0	87	9	4	100	0	0	98	2	0	51	49	0
United States	840	3	38	48	14	0	57	31	11	100	0	0	97	3	0	42	56	3
Venezuela	230	< 1	57	16	11	16	68	16	16	73	0	27	86	8	6	64	14	22
Virgin Islands (U.S.)	590	2	0	9	73	18	42	39	18	66	34	0	57	22	22	0	13	87
Regional Total	**25,960**	**100**	**36**	**21**	**33**	**10**	**67**	**17**	**16**	**66**	**15**	**20**	**87**	**10**	**4**	**39**	**29**	**32**

SOURCE:
WRI, *Reefs at Risk in the Caribbean*, 2004.

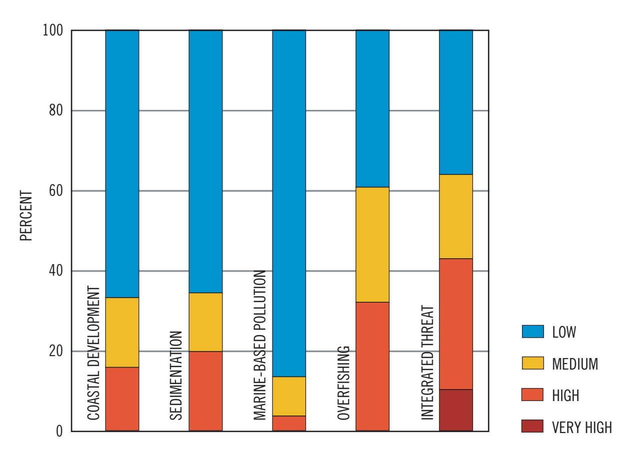
NOTES:
a. The Reefs at Risk Threat Index reflects cumulative threat from four individual threats at a single location. In areas where three or four of the threats were rated as high, the index is set to very high.
b. In the analysis, individual threats are classified high, medium, or low. Threats sum to 100%.
c. Guadeloupe includes the French islands of St. Martin and St. Barthelemy.
d. Netherlands Antilles North includes the islands of St. Maarten, St. Eustatius, and Saba.
e. Netherlands Antilles South includes the islands of Bonaire and Curaçao.

INTEGRATING THREATS: THE REEFS AT RISK THREAT INDEX

Around the world, but perhaps especially in the Caribbean, coral reefs are threatened from a multitude of sources. Quite often, a reef is sufficiently robust to survive a low level of threat from a single source. In many cases, however, reefs are subject to multiple stresses, and the combined, low-level impacts from multiple sources can drive reefs into steep decline. One of the best examples of such combined impacts can be seen in Jamaica's reefs. *(See Box 2.)*

Of the four threats modeled in this study, the most pervasive direct human threat to coral reefs is overfishing, threatening over 60 percent of the region's reefs. Pressures associated with coastal development and sedimentation and pollution from inland sources each threaten about one-third of the region's coral reefs. About 15 percent of the region's reefs are threatened by marine-based sources of pollution. *(See Figure 2 for a summary of these threats.)*

FIGURE 2. REEFS AT RISK BY CATEGORY OF THREAT



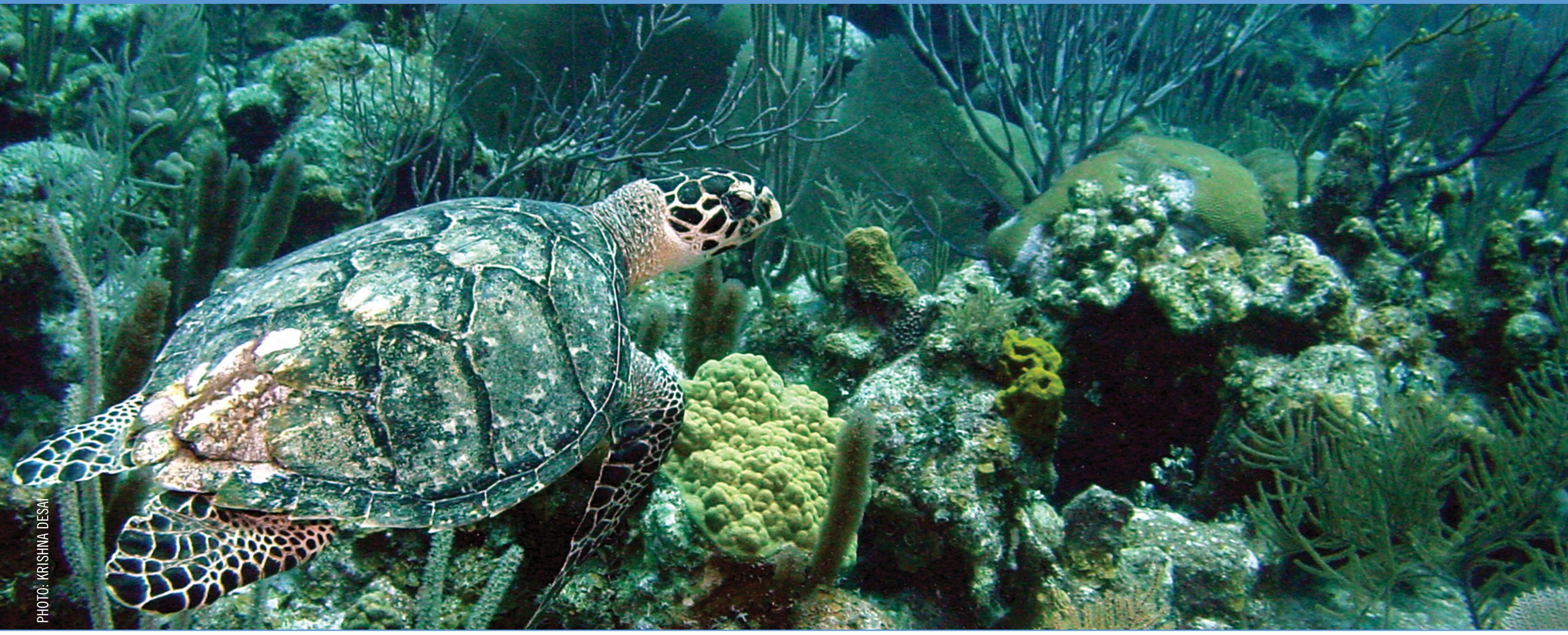
When these four threats are integrated into the Reefs at Risk Threat Index, nearly two-thirds of the region's coral reefs are threatened by human activities (about 20 percent at medium threat, one-third at high threat, and 10 percent at very high threat).[86] *(See Map 9.)* Areas with high threat levels include the Eastern Caribbean, most of the Southern Caribbean, Greater Antilles, Florida Keys, Yucatan, and the nearshore portions of the Mesoamerican Barrier Reef and the Southwest Caribbean. In areas identified as threatened, degradation of coral—including reduced live coral cover, increased algal cover, or reduced species diversity—may have already occurred. If not, it is considered likely to occur within the next 5 to 10 years.

In addition to these chronic threats, for which we were able to develop indicators, coral reefs are also affected by the currently less predictable threats of coral disease and coral bleaching. As ocean temperatures warm, increased incidence of coral bleaching can be expected, with some associated mortality. Also, trends over the last decade indicate that coral diseases may persist, or even proliferate—often after coral bleaching events, in response to new pathogens, or possibly in high-pollution or sediment-stressed areas. Taken together, coral diseases and bleaching are significant, region-wide threats that should be taken into account when considering the Reefs at Risk results. All told, the highly valued coastal resources of the region are severely endangered.

No coral reef is guaranteed immunity from the threats of bleaching, disease, or plunder from excessive fishing, but some reefs are at lower risk from land-based threats and from coastal fishing pressures. In several parts of the Caribbean, the analysis identified extensive tracts of reefs as being under low threat from the human activities evaluated. These include areas in the Bahamas, Turks and Caicos Islands, archipelagos off Colombia and Nicaragua, and some reefs off Cuba, Belize, and Mexico. Such areas may still have suffered from coral disease and bleaching, and some have also been targeted for the capture of high-value fish stocks, but overall they are likely to be in a relatively healthy state and may be important refuges for the wider region. Table 2 presents summary statistics by country for each threat examined.

The cumulative threat to reefs from these four categories demonstrates that, to manage development in the coastal zone and all the complex issues associated with it, a holistic, cross-sectoral approach is ideal. In Chapter 6, we discuss some of these management needs and the principle of Integrated Coastal Zone Management. In Chapter 4, threats around nine Caribbean sub-regions are examined in more detail.

Chapter 4. STATUS OF CARIBBEAN CORAL REEFS

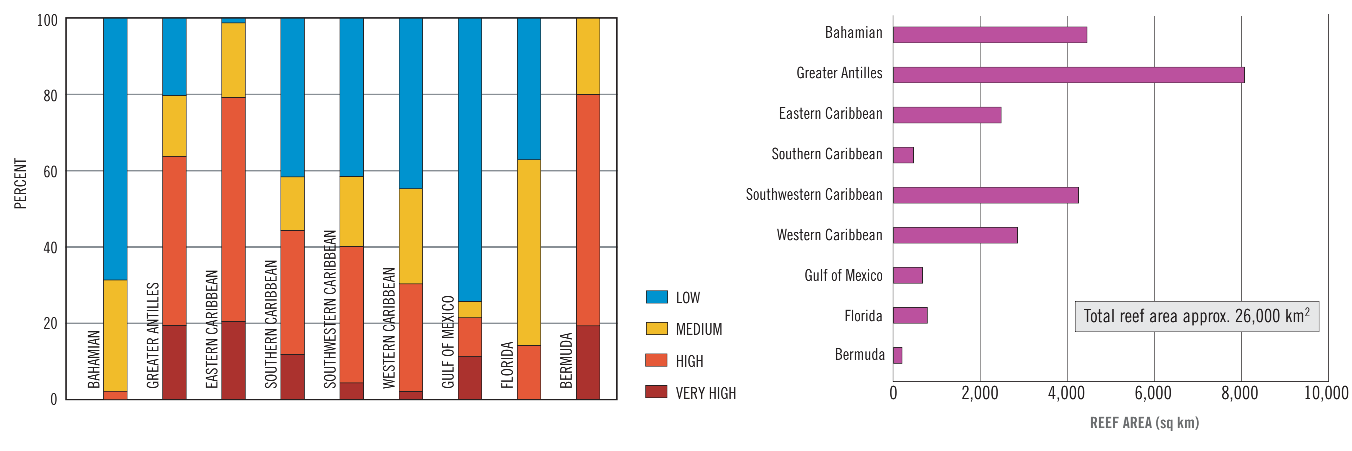


Coral reefs in the Caribbean have undergone massive changes over the past several decades[87] as they evolved from a coral-dominated to an algal-dominated state.[88] Evidence of decline is widespread. Surveys conducted between 1998 and 2000 under the Atlantic and Gulf Rapid Reef Assessment (AGRRA - *see Appendix C*) found coral diseases throughout most of the Wider Caribbean, with very few areas exhibiting no occurrences.[89] AGRRA surveys reported few sightings of large-bodied snappers and groupers, and Reef Check surveys recorded an absence of Nassau Groupers in over 80 percent of the sites surveyed across the region.[90] They were once among the commonest fishes of the Caribbean. This strongly suggests the entire region is overfished for many heavily targeted species.[91] Reef Check surveys have also identified sewage pollution as a problem in nearly one-quarter of sites surveyed since 1998.[92] Monitoring of live coral cover by the Caribbean Coastal Marine Productivity Program (CARICOMP – *see Appendix C*) between 1993 and 2001 found declines in live coral on nearly two-thirds of sites for which time series data were available.[93] However, the AGRRA program found a mean live coral cover of 26 percent on sites around 10 m depth, suggesting that despite significant loss from many large-scale disturbances, considerable coral remains.[94]

Chapter 3 examined threats to Caribbean coral reefs, on a region-wide, threat-by-threat basis. This chapter examines these threats, along with available information on condition and protection of reefs, in greater geographic detail for nine Caribbean sub-regions. *(See Map 10.)* Figure 3 provides a summary by sub-region of reef area and the Reefs at Risk Threat Index. More detailed country profiles—including information on status of, threats to, and protection of coral reefs for 35 Caribbean countries and territories—are available online at http://reefsatrisk.wri.org.

MAP 10. CARIBBEAN SUB-REGIONS

FIGURE 3. SUB-REGIONS BY REEFS AT RISK THREAT INDEX AND REEF AREA



BAHAMIAN

The Bahamian Banks form an extensive archipelago of islands, cays, and sandbanks separated by deep ocean channels, extending more than 800 km from Southern Florida to Hispaniola. The northern and central islands rest on two large bank systems—the Little Bahama Bank and the Great Bahama Bank—with water depths of less than 10 m.[95] Further south and east are a number of smaller banks and isolated islands, with the politically separate Turks and Caicos Islands (TCI), consisting of the Caicos Bank and Turks Bank, at the southeastern end.[96]

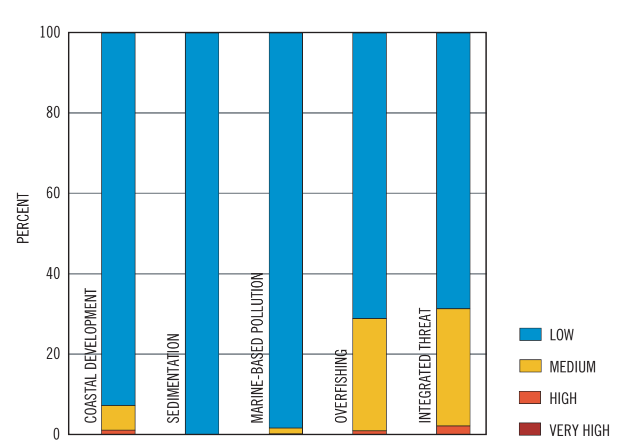
The reefs there are extensive. There are thousands of small patch reefs, dozens of narrow fringing reefs, and some bank barrier reefs, such as the Andros Barrier Reef. The reefs are most prominent on the windward north and eastern sides of the islands and cays.[97]

The Bahamas and TCIs possess some of the least threatened coral reefs in the Caribbean region. Only about 30 percent of the sub-region's coral reefs were identified as threatened by overfishing, and this is the only threat identified in most areas. Coastal development and pollution from marine-based sources threaten few coral reefs in the area, and watershed-based threats rated low, owing to the narrow, flat topography of most of the islands. This is reflected in observations of reef condition, which has declined in waters off the more developed and populated islands, but is generally good in isolated offshore banks.[98]

In the Bahamas, the commercial and export fishery is well-developed. In addition, a recreational and local consumption fishery[99] targets the commercially valuable lobster, conch, grouper, snapper, and jacks.[100] The populations of grouper and conch both show evidence of overfishing.[101] Reef fishes are little exploited in the TCIs, and fishing pressure on herbivores is almost nonexistent. There are concerns about poaching by foreign fishers, mostly from Haiti and the Dominican Republic, using illegal methods. Declines in lobster and conch populations are causing some fishers to turn to reef fish as an alternative resource, which may change the fishery situation.[102]

Growing tourism has led to localized problems—such as waste management,[103] destruction of coastal habitats for hotel and marina development, and diver damage to

REEFS AT RISK IN THE BAHAMIAN BANKS



corals[104]—on some of the islands. Several large developments and the likely introduction of cruise ships to the TCIs threaten the viability of the national parks, nature reserves, and sanctuaries adjacent to these areas.

Concerned about the continued degradation of its marine resources, the government of the Bahamas was a pioneer in reef protection, establishing its first Land and Sea National Park in 1958 in Exuma Cays. The park became a no-take fisheries replenishment area in 1986, the first of its kind in the Caribbean. The reserve supports a concentration of conch 31 times greater than outside the park.[105] This success contributed to the government's announcement of a policy decision in 2000 to protect 20 percent of the Bahamian marine ecosystem and 10 new national parks were established in 2002. In the TCIs, a Conservation Fund was recently established to provide monetary support for management, financed by a 1 percent share of all tourist and accommodations taxes.

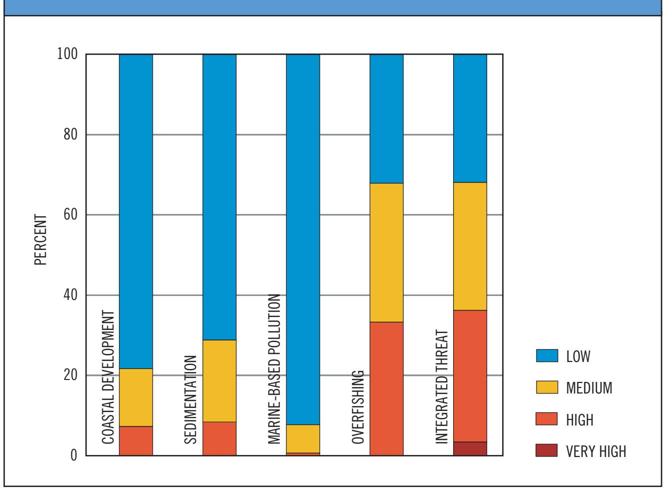
GREATER ANTILLES

Located in the center of the Caribbean Sea are the islands of the Greater Antilles: Cuba, the Cayman Islands, Jamaica, Hispaniola (made up of Haiti and the Dominican Republic), and Puerto Rico. This study estimates that coral reefs cover over 8,600 sq km within the Greater Antilles. More than one-third of them are located within the territorial waters of Cuba, which has a broad shelf area and chains of offshore islands and coral cays. The narrower shelves of the other islands support mainly fringing and small barrier reefs. Jamaica and the Dominican Republic also have important offshore bank reefs.

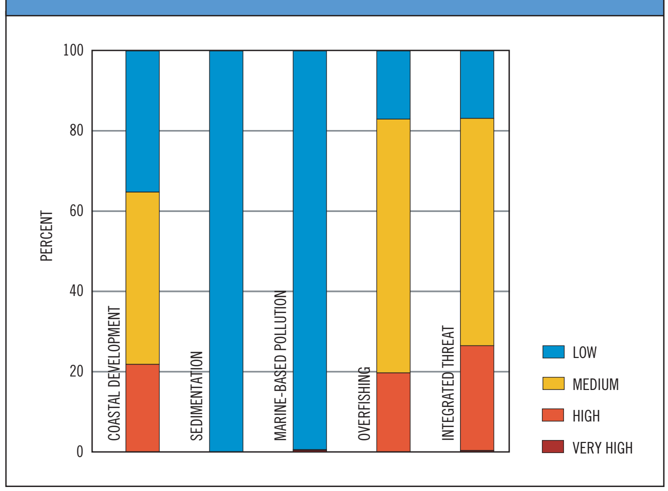
Overall, we rate more than two-thirds of Cuba's reefs as threatened, with over 35 percent at high threat. Overfishing is the main threat to Cuba's reefs, with over 65 percent of the reefs threatened. Landing statistics for the commercially important snapper and grouper indicate decreasing annual catches and decreasing maximum size over the last 20 years due to unsustainable fishing practices.[106] However, Cuba's coral reef fishery is probably in better condition than those of other Caribbean countries.[107] About one-quarter of reefs were rated as threatened by sedimentation and pollution from inland sources, around one-fifth by coastal development, and fewer than 10 percent by marine-based sources. The low sedimentation and coastal development threats are mainly due to the offshore location of many reefs, outside the influence of land-based sources of pollution,[108] and to Cuba's relatively undeveloped tourist industry. Remote reefs (e.g., around the southern archipelagos) are in very good condition but, near large population centers such as Havana, signs of decline are evident, with low coral cover, overgrowth by algae, and disease outbreaks.[109]

The reefs in the Cayman Islands are managed under strict marine conservation laws establishing a zoned system of MPAs. However, this has not prevented overfishing of conch and lobster, and increased human usage is a major concern.[110] The analysis found an estimated 80 percent of the reefs are threatened, predominantly from overfishing as well as coastal development (resulting from population

REEFS AT RISK IN CUBA



REEFS AT RISK IN THE CAYMAN ISLANDS

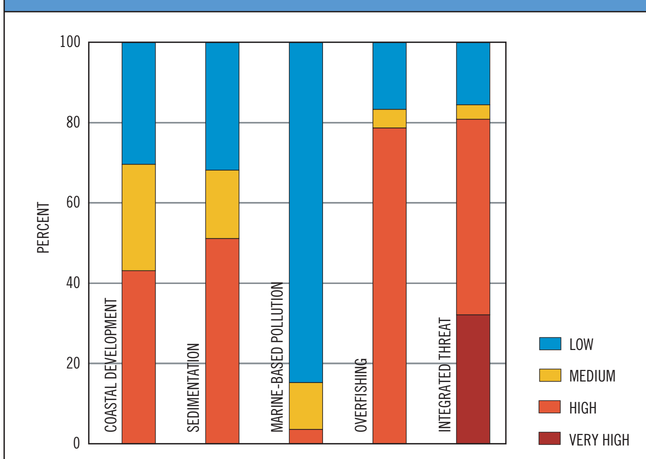


growth and intensive tourism, including impacts from cruise ships).[111] AGRRA surveys in 1999 and 2000 found the reefs to be in generally good condition, though with some obvious signs of impact, particularly on the more developed island, and focus of the dive industry, Grand Cayman.[112]

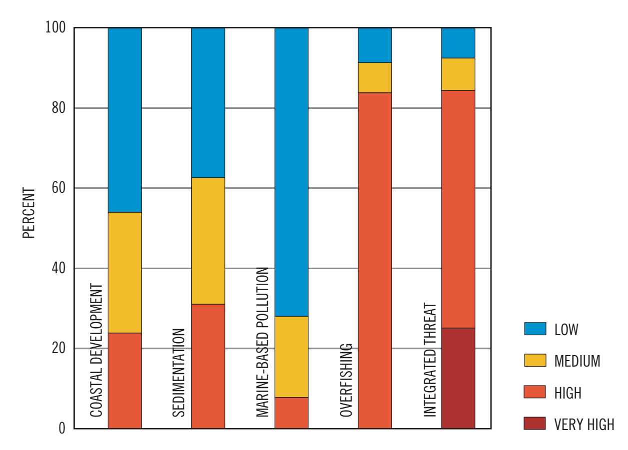
Over 80 percent of the reefs in Jamaica, Haiti, and the Dominican Republic are identified as threatened by human activities, with one-third under very high threat. The majority of reefs are threatened from multiple sources. Widespread unemployment, densely populated coastal zones, easy access to the reefs, and narrow shelf areas mean the reef resources have been heavily used to provide livelihoods and sustenance. Unfortunately, this open and unregulated access has reduced the overall productivity of the reefs for all. Illegal fishing activities are common, and capacity for enforcement of regulations is limited.[113] However, Jamaica is developing new regulations for reef fisheries and existing regulations for the Pedro Bank conch export fishery allow it to remain open under the Convention of International Trade in Endangered Species (CITES). In contrast, the international trade in conch from Haiti and the Dominican Republic is banned under CITES.

In Jamaica and the Dominican Republic, huge growth in the tourism industry has generated some alternative employment opportunities, but not enough to reduce fishing pressure. Also, mass tourism brings its own suite of problems, with swelling coastal populations and unmanaged coastal development threatening an estimated 70 percent of reefs.

REEFS AT RISK IN JAMAICA AND HISPANIOLA



REEFS AT RISK IN PUERTO RICO



Similar tourism-related pressures, compounded by rapid urban and industrial development over the past 40 years, threaten more than half of Puerto Rican coral reefs.[114] Both the permanent population and tourist traffic have grown rapidly,[115] and nearly 60 percent of the people live within 10 km of the coast. (*See Appendix A, Table A3.*)

Overfishing threatens over 90 percent of Puerto Rico's coral reefs. Puerto Rican reef fisheries have plummeted during the last two decades and show the classic signs of overfishing.[116] Reported fish landings fell 69 percent between 1979 and 1990.[117] This analysis identified sedimentation and pollution from inland sources as threatening over 60 percent of the commonwealth's reefs; coastal development as threatening over one-half, with marine-based threats jeopardizing about one-quarter. Overall, over 90 percent of Puerto Rico's reefs were rated as threatened, with over 80 percent at high risk and therefore among the most threatened in the Caribbean. Most common diseases have been observed on the degraded reefs surrounding the main island and have caused considerable damage to depths of 30 m.[118]

Except for the Caymans, all the island nations rely heavily on agriculture for livelihoods and export earnings from sugar, coffee, bananas, or tobacco. Land clearing and poor agricultural practices have led to increased erosion. Near the mouths of rivers, sedimentation from soil erosion threatens many reefs. Puerto Rico, with its more diversified economy, is less reliant on agriculture.

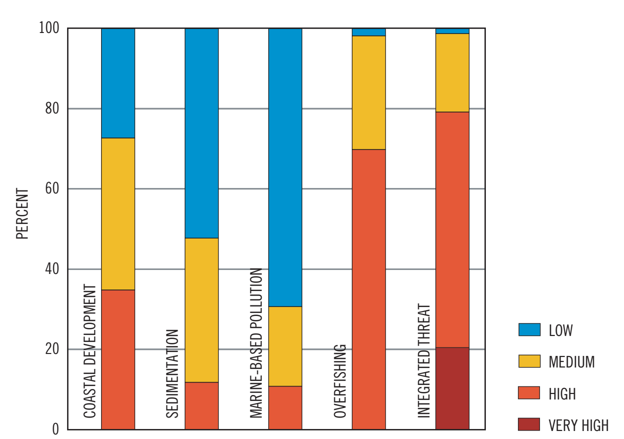
Lacking political and financial support, protection of the reef resource is limited in Cuba, Jamaica, and the Dominican Republic, and nonexistent in Haiti. Puerto Rico has put natural reserves under government jurisdiction, but these reserves afford coral reefs only slight protection, and effective management is limited by lack of laws regulating fishing activities and recreation.[119]

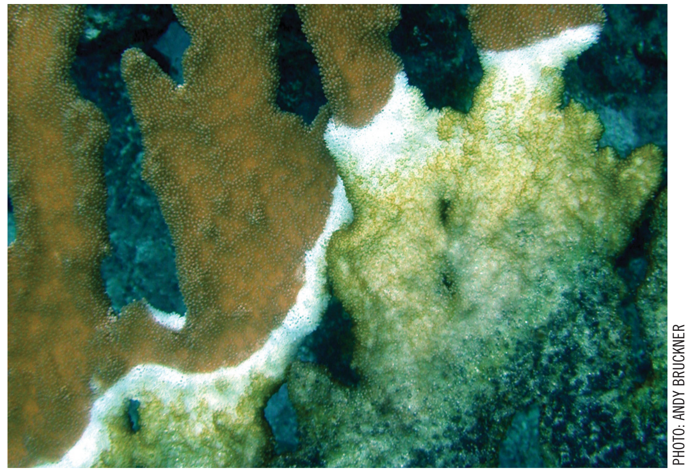
EASTERN CARIBBEAN

Extending from the U.S. Virgin Islands south to Grenada, the Eastern Caribbean sub-region encompasses one of the world's most compact aggregations of nations and autonomous territories.[120] The island chain consists mostly of mountainous and forested volcanic islands (from Saba 700 km south to Grenada), typically with small marine shelves, as well as a number of flatter coralline islands, with wider shelf areas (U.S. Virgin Islands, British Virgin Islands, Anguilla, St. Maarten/St. Martin, Antigua and Barbuda, and Barbados). Reef development has been most extensive along the sheltered western shorelines of the drier limestone islands. This study estimates a coral reef area of about 2,600 sq km in the Eastern Caribbean sub-region.

The analysis identified overfishing as the most pervasive threat to reefs within the Eastern Caribbean, affecting almost all reefs as evidenced by the absence of larger fish in the catch and scarcity of some of the larger species.[121] Though largely artisanal or small-scale commercial, fishing is an important activity on most of these islands.[122] Easy access to the reef resources, high population densities on many islands, and scarcity of other employment opportunities contribute significantly to the threat from overfishing.

REEFS AT RISK IN THE EASTERN CARIBBEAN





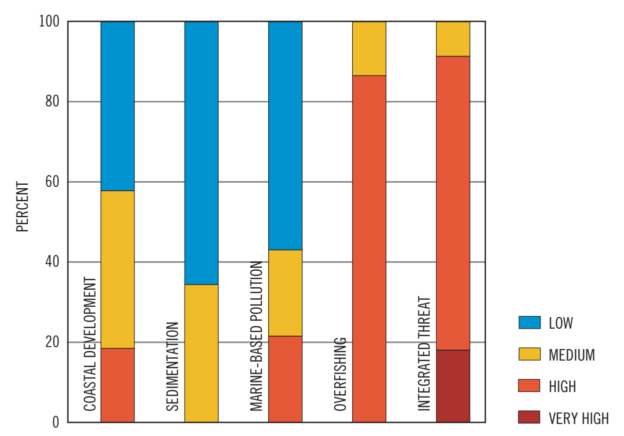
Coral diseases, such as white band, have affected reefs throughout the Caribbean.

Second in importance is coastal development, identified as threatening more than 70 percent of the sub-region's reefs. The development of the necessary infrastructure to support high population densities and tourism growth has resulted in coastal degradation through increased siltation from land reclamation, dredging and construction, and pollution from sewage outfalls. Also, tourist activities such as yachting have been cited as contributing to the degradation of reefs through anchor damage and local pollution.

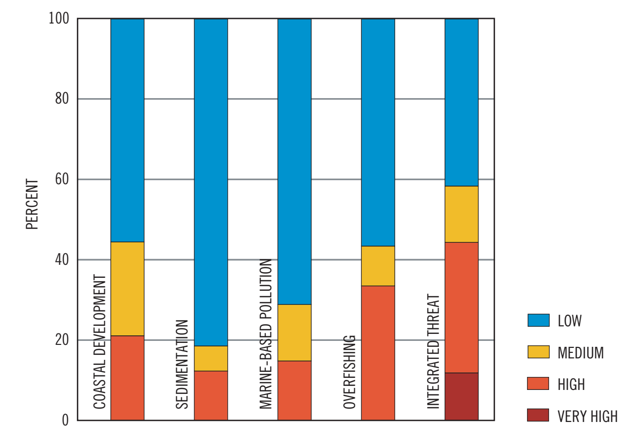
Historically, many of the islands depended on agriculture for export earnings, mainly from sugarcane and bananas. Although agriculture has been surpassed by tourism in terms of earnings,[123] it is still important, and poor land-use practices and excessive deforestation have led to increased sedimentation and pollution in the coastal zone. Sedimentation and pollution from inland sources were identified as threatening nearly one-half of the reefs in the Eastern Caribbean sub-region.

A number of MPAs have been established in the Eastern Caribbean, and many proposed, but inadequate funding, poor enforcement, and lack of local involvement in the management process have limited the effectiveness of resource protection, particularly against overexploitation. However, a few MPAs are outstanding for their effective planning and management of the reef resource, including Saba Marine Park and St. Eustatius Marine Park in the

REEFS AT RISK IN THE U.S. VIRGIN ISLANDS



REEFS AT RISK IN THE SOUTHERN CARIBBEAN



Netherlands Antilles, and the Soufrière Marine Management Area, St. Lucia. *(See Box 3.)*

Almost 600 sq km of coral reefs are found around the U.S. Virgin Islands (USVI). Overfishing is the main threat to reefs, with over 85 percent under high threat. Effects of intensive fishing are evident and fisheries are close to collapse—even those inside MPAs are deteriorating.[124] Marine-based pollution is also a significant threat, due to the many millions of visitors to the parks who arrive each year on cruise ships or smaller boats.[125] Growing tourism contributes to coastal development, and wastewater disposal poses a particular problem. Intense visitation of some reefs has also caused damage.

Frequent natural disturbances take their toll on reefs as well. Eight hurricanes have swept across the USVIs since 1979. Diseases have ravaged the corals over the last three decades,[126] and periodic bleaching episodes, particularly in 1998, all contribute to the overall stress and degradation of reefs here. The hard coral cover is declining. At the Buck Island National Monument, for example, the cover dropped from 85 percent in 1976 to 5 percent in 1988 because of hurricanes and disease.[127]

SOUTHERN CARIBBEAN

On the continental shelf of the Southern Caribbean, reef development is severely inhibited by upwelling and by freshwater and sediment runoff.[128] The best developed and more diverse coral reefs are found around the chain of islands and archipelagos running parallel to the continental coast: Curaçao and Bonaire (under the jurisdiction of the Netherlands) and the Venezuelan island systems of Islas las Aves, Islas los Roques, La Orchilla, and La Blanquilla. Reef development around Trinidad is slight, largely due to the influence of the Orinoco River, which delivers huge volumes of sediment-laden fresh water.[129]

This analysis did not identify any reefs around the offshore Venezuelan islands as threatened, due to low population pressure and little development. However, fishing and a growing tourism industry represent potential threats.[130] In contrast, human activities, particularly artisanal fishing, are estimated to threaten all the reefs around the offshore islands of Aruba and Tobago. Marine-based pollution is also a threat on Curaçao and Aruba, where large oil refineries have been operating since the early 1920s. The threat from coastal development on Bonaire comes mainly from the direct and indirect impacts of increasing dive tourism.[131]

The Bonaire Marine Park is a model for reef protection. Established in 1979 and declared a national park in 1999, it is protected under island legislation and has been under continuously active management since 1991. *(See Box 3.)*

Reefs along the continental Venezuelan coast are subject to pressure from overfishing, coastal development, and some port facilities. Deforestation has increased sediment loads to coastal waters,[132] and all reefs along the continental coast were identified as under high threat from land-based sources. Although most Venezuelan coastal coral reefs are located within national parks with protective regulations, inadequate staffing and logistical and financial capacity prevent full enforcement.[133]

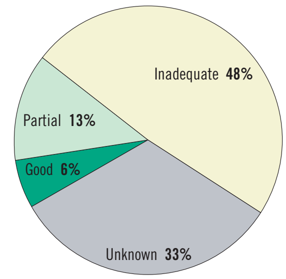
BOX 3. MARINE PROTECTED AREAS

To gain a better understanding of the actual protection afforded reefs in the region, the Reefs at Risk in the Caribbean Project asked experts to evaluate the effectiveness of Marine Protected Areas (MPAs). Particularly with the growth of tourism and fisheries in coral reef areas, MPAs are an important management tool for conserving coral reefs. Many Caribbean nations have established parks or protected areas to safeguard marine biodiversity while helping to maintain economically important marine resources.[a] The Reefs at Risk in the Caribbean Project identified 285 designated MPAs across the 35 states and territories of the Caribbean region *(see Appendix A, Table A5)*.

Because compiling detailed information on a region-wide basis is very difficult, the MPAs were assessed on only four broad criteria: existence of management activity, existence of a management plan, availability of resources, and extent of enforcement. Combined, these criteria were used to generate a simple measure of management effectiveness. Of the 285 parks, only 6 percent were rated as effectively managed and an additional 13 percent were judged to have partially effective management. Nearly half were rated as having an inadequate level of management and, therefore, offered little protection to the resources they were designed to protect. The level of management was unknown for about one-third. This lack of information most likely reflects a deficiency in human and financial resources. Thus, although about 20 percent of the region's coral reefs are contained within MPAs,[b] only about 5 percent of the region's reefs are within MPAs with effective or partially effective management.

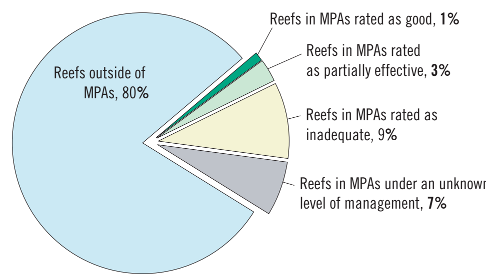
Common reasons for MPA failure are lack of long-term financial support and a lack of support from the local community, which can usually be traced to a lack of local involvement in planning and a failure to share financial or other benefits from protection. Sustainable financing for MPAs must be developed if they are to function well in the long term.[c] Only a handful of parks in the Caribbean directly generate income. For example, Bonaire Marine Park introduced an annual diver admission fee of US$10 in 1992, which currently raises 60 percent of the park's budget, and Saba Marine Park raises 70 percent of its income through diver fees. Revenues from a yacht-mooring system in the British Virgin Islands (BVI) exceeded US$200,000 in 2002, which allows the BVI Marine Conservation Program to be completely self-sustaining.[d]

Management Effectiveness of Caribbean MPAs



Number of MPAs in the region is approximately 285.

Protection of the Caribbean's Coral Reefs



Area of reefs in the region is approximately 26,000 sq km.

Notes:

a. J.A. Dixon, L. Fallon Scura, and T. van't Hof. 1993. "Meeting Ecological and Economic Goals: Marine Parks in the Caribbean." *Ambio* 22 (2-3): 117-125.

b. The scale of the data and the degree of completeness of the MPA data set limit the analysis. Many MPAs are represented only by points, not their actual spatial boundaries, so their extent had to be approximated. Thus, this analysis provides only a rough estimate based upon the best available data.

c. B. Kelleher, C. Bleakley, and W. Wells, *A Global Representative System of Marine Protected Areas. Volume II: Wider Caribbean, West Africa and South Atlantic* (Washington DC: The Great Barrier Reef Marine Park Authority, The World Bank and the World Conservation Union (IUCN), 1995).

d. J.C. Smith Abbott (Director, BVI National Parks Trust), personal communication, 12 January 2004.

SOUTHWESTERN CARIBBEAN

Large volumes of fresh water from extensive mainland water systems flow into the coastal waters of the Southwestern Caribbean, and therefore reef development close to shore is generally poor. Localized areas of significant reef development are found in the central Nicaraguan shelf (Miskito Cays and the Corn Islands),[134] off the Panamanian coast (the Bocas del Toro and San Blas archipelagos),[135] and in the Colombian oceanic archipelago of San Andrés and Providencia,[136] located more than 700 km from the Colombian continental coast.

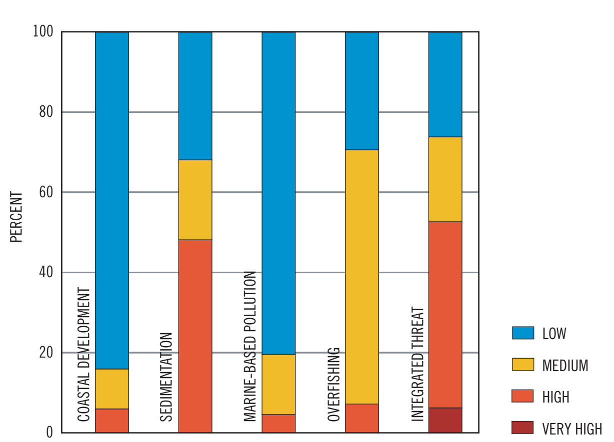
The Nicaraguan shelf is the broadest in the Caribbean, and most reefs around offshore cays and islands escape direct continental influences. Overfishing is the predominant threat to Nicaragua's reefs, with about 15 percent identified as threatened. Threats to reefs from land-based sources and marine-based sources are low. The only inhabited islands are the Corn Islands toward the south, where high population density, coastal development, and overfishing are affecting the reefs. The islands contribute significantly to the Nicaraguan lobster and scalefish export fishery.[137]

Farther south along the continental coast toward Costa Rica, Panama, and Colombia, sedimentation is the prevalent stressor, threatening all but a few reefs around some small Colombian coastal islands. Extensive and indiscriminate deforestation and poor agricultural practices in inland watersheds have increased runoff and erosion. Uncontrolled tourist activity is a large and growing problem for many continental areas. Marine-based pollution is harming Panamanian reefs in the west around the Bocas del Toro archipelago; however, these reefs still hold some of the most extensive stands of elkhorn coral remaining in the Caribbean.[138]

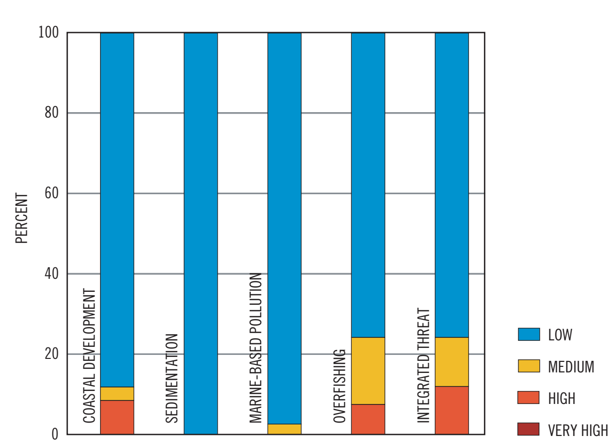
Some of the best reefs in Panama are found in the Kuna-Yala (San Blas) Reserve, managed independently of the government by the indigenous Kuna since 1938.[139] A unique threat not captured in the Reefs at Risk analysis, however, is the traditional Kuna practice of coral mining and landfilling, which significantly modified some reefs in the area over decades.[140] Growing tourism has further encouraged the Kuna to extract corals to sell as souvenirs.[141]

About two-thirds of Colombia's coral reefs in the Caribbean are found within a series of oceanic islands (San Andrés, Providencia, Santa Catalina), atolls, and banks that make up the San Andrés and Providencia archipelago. Only the three major islands are permanently inhabited; tourists and fishers visit the cays, atolls, and banks occasionally. Overfishing and coastal development are the main threats to reefs around the populated islands. Human pressure is a particular problem on San Andrés, where a resident population of more than 60,000 and a booming tourist industry inhabit a surface area of only 25 sq km, making this the most densely populated island in the Caribbean.[142] Reefs close to high-density coastal populations are also threatened by discharges of untreated sewage into coastal waters.

REEFS AT RISK IN THE CONTINENTAL SOUTHWESTERN CARIBBEAN



REEFS AT RISK IN THE SAN ANDRES AND PROVIDENCIA ARCHIPELAGO



Protection along the continental coast is minimal. Parks have been established in each country, but national legislation and institutional frameworks are weak, and funding for monitoring and enforcement is limited. The archipelago of San Andrés and Providencia was declared the Seaflower Biosphere Reserve in 2000 by UNESCO's Man and Biosphere (MAB) Program[143] Although extractive or disturbing activities are now regulated, infrastructure and resources are still scarce for effective control.

WESTERN CARIBBEAN

The Western Caribbean subregion includes one of the longest reef systems in the region. The Mesoamerican Reef stretches from the Mexican Caribbean coast of the Yucatan Peninsula to the Bay Islands off the coast of Honduras. This reef system includes a near continuous barrier reef, which runs for 220 km off the coast of Belize.

Overfishing is the most pervasive threat to reefs in the Mesoamerican reef. Off Mexico's Yucatan Peninsula, the Caribbean reefs have been subject to intense artisanal fishing since the 1960s,[144] when this formerly underdeveloped and isolated coast was opened to the pressures of modern development.[145] In Belize, there is evidence of overfishing by small-scale local fishers and industrial fishing fleets.[146] Intensive fishing in Honduras has affected the reef populations around the Bay Islands, and fishers also travel to remote offshore banks instead of fishing the heavily exploited fringing reefs.[147]

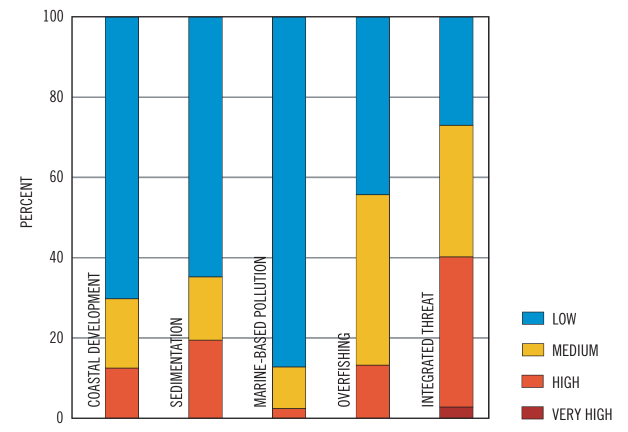
Coastal development is rapid, with tourism burgeoning in many coastal areas. The Mexican state of Quintana Roo has become a very successful resort area and is now the main tourist destination within the country. Coastal development is spreading quickly southward along the coast, and the government plans to build a huge, high-density tourist resort complex extending down to the Belizean border.[148] In Belize, larger cays and tourist centers, like Amergis Caye and San Pedro Town, are growing rapidly as a result of tourist-based economic activity.[149]

Sedimentation is a problem for reefs near the coasts, particularly off southern Belize and continental Honduras, where the intensification of agriculture and logging over the last few decades has resulted in increased erosion. Nutrient pollution is also a problem due to runoff of fertilizer from banana and citrus plantations, from southern Belize down through Guatemala and Honduras. However, standards for minimizing the environmental impact of banana cultivation are being encouraged through initiatives such as the Better Banana Project.[150]

Reefs in the Mesoamerican reef, particularly near Belize, were severely damaged by two large-scale, natural disturbances in 1998. A bleaching event, coinciding with high sea-surface temperatures,[151] was followed by Hurricane Mitch, a Category 5 storm. Bleaching caused catastrophic coral loss in the lagoonal reefs of Belize,[152] while the hurricane caused widespread coral destruction in fore reefs and outer atoll reefs.[153] The full consequences of these events will take years to emerge.

The Belize Coastal Zone Management Authority and Institute is a model of integrated coastal management for the region. The country's system of 13 MPAs is well-established, with most under active co-management with local NGOs.[154] Monitoring across the whole sub-region will increase under the World Bank/GEF Mesoamerican Barrier Reef System project, which has developed a standardized monitoring protocol for the region.[155]

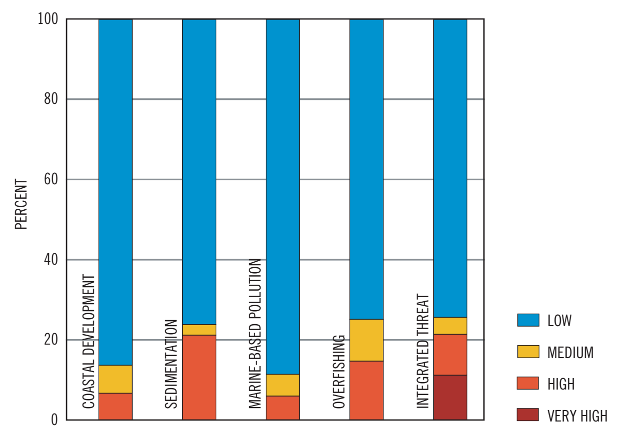
REEFS AT RISK IN THE MESOAMERICAN REEF



GULF OF MEXICO

Reef development in the Gulf of Mexico is extremely limited due to the large inputs of sediment-laden freshwater from the North American continent. In U.S. waters, there

REEFS AT RISK IN THE GULF OF MEXICO



are scattered coral and reef developments; the best documented is the Flower Garden Banks, located 190 km southeast of Galveston, Texas. In Mexican waters, isolated groups of small formations along the southwestern Gulf, and numerous slightly larger reefs are found along the outer Yucatan shelf, including the very large atoll-like reef at Alacranes in the northern Campeche Bank.[156]

The Flower Garden Banks National Marine Sanctuary is managed and protected by the National Marine Sanctuary Program run by the National Oceanic and Atmospheric Administration (NOAA). Illegal fishing by both commercial longliners and recreational spearfishers has been reported in the area.[157] Other threats are low, and the coral is in excellent condition.[158] The live coral cover has changed little since 1972, averaging 47 percent in 1995 and 52 percent in 1997.[159]

Pressures are high on nearshore Mexican reefs, such as those near the large port of Veracruz, due to urban, agricultural, and industrial wastes carried in the outflow of major river systems.[160] In the 1970s, disease caused massive mortality of *Acropora* coral in the southwestern Gulf and around Alcarnes.[161] In addition, Mexican reefs close to the shore and to urban areas have been exploited by fishers for hundreds of years and more recently by recreational users. Though not captured in this analysis, even the reefs farther offshore on the Campeche Bank are under pressure from fishers who navigate up to 300 km of open ocean to fish in outboard motor boats 24 feet long and equipped with just a small ice chest.[162] Also not captured in the analysis is the threat to offshore reefs from activities associated with the Gulf's many oil fields. The threat comes from oil and gas exploration, the associated vessel traffic, and risk of spills.

FLORIDA

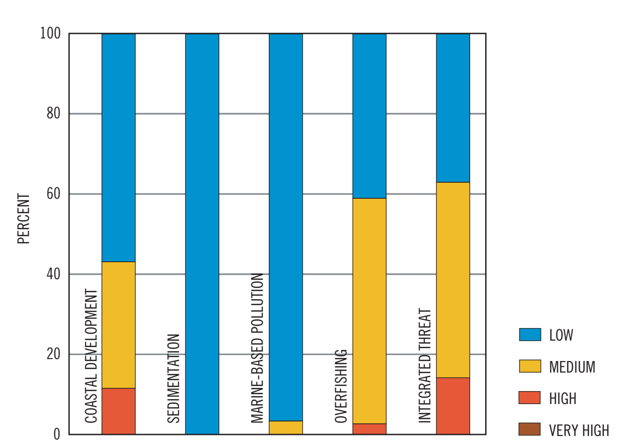
Florida's coral reefs are extensive. The Florida Keys are a chain of 822 low-lying islands. The reef tract arches 356 km along the shallow offshore waters of the Keys, from the 683-sq km Biscayne National Park south of Miami to the Dry Tortugas. The tract is almost continuous, and most of it lies within the boundaries of the 9,800-sq km Florida Keys National Marine Sanctuary (FKNMS).[163]

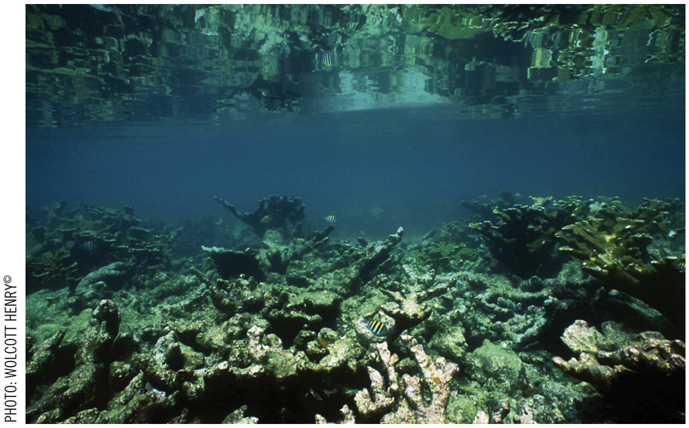
Our analysis probably understates the threat to coral reefs in Florida. Most of these reefs are more than 4 km offshore and thus do not register as threatened by development on the Keys. Also, because south Florida is very flat, the area does not score high for watershed-based threat. The analysis identified over 60 percent of Florida's reefs as threatened.

The decline in reef health in southeastern Florida and the Keys is well documented. For example, live coral cover in the FKNMS decreased by 38 percent from 1996 to 1999, and observations of coral disease increased.[164] Over the past 20 years, coral bleaching has become more frequent, lasted longer,[165] and been responsible for some of the dramatic declines in coral cover in the sanctuary since 1997.[166]

The predominant threat comes from overfishing, with almost 60 percent of reefs threatened. Serial overfishing throughout the Keys has dramatically altered reef fish popu-

REEFS AT RISK IN FLORIDA





Reef decline in the Florida Keys is well documented through extensive monitoring.

lations. Targeted reef fish are highly exploited. In the Florida Keys, 23 out of 35 market fish species are overfished,[167] and 26 of 34 fish species are considered overfished in Biscayne Bay.[168] Pressure comes not only from commercial fishing but also from recreational fishing in South Florida, which has grown exponentially since 1964, with no set limits on the number of boats allowed to fish.[169] Several, mostly very small, no-take zones have been declared in the FKNMS to conserve dwindling fish stocks, and early results show improvements.[170]

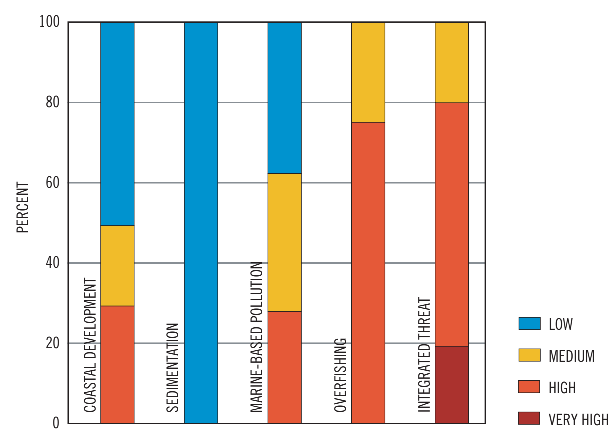
However, the greatest pressures, direct and indirect, on the reefs of the Keys come from the millions of seasonal and temporary visitors that swell local populations. Direct damage has been documented from boat groundings and anchors as well as divers and snorkellers who touch, kick, or stand on corals. Indirect impacts come from sewage pollution to nearshore waters because of increasing development and the use of septic tanks as the sole method of wastewater treatment.

The reefs are also subject to indirect impacts from altered freshwater flow into coastal waters. Water management systems for flood control, agriculture, and urban water supplies have dramatically altered freshwater flow through the Everglades and into the ocean. Florida Bay and nearshore waters provide critical nursery and juvenile habitat for a variety of reef species, and declines seen in these areas indirectly affect the overall health and structure of offshore reefs.[171] This freshwater also carries excess nutrients, and eutrophication of nearshore water has been documented.[172]

BERMUDA

Bermuda is a crescent-shaped chain of about 150 islands. Around them grow the most northerly coral reefs in the world, surviving because of warm water eddies from the Gulf Stream. The most pervasive threat identified in this analysis is from overfishing, affecting all reefs (although this is probably overestimated since no account is taken of the ban in the use of fish traps on Bermuda's reefs). Other threats to reefs come from marine-based sources since Bermuda is a popular cruise destination (over 60 percent of the reefs are rated as threatened), and coastal development (about half are rated as threatened). Sedimentation was not rated as an important threat, owing to the relatively small islands and gentle topography. The observed condition of the reefs is fairly healthy, with few declines in live coral cover since the early 1990s, and corals are relatively free from disease and bleaching.[173]

REEFS AT RISK IN BERMUDA



Chapter 5. ECONOMIC IMPLICATIONS OF CORAL REEF DEGRADATION

PHOTOS: FISH AND DIVER BY WOLCOTT HENRY© SHORELINE BY JON MAIDENS

Healthy coral reefs confer significant economic benefits to both coastal communities and national economies. These benefits diminish with coral reef degradation. Key economic and social benefits associated with healthy coral reefs include high fishery yields, high tourism-related incomes, protection from coastal erosion, and good nutrition for coastal communities.[174] The great diversity of life on coral reefs is also being explored for bioactive compounds for pharmaceuticals, and a few high-value products have already been discovered. Degradation of these reefs costs dearly through loss of fishing livelihoods, protein deficiencies and the increased potential for malnutrition, loss of tourism revenue, increased coastal erosion, and the need for investment to stabilize the shoreline.

Many damaging activities—including overfishing, dredging, or sewage discharge near reefs—occur because an individual or group seizes an immediate benefit, without knowing or caring about the long-term consequences. Often, the party who gains is not the one who pays the cost; for instance, a new development may pollute and degrade an offshore reef, but among those who suffer are the fishers or the divers who visited that reef. Some shortcomings in current management practices stem from inadequate information on the costs and benefits of different activities and management's focus on short- rather than long-term benefits when making decisions. Too often the full range of social and environmental impacts associated with proposed activities are not evaluated.[175] In land-use decisions, for example, rarely is the smothering of reefs by sedimentation associated with land clearing considered, much less compensated.

PURPOSE AND METHODS FOR VALUING CORAL REEF RESOURCES

Economic valuation is a powerful tool for raising awareness about the economic value of natural resources and about the implications of different development or management decisions. Credible valuation studies based on reasonable and fully disclosed assumptions can directly influence planning and development in areas adjacent to coral reefs. Economic arguments are also potent persuaders for a wider audience, convincing communities, politicians, and the general public of the important, lasting benefits of effective management and protection of coral reefs.

Several studies have looked at the economic value of coral reefs within the Caribbean.[176] Some of these studies have been narrowly defined assessments of the value of specific coral reef resources, such as the impact of a marine protected area on revenue from dive tourism in Bonaire,[177] the effects of changes in coral reefs on fisheries production in Jamaica,[178] and the value of coral reef-related tourism in the Florida Keys.[179] Other economic valuation studies have been broader-based attempts to quantify the diverse ecological services or "total economic value" of coral reefs. Estimates from these studies of the total annual economic benefits from coral reefs have ranged from roughly US$100,000 to US$600,000 per sq km of coral reef, the largest share of which were associated with tourism and recreation followed by shoreline stabilization services.[180] Obviously, the economic valuation of goods and services provided by specific coral reefs varies widely depending upon the area's tourism potential and the nature of the shoreline being protected.[181]

This chapter explores the economic value of Caribbean coral reefs in terms of their contribution to fisheries, tourism and recreation, and shoreline protection services. Estimates of the current value of goods and services derived from coral reefs are presented in terms of gross and net annual benefits and are standardized to the year 2000. Using the Reefs at Risk Threat Index to identify threatened areas likely to degrade within the next 10 years, the study estimated potential losses in the economic value of fisheries, tourism, and shoreline protection services due to coral reef degradation.

A number of limitations and caveats apply to this analysis. First, it is only a preliminary exploration of the economic value of coral reef goods and services on a region-wide basis. Many of the statistics for this analysis were compiled and synthesized from the literature. However, in some cases, particularly the value of shoreline protection services, few data were available. This necessitated many assumptions to extrapolate region-wide estimates of economic values. Thus, the valuation estimates derived are the product of a range of assumptions and are very sensitive to these assumptions. The assumptions incorporated in this analysis represent our best estimates, based on the available literature and expert opinion, about the nature and magnitude of factors that influence the economic value of coral reef goods and services.

This analysis focuses on three important goods and services, but omits many other values, such as bioprospecting, biodiversity, and a range of non-use or "existence" values. In addition, this regional-level valuation does not capture the economic contribution of coral reefs to subsistence livelihoods in many communities across the Caribbean. These values can be quite significant, as coral reefs provide critical sources of employment and food supply, often in places where there are few or no alternatives. Converting into monetary terms this contribution of reefs to nutrition and livelihoods is challenging where life, health, and welfare lie largely outside the cash economy.

PHOTO: MARK SPALDING

Fisheries are a vital source of nutrition and livelihood across the region.

The analysis approach, summarized in this chapter for each goods and service, is provided as technical notes, available online at http://reefsatrisk.wri.org.

FISHERIES

Food production is one of the most direct and tangible benefits associated with coral reefs. Reef fisheries are a vital source of protein for millions of people living in the Caribbean region.[182] Reef fish are popular on tourist menus and support a valuable export industry. The fisheries sector in the Caribbean is predominantly small-scale and artisanal, employing more than 120,000 full-time fishers[183] and many part-time workers. Fisheries also indirectly provide jobs for thousands of people in processing, marketing, boat building, net making, and other support services.[184]

The export value of all fish, crustaceans, and mollusks harvested in the Western Atlantic region (excluding the United States) was approximately US$1.9 billion in 2000,[185] but this includes fish, such as tuna, not directly related to coral reefs. (Available statistics do not distinguish the size or value of reef fish catches from other fish and

TABLE 3. ESTIMATED ECONOMIC VALUE OF FISHERIES PRODUCTION IN THE CARIBBEAN: HEALTHY REEFS VERSUS REEFS DEGRADED BY 2015

Fisheries Production Scenario	Assumed Maximum Sustainable Fisheries Production ($mt/km^2/yr$)	Reef Area (km^2)	Fisheries Production for Caribbean (mt/yr)	Gross Revenues (US$ million)	Net Revenues (US$ million)
Healthy reefs (in 2000)	4	26,000	104,000	624	312
Reef degradation by 2015 (using Reefs at Risk Threat Index values)					
Reefs under low threat	4	9,400	37,400		
Reefs under medium threat	2.3–2.9	5,400	12,700–15,600		
Reefs under high threat	0.7–1.7	11,200	7,400–19,200		
Total (in 2015)		26,000	57,500–72,200	346–434	173–217
Decline/Loss		—	**31,700–46,400**	**190–278**	**95–139**

SOURCE: Estimates developed at WRI (2004). Technical notes on methods and data sources available online at http://reefsatrisk.wri.org.

often fail to account for the very large sector of the fishery-that operates outside the formal markets, notably for home and local consumption.)

For this analysis of the economic value of coral-reef-related fisheries, the study looked at productivity differentials between fisheries located on healthy and degraded reefs. The Reefs at Risk Threat Index was used as a proxy for future reef condition in 2015 and estimated the area of coral reef in each threat category (high, medium, and low). Based on reports in the literature[186] a productivity coefficient for fisheries on healthy reefs was set at a maximum sustained yield of 4 metric ton (mt) of fish per sq km per year. Yields from reefs rated at medium or high threat were assumed to be significantly lower, ranging from 0.7 to 2.9 mt per sq km per year. *(See Table 3.)*

Using these assumptions, the study estimated maximum sustainable fisheries yield for the 26,000 sq km of Caribbean coral reef at a little over 100,000 mt of fish per year. This estimate focuses on reef crest, which is a smaller area than is typically fished, but assumes that all reefs were fully fished and are in good condition, which is better than the current case. These assumptions are considered to roughly offset one another. Considering reef degradation that has already occurred or is projected to occur in the near future, annual fisheries production could decline from about 100,000 mt to about 60,000 to 70,000 mt by 2015, a loss of some 30 to 45 percent from the estimated maximum catch on healthy reefs. *(See Table 3.)*

At current market prices (about US$6 per kg on average),[187] gross fisheries revenue from healthy Caribbean reefs was estimated at about US$625 million per year. Gross revenue from reefs degraded by 2015 was estimated to be 30 to 45 percent lower, representing potential lost gross revenues of approximately US$190 million to US$280 million.[188]

Net revenues from fishing—adjusted for the costs of vessels, fuel, gear, etc.—are considerably smaller, perhaps only 50 percent of gross revenues.[189] Thus, the study estimated annual net benefits of fisheries on healthy coral reefs at about US$310 million, while annual net benefits from fisheries on reefs degraded by 2015 could fall to around US$175 million to US$215 million, a loss of about US$95 million to US$140 million per year. The loss of millions of dollars worth of annual net benefits from fisheries could have significant consequences for local areas and national economies that rely on fishing to provide livelihoods, meet nutritional needs, and generate export earnings.

TOURISM AND RECREATION

Tourism is the lifeblood of many Caribbean countries, contributing more than 30 percent of GDP in 10 countries or territories within the region.[190] One Caribbean worker in six is employed directly in tourism.[191] In 2000, international tourism receipts in the Caribbean region (excluding the United States) totaled US$25.5 billion. Including supporting and related services, tourism contributes a total of about US$105 billion annually to the Caribbean economy.[192]

With tourism in the Caribbean projected to grow at 5.5 percent a year over the next 10 years,[193] it is an increasingly important source of foreign exchange.

How dependent is tourism on high-quality coral reefs? Many of the values that coral reefs provide to the Caribbean tourism industry are indirect, such as the value of reefs as a major contributor of sand to the region's famed beaches. One way to gauge the economic impacts of coral reef degradation on tourism is to look at a source of tourist revenue that is directly tied to pristine, healthy coral reefs: scuba divers.

Scuba divers look for high-quality coral reef habitats (as indicated by live coral coverage), coral and fish diversity, and water clarity.[194] Half of all diving in the Caribbean occurs within the region's marine protected areas, although these reefs represent a small fraction (about 20 percent) of all reefs within the region.[195] Divers in the region have indicated a willingness to pay an average of US$25 per diver per year to keep the Caribbean coral reefs healthy.[196] Multiplied by the estimated number of divers visiting the region, this translates into $90 million annually, which could be collected as user fees or other contributions in marine protected areas. Divers make up about 10 percent of all visitors but contribute about 17 percent of all tourism revenue.[197] The average diver spends about US$2,100[198] per trip to the Caribbean, compared to US$1,200 for tourists in general.[199] In 2000, the highest tourist expenditures in the Caribbean were reported by the Turks and Caicos Islands, a premier dive destination with high-quality coral reefs.[200]

To derive an economic valuation of coral-reef-related tourism in the Caribbean, the study estimated the number of divers visiting the region; gross revenue associated with these visits (using a base year of 2000), net benefits to the local economy, and losses in revenue from dive tourism associated with projected trends in coral reef degradation.

Market survey reports and other sources[201] indicate that about 3.6 million divers dove in the Caribbean region during 2000—1.2 million in Florida or Texas and 2.4 million in the rest of the Caribbean.[202] The latter group accounted for an estimated US$4.1 billion in gross expenditures.[203] A recent study of recreational reef use in southern Florida (where most diving in the continental United States occurs)


PHOTO: KRISHNA DESAI

Tourism takes many forms across the region and contributes an estimated $105 billion annually to the Caribbean economy.

estimated US$625 million in direct expenditures associated with diving on natural reefs in the year 2000.[204] This combined estimate of US$4.7 billion (i.e., US$625 million in the U.S. and US$4.1 billion in the rest of the Caribbean region) is a conservative one: it understates gross tourism revenue associated with coral reefs because it does not include the value of coral-reef-related tourism to non-diving visitors to the Caribbean, or their contribution to the local economy.

The study estimated net benefits to the local economy by adjusting these estimated gross expenditures for costs such as transportation, fuel, boat expenses, etc. (assumed to be 65 percent of total expenditure) and then accounting for a multiplier effect due to expenditures rippling through the local economy (assumed to be 25 percent).[205] Hence, net annual benefits of dive tourism in the Caribbean in 2000 were estimated at US$2.1 billion (i.e., US$4.7 billion (gross benefit) * 0.35 (net return) * 1.25 (multiplier)).

However, degradation of coral reefs will reduce their value to both divers and other tourists as a result of less interesting diving and snorkeling, less sport fishing, and erosion of beaches. To estimate potential losses in tourism revenue due to projected trends in coral reef degradation, the Reefs at Risk Threat Index was used as a proxy for future reef condition. It assumed a percentage decline in dive tourism (ranging between 1 and 10 percent) and associated lost revenue for reefs at medium or high threat. These percentage declines were conservative best estimates, based on a synthesis of expert opinion. Future gross revenue under a "no degradation" scenario was based on assumed continued growth of dive tourism at 7 percent per year,[206]

TABLE 4. ESTIMATED ECONOMIC VALUE OF CORAL REEF-RELATED TOURISM IN THE CARIBBEAN

Tourism Scenario	Source / Assumptions	Gross Revenues (US$ million)	Net Revenues (US$ million)
Tourism in 2000	• Based on current statistics and market surveys	4,700	2,100
Tourism in 2015 (Healthy Reefs)	• Dive tourism grows at 7 percent per year • No loss of revenue due to reef degradation	13,000	5,700
Tourism in 2015 (Degraded Reefs)	• Degradation of reefs results in loss of divers and revenue from a 7 percent annual growth trajectory • Loss is related to level of threat or degradation – Low threat - no loss – Medium threat - 1–5 percent loss – High threat - 4–10 percent loss	12,400–12,800	5,400–5,600
Annual Loss by 2015 due to degraded reefs		**200–600**	**100–300**

SOURCE: Estimates developed at WRI (2004). Technical notes on methods and data sources available online at http://reefsatrisk.wri.org.

which is higher than the projected annual growth rate of 5.5 percent for general tourism. By 2015, net benefits from diving on healthy reefs might grow to nearly US$6 billion, but with degradation could be US$100 million to US$300 million lower, a loss of 2–5 percent. *(See Table 4.)*

Moreover, these estimates of region-wide loss do not necessarily convey the disproportionately large losses that could be expected in particular locations, as regional dive tourism shifts away from areas with degrading reefs and toward other locations in the Caribbean with a reputation for healthy reefs. Many of the threats to coral reefs—such as poor water quality and increased sedimentation—are also considered undesirable by tourists. The local revenue losses associated with shifts in tourism toward healthy reef areas could be particularly harmful to specific communities and national economies with reefs at high threat of degradation.

SHORELINE PROTECTION

Coastal ecosystems provide important shoreline stabilization services. Coral reefs dissipate wave and storm energy and create lagoons and sedimentary environments favorable for the growth of mangroves and seagrasses. In turn, mangroves and seagrasses help to bind marine and terrestrial sediments, reducing coastal erosion and also supporting clear offshore waters favorable to corals. Decision-makers often undervalue the shoreline protection services afforded by natural landscapes and do not give this service appropriate weight when evaluating development options. One reason for this oversight is the difficulty in quantifying these services. However, the value of shoreline protection can be approximated by estimating the cost of replacing this service through artificial means.

In many parts of the world, efforts and investments to stabilize shorelines artificially have been substantial.[207] In Sri Lanka, for example, US$30 million was spent on revetments, groins, and breakwaters to curtail severe coastal erosion in areas where coral reefs had been heavily mined.[208]

The vulnerability of coastal areas to erosion and storms varies with topography, substrate, habitat types, coastal morphology, and climate. Sandy beaches are much more vulnerable to erosion, for example, than are rocky shorelines. In the Caribbean, hurricanes and tropical storms are a major cause of acute erosion. Increased development in coastal areas often amplifies erosion and storm risk in two ways. First, the destruction of natural habitats (notably mangroves, seagrasses, and coral reefs, but also coastal vegetation) exposes coastal sediments to greater movement, and hence to erosion and loss. Second, the development of the physical infrastructure to protect areas can itself enhance erosion. For example, the building of sea defenses and the canalization of water courses often leads to changed patterns of coastal water movements, with resultant erosion in adjacent areas. Studies of changing beach profiles in the Eastern Caribbean showed that between 1985 and 1995, 70 percent of monitored beaches eroded.[209] Antigua, the British Virgin

TABLE 5. RANGE OF ESTIMATED ECONOMIC VALUES OF SHORELINE PROTECTION SERVICES PROVIDED BY HEALTHY CORAL REEFS IN THE CARIBBEAN IN 2000

Level of Shoreline Development	Definition of Development	Percent of Coastline	Value for Reef-Related Shoreline Protection Services (US$ per km of coastline)[a]	Total value of Reef-Related Shoreline Protection Services (US$ million)
Low	Fewer than 100 people within 5 km	29	2,000–20,000	10–30
Medium	Between 100 and 600 people or a dive center located within 5 km	27	30,000–60,000	120–150
High	More than 600 people within 5 km	44	100,000–1,000,000	620–2000
TOTAL		**100**	**2,000–1,000,000**	**750–2180**

SOURCE: Estimates developed at WRI (2004). Technical notes on methods and data sources available online at http://reefsatrisk.wri.org.

NOTES:

a. Because only a few shoreline segments are likely to be at the high extreme of value, we developed our ranges as follows: Low = 100 percent of shoreline is at low end of value range; High = 75 percent at low end and 25 percent at high end of value range.

Islands, Doinica, Grenada, Nevis, and St. Kitts experienced beach losses ranging from 0.3 to 1.1 m per year.[210]

To analyze the economic contribution of shoreline protection services provided by Caribbean coral reefs, the study estimated the extent of the region's shoreline protected by coral reefs, the value of the shoreline protection services provided by these reefs (based on costs required to replace them by artificial means), and potential losses in the annual benefits of shoreline protection services due to reef degradation.

Using data on shoreline and coral reef location,[211] and identifying coastline within 2 km of a mapped coral reef as "protected" by the reef, the study estimated that coral reefs protect about 21 percent of the coastline of the Caribbean region (about 18,000 km in length). The economic value of the shoreline protection services provided along these coastlines varies with the level of development of the shoreline, its population density, and tourist activity. Values used in this study for annual coastal protection benefits ranged from US$2,000 per km of coastline for protection of less-developed shorelines to US$1,000,000 per km of coastline for highly developed shorelines.[212] Accounting for the length of shoreline in various categories of development (high, medium, and low), the value of annual benefits from the shoreline protection services of healthy coral reefs across the Caribbean region was estimated between US$740 million and US$2.2 billion per year. *(See Table 5.)*

The study used the Reefs at Risk Threat Index as a proxy for future coral reef condition and associated declines in the coastal protection function of reefs. The analysis assumed that shorelines near degraded reefs received 80 to 90 percent as much protection as shorelines near healthy reefs.[213] The study estimated that over 80 percent of the shoreline areas now protected by coral reefs will experience some future reduction in this service (over 15,000 km).[214] Such reductions might not be apparent as quickly as declines in fisheries or recreation because reefs must become severely degraded and eroded before loss of protection occurs. However, within the next 50 years, the net value of lost benefits from reef-associated shoreline protection could be on the order of US$140 million to US$420 million per year.

PHOTO: LAURETTA BURKE

Coral reefs protect shorelines by dissipating wave energy and are an important source of white sand for many beaches.

Summary of Values

Table 6 summarizes the results of preliminary efforts to quantify just a few of the many economic values provided by coral reef ecosystems in the Caribbean. In 2000, coral reefs provided annual net benefits in terms of fisheries, dive tourism, and shoreline protection services with an estimated value between US$3.1 billion to US$4.6 billion. The net benefits from dive tourism were the largest share of this total (US$2.1 billion), followed by shoreline protection services (US$ 0.7 to 2.2 billion), and fisheries (about US$300 million). The study estimates coral reef degradation could result in losses of between 30–45 percent of net benefits from fisheries and 2–5 percent of net benefits from dive tourism by 2015. By 2050, over 15,000 km of shoreline could loose 10–20 percent of current protection services. All told, coral reef degradation could reduce the net benefits derived from these three goods and services by an estimated US$350 million to US$870 million per year. *(See Table 6.)*

OTHER VALUES

Coral reefs provide many other sources of value that are not included in this study. One such source of value is bioprospecting. Coral reefs are one of the most diverse ecosystems known and are an important potential source of bioactive compounds for pharmaceuticals. The prospect of finding a new drug in the sea may be 300 to 400 times more likely than isolating one from a terrestrial ecosystem.[215] If species are lost before they are identified, there is an associated loss of potentially priceless biological information. Products from marine organisms include AZT, an HIV treatment developed from the extracts of a Caribbean reef sponge,[216] and Prialt, a painkiller developed from cone snail venom.[217] In addition, a large portion of new cancer drug research focuses on marine organisms, most of them associated with coral reefs.[218]

TABLE 6. SUMMARY OF ESTIMATED VALUES OF SELECTED GOODS AND SERVICES DERIVED FROM CORAL REEFS IN THE CARIBBEAN (2000) AND ESTIMATED POTENTIAL LOSSES DUE TO CORAL REEF DEGRADATION (BY 2015 AND 2050)

Good/Service and Valuation Method	Estimated Annual Value of Good/Service in 2000	Estimated Future Annual Losses Due to Coral Reef Degradation
Fisheries Annual net benefits of maximum sustainable fish production, estimated from sale of coral reef-associated fish and shellfish	US$312 million[a]	Fisheries productivity could decline an estimated 30–45 percent by 2015 with associated loss of annual net benefits valued at US$100–140 million (in constant-dollar terms, standardized to 2000).[b]
Tourism and Recreation Annual net benefits from dive tourism, estimated from gross tourism revenues	US$2.1 billion[c]	Growth of Caribbean dive tourism will continue, but the growth achieved by 2015 could be lowered by 2–5 percent as a result of coral reef degradation, with the region-wide loss of annual net benefits valued at an estimated US$100–300 million (in constant-dollar terms, standardized to 2000).[d]
Shoreline Protection Annual benefits of coral reef protection based on estimated cost of replacement	US$0.7–2.2 billion[e]	Over 15,000 km of shoreline could experience a 10–20 percent reduction in shoreline protection by 2050 as a result of coral reef degradation. The estimated value of lost annual net benefits is estimated at US$140–420 million (in constant-dollar terms, standardized to 2000).[f]
TOTAL	**US$3.1–4.6 billion**	**US$350–870 million**

SOURCE: Estimate developed at WRI (2004). Technical notes on methods and data sources available online at http://reefsatrisk.wri.org.

NOTES:

a. Fisheries production in 2000 assumes healthy coral reefs produce 4 mt/km^2/yr of fish or shellfish, which sell for an average of $6/kg, and that net revenue is 50 percent of gross revenue.

b. Fisheries production is predicted to decline depending on the level of future reef degradation (using the Reefs at Risk Threat Index as a proxy for future reef condition). This analysis assumes that threatened reefs are more degraded and have lower productivity. Of 26,000 sq km of reefs, the areas rated at low, medium, and high threat are 9,400, 5,400, and 11,200 sq km, respectively. Productivity factors used were 4.0 mt/km^2/yr on low-threat reefs; 2.3 to 2.9 mt/km^2/yr on medium-threat reefs; and 0.7 to 1.7 mt/km^2/yr on highly threatened reefs. Market price of $6/kg was used.

c. Estimates of 3.6 million divers in the Caribbean with associated net benefits of US$2.1 billion are a synthesis and cross-tabulation of data from six sources (see chapter endnotes and technical notes online at http://reefsatrisk.wri.org). Net revenue assumed to be 35 percent of gross revenue (costs are 65 percent). A multiplier of 25 percent was used to capture benefit flows in the economy.

d. Diving shifts within and outside the region based on perceived quality of diving and reef health. Reefs under low threat retain all divers; medium-threat reefs retain 95–99 percent of diving; high-threat reefs retain 90–96 percent of diving and associated revenue. Overall, the region suffers a loss of 2–5 percent of tourism revenue.

e. Coral reefs protect an estimated 21 percent of the Caribbean region's coastline. The estimated value of protection along the coastline varies between US$2,000 and US$1 million per km, depending upon the area's development. (See chapter endnotes and technical notes online at http://reefsatrisk.wri.org.)

f. This estimate is based on cross-tabulation of our estimates of level of development along a given shoreline length and threat estimate of the nearest coral reef. Reefs under low threat are assumed to provide 100 percent of their current coastal protection service; reefs under medium and high threat are assumed to provide 90 percent and 80 percent of current service, respectively.

The potential economic value of bioprospecting on coral reefs is difficult to estimate and such an estimation has not been attempted in this study. Part of the problem in deriving estimated values is that very little can be directly linked to individual reef localities. Biological samples can be taken from reefs at very low cost and screened for bioactive properties far away from the reef. The revenues and profits derived from successful biopharmaceuticals often do not make it back to the communities, or even to the countries, from which the original biological samples were taken. Although the potential economic value of bioprospecting and pharmaceutical development might be very high, given current free-market, free-access approaches to biological resources, these values are not likely to benefit local or even national populations associated with coral reefs.

Other sources of reef-associated economic value not accounted for in this study include the harvesting of non-food resources (aquarium fish, curios), the role of these ecosystems as places for research and education, the role of reefs in supporting adjacent coastal and oceanic ecosystems, and the contribution of coral reefs to regional and global oceanographic and climatological processes. A value that is only recently receiving recognition is the role of healthy coral reef ecosystems in maintaining and restoring stressed or degraded reefs. Healthy reefs can serve as a supply of coral larvae to other locations, increasing the recovery chances of stressed or degraded reefs lying downstream. As the total extent of degraded reefs increases, the restoration value of healthy reefs nearby will grow considerably.

PHOTO: WOLCOTT HENRY©

There is tremendous unrealized genetic potential in coral reef ecosystems.

Also extremely important, but notoriously difficult to translate into economic statistics are a range of non-use or "existence" values for natural resources, based on aesthetic, spiritual, cultural, or intrinsic value. Coral reefs are valued by many as places of beauty, excitement, and adventure. They are also seen as places of enlightenment and inspiration. Reefs have cultural significance through their role in ongoing traditions, notably fishing. Many argue that coral reefs and other natural treasures have intrinsic value that exists independent of human perceptions. Such values are, by their nature, unmeasurable.

AREAS FOR FUTURE RESEARCH AND ANALYSIS

This study represents a preliminary attempt to quantify the region-wide economic value of coral reefs in terms of fisheries, dive tourism, and shoreline protection. Further research is needed to improve these estimates and provide greater detail on a country-by-country basis. As more standardized coral reef maps become available, estimates of the value of goods and services per unit area can be refined. However, better statistics are needed on fish catch, by species and area, to improve estimates of productivity and changes in productivity resulting from changes in reef condition. Also sorely needed is better information on shoreline erosion in areas where coral reefs have degraded, and on investments in shoreline stabilization. In addition, better supporting data and means of evaluating potential bioprospecting value and non-use values are needed in order to develop fuller estimates of the total economic value of coral reefs. Application of standardized methods is important so that estimates from different areas or countries can be compared. Such survey and analysis is vital to our ability to make better informed decisions on the protection and management of these valuable resources.

Chapter 6. CONCLUSIONS AND RECOMMENDATIONS

The coral reefs of the Caribbean, a mainstay of the region's economic and social health, are beset by a wide range of threats resulting from human activities. Degradation of coral reefs damages not only the integrity of these important ecosystems but also the health, safety, and livelihoods of the human societies that depend on them. Although the potential human and economic losses are great, actions to reverse the threats to Caribbean coral reefs can often be undertaken at very low cost, with very high financial and societal returns, even in the short term.

Actions are required across a range of scales—from local to national and international. Such actions include the establishment of better management practices—to place fisheries on a more sustainable basis and to improve yields, to protect reefs from direct damage, and to integrate the sometimes conflicting approaches to management in the watersheds and adjacent waters around coral reefs. Fundamental to supporting these actions is wider involvement of the public and stakeholders in management processes, as well as an improved level of understanding of the importance of coral reefs. Better understanding of the economic value of coastal ecosystems, and of the linkages between human activities and changes in coral reef condition, will further support and underpin the necessary changes in management and will strengthen political and societal support for these changes.

To these ends, we recommend the following specific actions:

Create the Will for Change

- **Raise awareness of the importance, value, and fragility of coral reefs through targeted education campaigns.** Many residents and visitors to the Caribbean fail to realize and understand the connections between their own activities and the health of coral reefs. Targeted education and awareness-raising campaigns are needed to change behavior and create political will for policy change. Educators, universities, national governments, resource managers, NGOs, and others should work to raise awareness among residents and visitors alike through the development and dissemination of targeted educational materials. Key target audiences are community groups, fishers, workers in the tourist industry, tourists, developers, politicians, and students.

- **Factor the economic value of reef goods and services into development planning, policies, and projects.** The value of healthy coral reef ecosystems is poorly grasped by most people, but incorporating information on the economic value of the goods and services provided by coral reef ecosystems can help bolster arguments for strengthening and expanding reef protection and management programs. Greater efforts are needed to integrate information on the value of coral reefs and the potential costs of their degradation into economic and planning agendas. Universities, research organizations, and government agencies should undertake additional economic valuation studies of Caribbean coral reefs, using consistent methods that are applied in many different areas within the region. Planners, governments, and NGOs should use the results of these studies to debate the true costs of development options, select development that minimizes damage to reef ecosystems, and allocate sufficient financial resources for coastal management and conservation.

Build Capacity for Change

- **Develop local and national expertise for better management of coral reef ecosystems through training of resource managers and decision-makers.** Financial resources, educational levels, and availability of training vary widely across the region, and the small size of many countries may undermine their ability to sustain full scientific and administrative capacities. National governments, international organizations, NGOs, and others should support and implement expanded provision of training to managers and decision-makers across the region to strengthen the effectiveness of coastal planning and the implementation of management plans. For example, the UNEP-Caribbean "Training of Trainers" courses are designed to provide professionals from across the region with opportunities to strengthen their skills in all aspects of planning and management of marine protected areas. To multiply the impact of this training, participants, in turn, train additional practitioners back in their local communities.

- **Encourage free flow and exchange of information and experiences about management and protection of coral reef resources.** Across the Caribbean, there are examples of excellence in management, training programs, government and community involvement, research, and monitoring. Better systems are needed to encourage the free flow and exchange of information between scientists and management agencies, between countries, and between government agencies. Better networking and exchange is also needed to ensure that information and experience from one area can be accessed and used across the region. International NGOs and intergovernmental agencies should facilitate increased sharing of information and expertise on condition, management, and protection of coral reefs in the Caribbean. The International Coral Reef Action Network's (ICRAN) network of MPA demonstration sites and the Caribbean Coastal Marine Productivity (CARICOMP) network are examples of successful sharing.

- **Integrate socioeconomic and environmental monitoring to increase understanding of coastal habitats.** Good management requires continued access to information about natural resources and how they change over time and in response to natural and human influences. Monitoring programs that integrate human, physical, and ecological data are essential to improve our ability to

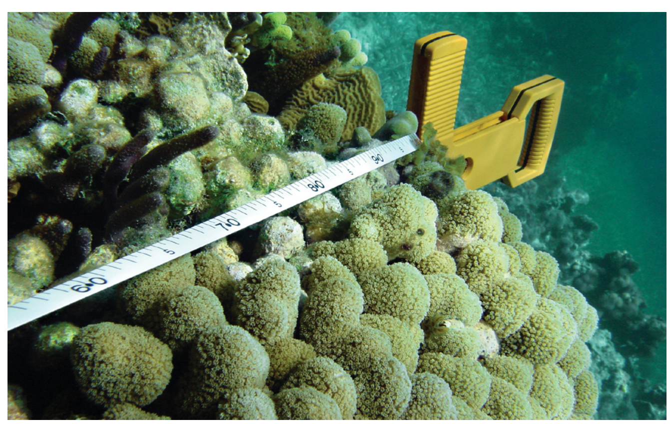


PHOTO: KRISHNA DESAI

Coral reef monitoring and assessment needs to be well integrated with socioeconomic and environmental monitoring to provide information needed for better understanding of changes occuring on coral reefs.

link, for example, changes in upland activities with downstream impacts. The scientific community and resource managers should move toward such integrated monitoring programs and make the information widely available in useable formats. Where possible, these integrated monitoring efforts should use existing methods and protocols to facilitate comparison of findings among sites and countries. For example, Socioeconomic Monitoring Guidelines for Coastal Managers in the Caribbean (SocMon) provides simple, standardized guidelines for establishing a socioeconomic monitoring program at a coastal management site in the Caribbean that could serve as a basis for a regional system in which data can be compared.

- **Facilitate stakeholder participation in decision-making about management and protection of coral reef resources.** The absence of community inclusion and participation has played a key role in the failure of many reef management efforts. When stakeholders are excluded from decision-making, local knowledge and capacity is left untapped and reef management programs may fail to respond to the needs of users. National governments and resource managers should apply collaborative and cooperative (co-management) approaches to coral reef management that will involve all stakeholders. National governments and NGOs can work with resource users to promote the concept of co-management, moving beyond pilot projects to full-scale initiatives. The Coastal and Marine Management Program (CaMMP) of the Caribbean Conservation Assocation (CCA) is working to develop guidelines for successful co-management of coastal resources in the Caribbean.

- **Create the systems of governance required for effective management of coral reefs.** In many cases, the activities of different groups, agencies, or even international bodies work in opposition to one another or fail to take advantage of potential synergies to better manage marine resources. Clear institutional frameworks, legal authority, and administrative capacity to manage marine resources are critically needed. National governments should facilitate good governance of the coastal zone by carrying out national assessments of the institutional and legal framework for executing policy and updating institutional and legal frameworks where necessary. For instance, Barbados and Belize have successfully implemented specific legislation on institutional arrangements for management of the coastal zone, cutting across the prior sectoral approaches.

- **Use the Reefs at Risk indicators and apply the analytical methodology at finer resolutions to support decision-making on coral reef management.** The analysis tool and standardized indicators developed under this project provide a valuable and low-cost means of understanding the potential pressures on coral reefs where specific information on reef conditions is not available. The project uses an approach that is reproducible and can be implemented at local scales (full technical notes available online at http://reefsatrisk.wri.org). Use of such indicators increases confidence in and support for management decisions. National, provincial, and local resource agencies should contribute to the development of finer-scale indicators to inform policy and decision-making.

Improve Management

- **Develop sustainable fisheries through education, stakeholder involvement, and reduced intensity of fishing practices.** Fishing is exceeding sustainable levels in most Caribbean countries. National governments should work with resource users to implement sustainable fishing policies and practices. Licensing, incentives for sustainable practices, and penalties for illegal fishing can help reduce the intensity of fishing practices. Education of fishers regarding the impacts of different fishing gear will also promote sustainable harvesting of fish. In addition, "no take areas" or "marine fishery reserves" should be adopted, in part, as a strategy to replenish depleted fish stocks and serve as a source for recruits to adjacent fisheries. Critical to the success of such reserves will be educating stakeholders about their effectiveness in supporting fisheries and in providing additional benefits such as alternative income generation and involving stakeholders to ensure community support for implementation.

- **Apply holistic approaches to coastal zone management.** Successful management of coral reef ecosystems entails dealing effectively with multiple influences and threats, many of which can be traced to activities taking place at considerable distances from the reefs themselves. Integrated coastal management (ICM) is the term given to such a holistic approach, involving participation from a wide range of stakeholders, including multiple government agencies, local communities, the private sector, and NGOs. National governments can provide incentives for agencies with disparate mandates and conflicting agendas to share information and work together holistically. Land management agencies (agriculture, forestry, etc.) need to have a stake in coastal management. Agencies at the national and provincial or district level should use the tools of ICM to help guide development and reduce impacts through zoning and regulation, and through planning and evaluation of the ecological carrying capacity of coastal areas.

- **Expand Marine Protected Areas and improve their management effectiveness in safeguarding coral reef ecosystems.** Marine Protected Areas (MPAs) are an important component of comprehensive coastal-area management; however, only a small minority of coral reefs are located within formally designated MPAs, and an even smaller percentage (5%) are located in MPAs rated as having fully or partially effective management. MPAs should be expanded to cover additional coral reefs, and the management effectiveness of many existing MPAs needs to be strengthened. Expansion of MPAs should reflect a regional perspective, recognizing the interdependence of reef communities and the transboundary nature of many of the threats. Siting of new MPAs should include reefs likely to be highly resistant to coral bleaching (such as deep reefs in areas of high water circulation) and/or highly resilient to disturbance to help reduce risks from changing climate. To bolster the management effectiveness of existing MPAs, national governments, donors, NGOs, and the private sector should provide financial and political support to help MPAs build needed capacity and adequately train staff. MPAs must also strive to be financially self-sustaining with a diverse revenue structure.

CREDIT: COURTESY OF NOAA

Effective coastal zone management must consider activities taking place on the land, far from reefs.

- **Develop tourism sustainably to ensure long-term benefits.** Tourism is vital to the Caribbean region. Decision-makers should be aware of the negative impacts of unplanned and unrestricted development and take steps to limit such damages. Education of tourists, particularly divers and snorkelers, is essential to reducing impacts. Informed tourists can become a driving force for better practices by demanding high environmental standards at their destinations. The development and use of certification schemes, accreditation, and awards for good environmental practices for hotels and dive-and-tour operators may also provide incentives for environmentally sensible development. Several organizations in the region are partnering with industry to reduce the impacts of tourism, including the Caribbean Tourism Organization, the Caribbean Hotel Association, and the Caribbean Association for Sustainable Tourism. However, wholly independent validation of environmental standards may be preferable to industry-led certification schemes.

- **Implement good marine practices to restrict dumping of waste at sea and the clearing of ballast waters.** Regional bodies, national governments, NGOs, and the private sector should work together to develop best practices (for example, in the cruise industry). Ports, harbors, and marinas need to develop pump-out and waste treatment facilities to reduce the pressure on vessels of all sizes to dump grey-water, bilge, and wastewater in the sea. Some of these needs are addressed under MARPOL, an international convention on the prevention of pollution from ships, which has been signed by most Caribbean nations. MARPOL should provide a framework for more national regulations across the region. Development of regulatory frameworks to implement these agreements should be expedited.

International Action

- **Ratify and implement international agreements.** International agreements are an important tool for setting targets and achieving collective goals. Important international agreements addressing the threats evaluated in this study include the protocols of the Cartagena Convention (addressing land-based sourses of pollution, oil spills, and protected areas and wildlife), the UN Convention on the Law of the Sea (on ocean governance), MARPOL (on marine pollution), and the UN Framework Convention on Climate Change. Signing such agreements is a first step, but implementation is essential.

- **Promote international cooperation and exchange.** Even in the absence of international legal instruments, regional collaboration on issues such as fisheries and watershed management could greatly reduce some threats. Priorities for the region should be coordinated through entities such as the Forum of Ministers of Latin America and the Caribbean and the Caribbean Small Islands Developing States Group. Sub-regional bodies, such as the Organization of Eastern Caribbean States (OECS) or the Central American Commission on Environment and Development (CCAD), could play a key role in dealing with sub-regional resource management issues. International NGOs, intergovernmental agencies, and funders should actively support cooperation and exchange to promote synergy and foster partnerships to protect Caribbean coral reefs. A good example is the Mesoamerican Barrier Reef Systems (MBRS) Project, funded by the Global Environment Facility (GEF) and the World Bank, which recognizes this reef system as a shared resource requiring a coordinated management approach. National bodies dedicated to the protection of reefs, such as the U.S. Coral Reef Task Force, should receive full support from their governments to engage issues of coral reef protection at regional as well as domestic levels.

The Caribbean presents a unique realm: a large, hyperdiverse marine ecosystem, with coral reefs at its heart. The threats to these reefs are many and complex. Because of the high degree of connectivity among coral reefs, a threat to one reef area can become a threat to many.

Much needs to be done if the serious and growing threats to Caribbean coral reefs are to be turned around, but there is reason for hope. Examples from across the region show that marine conservation not only can be done but can also generate considerable benefits for local communities. The tide can be turned, but it will require commitment and action from all relevant stakeholders—in government and in the private sector—across the Caribbean region.

PHOTO: TONI PARRAS

Appendix A. PHYSICAL, SOCIAL, AND ECONOMIC STATISTICS FOR THE CARIBBEAN REGION

TABLE A1. CORAL REEF AREA IN THE WIDER CARIBBEAN

	Estimates of Coral Reef Area		
Country/Territory	***Reefs at Risk in the Caribbean***	***World Atlas of Coral Reefs***	**UNEP-WCMC and NOAA**
	km²	km²	km²
Anguilla	70	<50	33
Antigua and Barbuda	180	240	220
Aruba	25	<50	47
Bahamas	3,580	3,150	2,805
Barbados	90	<100	92
Belize	1,420	1,330	1,152
Bermuda	210	370	332
British Virgin Islands	380	330	335
Cayman Islands	130	230	207
Colombia	2,060	900	2,541
Costa Rica	30	0	47
Cuba	3,290	3,020	2,783
Dominica	70	<100	47
Dominican Republic	1,350	610	567
Grenada	160	150	131
Guadeloupe[a]	400	250	400
Guatemala	0	0	0
Haiti	1,260	450	458
Honduras	1,120	810	811
Jamaica	1,010	1,240	1,206
Martinique	260	240	617
Mexico	1,220	1,350	1,216
Montserrat	25	<50	41
Navassa Island	10	n.d.	n.d.
Netherlands Antilles Total (North, South)[b]	250 (40, 210)	420 (n.a., n.a.)	386 (85,301)
Nicaragua	870	710	508
Panama	1,600	570	492
Puerto Rico	1,610	480	2,171
St. Kitts and Nevis	160	180	170
St. Lucia	90	160	98
St. Vincent and the Grenadines	140	140	131
Trinidad and Tobago	40	<100	62
Turks and Caicos Islands	1,190	730	2,002
United States	840	1,250	1,131
Venezuela	230	480	486
Virgin Islands (U.S.)	590	200	748
Regional Total	**25,960**	**20,000**	**24,860**

Sources:

1. *Reefs at Risk in the Caribbean* mapping was done at WRI and is based on the best data available at the time of publication. Data come from the University of South Florida, Institute for Marine Remote Sensing (IMaRS), Millennium Coral Reef Mapping Project (draft data, 2004); US National Oceanographic and Atmospheric Administration (NOAA) Benthic Habitats of Puerto Rico and the U.S. Virgin Islands, (2001); Coastal Zone Management Institute of Belize (1999); and UNEP-WCMC Biodiversity Map Library: Global Coral Reef Distribution (2002). In order to convert these sources to a single layer of broadly comparable resolution the maps were fitted to a 500-m resolution grid and it was from this gridded data layer that reef area estimates were generated.
2. The reef maps prepared for the *World Atlas of Coral Reefs* (Spalding et al., 2001) represented the best available information at the time of publication. Data were drawn from multiple sources, ranging from hydrographic charts and remote sensing studies, to much lower-resolution maps. To convert these sources to a single layer of broad comparable resolution, the maps were fitted to a 1-km grid, and estimates of reef area were generated from this gridded data layer.
3. The reef maps from UNEP-WCMC come from a variety of sources, including hydrographic charts, remote sensing, and much lower-resolution maps. Positional accuracy of some of these data were checked and improved by NOAA by rectifying the coral reef maps with bathymetric data from the 1-km resolution SeaWifs sensor. Data were gridded by NOAA at 1-km resolution and estimates of reef area were generated from this gridded data layer.

Notes:

Estimates include only Caribbean and Atlantic (not Pacific) reefs.

The three sources cited in this table use various map sources, and differing methods of estimating area. Reef area estimates are sensitive to the definition of coral reef, as well as the data sources and mapping techniques used (i.e., satellite imagery versus charts).

Efforts to map Caribbean coral reefs are rapidly advancing.

a. Guadeloupe includes the French islands of St. Martin and St. Barthelemy.

b. Netherlands Antilles North includes the islands of St. Maarten, St. Eustatius, and Saba. Netherlands Antilles South includes the islands of Bonaire and Curaçao.

TABLE A2. PHYSICAL GEOGRAPHY OF THE WIDER CARIBBEAN

Country/Territory	National Land Area	Land Area Draining to Caribbean	Maritime Claim in Caribbean/ Atlantic	Shelf Area to 30 m within Maritime Claim	Shelf Area to 200 m within Maritime Claim	Caribbean Coastline Length
	km^2	km^2	km^2	km^2	km^2	km
Anguilla	90	90	91,150	650	2,840	90
Antigua and Barbuda	440	440	110,225	2,385	4,820	270
Aruba	190	190	2,770	115	1,140	100
Bahamas	12,900	12,900	622,695	113,810	127,785	9,265
Barbados	430	430	187,535	80	695	95
Belize	22,965	22,965	34,735	7,850	9,115	2,220
Bermuda	55	0	449,735	840	1,400	140
British Virgin Islands	155	155	80,785	2,060	3,570	300
Cayman Islands	265	265	123,590	185	760	210
Colombia	1,038,700	678,745	490,680	18,635	40,680	3,445
Costa Rica	51,100	23,710	29,200	975	2,610	650
Cuba	111,950	110,860	342,615	50,870	58,210	12,005
Dominica	750	750	28,640	85	640	150
Dominican Republic	48,445	48,445	255,720	7,020	14,540	1,530
Grenada	345	345	27,380	960	3,670	195
Guadeloupe[a]	1,710	1,710	28,790	1,435	5,930	515
Guatemala	108,890	84,575	1,570	1,210	1,480	355
Haiti	27,750	27,750	124,590	3,305	5,905	1,820
Honduras	112,090	92,395	241,040	35,850	73,060	2,325
Jamaica	10,990	10,990	242,920	9,615	14,735	825
Martinique	1,100	1,100	18,740	415	1,515	320
Mexico	1,958,200	1,055,245	830,505	92,330	245,950	12,315
Montserrat	105	105	8,120	40	230	45
Netherlands Antilles North[b]	70	70	12,420	1,510	3,540	65
Netherlands Antilles South[c]	740	740	66,240	12	1,080	295
Nicaragua	120,255	110,110	63,845	39,470	52,150	2,075
Panama	75,520	22,295	142,565	6,105	11,570	2,905
Puerto Rico	8,950	8,950	205,410	3,500	6,680	930
St. Kitts and Nevis	270	270	9,835	460	1,415	120
St. Lucia	620	620	15,445	190	895	155
St. Vincent and the Grenadines	390	390	36,175	665	2,240	210
Trinidad and Tobago	5,130	5,130	73,460	5,925	24,045	665
Turks and Caicos Islands	430	430	149,315	7,005	8,510	745
United States	9,158,960	4,364,890	1,131,665[d]	233,830[d]	460,990[d]	22,875[d]
Venezuela	882,050	822,095	472,950	51,365	110,205	6,400
Virgin Islands (U.S.)	350	350	5,890	1,030	2,435	305
Other[e]		284,580				
Regional Total (excl. U.S.)	**4,604,390**	**3,430,190**	**5,627,280**	**467,955**	**846,045**	**64,055**
Regional Total (incl. U.S.)	**13,763,350**	**7,795,080**	**6,758,945**	**701,785**	**1,307,035**	**86,930**

Sources:

1. National Land Area: data were compiled from FAO (FAOSTAT, 1998), *CIA World Fact Book* (2002), *CARICOM Environment in Figures 2002*, and the Global Maritime Boundaries Database (GMBD) (Veridian - MRJ Technology Solutions, 2002).
2. Caribbean drainage area was calculated at WRI, using watershed boundaries developed by the *Reefs at Risk* project.
3. Maritime Claims were derived at WRI using data from the Global Maritime Boundaries Database (GMBD) (Veridian - MRJ Technology Solutions, 2002). Maritime claims are a sum of the Territorial Sea, Contiguous Zone, Exclusive Economic Zone, and Fishing Zones claimed by a country (up to 200 nautical miles from the coastline), on the Caribbean and Atlantic side only.

4, 5. Shelf Area within national waters was derived at WRI. Shelf areas were defined based on a bathymetric data set developed at WRI from depth point data from the Danish Hydrologic Institute's (DHI) C-MAP data product, interpolated at 1-km resolution. Teritorial claim is based on Veridian-MRJ's Global Maritime Database (2002).

6. Caribbean Coastline length was derived at WRI using World Vector Shoreline data as the base. For Central American countries, the Pacific coastline was excluded. Small islands with a perimeter of less than 3 km were excluded from the tally. Coastline measurements are scale-dependent, and vary with the scale of the data source. This estimate uses a standardized 1:250,000 data set.

Notes:

a. Guadeloupe includes the French islands of St. Martin and St. Barthelemy.

b. Netherlands Antilles North includes the islands of St. Maarten, St. Eustatius, and Saba.

c. Netherlands Antilles South includes the islands of Bonaire and Curacao.

d. For the US, only the coastline along the Gulf States (Texas, Louisiana, Mississippi, Alabama, and Florida) was included. In addition, the maritime claim and shelf area estimates only inlcude areas adjacent to these Gulf states.

e. Includes the parts of Brazil, Guyana, Surinam, and Canada draining to the Caribbean.

TABLE A3. POPULATION OF THE WIDER CARIBBEAN

Country/Territory	Population (1990)	Population (2000)	Population Change (1990–2000)	Population Density (2000)	Population in Watershed Draining into the Caribbean (2000)	Percentage of Population Living Within a Given Distance of the Coastline (2000)	
						10km	100km
	Thousands	Thousands	% Change	People/km^2	Thousands	%	%
Anguilla[a]	8	11	72.7	122	11	100	100
Antigua and Barbuda	63	65	3.3	147	65	100	100
Aruba	66	101	52.7	529	101	100	100
Bahamas	255	304	19.2	24	304	100	100
Barbados	257	268	4.0	622	268	100	100
Belize	186	226	21.9	10	226	29	100
Bermuda	59	63	7.0	1,189	0	100	100
British Virgin Islands	17	24	37.2	154	24	100	100
Cayman Islands	26	38	45.2	145	38	100	100
Colombia	34,970	42,105	20.4	41	38,142	7	18
Costa Rica	3,049	4,024	32.0	79	1,278	2	71
Cuba	10,629	11,199	5.4	101	11,199	41	100
Dominica	71	71	-1.1	94	71	100	100
Dominican Republic	7,061	8,373	18.6	173	8,373	28	100
Grenada	91	94	3.1	271	94	100	100
Guadeloupe[b]	391	428	9.5	250	428	100	100
Guatemala	8,749	11,385	30.1	105	6,202	1	5
Haiti	6,907	8,143	17.9	293	8,143	48	100
Honduras	4,870	6,417	31.8	57	4,271	8	47
Jamaica	2,369	2,576	8.7	234	2,576	53	100
Martinique	360	383	6.4	349	383	100	100
Mexico	83,223	98,872	18.8	50	55,328	3	15
Montserrat[a]	11	4	-36.4	39	8	100	100
Netherlands Antilles[c]	188	215	14.7	266	215	100	100
Nicaragua	3,824	5,071	32.6	42	3,673	1	7
Panama	2,398	2,856	19.1	38	964	6	90
Puerto Rico	3,528	3,915	11.0	437	3,915	58	100
St. Kitts and Nevis	42	39	-8.1	143	39	100	100
St. Lucia	131	148	12.5	238	148	100	100
St. Vincent and the Grenadines	106	113	7.1	291	113	100	100
Trinidad and Tobago	1,215	1,294	6.5	252	1,294	72	100
Turks and Caicos Islands	12	17	44.0	39	17	100	100
United States	254,776	283,230	11.2	31	115,958	4[d]	10[d]
Venezuela	19,502	24,170	23.9	27	24,167	21	73
Virgin Islands (U.S.)	104	121	16.0	346	121	100	100
Other[e]					1,002		
Regional Total (excl. U.S.)	**194,736**	**233,130**	**19.7**		**173,199**		
Regional Total (incl. U.S.)	**449,512**	**516,360**	**14.9**		**289,157**		

Sources:

1. Population for 1990 & 2000 from Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, *World Population Prospects: The 2000 Revision* (2002).
2. Population change: calculated at WRI as the percentage change in UN population estimates between 1990 and 2000.
3. Population density: calculated at WRI as the population in 2000 divided by national land area (see Table A2).
4. Population in watershed draining into the Caribbean: drainage area derived from watershed delineation work undertaken at WRI, population data from Center for International Earth Science Information Network (CIESIN), *Gridded Population of the World, Version 3* (Palisades, NY: CIESIN/ Columbia University, 2003).
5. Percentage of population living within a distance of the coastline (2000): calculated for 10 km or 100 km at WRI using gridded CIESIN (2003) population data at 1-km resolution and a 10-km buffer of 1:250,000 World Vector Shoreline (E.A. Soluri and V.A. Woodson. 1990. "World Vector Shoreline." *International Hydrographic Review*, vol 67, no. 1.).

Notes:

a. Population data for Anguilla and Montserrat were unavailable from the UN source. They were derived at WRI from CIESIN population density grid at 1-km resolution.

b. Guadeloupe includes the French islands of St. Martin and St. Barthelemy.

c. Netherlands Antilles includes Bonaire, Curacao, Saba, St. Eustatius, and St. Maarten.

d. US population within 10 and 100 km of the coast includes Texas, Louisiana, Mississippi, Alabama, and Florida only.

e. Other includes the parts of Brazil, Guyana, Suriname, and Canada draining to the Caribbean.

TABLE A4. TOURISM ECONOMY OF THE WIDER CARIBBEAN

Country/Territory	GDP Per Capita (PPP) (2000)	Tourist Arrivals (stay-over) (2000)	Cruise Arrivals (2000)	International Tourism Receipts (2000)	Tourism Penetration Ratio (2000)	Value of Tourism Economy (2002)	Contribution of Tourism Economy to GDP (2002)	Projected Travel and Tourism Growth Rate (2002-2014)
	US$	Thousands	Thousands	US$ (millions)	Avg. number of tourists per thousand inhabitants	US$ (millions)	Percent of GDP	Percent growth per annum
Anguilla	8,200	44	n.d.	55	76	58	58	5
Antigua and Barbuda	8,200	237	429	291	n.d.	528	72	5
Aruba	28,000	721	490	837	161	1,064	47	4
Bahamas	15,000	1,596	2,513	1,814	63	2,497	46	6
Barbados	14,500	545	533	711	56	1,032	37	5
Belize	3,200	196	58	121	16	194	23	6
Bermuda	33,000	328	210	431	86	729	26	4
British Virgin Islands	16,000	281	189	315	352	343	85	3
Cayman Islands	24,500	354	1,031	559	152	468	31	6
Colombia	6,200	557[a]	n.d.	1,028[a]	n.d.	5,541	6	5
Costa Rica	6,700	1,088[a]	n.d.	1,229[a]	n.d.	2,057	12	6
Cuba	1,700	1,774	n.d.	1,857	4	2,572	11	6
Dominica	4,000	70	240	47	23	64	22	5
Dominican Republic	5,700	2,973	182	2,860	11	4,136	18	6
Grenada	4,400	129	180	70	25	99	23	6
Guadeloupe	9,000	807	329	454	27	658	33	4
Guatemala	3,700	n.d.	n.d.	n.d.	n.d.	1,656	8	5
Haiti	1,800	140	305	54	n.d.	182	5	4
Honduras	2,700	471[a]	n.d.	262[a]	n.d.	568	8	6
Jamaica	3,700	1,323	908	1,333	14	2,025	27	5
Martinique	11,000	526	286	370	49	568	10	4
Mexico	9,100	3,045[b]	1,505[b]	2,346[b]	n.d.	60,700	9	8
Montserrat	5,000	10	n.d.	9	n.d.	n.d.	n.d.	n.d.
Netherlands Antilles[c]	11,400	693	347	765	64	n.d.	n.d.	n.d.
Nicaragua	2,700	486[a]	n.d.	111[a]	n.d.	204	7	7
Panama	6,000	484[a]	n.d.	576[a]	n.d.	1,527	15	6
Puerto Rico	10,000	3,341	1,302	2,388	6	3,506	5	4
St. Kitts and Nevis	7,000	73	165	58	43	93	25	5
St. Lucia	4,500	270	444	277	45	380	51	5
St. Vincent and the Grenadines	2,800	73	86	75	n.d.	110	29	5
Trinidad and Tobago	9,500	399	82	213	n.d.	787	9	5
Turks and Caicos Islands	7,300	151	n.d.	285	13	n.d.	n.d.	n.d.
United States	36,200	74,100[d]	n.d.	82,042[a]	n.d.	1,160,300	11	4
Venezuela	6,200	469	135	563[a]	n.d.	9,000	6	6
Virgin Islands (U.S.)	15,000	607	1,768	1,157	69	1,629	42	4
Regional Total (excl. U.S.)		**24,261**	**13,716**	**25,523**		**104,974**		
Regional Total (incl. U.S.)		**98,361**		**105,565**		**1,265,274**		

Sources:

1. Gross Domestic Product (GDP) per capita, (PPP) is gross domestic product converted to international dollars using Purchasing Power Parity (PPP) rates and divided by the population of the country that year. *World Factbook* (CIA, 2000). Published online at http://www.cia.gov/cia/publications/factbook/.
2. Tourist arrivals (stay-over) includes visitors staying in the country at least 24 hours. Caribbean Tourism Organization (CTO), *Caribbean Tourism Statistical Report 2001–2002* (St Michael, Barbados: CTO, 2002).
3. Cruise arrivals: CTO (2002).
4. Tourism receipts: includes expenditures by tourists, cruise passengers, and other same-day visitors. Estimates supplied by the relevant national agency. CTO (2002).
5. Tourism penetration ratio is a basic but useful measure of tourism interaction quantifying the average number of tourists per thousand local inhabitants, in the country at any one time. CTO (2002).
6. Value of tourism economy: WTTC (World Travel and Tourism Council) *The Impact of Travel & Tourism on Jobs and the Economy - 2002: Country Reports* (London, UK: WTTC, 2002).
7. Contribution of tourism economy to total GDP: CTO (2002).
8. Projected travel and tourism growth rate: CTO (2002).

Notes:

n.d. = no data

a. Supplementary data for Tourist Arrivals (stay-over) and International Tourism Receipts: when not available from CTO (2002), taken from Development Data Group, The World Bank, *World Development Indicators 2002* (Washington, D.C.: The World Bank, 2002). Online.

b. Mexico data from CTO refers to Cancun and Cozumel only.

c. Netherlands Antilles includes Bonaire, Curacao, Saba, St. Eustatius, and St. Maarten.

d. US tourist arrivals figure refers to Florida only and includes domestic and international tourist arrivals (source: "visit Florida" http://www.flausa-media.com/Subcategories/florida%20facts/Fact%20Pages/ffrecfct.htm).

TABLE A5. MANAGEMENT OF MARINE PROTECTED AREAS (MPAs) IN THE WIDER CARIBBEAN

Country / Territory	Number of MPAs	Management Effectiveness Rating: Good	Partial	Inadequate	Unknown	Percent of Reef Area Inside of MPAs
Anguilla	5	0	0	5	0	0
Antigua and Barbuda	6	0	0	4	2	13
Aruba	0	0	0	0	0	0
Bahamas	9	0	1	0	8	2
Barbados	1	0	1	0	0	6
Belize	12	1	8	2	1	27
Bermuda	35	1	1	33	0	14
British Virgin Islands	11	1	0	10	0	42
Cayman Islands[a]	1	1	0	0	0	15
Colombia	7	0	0	6	1	20
Costa Rica	4	0	0	0	4	55
Cuba	30	0	4	24	2	13
Dominica	2	0	0	2	0	4
Dominican Republic	15	0	4	2	9	43
Grenada	2	0	0	2	0	1
Guadeloupe[b]	6	1	2	1	2	12
Guatemala	3	0	0	1	2	0
Haiti	0	0	0	0	0	0
Honduras	12	0	1	2	9	11
Jamaica	4	0	1	3	0	22
Martinique	3	0	0	0	3	7
Mexico	9	0	0	7	2	67
Montserrat	1	0	0	1	0	0
Netherlands Antilles North[c]	3	1	2	0	0	67
Netherlands Antilles South[d]	2	1	0	1	0	65
Nicaragua	2	0	0	1	1	68
Panama	4	0	1	2	1	11
Puerto Rico	15	0	3	7	5	21
St. Kitts and Nevis	0	0	0	0	0	0
St. Lucia	20	1	4	15	0	6
St. Vincent and the Grenadines	1	0	0	1	0	16
Trinidad and Tobago	1	0	0	1	0	17
Turks and Caicos Islands	21	0	3	5	13	4
United States	9	7	0	0	2	52
Venezuela	18	0	0	0	18	48
Virgin Islands (U.S.)	11	2	1	0	8	8
Regional Total	**285**	**17**	**37**	**138**	**93**	**20**

Sources:

1. Number of MPAs: Reefs at Risk in the Caribbean (WRI, 2004). This table reflects summary statistics on the MPA database complied by the Reefs at Risk in the Caribbean Project. Data were assembled by WRI and project partners. The data for some countries may be incomplete. In addition, defintion of MPAs vary.
2. Management effectiveness rating: Project partners were asked to rate management effectiveness of MPAs based upon a limited set of criteria: existence of management activity, existence of a management plan, availability of resources (financial and human), and level of enforcement. Those ratings are summarized by country in this table and are available by MPA within the full database.
3. Estimated location and boundaries of MPAs were overlaid with a data set on coral reef locations to determine the percentage of a country's coral reefs within the boundaries of an MPA. These percentages should be regarded as rough estimates based upon available data.

Notes:

a. The Cayman Islands has a zoned system of protected areas, which was considered as a single unit in this analysis.

b. Guadeloupe includes the French islands of St. Martin and St. Barthelemy.

c. Netherlands Antilles North includes the islands of St. Maarten, St. Eustatius, and Saba.

d. Netherlands Antilles South includes the islands of Bonaire and Curaçao.

Appendix B. DATA SOURCES USED IN THE REEFS AT RISK IN THE CARIBBEAN THREAT ANALYSIS

Data used in the Reefs at Risk threat analysis, model results, and metadata are available on CD. Model results, accompanied by metadata, are available online at http://reefsatrisk.wri.org.

COASTAL DEVELOPMENT

- Cities and towns—Environmental Systems Research Institute (ESRI), "World Cities" and "U.S. Cities," 2002 and http://www.world-gazetteer.com.
- Ports—National Imagery and Mapping Agency (NIMA), "World Port Index," 2002.
- Airports—NIMA, "VMAP," 1997.
- Dive tourism centers—United Nations Environment Programme - World Conservation Monitoring Centre (UNEP-WCMC), "Caribbean Dive Centers," 2002 and M.D. Spalding, *Guide to the Coral Reefs of the Caribbean* (Berkeley, USA: University of California Press, 2004).
- Population density—U.S. Dept. of Energy (DOE), "LandScan," 2001.
- Population growth (by administrative district)—ESRI, "Administrative Districts", 2002 and http://www.ciat.cgiar.org.
- Annual tourism growth (by country)—Caribbean Tourism Organization (CTO), *Caribbean Tourism Statistical Report 2001–2002,* 2002.

WATERSHED-BASED SOURCES OF SEDIMENT AND POLLUTION*

- Watershed boundaries—Delineated at WRI from U.S. Geological Survey (USGS), "HYDRO1K" digital elevation model, 2000 (1-km resolution for the entire Caribbean region), and U.S. National Aeronautics and Space Administration (NASA), "Shuttle Radar Topography Mission" (SRTM) provisional data set, 2003 (90-m resolution for the Eastern Caribbean).
- Elevation and slope—USGS, "HYDRO1K", 2000 (1-km resolution for the entire Caribbean region), and NASA "SRTM," 2003 (90-m resolution for the Eastern Caribbean).
- Land cover—USGS, "Global Land Cover Characteristics Database," 2000 (1-km resolution for the Wider Caribbean); University of Maryland, "Global Percent Tree Cover at a Spatial Resolution of 500 Meters: First Results of the MODIS Vegetation Continuous Fields Algorithm," 2003 (500-m resolution for the Eastern Caribbean); Landsat data classified in 2003 by Jennifer Gebelein, Florida International University (30-m resolution for select islands in the Eastern Caribbean).
- Soil porosity—UN Food and Agriculture Organization (FAO), "World Soil Database," 1995.
- Precipitation—U.S. Army CERL and Center for Remote Sensing and Spatial Analysis (CRSSA), Cook College, Rutgers University, "Global ARC" CD, 1996.

MARINE-BASED THREATS

- Ports—NIMA, "World Port Index," 2002.
- Oil and gas extraction, processing, and pipeline locations—NIMA, "VMAP," 1997.
- Cruise ships (intensity of visitation)—Information for this data set was derived from the "Choosing Cruising" website http://www.choosingcruising.co.uk, and georeferenced at WRI, 2003.

OVERFISHING

- Population density—U.S. DOE, "LandScan," 2001.
- Shelf area—Developed at WRI based on data from the Danish Hydrological Institute (DHI), "MIKE C-MAP" depth points and data on coastline location—NASA, "SeaWiFS" and NIMA, "VMAP," 1997.
- Coral reef fish abundance—Reef Environmental Education Foundation (REEF) website http://www.reef.org (accessed 10 February 2003).

CORAL REEF LOCATIONS

Maps of coral reefs in vector format (ESRI ArcINFO line and polygon files) are the basis for the coral reef map for the region. These data were of multiple scales, generally ranging from approximately 1:30,000 to 1:1,000,000, and from multiple sources (listed below). To standardize these data, WRI converted them to raster format (ESRI ArcINFO GRID) at 500-m resolution for use in the analysis. Sources:

- University of South Florida, Institute for Marine Remote Sensing (IMaRS), "Millennium Coral Reef Mapping Project," 2004 (30 m Landsat data classified and converted to shapefile) for the Lesser Antilles (British Virgin Islands through Barbados), the Turks and Caicos Islands, Southern Bahamas, Dominican Republic, Haiti, Jamaica, Nicaragua, and Panama).**

* The watershed-based analysis of sediment and pollution was implemented at 1-km resolution for the entire Caribbean region and at 250-m resolution for the islands of the Eastern Caribbean. This finer scale of analysis provides better detail for the relatively small watersheds of the Eastern Caribbean islands.

** The Millennium Coral Reef Mapping Project developed a geomorphologic classification of coral reefs. To make data comparable to other map sources, the Reefs at Risk project selected a subset of 30 categories from the overall mapping effort. Categories with high probability of being living coral—such as forereef, intertidal reef flat, barrier reef pinnacle, and shallow terrace—were included, while categories such as drowned bank and undetermined envelope were excluded. Full details are available online at http://reefsatrisk.wri.org.

- US National Oceanographic and Atmospheric Administration (NOAA), "Benthic Habitats of Puerto Rico and the U.S. Virgin Islands," 2001, from high-resolution aerial photography.
- Coastal Zone Management Institute of Belize, 1999. (30-m Landsat data classified and converted to shapefile, for Belize).
- For other areas, UNEP-WCMC "Coral Reef Maps," 2002. Data have been acquired or digitized from a variety of sources. Scales typically range from 1:60,000 to 1:1,000,000.
- In addition, WRI edited and digitized maps for some areas based on input from project partners.

MODEL CALIBRATION AND VALIDATION

Data from a range of monitoring and assessment programs were used to explore patterns of degradation, calibrate the threat analysis, and validate the results:

- Caribbean Coastal Productivity Program (CARICOMP)—Coral reef habitat parameters for 27 reef locations across 20 countries (1993 – 2001).
- Atlantic and Gulf Rapid Reef Assessment (AGRRA)—This assessment protocol has been applied at over 730 reef locations in 17 countries across the region between 1997 and 2001, providing a (one-time) snapshot of many indicators of reef condition.
- Reef Check—Volunteer survey program. The protocol has collected social, physical, and biological parameters at 186 sites in 16 countries within the region since 1997.
- The Reef Environmental Education Foundation (REEF) Fish Survey—Data on coral reef fish populations from more than 2,500 locations across the region.

Model Calibration

Reefs at Risk project partners have provided valuable guidance on threat model development and review of model results. This expert opinion, coupled with observations of threats to reefs from Reef Check, was used to calibrate the estimates of threat from coastal development and watershed-based sediment and pollution. Data on coral reef fish populations from REEF were used to calibrate the estimate of threat from fishing pressure. Due to limited data of sufficient detail, expert opinion during the Reefs at Risk in the Caribbean workshop was the main source for calibration of the estimate of marine-based threat.

Threat Analysis Validation and Exploration of Relationships with Indictors from Assessment and Monitoring Programs

Using results from the 22 CARICOMP sites that have trend information (multiple years of data between 1993 and 2001) the study finds:

- Sites identified as threatened by sediment and pollution from inland sources had substantially higher average levels of decline in hard coral cover (loss of 9 percent in high-threat areas versus loss of 1 percent in low-threat areas).
- Sites identified as threatened (medium or high threat) from coastal development or marine-based pollution had a much larger average increases in extent of algal cover than sites rated as low threat. (Increase was about twice as large on threatened sites.)
- Few CARICOMP sites were identified as under low threat from overfishing. Sites identified as under high threat from overfishing pressure had larger average loss of hard coral cover and larger gains in algae cover as compared with medium threat sites.

Several coral condition indicators were developed for the 432 AGRRA assessment sites. These include coral density, ratios of different coral species, extent of hard coral cover, recent and old mortality, and a macroalgal index. Of these indictors, the macroalgal index, old mortality, and hard coral cover had the only statistically significant (95%) relationships with the threat indictors. The three pollution-related threats (coastal development, marine-based threats, and pollution and sediment from inland sources) were combined for this analysis. The findings:

- Average extent of old mortality was higher on sites identified as threatened by pollution. (29 percent on high versus 26 percent on low threat sites.)
- Average hard coral cover was slightly higher on sites identified as under low threat from pollution (8.2 percent) than on high threat sites (7.3 percent).
- The average macroalgal index was higher on sites identified as threatened by pollution (150 on high versus 123 on low threat sites.)
- In addition, the average macroalgal index was higher on sites identified as threatened by overfishing (170 on high versus 100 on low threat sites.)

Appendix C. INFORMATION ACTIVITIES IN THE CARIBBEAN

Information available and limitations of current information are presented in five broad categories—information on the location and extent of coral reefs (reef mapping); information on impacts to reefs and coral reef condition; accessibility of such information; information on protection and management of coastal resources; and valuation of these resources. Attempts are underway to address many of the deficiencies mentioned below.

CORAL REEF MAPPING

Estimates of coral reef area across the region vary widely (*see Table A1*). For many countries, there are no national maps of coral reefs, from which reef area can be estimated. The U.S. National Oceanographic and Atmospheric Administration (NOAA) has recently improved the mapping of benthic habitat within U.S. waters in the Caribbean region, and the Nature Conservancy's Bahamian Ecological Planning project is improving mapping of coral reefs in the Bahamas. In addition, the Millennium Coral Reef Mapping project, a collaboration of the University of South Florida and the U.S. National Aeronautics and Space Administration (NASA), is mapping global reef geomorphology from 30-m Landsat imagery. These maps are expected to be released for the entire Caribbean during 2004. (See http://eol.jsc.nasa.gov/reefs/.)

MONITORING AND ASSESSMENT

Information on coral reef condition is limited, partly due to the vast area of coral reefs, spread across 35 countries and territories, and partly due to the lack of financial resources devoted to monitoring coastal ecosystems. There are, however, many noteworthy efforts within the Caribbean:

- An important effort within the region is the Caribbean Coastal Productivity Program (CARICOMP), a long-term monitoring program that uses a standardized monitoring method. CARICOMP has collected data at 27 reef locations across 20 countries, beginning in 1993. As of 2001, repeat monitoring at 22 sites had established temporal trends in such parameters as live coral cover. (See http://www.uwimona.edu.jm/cms/ccdc.htm.)
- A more recent and more extensive effort in the region focuses on assessment, rather than monitoring, of resources. The Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol has been applied at more than 730 reef locations in 17 countries across the region. This assessment provides a snapshot of many indicators of reef condition that will support setting of regional norms and making comparisons among different areas in the region.
- Selected universities, marine labs, and government institutions across the region carry out a diverse array of research, mapping, and monitoring activities on coral reefs. The Association of Marine Labs of the Caribbean (AMLC) meets annually to share information. Other notable efforts are the Florida Keys National Marine Sanctuary and Sistema Nacional de Monitoreo de Arrecifes Coralinos en Colombia (SIMAC), which have good time-series data sets for those areas.
- Several other important activities enlist volunteer divers to monitor coral reefs. Since 1997, the Reef Check program has documented social, physical, and biological conditions at over 186 sites in 16 countries within the region, providing information on benthic habitat, invertebrates, and reef fish. (See http://www.reefcheck.org.)
- The Reef Environmental Education Foundation (REEF) Fish Survey project allows volunteer scuba divers and snorkelers to collect and report information on coral reef fish populations. REEF has assessed more than 2,500 locations across the region. Recently, the Ocean Conservancy has partnered with REEF to develop a benthic component for sport divers termed RECON. (See http://www.reef.org.)

DATA INTEGRATION AND ACCESSIBILITY

These assessment and monitoring activities provide valuable information on a relatively limited number of coral reefs across the Caribbean. At present, information from only some of these sources is publicly available, and little of this information has been consolidated into a central repository.

Noteworthy efforts to consolidate information on coral reefs include:

- **ReefBase** (http://www.reefbase.org)—Offers a wide range of information on the world's coral reefs including status summaries, a database on coral bleaching, satellite images, and an Internet map server.
- **The Caribbean Coastal Data Center, University of West Indies (UWI)** (http://www.uwimona.edu.jm/cms/ccdc.htm)—A central repository for information on Caribbean coral reefs and coastal environmental data. An Internet map server is planned for 2004.
- **The Global Coral Reef Monitoring Network (GCRMN)** (http://www.gcrmn.org/)—Using its collaborative network, GCRMN has produced a biannual publication on the status of the world's coral reefs since 1998. This publication provides a good text summary for each country based on monitoring information, anecdotal observations, and expert opinion on observed impacts to coral reefs and changes in the condition of coral reefs and the associated fisheries.
- **Coral Disease**—Attempts are being made to consolidate and maintain databases on coral disease and coral bleaching. The University of Puerto Rico, NOAA, and UNEP-WCMC provide extensive information on coral disease incidence across the region. (See http://www.wcmc.org.uk/marine/coraldis/home.htm.)
- **Coral Bleaching**—The Reef Base database maintains an online database on coral bleaching. NOAA is working on tools for predicting where bleaching might occur, given sea surface temperatures and weather conditions. (See http://www.osdpd.noaa.gov/OSDPD/OSDPD_high_prod.html.)

PROTECTION AND MANAGEMENT

Information on protection and management of coral reefs is limited. Mapping of marine protected areas across the region is inadequate, and associated information on the management policies and use restrictions within Marine Protected Areas (MPAs) is often unavailable. Also unavailable is information about effectiveness of management within MPAs, which would allow the differentiation of "paper parks" from areas offering actual protection. Information on protected areas and the sharing of experiences should improve in the future under the Caribbean Marine Protected Areas Network and Forum (CaMPAM), an initiative aimed at enhancing the effectiveness of MPAs.

ECONOMIC VALUE

The true economic value of coral reefs is often not recognized, and this reduces the incentives for effective management of these vital resources. Studies on the economic value of coral reefs within the Caribbean are few, and those that have been done have used such varied methods that comparison between studies is often difficult. Attempts are being made to encourage more consistent valuation of coastal resources in the Caribbean region. (See http://marineeconomics.noaa.gov/.)

PHOTO: TONI PARRAS

Acronyms and Glossary

ACRONYMS

AGRRA	Atlantic and Gulf Rapid Reef Assessment
CARICOMP	Caribbean Coastal Marine Productivity Program
CITES	Convention on International Trade in Endangered Species
ENSO	El Niño Southern Oscillation
GDP	Gross Domestic Product
GIS	Geographic Information System
ICM	Integrated Coastal Management
LBS	Land-Based Sources
MARPOL	International Convention for the Prevention of Pollution from Ships
MPA	Marine Protected Area
SPAW	Specially Protected Areas and Wildlife (Protocol of Cartagena Convention)
SST	Sea Surface Temperature
UNESCO	United Nations Educational, Scientific and Cultural Organization

GLOSSARY

Anthropogenic – made by people or resulting from human activities.

Bank reef – large reef growths, generally having irregular shape, surrounded by deeper waters.

Barrier reef – a long, narrow coral reef, roughly parallel to the shore and separated from it by a lagoon of considerable depth and width. It is often interrupted by passes or channels.

Bathymetry – the measurement of ocean depth to determine the topography of the sea floor.

Biodiversity – the total diversity and variability of living things and the systems (e.g., coral reefs), of which they are part.

Coral bleaching – the process in which a coral polyp, under environmental stress, expels its symbiotic zooxanthellae from its body. The affected coral colony appears whitened.

Coral disease – any impairment of the coral's vital functions or systems, including interruption, cessation, proliferation, or other vital function.

Eutrophication – the process by which an excess of nutrients stimulates the growth of plants, depleting the water of oxygen.

Fringing reef – a shelf reef that grows close to shore. Some develop around oceanic islands. A synonym of shore reef.

Greenhouse Gases (GHG) – atmospheric gases, primarily carbon dioxide, methane, and nitrous oxide, restricting some heat energy from escaping from the Earth's atmosphere directly back into space.

Larvae – juvenile stage of an animal's life cycle.

Passenger bed-days – a common measurement of occupancy used by the cruise line industry. "Bed days" are calculated by multiplying the number of beds occupied by the number of days they are occupied.

Pathogen – an organism that causes a disease within another organism.

Photosynthesis – process by which plants manufacture their own energy from the chemical reaction of carbon dioxide and water in the presence of sunlight and chlorophyll. Oxygen is a photochemical byproduct of photosynthesis.

Riparian – on a river bank.

Substrate – the material making up the base upon which an organism lives or to which it is attached.

Upwelling – a process in which warm surface water is drawn away from a shore by offshore currents (driven by wind for example), which is replaced by cold, often nutrient-rich water brought up from deeper regions to the surface.

Zooxanthellae – symbiotic single-celled plants living within reef-building corals. They provide food through *photosynthesis*, which are used as one source of energy for the coral polyps. They also provide coloration for the corals (see *coral bleaching*).

Notes

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187 Sary, Munro, and Woodley (2003).

188 A market price of US$6 per kg was used for 2000 and 2015. Although declines in productivity (and associated harvest) would tend to reduce supply and could lead to price increases, overfishing of reefs will also result in catches of smaller and less valuable fish, which would tend to offset any increase in price.

189 Fishing costs vary widely between the U.S. and developing countries within the region, ranging between 20 and 90 percent. Kearney and Centaur (Kearney and Centaur. 1984. "Economic Impact of the Commercial Fishing Industry in the Gulf of Mexico and South Atlantic Regions." *Final Report 8318 to the Gulf and South Atlantic Fisheries Development Foundation, Inc)* suggest returns in U.S. fisheries ranging between 11 and 36 percent. Pomeroy (*Economic Analysis for the Siting of Marine Protected Areas: A Case Study in the British Virgin Islands*, unpublished) found returns of about 80 percent in the British Virgin Islands. We chose 50 percent net return as an average for the region.

190 World Travel and Tourism Council (WTTC), *Caribbean Travel & Tourism - A World of Opportunity: The 2003 Travel & Tourism Economic Research* (London, UK: WTTC, 2003). International tourism receipts contribute more than 10 percent of GDP in Caribbean countries overall.

191 Pattullo (1996).

192 Tourism receipt data from CTO (2002) and Development Data Group, The World Bank, *World Development Indictors 2002* (Washington, D.C.: The World Bank, 2002); data on the value of the tourism economy from WTTC (2003).

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198 Cline Group 1997. "Diving Industry Consumer Study." Online at http://www.cline-group.net/diving.

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202 Ibid.

203 Ibid.

204 Johns et al. (2001). (4.5 million person days of scuba diving in South Florida contributed an estimated US$625 million in expeditures and 16,000 jobs. 4.2 million person days of snorkeling contributed an estimated US$340 million in expenditures and 7,400 jobs.)

205 Net benefits from tourism and the multiplier used were adapted from H. Cesar, P. Beukering and G. Berdt Romilly, *Mainstreaming Economic Valuation in Decision Making: Coral Reef Examples in Selected CARICOM-Countries* (Arnhem, The Netherlands: World Bank and ARCADIS Euroconsult, 2003) Their analysis used "value added of direct expenditures" of 25–40 percent and a multiplier of 25 percent.

206 PADI certifies most of the world's scuba divers. During the 1990s, dive certification increased at an average of 7 percent a year. Online at http://www.padi.com/english/common/padi/statistics/3.asp.

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211 Shorelines—World Vector Shoreline (E.A. Soluri and V.A. Woodson. 1990. "World Vector Shoreline". *International Hydrographic Review*, LXVII(1)) and NIMA. 1997. "VMAP National boundaries". Land areas of 100 hectares minimum were identified, and the associated shoreline was converted into a GRID for the analysis. Coral Reefs— See Appendix B for data sources.

212 To estimate the economic value of the shoreline protection services provided along these coastlines, we relied on earlier studies (H. Cesar, ed., *Collected Essays on the Economics of Coral Reefs* (Kalmar, Sweden: CORDIO, 2000); Cesar, Burke, and Pet-Soede (2003)) and estimates of past expenditures for artificial replacement of this protection (Berg (1998); S.J. Williams, K. Dodd, and K.K. Gohn. 1995. "Coast in Crisis." *US Geological Survey Circular* 1075; Herman Cesar, personal communication). These estimates ranged from about US$50,000 to US$800,000 or more for each km of coastline protected by coral reefs.

213 Assumptions of the degree of loss of shoreline protection function provided by coral reefs were made by the Reefs at Risk project based upon input from project partners. Information from the literature on this topic is quite limited. Reefs under low threat are assumed to provide 100 percent of their current coastal protection service; reefs under medium and high threat are assumed to provide 90 percent and 80 percent of current service, respectively.

214 Shoreline segments were assigned the threat category of the nearest reef. About two-thirds (67 percent) of shoreline areas were near high-threat reefs, 18 percent were near medium-threat reefs, and 16 percent were near low-threat reefs. Shoreline near high- and medium-threat reefs (a total of 84 percent) were assumed to experience a reduction in shoreline protection services. The estimate of loss in coastal protection function is based on cross-tabulation of estimates of level of development along a given shoreline area and threat estimate of the nearest coral reef.

215 A. Bruckner. 2002. "Life-Saving Products from Coral Reefs." *Issues in Science and Technology* 18 (3): 39-44.

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Reefs at Risk in the Caribbean Threat Assessment Workshop

OCTOBER 22–24, 2002 IN MIAMI, FLORIDA

PHOTO: BRUCE POTTER

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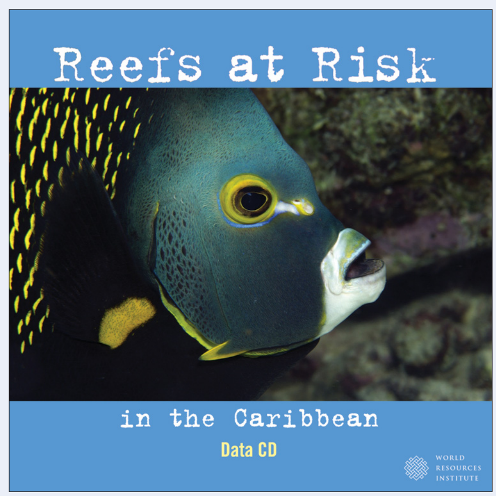
Reefs at Risk in the Caribbean Data CD

The Reefs at Risk in the Caribbean Data CD contains the range of data assembled and model results developed under the project (with metadata). (*See Appendix B for list of data sources.*) Included on the CD are over thirty spatial data sets reflecting physical, environmental, and socioeconomic variables for the Wider Caribbean as well as results from the modeling of human pressure on coral reefs in the region.



The CD also includes user-friendly map viewing software (ESRI ArcReader), which requires no specialist knowledge to use.
Users will be able to view the data sets in detail, pan and zoom to areas of interest, view data layers individually or in combination, query data sets, and print maps of your choice.

The CD also provides:

- The *Reefs at Risk in the Caribbean* report in PDF format;
- Detailed country profiles for 35 Caribbean countries and territories (including information on status of, threats to, and protection of coral reefs and information on fisheries and status of exploitation);
- Full technical notes on the threat modeling method;
- Technical notes on data sources and methods for the economic valuation;
- Complete set of maps in high and low resolution JPEG format.

To obtain a copy of the CD, please complete a request form online at http://reefsatrisk.wri.org/.

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REEFS AT RISK IN THE CARIBBEAN

The Reefs at Risk in the Caribbean project was implemented by WRI in collaboration with many partner organizations (*see inside front cover*). The project is a component of the International Coral Reef Action Network (ICRAN) and was implemented in close collaboration with the Caribbean Environment Programme. This report is a summary of a two-year effort. In addition to the report, all maps, model results, technical notes, and GIS data are available from the Reefs at Risk web site, **reefsatrisk.wri.org**.

WORLD RESOURCES INSTITUTE

The World Resources Institute (WRI) is an environmental policy research institute that strives to create practical ways to protect the Earth and improve people's lives. Our mission is to move human society to live in ways that protect the Earth's environment for current and future generations. In all of its policy research and work with partners, WRI tries to build bridges between ideas and action, meshing the insights of scientific research, economic and institutional analyses, and practical experience with the need for open and participatory decision-making.

INTERNATIONAL CORAL REEF ACTION NETWORK (ICRAN)

ICRAN is a global partnership implementing a set of interlinked and complementary activities to enable the proliferation of good practices for coral reef management and conservation, which also undertakes the implementation of the International Coral Reef Initiative's (ICRI) *Framework for Action*. The activities of ICRAN fall into three components, namely, management action, coral reef monitoring and assessment, and communication. In addition, the UNEP-Regional Seas Programmes, such as the Caribbean Environment Programme, play a leading role in practical action to protect and manage targeted coral reef ecosystems in a network of sites worldwide, and help to alleviate poverty in communities whose livelihoods depend on coral reefs. This work is combined with assessment and information components, such as the activities of WRI and other partners, to raise awareness, promote good practices, and enhance effective management of people's actions and their impacts upon coral reefs.

THE CARIBBEAN ENVIRONMENT PROGRAMME

Established by the nations and territories of the Wider Caribbean Region in 1981, the Caribbean Environment Programme (CEP) promotes cooperation for the protection of the marine and coastal environment. The CEP is an integral part of the Regional Seas Programme of the UNEP, and is administered by its Regional Coordinating Unit (CAR/RCU) in Kingston, Jamaica. The legal framework for the CEP, adopted in 1983, is provided by the Cartagena Convention. This Convention, the only region-wide environmental treaty for the Wider Caribbean, is a framework agreement setting out the political and legal foundations for environmental actions for the conservation and sustainable use of the Caribbean Sea, the Gulf of Mexico, and adjacent areas. These actions are directed by a series of operational protocols, addressing oil spills, protected areas and wildlife (SPAW Protocol), and land-based activities and sources of marine pollution (LBS Protocol). The activities of the UNEP-CAR/RCU assist nations of the Wider Caribbean to undertake sustainable development and environmentally sound practices. The CEP assists in the co-ordination of international initiatives in the region, such as the ICRI and the ICRAN and has established co-operation with global agreements such as the Convention on Biological Diversity and Ramsar.

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ISBN 1-56973-567-0