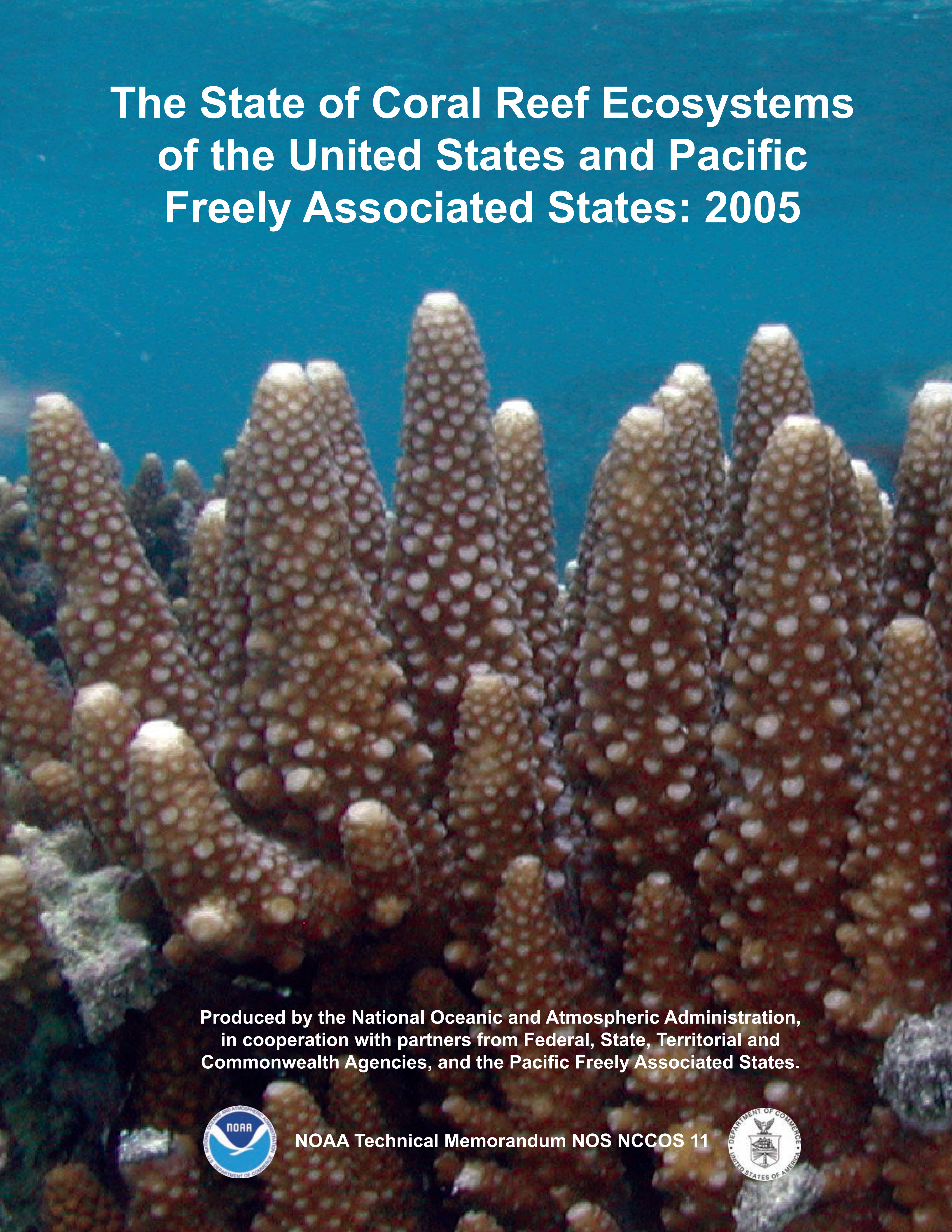

The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005

Produced by the National Oceanic and Atmospheric Administration, in cooperation with partners from Federal, State, Territorial and Commonwealth Agencies, and the Pacific Freely Associated States.

NOAA Technical Memorandum NOS NCCOS 11

CITATIONS:

Citation for the entire document:

Waddell, J.E. (ed.), 2005. The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD. 522 pp.

Citation for an individual chapter (example of Main Hawaiian Islands chapter):

Friedlander, A.M., G. Aeby, E. Brown, A. Clark, S. Coles, S. Dollar, C. Hunter, P. Jokiel, J. Smith, B. Walsh, I. Williams, and W. Wiltse. 2005. The State of Coral Reef Ecosystems of the Main Hawaiian Islands. pp. 222-269. In: J. Waddell (ed.), The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005. NOAA Technical Memorandum NOS NCCOS 11. NOAA/NCCOS Center for Coastal Monitoring and Assessment's Biogeography Team. Silver Spring, MD. 522 pp.

ACKNOWLEDGEMENTS:

The production of this report would not have been possible without the participation of the people recognized below. Their efforts to help compile, format, edit, and review the document are very much appreciated. Particular recognition goes to Julie Kellner, who formatted the figures and tables in the document; Aurelie Shapiro, who created the maps; Lynn Dancy, who editied the text for grammatical accuracy and consistency; and Kevin McMahon, who formatted the references.

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The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005

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NOAA Technical Memorandum NOS NCCOS 11
May 2005

United States Department of Commerce	National Oceanic and Atmospheric Administration	National Ocean Service
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PREFACE

The purpose of this report is to provide an assessment of the current condition of coral reef ecosystems in U.S. jurisdictions, including the U.S. Virgin Islands, Puerto Rico, Navassa, Florida, Flower Garden Banks and other banks of the Gulf of Mexico, Hawaii, the Northwestern Hawaiian Islands, American Samoa, the Pacific Remote Island Areas, Guam, and the Commonwealth of the Northern Mariana Islands (CNMI). The report also provides an examination of coral reefs in the Pacific Freely Associated States (FAS), including the Republic of the Marshall Islands, Federated States of Micronesia, and Republic of Palau. The report focuses primarily on shallow-water portions of these states and territories, from the shoreline to the maximum depth at which sunlight-dependent corals can survive. Coral communities occuring in deep and cold waters are the subject of a complementary report currently under development.

This report is the second in a series of national coral reef ecosystem status reports. The initial report, The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2002 (Turgeon et al., 2002), is similar to this report in that it incorporates the work of many scientists and managers from across the world. The first report provided a broad introduction to and a preliminary look at the status of coral reef ecosystems and was based primarily on qualitative information from the contributing authors. The initial report also included a considerable amount of background information that is not included in this report.

The lead entity coordinating the development of this report was the National Oceanic and Atmospheric Administration's (NOAA) Center for Coastal Monitoring and Assessment's Biogeography Team (CCMA-BT), which is part of the National Centers for Coastal Ocean Science. CCMA-BT scientists are responsible for three main tasks related to coral reef ecosystem conservation: 1) administration of a Federal grant program that supports selected monitoring efforts in U.S. jurisdictions and the FAS; 2) collection of standardized monitoring data in several U.S. jurisdictions through a well-established scientific field program; and 3) systematic production of benthic (sea floor) habitat maps depicting the spatial extent of the primary habitats comprising U.S. coral reef ecosystems. CCMA-BT was assisted in this reporting effort by NOAA Fisheries' Office of Habitat Conservation and NOAA's Coral Reef Conservation Program.

This report differs from the 2002 status report in several ways. The current report is based primarily on the analysis of monitoring data collected by scientists rather than qualitative assessments of ecosystem conditions. It utilizes the most recent monitoring data from all available sources, including but not limited to the activities supported by the grant program mentioned above. This report also includes a mapping component, which provides an analysis of the spatial extent of coral reef ecosystem habitats within each jurisdiction based on the estimated area in nearshore waters to 20 meters of water depth. It is critical to keep in mind that the term 'coral reef ecosystems' includes not only the coral reefs themselves, but also the associated habitats that are functional components of the ecosystem, such as mangroves, seagrass and macroalgae beds, and unconsolidated sediments.

Because the chapters reflect the hard work and dedication of writing teams from each jurisdiction, the teams should be cited as primary authors for the jurisdictional chapters of this report. Over 160 individuals from 14 jurisdictions contributed to this report, providing not only their time, attention, and hard work, but also in many cases, unpublished data that would otherwise not be available to the public at this time. The writing teams were assembled by each jurisdiction's report coordinators, who deserve praise for undertaking the daunting task of identifying and coordinating writing teams, arranging meetings, assigning tasks, assembling data sets, filling information gaps, and responding to requests from the report editor. The report would not be possible without their coordination efforts.

To assist in the challenging task of assimilating data and study results from 14 jurisdictions spanning 16 time zones, CCMA-BT scientists held two regional workshops in the spring of 2003–one in Saipan, CNMI and one in San Juan, Puerto Rico. Coordinators and authors from each of the jurisdictions attended the meetings and helped develop a report outline that would provide a common structure to guide chapter development. The coordinators, many of whom are the designated point of contact for all coral reef activities in their area, then assembled a writing team of coral reef ecosystem experts from academic, non-governmental, state, territorial, and Federal organizations. These teams were tasked with compiling an inventory of current monitoring efforts in their jurisdiction to determine which data sets should be used to assess ecosystem status within the established reporting structure. Subsequently, each team summarized the available data and provided a quantitative assessment of the condition of the ecosystem based on three broad themes: water quality, benthic habitats, and associated biological communities. When considered altogether, these themes provide a basis for assessing overall condition and diagnosing potential contributing factors to threatened and impacted ecosystems.

Ongoing agency efforts to assess and monitor elements of coral reef ecosystems form the basis for this report. However, it is important to realize that monitoring data are rarely collected in the same way or with the same frequency. Indeed, methods differ considerably among jurisdictions. These differences preclude the comparison of data or important metrics across jurisdictions in the National Summary section of this report. Instead, conclusions drawn across jurisdictions are limited to whether a particular attribute is being measured and whether these measurements result in data that are sufficiently robust to illuminate trends or patterns. Therefore, the condition of coral reef ecosystems within each jurisdiction is evaluated independently and is not comparable to other jurisdictions. Unless all of the jurisdictions implement a standard protocol, it is unlikely that interjurisdictional comparisons can ever be made with any scientific rigor. A few agencies have already initiated a standard complement of monitoring activities across multiple jurisdictions in an attempt to address this problem. If met with success, these integrated programs may aid coral resource managers throughout the U.S. and FAS in the development of a common set of diagnostic tools to help affect positive change in coral reef ecosystems.

This report is structured to provide information according to the primary threats, topics, and goals outlined in the *National Coral Reef Action Strategy* (NCRAS; NOAA, 2002) and other guidance documents developed by the U.S. Coral Reef Task Force (USCRTF) and its member organizations. Following the Executive Summary, which distills general conclusions from the entire document, an introductory chapter provides background information about the distribution of coral reef ecosystems in the U.S. and FAS, the different types of reefs that occur in these areas, and an estimate of the potential extent of coral reef ecosystems (including reefs, seagrass and macroalgae beds, sand patches, etc.) for each jurisdiction. The third chapter summarizes the current understanding of the 13 key natural and anthropogenic threats to coral reef ecosystems that were identified in the NCRAS. An additional 'other' threat category was included to allow writing teams to characterize threats that may be important or unique to a specific jurisdiction, but do not appear on the NCRAS list of key threats.

Chapters 4 through 17 comprise the heart of this report. In these chapters, the local writing teams characterized the current understanding of the condition of the coral reef ecosystems in their jurisdictions. Writing teams were asked to: 1) describe the geographical distribution of reefs and provide salient background information; 2) discuss how each of the key threats has manifested in their area; 3) describe existing monitoring programs and identify specific data sets upon which their assessments are based; 4) present methods, results, and discussion for each monitoring data set, organized around the three primary themes of water quality, benthic habitats, and associated biological communities; 5) introduce the conservation and management actions currently being undertaken to respond to issues of concern; and 6) provide an overall summary of the status of each jurisdiction's coral reef ecosystems and priority recommendations for future research and management alternatives.

Finally, the National Summary chapter synthesizes and integrates the results and conclusions from each of the preceding chapters to present broad-scale conclusions from a national perspective. The structure of the National Summary chapter reframes the results of the jurisdiction chapters in the context of the goals identified in the NCRAS. Grouping the information in this way clearly demonstrates how the report conclusions can help measure progress towards overarching NCRAS goals and provide a means to evaluate the effectiveness of management actions.

This report represents an evolving effort to determine the condition of coral reef ecosystems at both local and national scales. To do this, scientists must ask the right questions, and then design effective studies to gather data with sufficient frequency to confidently answer those questions. This report serves as a vehicle for the dissemination of information about data collection activities in the U.S. and FAS. As more monitoring data are collected and analyzed, scientists will be better equipped to present time series information and provide condition reports that address all aspects of these complex and dynamic ecosystems.

Another objective of this report is to increase the participation of scientists and managers at all levels in synthesizing all available information to provide the most robust, integrated assessments possible. Data collection and integrated reporting of information are crucial to management efforts that strive to protect and conserve coral reefs, their associated habitats, and the organisms that depend on them. It is hoped that, through this and future reporting efforts, gaps in the current state of knowledge about U.S. coral reef ecosystems will be identified and filled, and that the availability of up-to-date, accurate, comprehensive scientific information will enable managers to slow or even halt the general decline in coral reef ecosystem health that has become evident in the last several decades.

EXECUTIVE SUMMARY

For over three decades, scientists have been documenting the decline of coral reef ecosystems, amid increasing recognition of their value in supporting high biological diversity and their many benefits to human society. Coral reef ecosystems are recognized for their benefits on many levels, such as supporting economies by nurturing fisheries and providing for recreational and tourism opportunities, providing substances useful for medical purposes, performing essential ecosystem services that protect against coastal erosion, and providing a diversity of other, more intangible contributions to many cultures. In the past decade, the increased awareness regarding coral reefs has prompted action by governmental and non-governmental organizations, including increased funding from the U.S. Congress for conservation of these important ecosystems and creation of the U.S. Coral Reef Task Force (USCRTF) to coordinate activities and implement conservation measures [Presidential Executive Order 13089].

Numerous partnerships forged among Federal agencies and state, local, non-governmental, academic and private partners support activities that range from basic science to systematic monitoring of ecosystem components and are conducted by government agencies, non-governmental organizations, universities, and the private sector. This report shares the results of many of these efforts in the framework of a broad assessment of the condition of coral reef ecosystems across 14 U.S. jurisdictions and Pacific Freely Associated States. This report relies heavily on quantitative, spatially-explicit data that has been collected in the recent past and comparisons with historical data, where possible. The success of this effort can be attributed to the dedication of over 160 report contributors who comprised the expert writing teams for each jurisdiction. The content of the report chapters are the result of their considerable collaborative efforts.

The writing teams, which were organized by jurisdiction and comprised of experts from numerous research and management institutions, were provided a basic chapter outline and a length limit, but the content of each chapter was left entirely to their discretion. Each jurisdictional chapter in the report is structured to: 1) describe how each of the primary threats identified in the National Coral Reef Action Strategy (NCRAS) has manifested in the jurisdiction; 2) introduce ongoing monitoring and assessment activities relative to three major categories of inquiry – water quality, benthic habitats, and associated biological communities – and provide summary results in a data-rich format; and 3) highlight recent management activities that promote conservation of coral reef ecosystems.

Due to the wide variety of monitoring and assessment techniques employed by each jurisdiction, as well as the variations in spatial and temporal resolution of the data being collected, it is necessary to evaluate each jurisdiction independently over time and resist the temptation to compare jurisdictions. Only data collection efforts that employ consistent methods across jurisdictions will allow for the comparison of data values; such regional efforts are underway and are beginning to yield results. At this point, however, the limited ability to make cross-jurisdictional data comparisons restricted the authors of the National Summary chapter to conclusions that are primarily qualitative. Still, useful conclusions can be drawn with regard to variables being monitored, data gaps that exist, general trends in the condition of resources, and national-level progress toward conservation activities.

Ultimately, the goal of this report is to answer the difficult but vital question: what is the condition of U.S. coral reef ecosystems? Coral reef ecosystems clearly are beset by a wide array of significant threats, and while managers and scientists may be able to demonstrate improvements in some aspects of an ecosystem, deterioration in other aspects may yield an overall conclusion of 'no change' or decline. A valid response to the above question is that it is too soon to tell, not because deterioration or recovery is in an early stage, but because the necessary long-term datasets that quantify such conditions have not been amassed. Few monitoring programs have been in place for longer than a decade, and many have been initiated only within the past two to five years. Some of these monitoring programs are still in their infancy and have not collected enough data to provide conclusive results. With continued support of these critical monitoring activities, however, trends may become more apparent over time.

Major conclusions of this report related to the threats and stressors impacting coral reef ecosystems indicate that some appear to be intensifying while others are decreasing in intensity. Climate change was identified by 11 of the 14 jurisdictions (78%) as being a moderate (6) or high (5) threat to coral reef ecosystem resources.

Climate change, whether due to natural variability or human activity, is central to several of the threats impacting coral reef ecosystems. Potential impacts from climate change on coral reef ecosystems include modification of water chemistry and sea level rise that may affect coral growth, the greater incidence and prevalence of coral bleaching associated with increased sea surface temperatures, and the increased intensity and frequency of storm events. Coastal development was cited as a moderate (2) or high (8) threat in 10 of the jurisdictions. Coastal development and population growth, whether permanent or temporary (such as in the case of tourism), are correlated with the intensification of several threats because development frequently translates to increases in pollution entering the marine environment; sedimentation from construction, agriculture, and road-building activities; and physical damage from recreational users through trampling, vessel groundings, or the use of anchors in fragile habitats. Another urgent threat, which was cited as a moderate (6) or high (8) threat by all of the 14 jurisdictions, stems from fishing. Changes in the populations of marine organisms, and fish in particular, can have far-reaching cascade effects throughout the ecosystem. For example, the removal of herbivorous fish may precipitate changes in benthic communities by favoring algal species that can outcompete corals following a release of predation pressure. The removal of top level predators may have a cascading effect on the entire ecosystem by reducing overall ecosystem productivity and upsetting the balance of energy flow throughout the system with unknown consequences.

Improvements in the status of some threats have also been documented. One positive development has been the removal of over 400 tons of marine debris, largely nets and fishing line, from the shallow reefs of the Northwestern Hawaiian Islands. In addition, many jurisdictions continue to install mooring buoys to help minimize anchor damage while facilitating access for recreational activities. Management of the trade in aquarium fish has resulted in more protection for some U.S. coastal areas, and implementation of the provisions of the Convention on International Trade in Endangered Species of Wild Flora and Fauna and the Federal Endangered Species Act extend protection to coral species, largely prohibiting their sale or exportation. In addition, nine grounded, rusted-out fishing vessels were removed from a reef flat in Pago Pago Harbor, American Samoa. These and other important improvements are detailed in the jurisdictional chapters.

Other important conclusions can be drawn in relation to advancements in management and conservation science. Major highlights include the progress made in the development of tools that scientists and coastal managers use to measure the condition of the resources. Digital map products of nearshore (< 30 m) coral reef habitats now exist for most jurisdictions and are being used to structure monitoring programs, inform management decisions, and build capacity in current and future coastal managers. Complementary multibeam maps of mid-depth (>20 m) environments are also being developed, and products are becoming increasingly available. Techniques to investigate genetic linkages among populations and identify and track the spread of coral disease are becoming more sophisticated and more widely disseminated. Other research is being conducted to determine optimal restoration techniques and calculate resource damages, which enables natural resource trustees to seek compensation for injured coral reef ecosystems and devote those funds toward restoration and monitoring activities. Advances in satellite observing systems and the deployment of additional buoys that monitor oceanographic conditions continue to improve the ability to characterize coral reef ecosystems.

As implementation of the NCRAS continues, it is crucial that existing gaps, especially in the shortage of trained personnel and infrastructure, be filled with additional resources. Without the availability of reliable, consistent data collected at sufficient spatial and temporal resolutions, answering management questions and evaluating management effectiveness cannot be confidently achieved.

This report represents the second in an ongoing series of reports that integrate the wealth of quantitative and qualitative information on the condition of U.S. coral reef ecosystems that has emerged since the inception of the USCRTF. Future reporting efforts will continue to document progress toward the goals outlined by the USCRTF and in the NCRAS and contribute to a broader understanding of U.S. coral reef ecosystems.

INTRODUCTION

Much of the vast ocean realm that covers the planet is composed of very deep water. Thousands of meters below the surface, the bottom of the ocean lies in complete darkness and is sparsely populated. However, where the seafloor slopes up toward the continental shelf and the flanks of oceanic islands, marine life becomes more concentrated due to the greater availability of sunlight and nutrients from upwelled water and terrestrial inputs. Tropical nearshore areas are comprised of a variety of habitats which are frequently classified according to their dominant substrate, geological, and biological features. While some sandy or rocky substrates are sparsely colonized or devoid of life, others provide habitat for seagrasses and other plant and algal communities. In some hardbottom areas where conditions are right, the seafloor is colonized by a variety of tiny colonial invertebrates known generally as corals. Over millions of years, these tiny organisms have created enormous underwater structures that provide a foundation for an elaborate community of creatures that together constitute one of the most amazing and diverse ecosystems on the planet. An oasis in a vast ocean, coral reefs attract and concentrate a breathtaking assemblage of colorful and fanciful organisms that challenge the limits of the imagination (Figure 2.1). Scientists estimate that this highly complex interdependent system supports over one million species, with potentially millions more yet to be described. In addition to their importance for biodiversity, coral reef ecosystems are important for human communities as well, by performing essential ecosystem services; supporting major fishery resources; providing educational, social, recreational, cultural, and medicinal opportunities; and generating economic benefits for millions of people, especially through coastal tourism.

Figure 2.1. Coral reefs provide the structure that attracts and concentrates a colorful assortment of interesting organisms. Photo: NOAA NOS.

The vibrant underwater world of coral reefs comprises less than 1% of the surface of the planet, primarily due to the narrow physiological tolerances of hermatypic, or reef-building, corals. Nearly all coral reefs are found throughout tropical and subtropical oceans between 30ºS and 30ºN latitude, primarily in waters less than 30 m deep (Huston, 1985; Grigg and Epp, 1989). Their distribution is influenced by nutrient availability, salinity, light, substrate, sediment type, temperature, and exposure to wave action (Lalli and Parsons, 1995; Hoegh-Guldberg, 1999; Szmant, 2002; Leichter et al., 2003; Wolanski et al., 2003). Seawater temperatures in coral ecosystems generally range between 18°–29°C (Glynn, 1996; Barnes and Hughes, 1999), although some corals seem to have adapted to tolerate slightly higher temperatures for short periods of time. Many organisms living in coral reef ecosystems are photosynthetic and are restricted to shallow depths with sufficient light penetration (Veron, 1986; Barnes, 1987).

Shallow-water coral reef ecosystems under United States jurisdiction occur in the shared waters of the Caribbean Basin, Gulf of Mexico, and Atlantic Ocean near the east coast of Florida, and across the Pacific Ocean on both sides of the equator. The Freely Associated States of the Republic of Palau, the Federated States of Micronesia (FSM) and the Republic of the Marshall Islands (RMI) are located in the tropical western Pacific Ocean. Pacific reef systems tend to proliferate on oceanic islands in a number of habitats ranging from offshore banks to shallow atoll lagoons. Many Pacific islands formed as a result of volcanic activity beneath the earth's surface and/or uplift of limestone or sedimentary rock. Movement of the enormous Pacific plate across tectonic 'hot spots' resulted in the creation of several long island chains which developed complex reef systems over time. In general, as soon as lava cools and forms stable, hard substrate, corals begin to colonize the submarine margins of islands as narrow fringing reefs. As the islands age, coral reefs continue to gradually accrete while the central land area slowly erodes and subsides, until, after millions of years, the island itself may disappear completely, leaving a necklace of low sand islets and extensive reefs surrounding a broad lagoon (Figure 2.2). Cores taken from coral reefs near Bikini and Enewetak Atolls, Marshall Islands revealed coral deposits nearly 1.4 km thick, which are believed to be 50-59 million years old (Spalding et al., 2001). Many stages of island development, from creation by active volcanoes to submergence beneath the surface, are evident in the archipelagos of the Pacific.

In contrast to most Pacific reefs, many reef formations in the Caribbean Basin have developed in shallow-water environments near relatively stable continental land masses. Coral reef ecosystems near continents tend to be older than reef systems on many oceanic islands, and are often subject to greater terrestrial inputs, such as freshwater, sediments and nutrients. To a large extent, reefs located on broad continental shelves benefit from their close association with estuaries and mangrove forests which filter out harmful nutrients and sediments as well as nurture large juvenile fish populations important to reef ecosystems. In turn, shallow or emergent reefs protect fragile coastlines by absorbing wave action during storms and high swells.

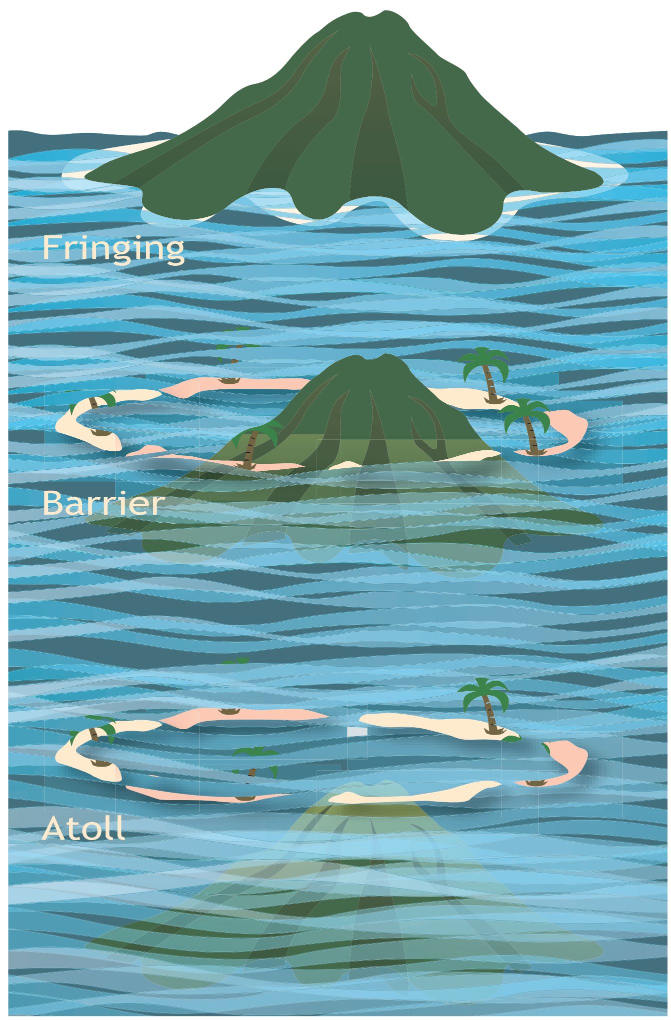

Figure 2.2. A diagram depicting the evolution of a coral ecosystem on a volcanic island. As the island ages, wind and rain erode the land while reefs along the island perimeter accrete.

Coral Reef Ecosystem Components

A coral ecosystem can be considered a mosaic of habitats defined by substrate, cover, and structural zones (Figure 2.3). Benthic habitats found in a coral ecosystem include unconsolidated sediments (e.g., sand and mud); mangroves and other emergent vegetation; submerged vegetation (e.g., seagrass and macroalgae); hermatypic coral reefs and associated colonized hardbottom habitats (e.g., spur and groove, individual and aggregated patch reefs, and gorgonian-colonized pavement and bedrock); and uncolonized hardbottom (e.g., reef rubble and uncolonized bedrock). Typical structural zones include the reef crest, forereef, reef flat, backreef and lagoon (FMRI, 1998; Kendall et al., 2001; Coyne et al., 2003; NOAA, 2003). While hermatypic coral reefs are important marine habitats, other habitats, such as bare sand or seagrass, are also important to the overall ecology and function of the ecosystem. Mangrove forests, hardbottom coral habitats, submerged vegetation habitats, and softbottom sand and mud habitats serve as important spawning and growth areas (Ogden and Ehrlich, 1977; Lindeman, 1986; Parrish, 1989; Christensen et al., 2003; Kendall et al., 2003; Mumby et al., 2004).

Humans in Coral Reef Ecosystems

For thousands of years, humans have lived in coastal areas adjacent to coral reef ecosystems. Coastal and island communities regularly harvested marine resources for food, and in some areas, marine resources provided the primary, if not only, source of protein. In addition to providing basic sustenance to island and coastal communities, reefs have inspired art and legends and provided humans with natural products, jewelry, pharmaceuticals, building materials, transportation pathways, and recreational opportunities. Many cultures cite strong cultural ties to reef ecosystems and resources, and have gone to great lengths to protect the resources from overexploitation, as evidenced by the elaborate systems of reef tenure and conservation practices devised by some Pacific island communities to regulate the use of marine resources.

Figure 2.3. Examples of some of the types of benthic habitats found in the shallow-water coral ecosystems of the United States. Left to right and top to bottom, these are:
1. Mangrove, Salt River, St. Croix, USVI
2. Bare Sand, Midway Atoll, NWHI
3. Macroalgae and sand, Puerto Rico
4. Hardbottom with macroalgae, Kure Atoll, NWHI
5. *Thalassia* seagrass, St. Croix, USVI
6. Linear reef with live coral, Midway Atoll, NWHI
7. Hardbottom with crustose coraline algae, Lisianski, NWHI
8. Spur and groove, Mona Island, Puerto Rico
9. Uncolonized pavement with sand channels, Mona Island, Puerto Rico
Photos: CCMA-BT.

Reef ecosystems also provide intangible benefits that have inspired a long romance with the coast and draw millions of people each year to visit or live near coastal areas of the tropics. On the U.S. mainland alone, 10.5 million people live in areas adjacent to coral reef ecosystems, and island populations continue to increase through population growth and immigration. In fact, population growth and associated development has been identified as a key threat in American Samoa and several other small island states. Tourism and recreational activities also temporarily increase the number of people inhabiting coastal areas. A recent report by the U.S. Commission on Ocean Policy (2004) provides evidence of the increasing importance of tourism and recreation to the economies of coastal communities. Staggering numbers of people visit coastal areas every year to fish, dive, surf and recreate. As a result, the economic benefits from coastal and ocean resources have experienced a fundamental shift from a products-based to services-based system, with tourism and recreation generating more income than mineral and living resource extraction, transportation, and shipbuilding (U.S. Commission on Ocean Policy, 2004).

Coral reef ecosystems found in the U.S. support millions of dollars worth of goods and services (e.g., commercial and recreational fisheries, tourism, etc.). Recent estimates indicate that activities associated with Hawaii's coastal ecosystems produce about $364 million for the state's economy every year (Davidson et al., 2003). Activities associated with Florida's coastal ecosystems contribute an estimated $2.7 billion annually to its economy (Johns et al., 2001). The intangible values of U.S. coral reef ecosystems–such as aesthetic, ecological, and cultural values–are difficult to quantify and are excluded from these economic value estimates.

All of this attention and interest in coastal areas in general, and coral reef ecosystems in particular, are not without consequence. Against a background of natural disturbances, increased disturbance from human activities reduces the resilience of coral reef ecosystems and can contribute to alarming declines in their overall health. Key anthropogenic stressors include climate change and bleaching; disease; urban and tourism-related coastal development; sedimentation; toxic chemical pollution; overfishing; physical damage from ships, boats, and anchors; invasions of exotic species; and marine debris (Davidson, 2002; Wilkinson, 2002; Gardner et al., 2003; NCRAS, 2002).

Setting

The U.S. is responsible for managing and conserving extensive shallow-water coral reef ecosystems within its maritime boundaries in cooperation with local governments of various types. U.S. States with coral reef ecosystems include Florida and Hawaii. U.S. Territories include the U.S. Virgin Islands (USVI), American Samoa, and Guam. The Commonwealths of Puerto Rico and the Northern Marianas Islands also have coral reef ecosystems. Navassa Island is an unincorporated U.S. Territory near Haiti. The Flower Garden Banks lie in Federal waters off the coast of Texas, and some of the banks are managed by the National Oceanic and Atmospheric Administration's (NOAA) National Marine Sanctuary Program in cooperation with the U.S. Department of the Interior's Minerals Management Service. The Northwestern Hawaiian Islands (NWHI) are jointly managed by the U.S. Fish and Wildlife Service (USFWS), the State of Hawaii, and the NWHI Coral Reef Ecosystem Reserve, but the islands have been proposed as the nation's 13th national marine sanctuary, and sanctuary designation seems likely in the near future. The Pacific Remote Island Areas (PRIAs) of the Line and Phoenix Islands and Johnston Atoll are primarily managed by the USFWS as national wildlife refuges, and jurisdiction over Wake and Johnston Atolls is currently in the process of being transferred from the U.S. Department of Defense to the USFWS. The Freely Associated States (FAS) of the RMI, FSM, and the Republic of Palau are sovereign nations that maintain a close economic association with the U.S. and claim similar maritime boundaries. Coral ecosystems of the U.S. and FAS cover a vast area and are distributed across large portions of the earth's surface (Figures 2.4 and 2.5).

Using depth curves depicted on nautical charts as a surrogate for the potential distribution and extent of shallow-water coral ecosystems, Rohmann et al. (in press) estimated that 36,816 km^2 of coral ecosystems may potentially be found in U.S. waters less than 10 fathoms (approximately 18 m) deep, and an estimated 143,058 km^2 in waters less than 100 fathoms (approximately 183 m) deep (Table 2.1).

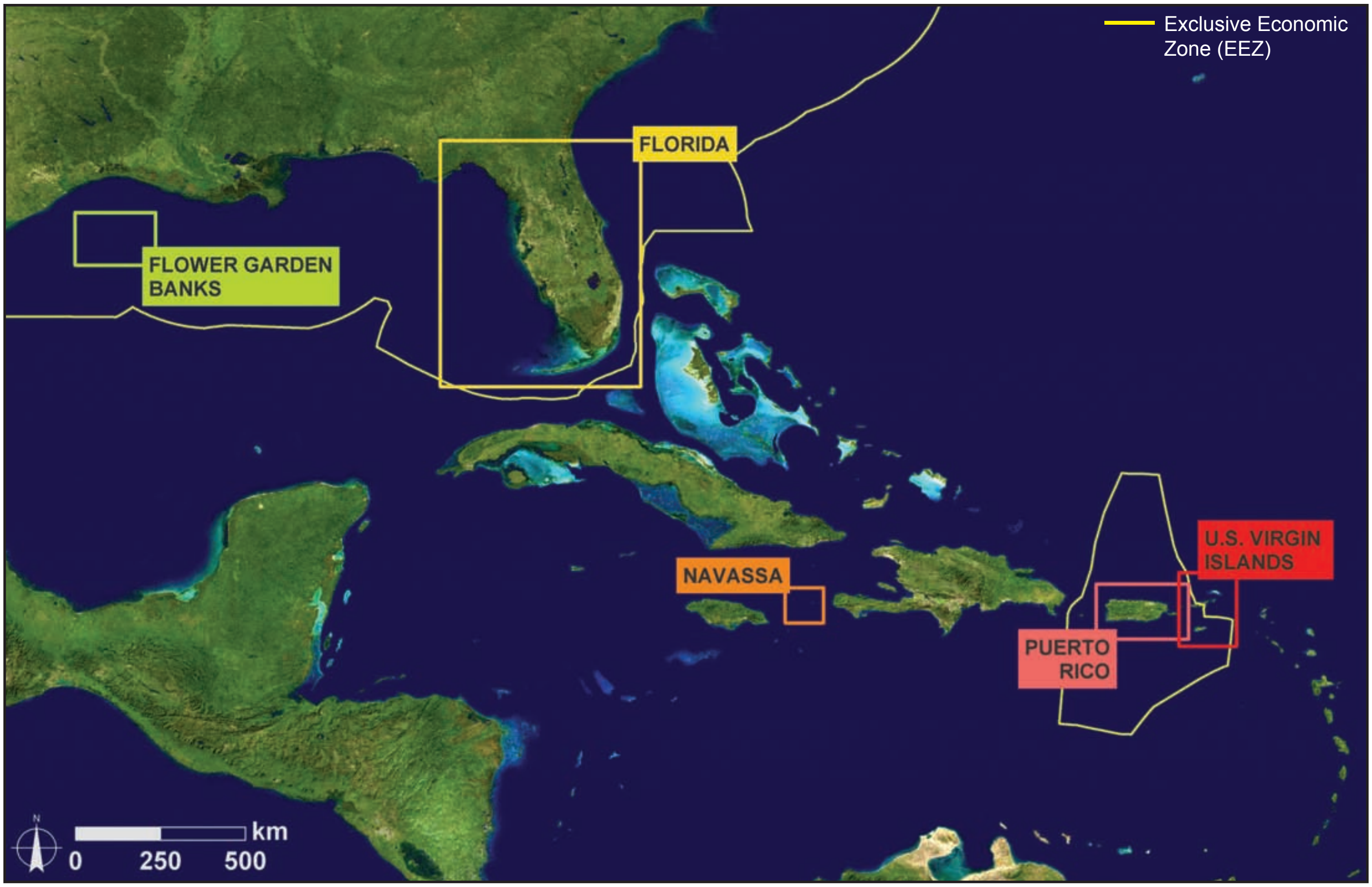

Figure 2.4. A map depicting the location of U.S. coral reef ecosystems in the Atlantic Ocean, Gulf of Mexico, and Caribbean Sea.

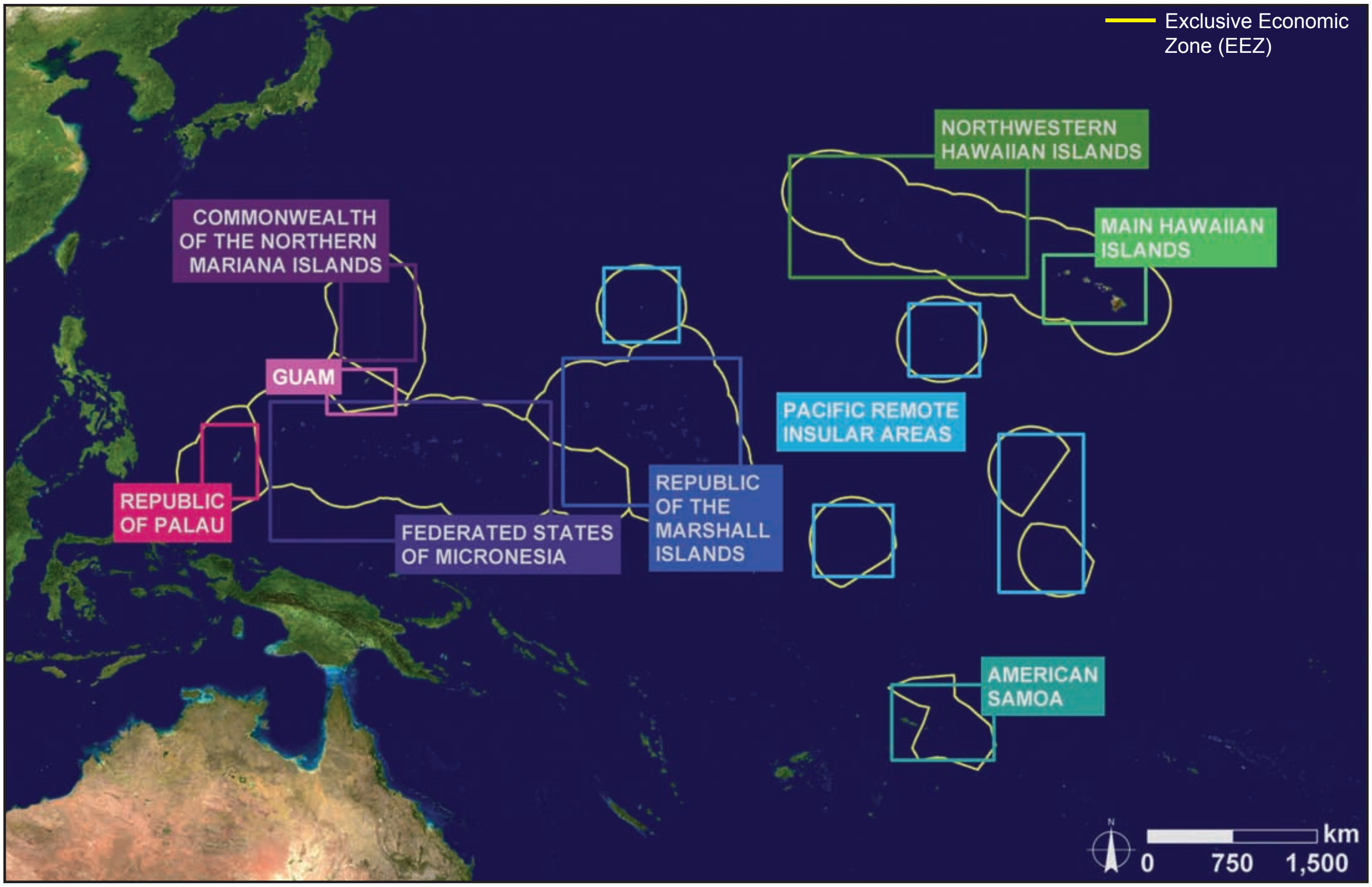

Figure 2.5. A map depicting the location of U.S. coral reef ecosystems in the Pacific Ocean. Maps: A. Shapiro.

Table 2.1. The potential area of coral ecosystems within the United States territorial sea and exclusive economic zone.[a] The area inside the 10-fathom (18 m) or 100-fathom (183 m) depth curves was derived from NOAA nautical charts.[b] Estimates for the RMI, FSM, and Republic of Palau were derived from Landsat satellite imagery. Source: Rohmann et al., in press.

LOCATION	ESTIMATED AREA INSIDE 10-FATHOM (18 M) DEPTH CURVE (km^2)	ESTIMATED AREA INSIDE 100-FATHOM (183 M) DEPTH CURVE (km^2)	AREA OF SHALLOW WATER (<15 M) ESTIMATED FROM LANDSAT IMAGERY (km^2)
USVI[3]	344	2,126	
Puerto Rico[4]	2,302	5,501	
Navassa	3	14	
Southern Florida[5]	30,801	113,092	
Flower Gardens NMS[6]	0	164	
Main Hawaiian Islands[7]	1,231	6,666	
Northwestern Hawaiian Islands[8]	1,595	13,771	
American Samoa[9]	55	464	
Pacific Remote Island Areas[11]	252	436	
Marshall Islands[12]			13,456
Federated States of Micronesia[12]			14,517
Northern Mariana Islands[10]	124	476	
Guam	108	276	
Palau[12]			2,529

1 The U.S. territorial sea (and contiguous zone) extends 12 nautical miles from the baseline of each territory or coastal State. The U.S. exclusive economic zone extends 200 nautical miles from a line coterminous with the seaward boundary (baseline) of each territory or coastal State.
2 Area estimates from Rohmann et al., in press.
3 The U.S. Virgin Islands includes the islands of St Thomas, St John, and St Croix.
4 Puerto Rico includes the islands of Puerto Rico, Desecheo, Culebra, Vieques, and Mona.
5 Southern Florida extends along the Atlantic Ocean coast of Florida to Jupiter Inlet, Florida and along the Gulf of Mexico coast of Florida to Tarpon Springs, Florida.
6 The NOAA nautical chart depicts only the 100 fathom depth curve for this location.
7 The Main Hawaiian Islands includes the islands of Hawaii, Maui, Molokai, Lanai, Kahoolawe, Oahu, Kauai, and Niihau.
8 The Northwestern Hawaiian Islands includes the islands and atolls of Nihoa, Necker, French Frigate Shoals, Gardner Pinnacles, Maro Reef, Laysan, Lisianski, Pearl and Hermes, Midway, and Kure. Numerous shallow-water seamounts, such as St. Rogatein Bank or Raita Bank, also are located in the NWHI.
9 American Samoa includes the islands of Tutuila, Ofu, Olosega, Tau, Swains, and Rose Atoll.
10 The CNMI includes the islands of Rota, Aguijan, Tinian, Saipan, Farallon de Medinilla, Anatahan, Sarigan, Guguan, Alamagan, Pagan, Agrihan, Asuncion, Maug, and Farallon de Pajaros.
11 The U.S. Flag Islands include Howland, Baker, and Jarvis Islands, Palmyra, Johnston, and Wake Atolls, and Kingman Reef.
12 Unpublished estimates of potential coral ecosystem area visible in Landsat satellite imagery. Area estimates generally include seafloor features visible in water 18–27 m (10–15 fathoms) deep. NOAA does not produce nautical charts of these locations.

At this time, nautical charts depicting either depth or extent of shallow-water coral ecosystems for the FAS are unavailable. However, an analysis of seafloor features visible in Landsat satellite imagery suggests that coral ecosystems in the FAS may comprise about 30,501 km^2 (Table 2.1).

The spatial extent of shallow water coral ecosystems is just one of several variables that differentiate coral reef ecosystems among U.S. jurisdictions. Perhaps an even more important metric is habitat quality. This metric can be characterized in a number of ways, but high habitat quality conveys the presence of a rugose and varied assemblage of healthy benthic organisms that provide structure for a robust and diverse assemblage of organisms within an environment characterized by excellent water quality with low turbidity, limited nutrients, and few contaminants. Such healthy reef ecosystems tend to support more biomass and a greater number of species than degraded areas.

Biodiversity, or the number and abundance of species that exist within a region, is another important variable. Global marine biodiversity is believed to be highest in the western Pacific Ocean, near eastern Indonesia, and the total number of species tends to decline with distance from this biological hot spot. As a result, among U.S. and FAS jurisdictions, the Republic of Palau and other western Pacific locations (i.e., Guam, CNMI, FSM and the Marshall Islands) naturally contain a higher number of species than do locations in the eastern Pacific, Caribbean, Atlantic or Gulf of Mexico.

The degree of endemism, or the number of species that are found only within a particular location or region, is another important factor that distinguishes the jurisdictions. Scientists studying remote areas, such as the NWHI, which have a relatively low overall number of species, have recorded a large number of endemic species. Endemic species contribute greatly to the overall diversity of life on the planet and thus constitute an important conservation priority.

Among other important distinguishing characteristics among the jurisdictions is the actual composition of the coral and fish communities. Highly disturbed ecosystems often are dominated by species of coral and macroalgae that are opportunistic and tolerant of negative natural and anthropogenic impacts. Heavily fished ecosystems often are dominated by small, undesirable food fish not targeted by fishers. For corals, the prevalence of long-lived versus opportunistic species may provide some indication of the level of disturbance experienced in a region and thereby the health of the system as a whole.

The prevalence of threats and stressors to coral reef ecosystems also varies among and within jurisdictions. The NCRAS identified thirteen major threats and stressors to coral reef ecosystems that are introduced in the following chapter (NCRAS, 2002). Chapter 4 begins a series of fourteen jurisdiction chapters, in which each jurisdictional writing team provides a condition report according to a standardized structure. Each chapter begins with a few paragraphs of contextual information and a discussion of how each of the thirteen primary threats currently affects their jurisdiction. That information is followed by a summary of current monitoring activities, and project results which are grouped into the three categories of water quality, benthic habitats, and associated biological communities. They then discuss current conservation management activities pertinent to their jurisdiction before providing overall conclusions and recommendations for further action. The final chapter serves as a national-level summary of the preceding information, in addition to providing information about selected national-level developments that are pertinent to all the jurisdictions.

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Threats and Stressors to U.S. Coral Reef Ecosystems

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Human activity is commonly identified as a major contributor to the observed global deterioration of coral reef ecosystem health, with loss of live coral cover, declining species diversity, and reduced abundance reported in many areas (NOAA, 2002a; Wilkinson, 2002; Turgeon et al., 2002). Degradation in the structure and functioning of coral reef ecosystems results in a concomitant loss in the intrinsic value of the ecological system, as well as a significant loss in the provision of goods and services for society. Approximately 8% of the global population live within 100 km of a coral reef (Bryant et al., 1998) and many local communities and national economies are directly dependent on coral reef ecosystems for tourism revenue, food, and coastal protection (Spurgeon, 1992). As such, human pressures can be intense, and developing strategies to mitigate stressors is a complex task.

Shallow-water coral reef ecosystems experience a wide range of physical, biological, and chemical threats and stressors, which stem from both anthropogenic and natural causes. Threats are defined as environmental trends with potentially negative impacts. Stressors are defined as factors or processes that harm ecosystem components, causing lethal or sublethal negative effects. Categories of stressors include chemical (e.g., pollution), physical (e.g., extreme events), and biological (e.g., invasive species) stressors, and the relationship between key stressors and the threats discussed in this document are listed in Table 3.1. The relative importance of each threat varies substantially among jurisdictions and individual reefs.

Table 3.1. This table is a crosswalk between the threats identified in "A National Coral Reef Action Strategy" (NOAA, 2002a) and the stressors identified by the National Science and Technology Council's Committee on Environmental and Natural Resources. Source: CENR, 2001.

STRESSORS	POLLUTION	INVASIVE SPECIES	EXTREME EVENTS	RESOURCE AND LAND USE	CLIMATE CHANGE
Climate Change and Bleaching					X
Diseases	X				
Tropical Storms			X		
Coastal Development and Runoff	X			X	
Coastal Pollution	X				
Tourism and Recreation				X	
Fishing				X	
Trade in Coral and Live Reef Species				X	
Ships, Boats and Groundings				X	
Marine Debris	X				
Aquatic Invasive Species		X			
Security Training Activities				X	
Offshore Oil and Gas Exploration				X	

Multiple Stressors

The occurrence of multiple sequential stressors and the synergistic interaction between stressors can be especially detrimental to coral reef ecosystems. For example, in many parts of the Caribbean, the compounding effects of eutrophication, decline of key herbivores from disease and overfishing, and impacts of hurricanes and coral bleaching have likely led to the observed shifts in community structure from coral-dominated to macroalgal-dominated reefs (Hughes, 1994; McManus et al., 2000). Generally, the effects of multiple stressors are poorly understood, making it difficult or even inappropriate to assign a single cause to local or regional

1 NOAA Fisheries, Office of Habitat Conservation
2 NOAA Oceans and Coasts, NCCOS, Center for Coastal Monitoring and Assessment, Biogeography Team
3 NOAA Oceans and Coasts, National Centers for Coastal Ocean Science
4 NOAA Satellites and Information, Coral Reef Watch Program
5 NOAA Oceans and Coasts, Special Projects Office

widespread decline. The challenge now is to understand the complex interactions among stressors by refining existing techniques and developing new multidisciplinary approaches aimed at detailing mechanisms and predicting effects at multiple spatial and temporal scales.

Determining how humans utilize coral reef ecosystems and estimating the social and economic costs and benefits of those uses are key steps for resource managers. Techniques such as causal chain analysis (e.g., in Belausteguigoitia, 2004) may provide a useful approach for modeling and communicating the many significant cause-effect linkages between human systems and coral reef ecosystems.

Climate Change and Coral Bleaching

Climate change refers to any change in climate over time, whether due to natural variability or human activity (IPCC, 2001). Over the 20th century, mean near-surface air temperature over land and mean sea surface temperature (SST) increased 0.6 ± 0.2°C, with the 1990s being the warmest decade and 1998 being the warmest year since 1861 when instrumental records began (IPCC, 2001; Figure 3.1).

Most of the observed warming over the last 50 years may have resulted from an increase in concentrations of greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4) in the atmosphere (IPCC, 2001; NRC, 2001). The atmospheric concentration of CO_2 has increased by 31% since the beginning of the industrial revolution, and represents a level that has not been exceeded in at least the last 420,000 years (Petit et al., 1999), and probably not exceeded in over 24 million years (Pearson and Palmer, 2000). The rate of increase of CO_2 concentration has been about 0.4% per year over the last two decades (IPCC, 2001). Such increases have been shown to decrease the calcium carbonate ($CaCO_3$) saturation state of seawater and the calcification rates of corals (Kleypas et al., 1999; Feely et al., 2004). In combination with potentially more frequent bleaching episodes, reduced calcification could reduce the energy that a coral would otherwise apply to reproduction and thereby impede a reef's ability to keep pace with sea level rise (IPCC, 2001) or recover from other potential impacts of climate change.

Elevated water temperatures cause corals to bleach, a process that is characterized by the loss of zooxanthellae (a symbiotic alga) from coral tissues. Increased ultraviolet irradiance, typically from unusually calm, clear waters, may aggravate the impact of increased temperatures (Lesser and Lewis, 1996). Although corals may recover from brief episodes of bleaching, if ocean temperatures warm too much or remain high for an extended period, bleached corals often will die. Several correlative field studies show a close association between warmer than normal conditions (at least 1°C higher than the annual maximum) and the incidence of bleaching (Hoegh-Guldberg, 1999). In 1997-1998, an estimated 16% of the world's coral reefs were seriously damaged in a global coral bleaching event associated with high SST

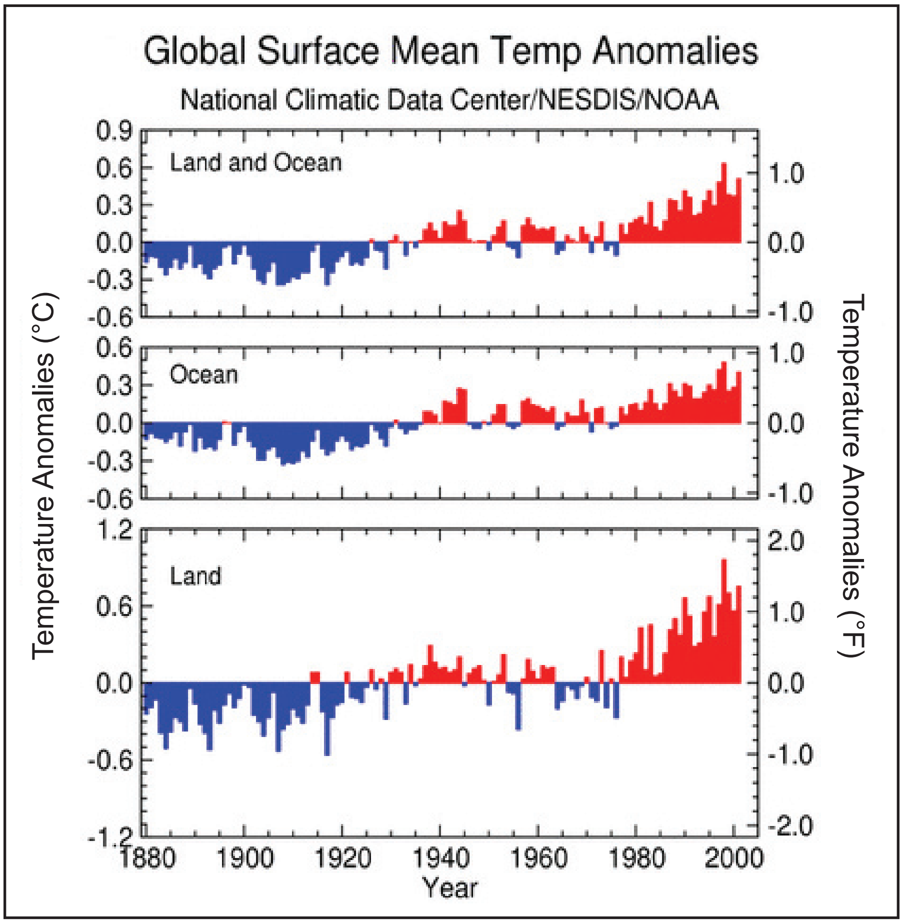

Figure 3.1. Mean global temperature anomalies over the period 1880-2001. Zero line represents the long term mean temperature throughout the period, while red and blue bars indicate annual departures from that mean. Source: NOAA's National Climactic Data Center.

which was apparently enhanced by an extreme El Niño event (Wilkinson, 1998). A U.S. Department of State report to the U.S. Coral Reef Task Force (USCRTF; Pomerance, 1999) concluded that the severity and extent of the 1998 event cannot be explained by El Niño alone, and that the "...geographic extent, increasing frequency, and regional severity of mass bleaching events are likely a consequence of a steadily rising baseline of marine temperatures..."

Several bleaching events in Florida, the U.S. Caribbean, and the U.S. Pacific have been associated with elevated SST events during the 1980s and 1990s, and especially in 1997-1998. The occurrence of bleaching is highly variable in both time and space, but generally affects shallow-water reefs with reduced water circulation. In U.S. waters, substantial bleaching has been observed on shallow reefs off the coasts of Florida, the Commonwealth of the Northern Mariana Islands (CNMI), Palmyra Atoll (PRIAs), and portions of the Northwestern Hawaiian Islands (NWHI), and recent data suggest that elevated SST is still a significant threat to coral reefs in the U.S. Caribbean (Nemeth and Slakek-Nowlis, 2001). Palau suffered the worst coral bleaching mortality of any U.S. associated region during the 1997-1998 global bleaching event (Wilkinson, 2000). During a 2002 summertime warm water event in the higher latitudes of the mid-Pacific, Midway Atoll (NWHI) experienced unprecedented bleaching, including considerable mortality (Liu et al., 2004). Mass bleaching episodes are predicted to reoccur in the future with increasing frequency (IPCC, 2001).

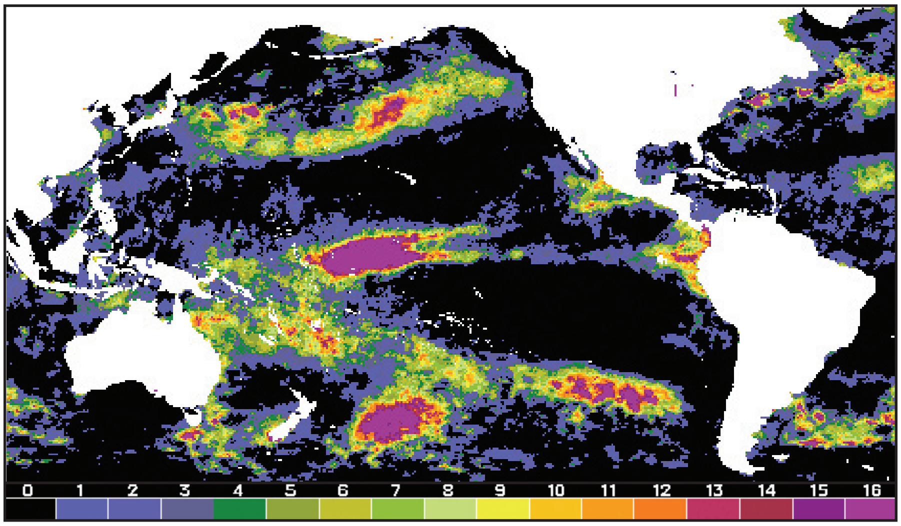

Figure 3.2. 2002 Maximum annual DHW values indicate locations that experienced significant thermal stress, which has been shown to be highly correllated with coral bleaching. Values above 4 represent areas that are likely to experience bleaching, while values above 8 represent areas that are likely to experience significant bleaching with widespread mortality. Source: NOAA's Coral Reef Watch Program.

Coral reef ecosystem managers and stakeholders consistently use one particular satellite-derived index–the Degree Heating Week (DHW)–to gauge accumulated thermal stress on reef ecosystems. The DHW, which was developed by scientists in the National Oceanic and Atmospheric Administration's (NOAA) Coral Reef Watch (CRW) Program, represents the accumulated temperature stress for each 50 x 50 km^2 pixel during the preceding 12-week period as compared to the baseline value calculated for that pixel. The unique baseline value, roughly equal to the expected annual maximum temperature, was empirically determined for each of the 250 km^2 pixels shown in Figure 3.2. To calculate the DHW, temperature deviations (in degrees Celsius) above this baseline are multiplied by the duration of the elevated temperature event (in weeks). For example, if there is a sustained SST of 1°C above the threshold for one week , during a 12-week period, the DHW value will be one; if SST is 2°C above the threshold for three weeks, the DHW value will be six. Figure 3.2 illustrates the distribution of the maximum DHW values for each pixel for 2002.

In-situ observations show that widespread bleaching is most likely to occur at locations where DHW≥4; significant bleaching with widespread mortality is expected where the DHW >8. Table 3.2 shows the maximum annual DHW value in the 14 U.S. jurisdictions with coral reefs for 2001-2003. The DHW values are color-coded to reflect the intensity of accumulated thermal stress [Blue, DHW=0; Green, DHW <4; Orange, 4≤ DHW ≤8; Red, DHW >8]. If a thermal stress event spans two calendar years (e.g., November-January), then the maximum DHW for each of those years may occur during that single event. This is most likely to occur at reefs located near the equator. Such occurrences are shown in Table 3.2 as DHW values enclosed in a grey box. The CRW Program utilizes satellite and *in situ* tools for near real-time, hindcast, and long-term monitoring, modeling, and reporting of environmental conditions that affect domestic and foreign coral reef ecosystems. A full list of the CRW Program's operational products can be found on-line at http://coralreefwatch.noaa.gov (Accessed 2/16/05).

Table 3.2. Maximum annual DHWs for each of the 14 jurisdictions for 2001-2003. The DHW values are color-coded to reflect the intensity of accumulated thermal stress [Blue, DHW=0; Green, DHW<4; Orange, 4≤DHW≤8; Red, DHW>8]. If a thermal stress event spans two calendar years (e.g., November-January), then the maximum DHW for each of those years may occur during that single event. Such occurrences are shown by enclosing the DHW values in a grey box.

JURISDICTION	LOCATION	2001	2002	2003
USVI		Green	Green	Orange
Puerto Rico		Green	Green	Orange
Navassa		Green	Blue	Orange
Florida		Green	Green	Orange
Flower Garden Banks		Blue	Green	Blue
Hawaii	Hawaii	Blue	Blue	Blue
	Oahu	Blue	Blue	Green
	Kauai	Blue	Blue	Blue
Northwestern Hawaiian Islands	Nihoa	Blue	Blue	Blue
	French Frigate Shoals	Blue	Blue	Blue
	Maro Reef	Blue	Blue	Blue
	Lisianski	Blue	Green	Blue
	Midway	Blue	Orange	Blue
	Kure	Green	Red	Blue
American Samoa	Tutuila	Green	Green	Orange
	Rose Atoll	Blue	Green	Orange
USPRIAs	Johnson	Blue	Blue	Blue
	Palmyra	Green	Red (grey box)	Orange (grey box)
USPRIAs (cont.)	Kingman	Green	Red (grey box)	Orange (grey box)
	Baker	Green	Red (grey box)	Red (grey box)
	Wake	Blue	Blue	Blue
	Jarvis	Green	Red (grey box)	Red (grey box)
	Howland	Green	Red (grey box)	Red (grey box)
Marshall Islands	Bikini	Green	Green	Green
	Kwajalein	Green	Orange	Green
	Majuro	Blue	Blue	Green
Federated States of Micronesia	Yap	Green (grey box)	Green (grey box)	Green
	Chuuk	Green (grey box)	Green (grey box)	Green
	Pohnpei	Orange (grey box)	Green (grey box)	Green
	Kosrae	Green	Green	Orange
CNMI	Asuncion	Red	Green	Orange
	Agrihan	Red	Green	Orange
	Pagan	Red	Blue	Green
	Saipan	Green	Green	Green
Guam		Green	Blue	Green
Palau		Green	Green	Green

Diseases in Coral Reef Ecosystems

In the past two decades, there has been a worldwide increase in the reporting of diseases affecting marine organisms, with the Caribbean Basin emerging as a hot spot (Harvell et al., 1999). The first documented coral reef epizootic was the mass mortality of the keystone herbivore, *Diadema antillarum*, which was caused by an unknown waterborne pathogen (Figure 3.3). This disease spread throughout the Caribbean between 1982 and 1983, moving with Caribbean oceanic currents and causing the loss of up to 90-95% of the *Diadema* population (Lessios et al., 1984). Mass mortalities of *Diadema* have contributed to phase-shifts from coral- to algal-dominated reefs in many locations, and the recovery of urchin populations has been slow. Another Caribbean-wide epizootic observed during the 1980s was attributed to a fungal infection in *Thalassia testudinum* seagrasses. In Florida Bay, an estimated 4,000 ha of seagrasses were lost and severe declines were observed across an additional 23,000 ha (Roblee et al., 1991). During one of the best documented of coral disease outbreaks which occurred in the 1980s, two of the dominant reef-building coral species on shallow western Atlantic reefs (*Acropora palmata* and *A. cervicornis*) were virtually eradicated by white-band disease (Aronson and Precht, 2001). The frequency and severity of outbreaks of common as well as newly emerging diseases may increase with changing environmental conditions such as a rise in SST and anthropogenic impacts that: 1) increase the prevalence and virulence of pathogens; 2) facilitate invasions of new pathogens from terrestrial or aerial sources; and 3) reduce host resistance and resilience, thereby facilitating pathogen transmission and infection (Sutherland et al., 2004).

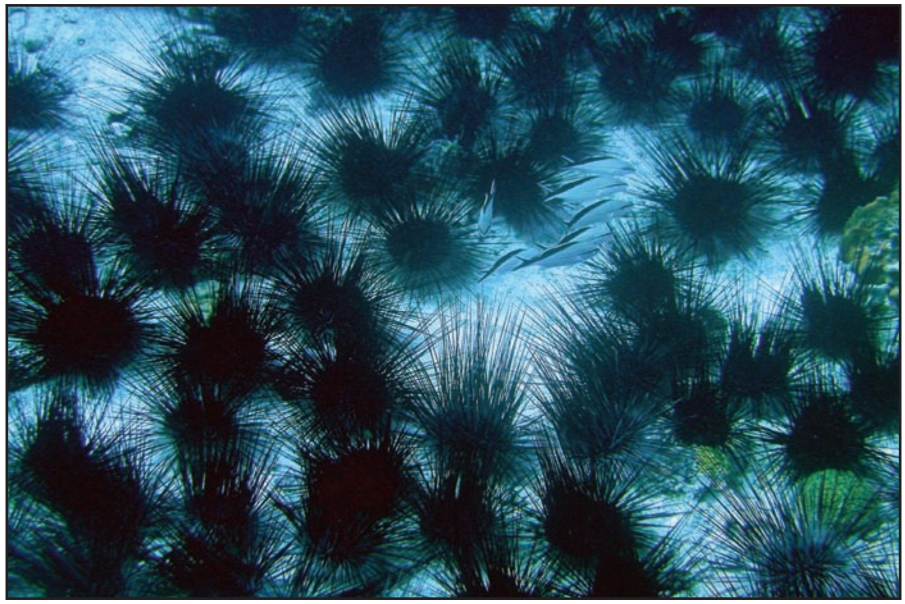

Figure 3.3. Coral disease and mortality from numerous pathogens have been reported with increased frequency since the 1970s. Disease in other ecosystem organisms can also result in cascading effects that can disrupt the entire system. Scientists believe that ~90% of the Caribbean population of *Diadema antillarum*, an important herbivore, was killed by disease in the late 1980s, and the subsequent reduction in grazing pressure allowed for algal overgrowth on many reefs. Populations are beginning to rebound as shown in this photo taken in St. Croix in October 2004. Photo: R. Clark.

Since the early 1990s, scientists have documented a rapid emergence of diseases among corals, with increases in the number of diseases reported, coral species affected, geographic extent, prevalence and incidence, and rates of associated coral mortality (Richardson, 1998; Harvell et al., 1999; Knowlton, 2001; Sutherland et al., 2004). A survey of the coral disease literature conducted by Green and Bruckner (2000) described 29 differently named diseases on 102 scleractinian coral species. At least 12 new syndromes have been reported in recent years, with a dramatic increase in observations from the Indo-Pacific. More than 150 scleractinian, gorgonian, and hydrozoan zooxanthellate species are now known to be susceptible to diseases (Sutherland et al., 2004). Despite an increase in coral disease research, the understanding of the causative agents, host-pathogen interactions, and impacts on host populations and associated communities is still very limited (Richardson, 1998; Harvell et al., 1999; Sutherland et al., 2004). For instance, microbial pathogens have been isolated, identified, and defined as the causative agent in only five diseases; while several other putative pathogens have been reported, it is unclear whether these are the cause or merely opportunistic infections (Bythell et al., 2002; Sutherland et al., 2004).

Diseases directly and indirectly alter reef community structure and function, and are considered to be playing an increasingly important role in regulating coral population size, diversity, and demographic characteristics (Porter and Tougas, 2001; Aronson and Precht, 2001; Bruckner, 2004). For example, the Caribbean-wide loss of Acroporid corals, the two dominant space occupants and most important framework builders in reef crest and forereef habitats, is the leading cause of the decline in coral cover in the Caribbean reported during the 1980s and 1990s (Richardson and Aronson, 2002). Coring studies from Belize and other locations revealed that mass mortalities at this scale had not occurred in at least the previous 3,000-4,000 years (Aronson et al., 2004). More recently, *Montastraea annularis* complex populations are experiencing significant declines as a result of multiple diseases including black-band disease, yellow-band disease, and white plague (Santavy et al., 1999; Kuta and Richardson, 2002; Gill-Agudelo and Garzon-Ferriera, 2001; Richardson and Aronson, 2002; Bruckner and Bruckner, 2003, 2004).

Understanding the relationships between coral health and environmental parameters is of key importance in the study of coral disease (Harvell et al., 1999; Green and Bruckner, 2000; Kuta and Richardson, 2002). Environmental stressors, including those associated with degraded water quality and climate change, are often cited as potential factors causing coral mortality, yet rarely have studies adequately identified causal linkages to specific environmental stressors (Woodley et al., 2003). In addition, human activity may enhance the global transport of pathogens, such as *Aspergillus sydowii* (a fungus of terrestrial origin) that causes infection and mortality in sea fans and other gorgonians, and is postulated to have entered the marine environment via terrestrial runoff or clouds of dust from West Africa (Harvell et al., 1999; Richardson and Aronson, 2002). White pox, a disease only known to affect *Acropora palmata* in Florida, is caused by a common fecal enterobacterium *Serratia marcescens*, which may enter the marine environment via sewage discharge (Patterson et al., 2002). Other diseases are thought to be caused by known microorganisms that have changed hosts or exhibited increased virulence in response to environmental stresses and reduced resistance of the host coral (Santavy and Peters, 1997; Harvell et al., 1999; Sutherland et al., 2004). At least four coral diseases (black-band disease, white plague, dark-spots disease, and Aspergillosis) are associated with high water temperatures (Kuta and Richardson, 1996; Bruckner et al., 1997; Richardson et al., 1998; Gill-Agudelo and Garzon-Ferriera, 2001; Alker et al., 2001). Nutrient input, sedimentation, and runoff have also been implicated as potential contributing factors in the initiation and elevated virulence of a disease, although few quantitative data have been published (Bruckner et al., 1997; Harvell et al., 1999; Kim and Harvell, 2001; Richardson and Aronson, 2002).

It appears that the ability of corals and other organisms to withstand infection has been compromised by climate change, eutrophication, sedimentation (Rogers, 1990), and other human-induced ecosystem perturbations (Knowlton, 2001). The vulnerability of tropical coral reef ecosystems is related to the fact that many warm water corals grow slowly and persist only within a narrow range of light, temperature, dissolved oxygen and salinity fluctuations, and, in an evolutionary sense, they are thought to have a limited ability to recover from disease (Knowlton, 2001). However, the relative importance of anthropogenic influences is still unclear, especially since disease outbreaks are being reported with increasing frequency on reefs that exist in areas relatively far from the direct effects of human activity (Bruckner and Bruckner, 2004).

A decline in the health of many coral reefs worldwide has created an urgent need for multidisciplinary studies of coral health and disease, with emphases on coral physiology, biology, and disease etiology, including mechanisms of resistance and susceptibility to disease, factors affecting the transmission, spread and virulence of pathogens, and relationships between environmental factors and disease. By better understanding causative agents and factors responsible for the emergence and proliferation of diseases, scientists will be able to contribute to the development of strategies that can be used by resource managers to mitigate disease impacts.

Tropical Storms

Most coral reef environments are found in tropical climates and periodically experience cyclonic storm events. Cyclonic storms are an important process in the structure and dynamics of coral reef ecosystems (Hughes and Connell, 1999). They are classified as “pulse disturbances” since they are typically intense and of relatively short duration, yet are a powerful mechanism for change and can dramatically disrupt ecosystems, communities, population structure, resource availability, and the physical environment (Pickett and White, 1985). Coral reefs, however, are often located in dynamic regions of the ocean and have clearly shown resilience to historical bouts of disturbance. In fact, such disturbances are thought to maintain high species diversity, particularly when the disturbance alters the structure of the reef by opening up bare substratum, thereby creating space available for the settlement of new coral recruits (planulae). The influence of disturbance in community structure and dynamics has been illustrated by the intermediate disturbance hypothesis, which states that the highest number of species in a community will occur at intermediate levels (frequency and size) of natural disturbance. Lower diversity will exist where disturbances are either very large or very small, or very frequent or very infrequent (Connell, 1978, 1979). The size of the new space also influences the type of recruitment. Small patches are usually colonized by the nearest dominant species, while larger areas provide an opportunity for less dominant species to establish. Interestingly, many Caribbean corals release planulae in late summer/early fall, which coincides with the hurricane season in the Atlantic, and this may enhance recolonization (Rogers, 1993).

The effect of storms is strongly dependent on the ecology and geology of a specific area and the characteristics of the storm. For instance, a wide range of reef-specific variables influence the magnitude of the impact including spatial location, community structure, coral age, size, morphology, and reef depth. Variables associated with the storm itself include the path of the storm and its strength (measures of wind velocity and wave height), and heavy rain can cause excessive runoff as well as localized decreases in salinity which have been linked to a reduction in the planulae production (Figure 3.4; Jokiel, 1985). Some species of corals exhibit a growth form that is more robust to storm energy than others (e.g., boulder shapes). In contrast, corals with fragile skeletons and typically those with branching morphology will be more easily damaged by extreme wave action. In the Caribbean, *Acropora palmata* and *Acropora cervicornis* are very susceptible to storm damage (Brown, 1997). Breakages may be advantageous to these species since they produce relatively few larvae and instead are thought to rely primarily on asexual reproduction through fragmentation to produce new colonies (Bak and Engel, 1979; Hughes, 1985). Furthermore, delayed mortality from outbreaks of disease among injured corals, bioerosion of damaged skeleton, and altered predator-prey relationships may occur for years after a hurricane has struck (Knowlton et al., 1990).

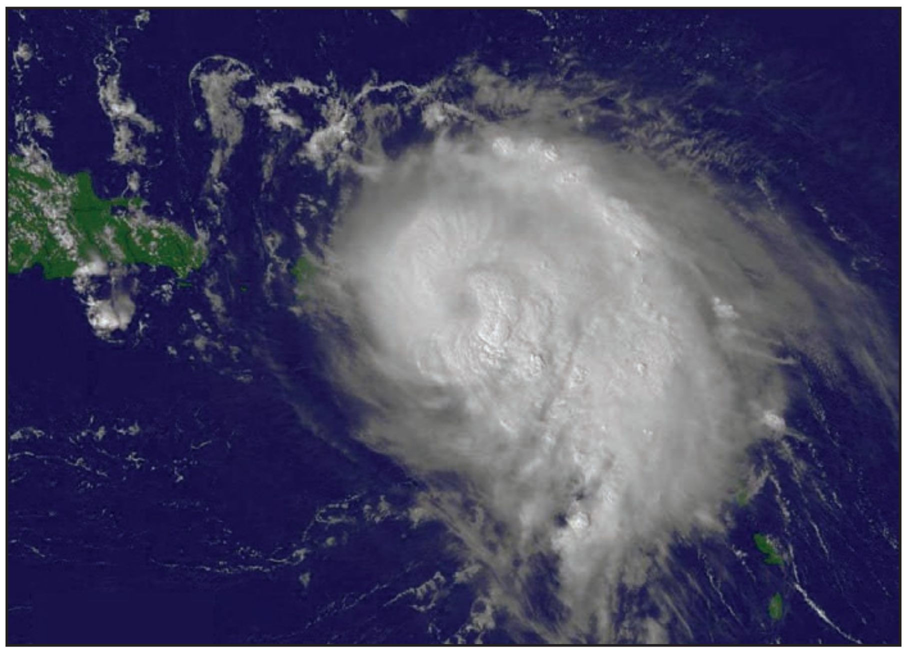

Figure 3.4. Hurricane Georges, a category 3-4 storm hit the USVI, Puerto Rico, and the Florida Keys in September, 1998. Damage included the physical breakage of corals and a massive pulse of sediment and nutrients that were discharged into nearshore waters. Georges was one of four hurricanes in progress in the Caribbean at the time. Photo: NASA and NOAA, http://rsd.gsfc.nasa.gov/rsd/images/Georges.html, Accessed 2/10/05.

Age is another factor that influences the ability of a coral colony to withstand the mechanical stresses of large storms. As corals grow, they become more vulnerable to breakage and dislocation (Brown, 1997). The majority of wave impacts occur in the shallowest (0-20 m) depth range, so corals at greater depths are generally less directly impacted. Deeper corals, however, can be significantly damaged indirectly by large blocks that tumble down from shallower waters (Brown, 1997). Damage to corals can indirectly impact other reef-associated organisms through the reduction of coral cover and topographic complexity which influence biological interactions such as predation, succession, and competition. As coral cover is reduced, the refuge function for many fish and invertebrates is diminished. Also the removal of organisms from substrate via scouring reduces the abundance of food available for some species. In addition, increases in turbidity and sedimentation that often accompany storms can affect the emergent community by impairing photosynthesis and feeding, and limiting sexual reproduction (Kojis and Quinn, 1985).

The direct effects of cyclones on fish are size-specific. Lassig (1983) noted that during the final stages of Cyclone Peter, many fish that were normally associated closely to the benthos were found in the water column and some had fresh wounds. This suggests that fish try to weather the storm in the water column, where they are less likely to be injured. It was also noted that after the storm, overall fish abundance decreased significantly, with juveniles sustaining higher mortality than adults due to strong storm-driven currents.

To understand how a cyclonic storm affects a reef requires examination of the recovery patterns and processes. Detailed comparative investigations of pre- and post-hurricane coral reef ecosystems that include variables such as amount of coral, number of species, settlement characteristics and growth rates, and nutrient cycling may provide valuable insights. Multiple year trends using continuous monitoring data, however, are likely to provide the most accurate assessment of both short- and longer-term impact and recovery (Hughes and Connell, 1999). The trajectory and rate of recovery will be influenced by a number of interacting factors including the rates of recruitment, species involved, and sequence of colonization (Brown, 1997). Research also suggests that anthropogenic impacts can interfere with the recovery process. Finally, separating storm effects from those caused by direct human activity and phenomena such as coral bleaching and competition with algae, is problematic due to the level of degradation of some reef systems (Brown, 1997).

The terms “hurricane” and “typhoon” are regionally specific names for a strong tropical cyclone. This report follows the geographically-specific naming convention recognized by NOAA (i.e., NOAA Research’s Hurricane Research Division, http://www.aoml.noaa.gov/hrd/tcfaq/A1.html, Accessed 01/07/05) whereby the term “hurricane” applies to the North Atlantic Ocean, Northeast Pacific Ocean east of the dateline, and South Pacific Ocean east of 160E; “typhoon” applies to the Northwest Pacific Ocean west of the dateline; “cyclone” applies to the Southwest Pacific Ocean west of 160E and Southeast Indian Ocean east of 90E. The characteristics of storm and hurricane categories are given in Table 3.3.

Table 3.3. The Saffir-Simpson scale for tropical storm and hurricane classification and associated storm characteristics provide a consistent way to characterize major storm events. na=not applicable. Source: NOAA National Hurricane Center.

SAFFIR-SIMPSON SCALE FOR HURRICANE CLASSIFICATION					
Storm Type	**Category**	**Wind Speed (kts)**	**Wind Speed (mph)**	**Pressure (millibars)**	**Damage Potential**
Tropical Depression	na	20-34 kts	23-39 mph	1007 mb	na
Tropical Storm	na	35-64 kts	39-74 mph	1006-1000 mb	na
Hurricane	1	65- 82 kts	74- 95 mph	980-999 mb	minimal
Hurricane	2	83- 95 kts	96-110 mph	965-979 mb	moderate
Hurricane	3	96-113 kts	111-130 mph	945-964 mb	extensive
Hurricane	4	114-135 kts	131-155 mph	920-944 mb	extreme
Hurricane	5	>135 kts	>155 mph	919 mb	catastrophic

Coastal Development and Runoff

In the past several decades, there has been a well-documented demographic shift toward higher concentrations of human settlement in the coastal zones of many countries including the U.S. (Culliton et al., 1990; Figure 3.5). More than half of the U.S. population now lives in coastal counties, a trend that is expected to continue to increase (Pew Oceans Commission, 2003; Cicin-Sain et al., 1999). This trend has increased the frequency and magnitude of impacts from activities such as the construction of residential developments, hotels and resorts, recreational facilities, and infrastructure such as roads and wastewater treatment plants (WWTPs).

Terriginous sediments in runoff from construction sites and roads are often a major threat to nearshore areas. Dredging of nearshore sediments for marina facilities, ship access and navigation, beach nourishment, and building materials can introduce significant quantities of particulate matter into the water column. While strong currents tend to dissipate some of the added sediments, nearshore areas with gentle slopes and low flushing rates tend to accumulate sediments, which can have detrimental effects on sessile invertebrates like corals (Rogers, 1990). Physical smothering may be the most obvious effect of sedimentation. Although most corals have some ability to rid themselves of foreign particles, the removal of sediments requires the diversion of energy from vital activities such as reproduction and feeding. The negative effects of the accumulation of

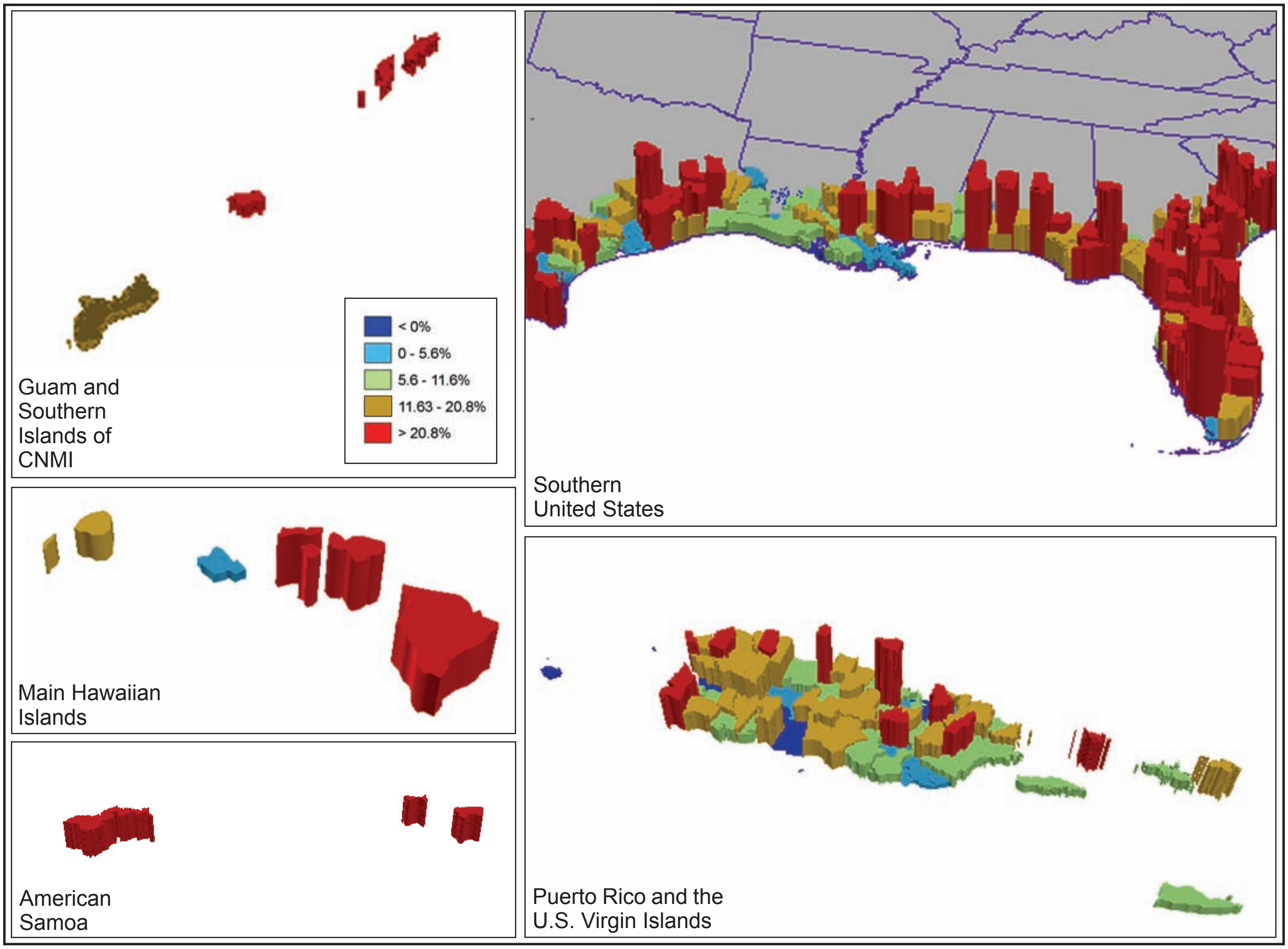

Figure 3.5. Coastal population change between 1990 and 2000 and associated development pressure pose a significant threat to coral reef ecosystems, particularly in island jurisdictions with limited land area. Maps not drawn to scale. Maps: K. Buja. Data: U.S. Census, 1990, 2000; Secretariat of the Pacific Community, http://www.spc.org.nc/prism, Accessed 2/15/05.

sediments on corals can be exacerbated by wave action that repeatedly resuspends sediments into the water column (Rogers, 1990). Increased turbidity in the water column, whether episodic or chronic, reduces light availability for photosynthesis and growth. Increases in nearshore sediment loads have been shown to affect morphology of corals and gorgonians as well as inhibit the development and recruitment of coral larvae (Rogers, 1990). Coral species react differently to this stressor, and coral reefs in waters experiencing increased turbidity may exhibit a shift in community composition toward greater dominance of corals that are more tolerant of lower light levels and better adapted to remove sediments.

Alteration of watersheds and associated changes in vegetative cover often decrease the ability of the land to absorb rainfall, which flows through streams and channels, carrying sediments and pollutants into nearshore areas. Generally, runoff from developed watersheds carries higher sediment loads than from undeveloped areas, and this is more pronounced in areas where the topography is characterized by steep slopes. Removal of mangrove forests that normally trap sediments may allow a greater proportion of terriginous sediments to reach reef ares.

In addition to sediments, runoff from developed watersheds tends to have higher concentrations of waste products. Increased freshwater inputs are actually considered pollutants as they can decrease the salinity levels in some nearshore areas. Other contaminants derived from human use of nearshore areas include oil leaking from vehicles, pesticides and lawn fertilizers applied to yards, parks and golf courses, chemicals in asphalt that wash off roads, excrement from livestock and domesticated animals, and litter.

The development of infrastructure is also a major concern. In many areas, coastal development often occurs without a commensurate improvement in the wastewater infrastructure, and existing systems cannot adequately accommodate the added burden. As a result, untreated or partially-treated sewage overflows into nearshore areas. Outside of urban areas, many homeowners are not able to access WWTPs and often must rely on septic tanks, which are subject to corrosion and leakage. The hard-to-detect leaks often allow untreated sewage to seep into groundwater and nearshore waters. A recent report (Carter and Burgess, Inc., 2002) assessing the sustainability of tourism in Hawaii noted that many of the island's municipal wastewater systems are nearing capacity. While most new developments have private WWTPs to satisfy permit conditions, many residents still rely on private systems, such as septic tanks, which are in various stages of disrepair. Though they considered myriad aspects of tourism, the authors of the study contend that such nonpoint source pollution is "one of Hawaii's greatest environmental threats" (Carter and Burgess, Inc., 2002).

Other infrastructural issues include the problems of adequate waste disposal and the construction of docks and piers that can result in habitat loss. In summary, coastal development presents a wide range of challenges for coastal areas, especially in terms of the number and scale of construction projects, capabilities of infrastructure, intensity and type of land use, and increases in sedimentation and pollution levels.

Coastal Pollution

Worldwide, the threat to coral reef ecosystems from pollution is surpassed in severity only by coral bleaching and fishing (Spalding et al., 2001). Model estimates indicate 22% of the world's coral reef ecosystems are threatened by land-based pollution and soil erosion (Bryant et al., 1998). Pollution often desensitizes the ecosystem, so that it becomes more susceptible to other stressors such as climate change, disease, and invasive species. The primary stressors from land-based sources are nutrient and chemical pollution from fertilizers, herbicides, pesticides, human-derived sewage, and increased amounts of sediment from coastal development and storm water runoff. Other pollutants, such as heavy metals and oil, can also be prominent at specific locations.

This section focuses on point source pollution. Point sources of pollution originate from confined or discrete conveyances, such as a pipe, tunnel, ditch, channel, well, or fissure. Examples of point source pollution include sewage outfalls, factory wastewater, and dumping of chemicals. Household chemicals and untreated industrial wastewater may also be discharged into the domestic wastewater stream. Finally, short outfalls contribute to the pollution of nearshore waters. Other point sources include vessels without holding tanks that discharge their wastes in marinas and nearshore coastal areas. Dredging for shipping lanes, marinas, and coastal construction projects resuspends sediments that increase turbidity and decrease coral reef ecosystem productivity. Industrial point sources include manufacturing operations, effluent discharges, accidental oil spills and the release of contaminants discharged as a byproduct of oil-drilling (e.g., toxic poly-aromatic hydrocarbons (PAHs), benzene, ethylbenzene, xylene) and heavy metals, such as lead, copper, nickel and mercury.

Direct impacts of pollutants include reduced recruitment, loss of biodiversity, altered species composition (a shift from predominantly phototrophic to heterotropic fauna), and shallower depth distribution limits. Sewage pollution causes nutrient enrichment around population centers, treatment facilities, and sewage outfalls. Increased nutrient concentrations promote increased algal and bacterial growth, can degrade seagrass and coral reef ecosystems, and ultimately may decrease fisheries production. Sediments smother benthic organisms, which can become diseased when exposed to dredged sediments contaminated with toxic heavy metals and organic pollutants. Toxic chemicals can decrease coral reef ecosystem productivity and biodiversity and increase human health risks through food contamination.

Management actions by NOAA to address water quality concerns are taken in partnership with the Environmental Protection Agency (EPA), the Department of Agriculture, and local or state governments. Research is needed to understand how coral reef ecosystems respond to poor water quality, and to provide mangers with tools to detect, assess, and remedy negative impacts from pollution. Therefore, the sources of the substances that adversely affect water quality must be identified, and relevant policies and control strategies for limiting pollutants must be developed and validated. Monitoring pollutants in highly polluted or "at risk" areas can alert managers to changes in pollutant inputs and impacts. To be most useful, results from pollution monitoring programs should be integrated into modeling efforts that quantify the relative amounts of natural and anthropogenic inputs to ecosystems Additionally, monitoring results should be used to develop models and indicators that assess threats or identify stressors causing coral reef ecosystem decline.

Tourism and Recreation

Tourism and recreation are by far the fastest growing sector of coastal area economies. This growth is predicted to continue as incomes rise, more Americans retire, leisure time expands and accessibility to the coasts and oceans increases (U.S. Commission on Ocean Policy, 2004). Coral reefs, in particular, have a major economic value. Cesar et al. (2002) calculated that the greatest contribution to the annual value of coral reefs in Hawaii is tourism and recreation, which brings in $304 million per year. Coastal tourism contributes $9.9 billion to the Californian economy annually and is considered the largest sector of the “ocean industry” compared with $6 billion/year for ports, $860 million/year for offshore oil and gas development, and $550 million/year for fisheries and mariculture (Wilson and Wheeler, 1997; Cicin-Sain and Knecht, 2000). Travel and tourism are estimated to have provided $746 billion annually to the U.S. gross domestic product (GDP), making travel and tourism the second largest contributor to GDP (Houston, 1995). Tourism is particularly significant in many Caribbean and Pacific islands surrounded by coral reef ecosystems. In the Florida Keys alone, over four million tourists purchase about $1.2 billion in services annually. Over three million tourists visit at least one of Hawaii’s coral reef sites per year, and approximately 90% of new economic development in Guam and the CNMI is related to coastal tourism (NOAA, 1997). The vast demand for tourism and recreational services associated with coral reefs generates considerable income for many local communities. Those who engage in reef-related recreational activities purchase goods and services, such as charter boats and diving trips via dive centers. In addition, they spend money on lodging, travel, food and beverages, etc. English et al. (1996) estimate an annual economic impact of $1.2 billion in visitor spending in the Florida Keys which results in a total sales impact of $1.3 billion, $506 million in income, and over 33,000 jobs. Leeworthy and Wiley (1997) estimate an annual economic impact of $94.3 million in resident spending in the Florida Keys, resulting in a total sales impact of $105.6 million and supporting over 2,400 jobs. Cesar et al. (2002) estimated that recreational use values in Hawaii represent 85% of annual benefits accrued from coral reefs (the others being amenity/property values, biodiversity, fisheries, and educational spillover), which amount to $304.16 million/year. In southeast Florida, the annual use value accrued from coral reefs is estimated at $229.3 million (Johns et al., 2003).

Human uses of coral reefs are both direct and indirect, with recreation and tourism among the most prominent uses. Recreational activities on U.S. coral reefs include snorkeling, scuba diving, boating, fishing, and shell-collecting. The intensity of each activity varies widely from region to region, but can be considerable in some areas. In southeast Florida, residents and visitors spent 28 million person-days using artificial and natural reefs during a 12 month period (June 2000 to May 2001) and 4.94 million person-days snorkeling and scuba diving (Johns et al., 2003; Figure 3.6). Water-based activities such as scuba diving are increasing in popularity, and over 3 million people are currently certified to dive in the U.S. Scientific studies have now shown that divers and snorkelers can have a significant negative impact on coral reefs in terms of physical damage and a concomitant reduction in their aesthetic appeal (Hawkins and Roberts, 1993; Hawkins et al., 1999; Rouphael and Inglis, 2001). For example, a snorkeling trail created in the Virgin Islands National Park’s Trunk Bay in the 1960s had deteriorated substantially when observed in

Figure 3.6. Some reef areas in the Florida Keys may have hundreds of visitors per day. Photo: Bill Harrigan.

1986 with visitor numbers estimated at over 170,000 per year. Only 10 of 50 tagged Elkhorn coral colonies remained undisturbed during a seven-month period of observation (Rogers et al., 1988). Plathong et al. (2000) examined the effects of snorkelers using self-guided interpretative trails around a reef within the Great Barrier Reef Marine Park, Australia and found that despite comparatively low levels of use (approximately 15 snorkelers per trail per week), snorkelers caused significant damage to corals along the trails. Hawkins et al. (1999) examined the impacts of diving on a reef off the Caribbean island of Bonaire and concluded that impacts would be minimized by maintaining a site carrying capacity of between 4,000 and 6,000 dives per year. In contrast, Rouphael and Inglis (2002) suggested that management actions should focus on identifying and mitigating the causes of damaging behavior rather than setting numerical limits to site use.

Concern has also been directed at the activity of fish-feeding. Feeding fishes negatively impacts both fishes and habitat in several ways including: (1) fish consume food that is very different to their normal diets; 2) the concentration of fish at feeding stations disrupts normal distribution/abundance patterns; (3) fish behavior changes with some individuals or aggregations exhibiting abnormal aggression; and (4) inputs of nutrients and incidental damage to benthic structure can result in an increase of macroalgae (Perrine, 1989; Alevizon, 2004).

In addition to these direct threats, indirect threats can be equally, if not more devastating to coral reefs. Indirect threats include development of hotels and resorts, construction of the infrastructure needed to support such resorts, seafood consumption, beach replenishment, construction of airports and marinas, as well as the operation of cruise ships. The impacts resulting from these activities include increased sedimentation, nutrient enrichment, pollution, exploitation of endangered species, and increased litter and waste (UNEP, 2002). Mitigation of the impacts of tourism often involves education and raising awareness with the goal of behavioral change (UNEP, 2002). In Hawaii, a strategy for both defining a carrying capacity and influencing visitor behavior through education has been implemented. Oahu's Hanauma Bay Nature Preserve in Hawaii has an estimated three million visitors annually and 13,000 per day in the high season. Impacts at Hanauma Bay, including widespread trampling of reefs and resuspension of sediments, fish-feeding, littering, and other pollution, prompted a management strategy to limit visitor numbers (NOAA CSC, 2004). Determining the carrying capacity for this area was critical to its long-term sustainability and was supported by the development of an education center aimed at influencing visitor behavior (Cesar et al., 2002).

Clearly, tourism is a major source of economic welfare and livelihood for many coastal communities. Unfortunately, detrimental side effects and physical damage often result from direct visitor activity and the development of facilities to support tourism. Without long-term planning for tourist activities at these fragile sites, both resourcse and revenues are at risk. Sites such as Hanauma Bay Nature Preserve have had to make operational adjustments and offer education and instruction to visitors. Managers are increasingly challenged to develop strategies that mitigate unsustainable usage, while continuing to support the tourism industry.

Fishing

Coral reefs and associated habitats support important commercial and recreational fisheries. Over 4,000 species of fishes (>25% of all marine fishes) inhabit shallow coral reefs (Spalding et al., 2001), along with a large number of marine plants and invertebrates – many of which are exploited for human use. Coral reef fisheries support and sustain communities by providing food and sources of income. Fishing also plays a central social and cultural role in many island communities. Coral reef fisheries are generally small-scale, but coral reef fishers exploit hundreds of species of fishes and invertebrates using a wide variety of fishing gear. In a number of U.S. reef areas, recreational fishery catch now equals or exceeds the commercial catch. The rich biodiversity of coral reefs also supports a valuable marine aquarium industry, especially in Hawaii and Florida, and provides materials for a range of natural products developed by the biotechnology and pharmaceutical industries.

Unfortunately, these fishery resources and the ecosystems that support them are under increasing threat from overfishing and fishery-associated impacts on habitats and ecosystems. Fishery-related impacts include: 1) direct overexploitation of fish, invertebrates, and algae for food and the aquarium trade; 2) removal of a species or group of species which can impact multiple trophic levels; 3) by-catch and mortality of non-target species; and 4) physical impacts to reef environments associated with fishing techniques, fishing gear, and anchoring of fishing vessels.

Overfishing

Overfishing, along with pollution and global climate change, is generally considered to be one of the greatest threats to the health of coral reefs. It is also the most widespread threat, estimated to be of medium or high threat to over 35% of the world's reefs (Bryant et al., 1998). In many cases, significant depletion of reef resources (especially large fishes and sea turtles) had already occurred before 1900 (Jackson et al., 2001; Pandolfi et al., 2003). Since then, increases in coastal population, improved fishing technology, and over-capitalization of fishing fleets driven by demand from rapidly growing export markets have greatly accelerated resource depletion. Many reef fishes have relatively slow growth rates, late maturity, and irregular recruitment - characteristics that make overexploitation more likely. The trend is for high-value or vulnerable resources – generally large predators such as groupers, jacks and sharks – to be removed first, and then target species further down the food chain are subsequently fished (Pauly et al., 1998).

Overfishing has been identified as a major concern in all U.S. states and territories with coral reefs and has been identified by the USCRTF as a priority reason for the development of local action strategies. In most cases, the large number of species in these multi-gear, small-scale fisheries has made it impractical to conduct standard stock assessments for more than a fraction of the species (see Table 3.4), and such data-intensive, single-species approaches have been criticized as unrealistic for most reef fish systems (Sale, 2002). There is evidence of serial depletion of reef resources in Florida and around all populated U.S. islands. In Hawaii, long-term catch rates suggest that stocks of nearshore fishes have declined by nearly 80% between 1900 and the mid-1980s (Shomura, 1987). Catch per unit effort (CPUE) of reef fishes in Guam fell by more than 50% between 1985 and 2000 (Birkeland et al., 2000), while the CPUE fell 70% in the American Samoan reef fishery, accompanied by a shift in species composition, over a period of 15 years between 1979 and 1994 (Birkeland, 1997). The Nassau grouper fishery, the highest value commercial fishery in Puerto Rico and the U.S. Virgin Islands (USVI), collapsed in the 1980s due to overexploitation of spawning aggregation sites and the species was identified as a candidate to be listed as threatened or endangered under the Federal Endangered Species Act (16 U.S.C. § 460 et seq.) in 1991. In the Florida Keys, the nation's most extensive and long-term reef fish monitoring program has revealed that 77% of the 35 individual stocks that could be analyzed in Biscayne Bay are overfished (Ault et al., 2001).

Table 3.4. Overfished Coral Reef Species in Federal Fishery Management Plans (FMPs). Source: 2003 Status of U.S. Fisheries Report (NOAA, http://www.nmfs.noaa.gov/sfa/reports/html, Accessed 2/14/05) and Western Pacific Coral Reef Ecosystem Fishery Management Plan (NOAA, http://www.wpcouncil.org/coralreef.htm, Accessed 2/14/05).

Table: Overfished Coral Reef Species in Federal Fishery Management Plans[1]

Region	Total Number of Federally Managed Coral Reef Species	Number of Species Overfished or Approaching Overfished	Number of Species Not Overfished	Species with Insufficient Data
South Atlantic[2]	62	8	12	42
Gulf of Mexico[2]	44	5	4	35
Caribbean[2]	154	3	1	150
Western Pacific[3]	28	0	0	28
Total	422	16	16	389

Notes:

1 Overfished analysis includes only stocks in Federal waters–most reefs and fishing pressure occur in state and territorial waters.
2 Excludes coral species for which the fishery is closed.
3 From the Bottomfish, Precious Coral and Crustacean FMPs only–does not include the hundreds of species covered by the new Coral Reef Ecosystem FMP.

Because of long-term trends in the exploitation of mixed reef fisheries, there are few places that maintain relatively intact fish populations to serve as experimental controls. The Northwestern Hawaiian Islands (NWHI) and some of the uninhabited U.S. Pacific Remote Island Areas probably represent the closest approximation to unexploited coral reef ecosystems in U.S. waters. The average fish biomass in the NWHI is 2.6 times greater than in the Main Hawaiian Islands (MHI). More than 54% of the total fish biomass in the NWHI is composed of apex predators, compared to less than 3% in the MHI. These differences have been attributed to overfishing in the MHI (Friedlander and DeMartini, 2002).

Ecosystem Shifts

There is increasing evidence that overfishing on reefs results not just in shifts in fish size, abundance, and species composition, but that it is also a major driver altering the ecological balance and contributing to the degradation of coral reef ecosystems (Bellwood et al., 2004). In particular, overfishing of herbivorous fishes has been linked to phase-shifts from high-diversity coral-dominated systems to low-productivity algal-dominated communities (Hughes, 1994). U.S. reefs, especially in the Atlantic, are increasingly facing coral declines, though uncertainty remains about the processes and links to fishing levels, especially in the Pacific (Jennings and Polunin, 1997). Herbivores comprise a significant component of the catch in the MHI, Guam, CNMI, and American Samoa. Parrotfishes and surgeonfishes are increasingly important in Puerto Rico and in St. Croix, where they represent the predominant catch. In nearly all areas except Florida, declines in the abundance of these species have been observed. There is also evidence that heavy fishing pressure on certain invertebrate-feeding fishes has played a key role in outbreaks of crown-of-thorns (COTS) starfish, snails, and herbivorous sea urchins (Hay, 1984; McClanahan, 2000; Dulvy et al., 2004). There is no clear evidence of the extent to which this has been an important factor in bioerosion on U.S. reefs, nor is there a clear understanding of the ecosystem effects due to the removal of top predators. Overfishing can also compound the impact of other threats. For example, overfishing of herbivorous fishes and enhanced nutrient flows to reefs may lead to reef overgrowth by macroalgae. Likewise, reefs devoid of herbivores may be less likely to recover from coral bleaching events (Westmacott et al., 2000).

Impacts from Fishing Gear

A number of protected species, such as hawksbill and green sea turtles as well as a number of seabird species are untargeted victims of fishing activity and are especially vulnerable to longline fishing and shrimp trawling. Traps and gill nets also result in mortality of non-target species.

Physical damage to the benthos from certain fishing techniques is well-documented. Traps set for fishes or lobsters can cause physical damage to corals, gorgonians, and sponges. They may also result in by-catch and "ghost fishing" if they are lost or not regularly checked. Trap fisheries are most common in Florida (lobster and stone crab) and the U.S. Caribbean (fish and lobster), and are generally less prevalent in the U.S. Pacific. Large gill and trammel nets have also been identified as a growing concern, particularly in St. Croix (USVI) and Hawaii. Large gill nets are set on reefs and their lead-lines can cause extensive damage when the nets are hauled into the boats. In addition to legal fishing activities, illegal techniques can cause severe damage to reefs. Use of chlorine bleach has been reported in Hawaii, Guam, and Puerto Rico (USCRTF, 1999), and traditional plant-derived poisons are still used occasionally in the subsistence fishery in American Samoa. The use of cyanide for fishing has not been reported on U.S. reefs, although the expansion of the live food fish trade to the Marshall Islands has raised concerns about its potential use there. Blast fishing, probably the most destructive technique, has rarely been reported on U.S. reefs.

Other indirect impacts to coral reefs associated with fisheries include anchor damage from fishing boats, which has been identified as a problem in Florida and the U.S. Caribbean. Trawling damage to coral areas has been identified as a problem in deeper coral areas in the Gulf of Mexico. It was also a major cause of destruction of the deep water *Oculina* coral banks off the east coast of Florida before the development of the Experimental Oculina Research Reserve. In general, such damage is inadvertent rather than due to directed fishing, but trawls can cause tremendous damage when hauled over hard bottoms with coral. Furthermore, groundings of fishing vessels have had major, albeit localized, impacts on certain reefs.

Trade in Coral and Live Reef Species

Many coral reef species are harvested domestically and internationally to supply a growing international demand for seafood, aquarium pets, live food fish, construction materials, jewelry, pharmaceuticals, traditional medicines and other products. In many locations, collection is occurring at unsustainable levels, and overharvesting may lead to reductions in the abundance and biomass of target species, shifts in species composition, and large-scale ecosystem shifts including population explosions of non-target species or the replacement of thriving, coral-dominated systems with low-productivity algal reefs (Hughes, 1994; McClanahan, 1995; Jennings and Polunin, 1996). In addition to overfishing, there is widespread use of destructive techniques such as cyanide poisoning of fishes and coral colony breakage. Cyanide is used illegally in Southeast Asia and other parts of the Indo-Pacific to capture live reef fish for the aquarium trade and live fish markets, and has been found to: 1) kill many non-target species, 2) cause habitat damage, and 3) pose human health risks (Barber and Pratt, 1997). High levels of mortality associated with cyanide and inadequate handling and transport practices pose significant challenges to achieving sustainability. The use of cyanide has not been reported or observed in the U.S., with the possible exception of limited use in some of the Freely Associated States (e.g., Marshall Islands) associated with the live reef fish food trade. In addition, unsafe diving practices resulting from the collection of corals, sea cucumbers, fish, and other species in deep water are causing a high incidence of illness, paralysis, and even death of collectors in some regions (Johannes and Riepen, 1995; Barber and Pratt, 1997).

The Marine Aquarium Trade

The marine aquarium trade has an estimated value of $200-300 million per year (Larkin and Degner, 2001). The global trade in coral has increased by 500% over the last 10 years, with over one million live corals and 1.87 million kg of live rock traded in 2002 (Bruckner, 2003). In addition, an estimated 20-24 million reef fishes are traded annually, representing 1,450 species in 50 families (Balboa, 2002; Wabnitz et al., 2003). The U.S. is the world's largest consumer of ornamental coral reef species, importing 60-80% of the live coral, over 50% of the curio coral, 95% of live rock, and 50-60% of the marine aquarium fishes each year (Wood, 2001; Bruckner, 2003). The most important sources of coral are currently Indonesia, Fiji, and Vietnam (Bruckner, 2001). Indonesia and the Philippines each supply about 30% of the total global trade in reef fishes, with another 30% exported from five locations (Brazil, the Maldives, Hawaii, Sri Lanka, and Vietnam); Florida and Puerto Rico are currently the largest exporters from the wider Caribbean (Wood, 2001; Balboa, 2002).

Although it is illegal to harvest stony corals and live rock in U.S. waters, ornamental reef fishes and many motile invertebrates are collected in U.S. waters both for domestic use and export. In Florida, 318 marine species (181 fishes and 137 invertebrates) have been collected for commercial purposes, with a total annual value of up to $4.2 million. Over 200,000 ornamental reef fishes are landed in Florida each year, with a maximum of 425,781 fishes in 1994 (Larkin, 2003). Annual reported harvest of ornamentals from West Hawaii rose from 90,000 in 1973 to 422,823 in 1995 (Tissot and Hallacher, 1999).

The Live Reef Food Fish Trade

Groupers, humphead wrasse, coral trout, and other large fishes that use coral reefs are harvested live to supply restaurants in Hong Kong. Exports increased rapidly during the 1990s and peaked at 32,000 metric tons (mt) in 1997, with a slight decline between 1998 and 2000 due to the Asian economic crisis (Lau and Parry-Jones, 1999). More recently an estimated 22,000 to 28,000 mt of live reef fishes have been imported by Hong Kong, China, Taiwan, and other Asian markets, with Hong Kong imports comprising 65-80% of the total regional trade (Graham et al., 2001). In addition to widespread use of cyanide to capture the fish live, fishers target spawning aggregations and have been reported to eliminate entire breeding populations relatively rapidly (Lau and Parry-Jones, 1999). In addition to concerns regarding the use of destructive fishing techniques, most of these species are vulnerable to heavy fishing pressure due to their longevity, late sexual maturation, aggregation spawning, and sex change habits (Sadovy et al., 2004).

Curios and Jewelry Trade

Coral reef species harvested for curios and jewelry include mollusk shells; stony coral skeletons; and black, pink, gold, bamboo, and other precious corals (Figure 3.7). Of these species, only stony corals, black coral, and giant clams are internationally regulated through the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). International trade in shells involves as many as 5,000 species of an unknown volume primarily supplied by the Philippines, Indonesia, Thailand, Singapore, Taiwan, Mexico, India, Africa, and Haiti (Wells, 1989). Shells are used for construction materials; shell craft; mother of pearl and other collectors items; as well as additives to floor tiles, toothpaste, pottery, and poultry feed (Marshall et al., 2001). The volume of trade in coral skeletons has varied over the years, with the Philippines being the major supplier in the 1970s and 1980s; exports from the Philippines were prohibited in the late 1980s, with a temporary lifting of trade bans in 1992 during which over three million kg were exported. Fiji and Vietnam are currently the major source countries for coral skeleton (Bruckner, 2001).

Figure 3.7. The shells of reef organisms are often sold at curio shops, such as this one in Palau. Although many of the shells were probably imported from Southeast Asia, some local collection is thought to occur as well. Photo: J. Waddell.

International trade in black coral, according to the CITES trade database, has averaged 430,000 items per year since 1983, with the maximum trade in 1994, and 320,000 items traded in 1998 (CITES Trade Database, http://www.cites.org/eng/resources/trade.shtml, Accessed 02/16/05). The world's largest supplier of worked black coral is Taiwan (>90% of the total), with most reported to be harvested in the Philippines. Commercial harvest occurs in U.S. waters in Hawaii, with annual landings averaging 1,014 kg/year; about 90% of this is for domestic use.

International Protection

CITES is an international agreement among the governments of 165 countries to protect wildlife by ensuring that international trade does not threaten the survival of a species in the wild. CITES regulates international trade in wildlife according to three levels, or appendices, of threat. Species listed in Appendix I, which includes marine turtles and most whales, are believed to be threatened with extinction and thus, commercial trade of these species is generally prohibited. Most species are listed in Appendix II which includes organisms that are not presently threatened or endangered, but may become so if trade is not regulated. These species can still be commercially traded with export permits which require the exporting country to ensure that the species was legally harvested and its export will not be detrimental. Coral reef species currently listed in Appendix II include about 2,000 species of stony corals (including all scleractinian corals), black coral, giant clams, queen conch, and seahorses. Trade of Appendix III species requires an export permit ensuring that the organism was harvested legally and prepared and shipped so as to minimize damage, injury or cruel treatment.

Ships, Boats, and Groundings

Of all physical damage caused to coral reefs by human activity, ship groundings and the impacts of boats and anchors are perhaps the most destructive. The U.S. Coast Guard (USCG) reports that over 2,100 grounding accidents are reported annually, with about 440 vessels sinking each year. In addition, over 800 abandoned barges litter the inland and coastal waters of the U.S., many still loaded with hazardous cargo (Helton, 2003). As recreational and commercial boating traffic increases in nearshore ocean waters, these shipwrecks pose a threat to coral reef habitat. When anchors, especially the enormous anchors of cruise ships, are carelessly dropped and dragged on fragile reef, hundreds of meters of habitat can be destroyed. Recent studies demonstrate the extensive impacts of groundings when hazardous cargo is released. However, once cargo and fuel are spilled, the vessel may continue to cause repeated physical damage to the reef due to movement by wind and waves. Furthermore, abandoned barges can often become illegal dump sites for other hazardous materials, trap wildlife, and become public safety hazards (Helton and Zelo, 2003).

Initially many considered the impacts of grounded vessels to be significant only at a local level, but the widespread effects of these events have recently been the subject of closer examination (Precht et al., 2001; Ebersole, 2001). Damage resulting from ship groundings often continues well beyond the initial event of impact as a result of slow recovery and fragmentation of keystone species essential to reef structure and function. In particular, spur and groove reefs do not seem to recover their diverse fish assemblages following a ship grounding incident (Ebersole, 2001). The potential threats of grounded vessels became the subject of increased political attention in 1999 when nine vessels were cleaned, cut apart, and removed from a reef in Pago Pago, American Samoa and the grounding sites were restored by the USCG, NOAA, and American Samoan government. The increasing frequency of vessel groundings in coral reef environments led to the development of the National Action Plan to Conserve Coral Reefs (USCRTF, 2000) which recognizes the impact of grounded vessels to coral reefs and their associated habitats (Helton and Zelo, 2003). In response, NOAA initiated the Abandoned Vessel Project, which seeks to increase awareness of abandoned vessels, particularly where they occur in coral reef systems, as well as provide the technical assistance necessary to remove the vessels (NOAA OR&R, http://response.restoration.noaa.gov/dac.vessels/overview.html, Accessed 6/2/04).

A study conducted on the site of the 1984 grounding of the M/V *Wellwood* in the Florida Keys National Marine Sanctuary suggested that damaged spur and groove habitat will take decades to recover without substantial restoration efforts (Smith et al., 1998). A reduction of topographic complexity also influences local hydrodynamics and the structure of reef fish and invertebrate communities (Miller et al., 1993; Szmant, 1997).

The damage caused to a coral reef habitat by boat anchors is an additional threat resulting from frequent boat traffic. A study conducted in a 220 ha area of coral reef in Fort Jefferson National Monument, Dry Tortugas, Florida documented the extensive damage that can be caused by anchors (Davis, 1977). Cruise ship anchors present a significant and increasing threat to coral reefs. In Grand Cayman, an estimated 1.2 million m^2 of coral reef have been destroyed by cruise ship anchors (Smith, 1998), while cruise ships in the Cancun National Park in Mexico, are thought to have impacted over 80% of the coral reefs there (Schultz, 1998). Designation of anchorages in less sensitive areas, installation of mooring buoys, and identification of areas sensitive to anchor damage are necessary to reduce the destructive practice of unregulated anchor dropping and dragging.

Major vessel groundings in the FKNMS such as the M/V *Alec Owen Maitland* and M/V *Elpis* in 1989 and the R/V *Iselin* in 1994 are examples of events in which waves and currents occuring between the grounding and restoration resulted in further injury to the reef. Loose coral rubble threatened adjacent undisturbed coral habitat, and restoration efforts involved removing broken pieces of coral from the seafloor and re-attaching them before the arrival of winter storms. The extent of the broken coral can be extensive. For example, the 325-foot M/V *Fortuna Reefer* container ship ran aground near Mona Island, Puerto Rico in July 1997 and damaged over 6,400 m^2 of elkhorn coral (Figure 3.8; Zobrist, 1998).

Figure 3.8. The *M/V Fortuna Reefer*, a container ship that ran aground near Mona Island, Puerto Rico, damaged a large area of reef including stands of *Acropora palmata*. NOAA scientists have undertaken restoration efforts at the site and have monitored the recovery of the coral community there since 1998. Photo: NOAA Fisheries.

An additional impact of ship groundings involves contamination from Tributyltin (TBT), a component of antifouling paint. TBT-based paints have been banned for use on small craft, but TBT-based paints are still widely used on large ships which navigate routes that pass through coral reef habitat. The effects of this paint on a reef were examined following the grounding of a 184 m cargo ship *Bunga Teratai Satu* on Sudbury Reef, Australia in 2000. Results demonstrated that this kind of contamination can significantly reduce coral recruitment in the area of the grounding and may consequently hinder recovery of the community (Negri et al., 2002).

With boat traffic rapidly growing, it is crucial to better understand the ecological implications of vessel groundings and anchor damage, and to take steps to limit or prevent damage through education and guidance supported by strong legislation. Severe physical damage to coral reefs by vessels requires a rapid response and carefully designed methods of removal and restoration to limit the extent of the impact (NOAA, 2002b).

Marine Debris

Globally, marine debris presents a continuous threat to the marine environment. Marine debris adversely impacts marine life through the destruction of essential habitat as well as entanglement and ingestion by marine organisms and seabirds. Typically, the majority of marine debris comes from land-based sources, particularly urban centers, but a significant proportion comes from ships.

All U.S. jurisdictions with coral reefs participate in the International Coastal Cleanup to remove marine debris from their shorelines and nearshore waters. Additional community-based cleanup efforts have been conducted at many locations, including South Point and Kahoolawe in Hawaii. Typical debris collected from the shorelines includes beverage cans and bottles, cigarettes, disposable lighters, plastic utensils, food wrappers, and fishing line (Figure 3.9). Underwater cleanups conducted by snorkelers and divers have found similar materials beneath the surface.

Figure 3.9. Tons of marine debris wash up on the shores of the NWHI every year. Though NOAA's Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division has removed 401,055 kg of debris from the shallow waters of the NWHI since 2001, resource limitations prevent debris removal on land. Photo: S. Holst.

The most notable impacts of marine debris on coral reef ecosystems come from derelict fishing gear including nets, fishing line, and traps. Prior to the 1950s, fishing gear was composed of natural fibers, such as cotton and linen, and was susceptible to environmental degradation. Since the 1950s, fishing gear has primarily been constructed with synthetic materials, such as nylon and polyethylene, which is less susceptible to environmental degradation. Synthetic nets and fishing line can persist in the ocean for decades and can be transported for thousands of kilometers.

The NWHI has been a focal point for the removal of abandoned fishing gear comprised of conglomerates of netting and fishing line that roll across coral reef habitats, crushing corals and dislodging sessile organisms (Figure 3.10). Fishing gear frequently becomes snagged on corals and continues to trap fish ("ghost fishing") and endangered monk seals and sea turtles (Boland and Donohue, 2003; Donohue et al., 2001; Henderson, 2001; Balazs, 1985). Since 2001, NOAA's Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Division (PIFSC-CRED) has led a large-scale interagency partnership to study and remove derelict fishing gear from the NWHI. NOAA collaborates with the State of Hawaii, City and County of Honolulu, U.S. Fish and Wildlife Service (USFWS), USCG, U.S. Navy, University of Hawaii, Hawaii Sea Grant, Hawaii Metals and Recycling, Honolulu Waste Disposal, and other partners from local agencies, businesses, and non-governmental organizations. From 2001 to 2004, this large-scale effort removed 401,055 kg of fishing gear from these remote islands and atolls (R. Brainard, pers. comm.). Types of fishing gear removed included monofilament gillnet, seine net, and trawl nets, the majority of which was thought to have originated from fisheries operating around the continental shelves of the North Pacific Rim which are located thousands of kilometers from the NWHI.

Figure 3.10. A tangle of abandoned fishing gear removed from Pearl and Hermes Atoll in the NWHI by a team of divers from PIFSC-CRED and the Joint Institute for Marine and Atmospheric Research (JIMAR). The net had to be freed from the reef, lifted to the surface, and towed to shallow water before debris team members could cut it into smaller pieces and remove it. Photo: A. Hall.

Derelict fishing gear has also been a concern in other U.S. coral reef ecosystems. Chiappone et al. (2002) surveyed the Florida Keys for fishing gear and other marine debris and concluded that lobster trap debris was often found in offshore and mid-channel patch reefs, while hook and line gear was more common in shallow and deep forereef areas. Since 1994, the FKNMS, The Nature Conservancy, The Bacardi Foundation, and local dive operators have supported an annual effort to clean the reefs around the Florida Keys. In 2002, divers removed over 1,800 kg of marine debris including fishing line from the Keys. In 2003 and 2004, Amigos de Amoná, Inc. and other partners removed 3,235 kg of marine debris from the islands in Puerto Rico's Mona Channel. The debris consisted of fishing gear (48%), plastics (13%), glass (14%), metal (8%), and miscellaneous items such as refrigerator doors, rubber shoes, packing and insulation materials, and washing machines (17%; Amigos de Amoná, Inc., 2004).

Aquatic Invasive Species

Aquatic invasive species are aquatic organisms that have been introduced, either intentionally or unintentionally, into new ecosystems which result in harmful ecological, economic, and human health impacts (USDA, http://www.invasivespecies.gov, Accessed 2/11/05). Aquatic invasive species have been reported in all U.S. reions and probably exist in every region of the world. Invasive species are generally second only to habitat destruction in causing declines in biodiversity and are thought to impact nearly half of the species currently listed as threatened or endangered under the Federal Endangered Species Act (Wilcove et al., 1998).

The impacts are not only ecological. Damages to infrastructure, such as clogged intake pipes, and environmental losses due to terrestrial and aquatic invasive species cost over $120 billion per year in the U.S. alone (Pimentel et al., in press). The cumulative effects and costs of aquatic invasive species are difficult to quantify, but evidence clearly indicates that the impacts will continue to increase. In fact, the frequency of aquatic invasions has increased exponentially since the late 1700s and shows no signs of diminishing (Ruiz et al., 2000).

Although there have not been many studies that focus specifically on the impacts of aquatic invasive species on shallow-water coral reef ecosystems as a whole, there have been a handful of smaller studies. In Hawaii, it has been determined that the number of marine and estuarine invasive species is approximately 343, including 287 invertebrates, 24 algae, 20 fish, and 12 flowering plants (Bishop Museum, http://www2.bishopmuseum.org/HBS/invertguide, Accessed 02/14/05). Pearl Harbor alone contains more than 100 invasive species. Additionally, some of Hawaii's worst invaders have been intentionally introduced, such as algal species, *Kappaphycus alvarezii* and *K. striatum*, which smothered large tracts of coral reefs in Kaneohe Bay, thus diminishing the ecological and economic value of the area (Carlton, 2001).

Shallow-water coral reef ecosystems are particularly sensitive to a number of non-native species introduction pathways, including ships (due to ballast water discharges and hull fouling), aquaculture of non-native species, releases by aquarium hobbyists, and marine debris.

Introductions from Ballast Water

By 1996, 80% of all commercial goods were being transported aboard ocean-going vessels (NRC, 1996). That percentage is likely to increase as global trade increases. In addition to greater movement of goods across the world's oceans, the speed and size of ships have greatly increased, resulting in faster voyages and larger volumes of ballast water. Because most marine species have planktonic stages as part of their life cycle, they are subject to entrainment during the uptake and discharge of ballast water. Furthermore, because voyage times have greatly decreased, the chances of survival are greater. Ballast tanks have been shown to carry bacteria, protists, dinoflagellates, diatoms, zooplankton, algae, benthic invertebrates (e.g., mollusks, corals, sea anemones, and crustaceans), and fish (LaVoie et al., 1999; NRC, 1996).

Releases by Aquarium Hobbyists

Although there are relatively few documented marine fish invasions, 94 of the 241 documented invasions involved tropical marine species. Additionally, a link has been identified between invasions and marine aquarium imports. Such findings highlight the susceptibility of warm water coral reef ecosystems to intentional introductions by hobbyists and the need for public education. For example, a species of lionfish (*Pterois volitans*) common to the Indo-Pacific regions that was thought to have been introduced from a home aquarium in 1992 has established viable populations all along the southeastern coast of the U.S., with juveniles recently found as far north as Long Island (Figure 3.11; Whitfield et al., 2002).

Figure 3.11. The Red Lionfish, *Pterois volitans*, is native to the Indo-Pacific but has established viable populations along the southeastern coast of the U.S. This fish was photographed off the coast of Beaufort Inlet, North Carolina in about 40m of water. Photo: P. Whitfield.

Introductions from Marine Debris

The amount of marine debris generated as waste from society has increased at a rapid rate in recent years (Silvia-Iniguez and Fischer, 2003; Moore, 2003). For instance, the amount of marine debris in the waters around Great Britain doubled from 1994 to 1998 (Barnes, 2002). Much of the debris is fisheries related, comprised mostly of netting. Floating material provides habitat for many organisms and can result in the transportation of species into new areas, often many thousands of kilometers from their existing species range (Barnes and Fraser, 2003). Problems occur when newly arrived alien species successfully colonize and overwhelm local marine ecosystems. Barnes (2002) found that marine debris was typically colonized by bryozoans, barnacles, polychaetes, hydroids and mollusks.

Security Training Activities

U.S. military installations near coral reefs include operations in Hawaii (Hickam Air Force Base, Pearl Harbor, and Kaneohe Bay); Johnston Atoll (PRIAs); Wake Atoll (PRIAs); Kwajelein Atoll (Republic of the Marshall Islands); Guam; CNMI; Key West and Panama City, Florida; Puerto Rico; USVI; Cuba; and Diego Garcia in the Indian Ocean. Military bases and associated activities including exercises, training, and operational procedures (i.e., construction, dredging, and sewage discharge) have the potential for adverse ecological impacts on coral reefs such as excessive noise, explosives and munitions disposal, oil and fuel spillage, wreckage and debris, breakage of reef structure, and non-native species introductions from ship bilge water or aircraft cargo (Coral Reef Conservation Guide for the Military, https://www.denix.osd.mil/denix/Public/ES-Programs/Conservation/Legacy/Coral/coral.html, Accessed 12/6/04).

In recent years, the military has decommissioned several properties and transferred management responsibility to other agencies. In June 1997, the U.S. Navy officially turned over the management of Midway Atoll (NWHI) to the USFWS for use as a national wildlife refuge. Parts of the island required major remediation to mitigate contamination by lead-based paints, asbestos, fuels and chemicals, but the refuge soon offered fishing, diving, and eco-tour opportunities. When the military decommissioned Kaho'olawe, a former naval bombing range in the MHI, they established a framework for cleanup that included government-appropriated funds and a transfer of the island to a native Hawaiian organization with a state-appointed council to oversee the cleanup process. In June 1995, an evaluation of the nearshore coral reef resources of Kaho'olawe documented the continued presence of metal debris, but reported that relatively few pieces of ordnance were found despite many years of bombing exercises on the island (Naughton, 1995). The 10-year, $460 million cleanup on Kaho'olawe ended November 11, 2003. At that time, the Navy ceased active remediation and access control was returned to the State of Hawaii. The Navy continued surface clearance as a further risk reduction measure until April 2004 when final demobilization occurred. At that point, full-time management of the island shifted to the state. In May 2003, the U.S. Navy ceased military training on the eastern side of Vieques Island, Puerto Rico and transferred management of all remaining Navy property on Vieques, including the bombing training range on the easternmost parcel, to the USFWS. According to the statute governing such transfers, the property can only be used as a wilderness area. Vieques and the surrounding waters have been proposed by the U.S. Environmental Protection Agency (EPA) for listing on the National Priorities List, which EPA uses to determine which uncontrolled waste sites warrant further investigation. As such, the Navy, EPA, and Puerto Rico Environmental Quality Board will work cooperatively on conducting investigations required by the Comprehensive Environmental Response, Compensation and Liability Act (42 U.S.C. § 9601 et seq.). The investigation may conclude the need for the Navy to complete hazardous substances remediation and/or munitions clearance in some areas. Baseline assessments of 24 permanent coral reef monitoring sites at Vieques Island were commissioned by the U.S. Navy and completed in 2001-2002 in an effort to comply with Executive Order 13089 and the U.S. Department of Defense (DoD) Initiative for Coral Reef Protection at the Roosevelt Roads Naval Station in Puerto Rico (Deslares et al., 2004).

According to the DoD Coral Reef Implementation Plan (2000), U.S. military services (i.e., the Air Force, Army, Navy, and Marine Corps) "generally avoid coral reef areas in their normal operations except for some mission-essential ashore and afloat activities." DoD policy is to avoid adversely impacting coral reefs during military operations and ensure safe and environmentally responsible action in and around coral reef ecosystems, to the maximum extent practicable. However, exceptions to this policy can be made during wars; national emergencies; and threats to national security, human health, and the safety of vessels, aircraft, and platforms (Executive Order 13089, 1998). DoD has implemented a number of actions to comply with natural resource and environmental protection laws, and has developed programs to protect and enhance coral reef ecosystems. These efforts include developing geographic information system (GIS) planning tools, coral surveys to evaluate impacts from bombing exercises, assessments to determine the impact of amphibious training exercises on reef ecosystems, pollution and oil spill prevention programs, and invasive species management and effective land management programs (Defense Environmental Network and Information Exchange, https://www.denix.osd.mil, Accessed 2/14/05).

Oil and Gas in Coral Reef Ecosystems

The introduction of oil and other hydrocarbons into the marine environment can have serious consequences for coral reef ecosystems. Whether from chronic or episodic oil spills or from activities related to the exploration, production or transport of energy resources, oil can impact reefs through physical breakage, sedimentation and smothering, toxic contamination by heavy metals, and by inhibition of growth and recruitment. Sources of oil entering the marine environment vary. Summary information for North America is provided in Figure 3.12.

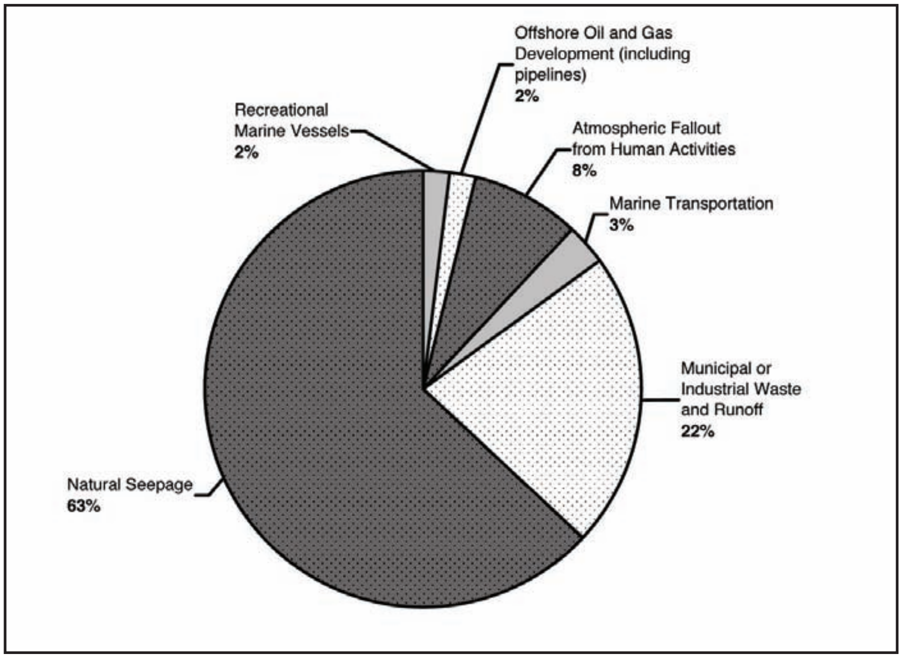

Figure 3.12. Sources of oil entering the marine environment of North America. Source: Minerals Management Service, 2002.

Once introduced, oil tends to persist in sheltered tropical coastal environments. Because of the difficulty of navigation in shallow-water coral reef environments, cleanup following a spill is often extremely difficult. Booms and skimmers can be used in lagoon areas when the oil is on the surface, but these responses become less useful over time as the oil combines with mineral particles in the water and sinks or is churned into the water column during inclement weather. The use of dispersants is often discouraged in shallow-water areas because they cause the oil to sink to the bottom where it comes into contact with sensitive reef habitats. Reduced water circulation in nearshore areas hinders natural dissipation by currents. When spills occur in shallow-water coral reef ecosystems, the best option may be to let natural processes handle the task of removing oil from the fine sediments of mangrove forests, seagrass meadows, and complex reef frameworks (Corredor et al., 1990; Guzman et al., 1994). Oil spill recovery in shallow-water reef ecosystems can require decades. Five years after a major oil spill on a Panamanian reef (April 1986), scientists found that surviving colonies of the four most massive species of reef-building corals were still experiencing extensive, chronic effects on vital processes (Guzman et al., 1994).

Several studies have been undertaken to determine the impact of oil on the physiology of coral reef organisms (reviews in Shigenaka, 2001). Laboratory experiments have demonstrated that exposure of coral species to oil can result in decreased growth, reproduction, and colonization capacity, as well as other negative effects on feeding, behavior, and mucous cell function (IPIECA, 1992). A field study in the Gulf of Eilat, Red Sea demonstrated that repeated discharges of oil onto a coral reef caused many changes to the reef system as a whole, and in particular damaged the reproductive system of scleractinian corals (Rinkevich and Loya, 1979).

In southern Florida, Dustan et al. (1991) evaluated the impacts of drilling wells on reef building corals, gorgonians, sea grasses, macroalgae, and reef fishes. Primary impacts included physical destruction by drilling machinery and the accumulation of drilling debris, although no organisms appeared to be damaged by drilling fluids or cuttings. The results implied that exploratory drilling, in light of present technology and stringent dumping regulations, may be achieved without leaving lasting impacts; however, no conclusions could be drawn from this study relative to the drilling production wells (Dustan et al., 1991).

In the North Sea, Olsgard and Gray (1995) assessed the spatial and temporal effects of production discharges on benthic fauna along contamination gradients. Results suggested that discharges reduced abundance of benthic fauna, many of which were key prey species for bottom-living fish. The fauna that became established in the contaminated sediments was considered less valuable as a food source for fish populations.

In addition to spills, exploration for offshore oil and gas reserves has the potential to have major impacts on marine ecosystems. Petroleum resources are difficult to find, and the process of locating, recovering, transferring and transporting them can pose a significant potential hazard to species living in the surrounding area. In the early stages, exploration for oil and gas involves seismic testing which involves emitting loud booming shock waves in order to determine what lies under the seafloor. The impacts of seismic testing on marine organisms are not well understood (The Ocean Conservancy, 2003). Once oil and gas reserves are located, energy exploration and production requires platform installation; dredging; drilling; the discharge of liquid, solid, and gaseous wastes and drill cuttings; noise and light pollution; and polluted air emissions. These impacts, in addition to the physical effects related to the movement of ships and equipment, can all present significant threats to the environment where the activity is taking place (http://earthsci.org/energy/gasexpl/exproil.html, Accessed 6/25/04).

The primary drilling areas in the U.S. Exclusive Economic Zone that occur near reef ecosystems are in the Gulf of Mexico, where major development has resulted in the installation of 6,500 production platforms and over a 160,900 km of pipelines and other infrastructure. Numerous wells, platforms and pipelines surround the Flower Garden Banks National Marine Sanctuary (FGBNMS) in the northwestern Gulf of Mexico (see Chapter 8), and one oil production platform even lies within the boundaries of the sanctuary, less than 1.6 km from the East Flower Garden coral cap. Fortunately, FGBNMS managers report that no major spills or impacts have occurred to date within sanctuary waters.

Because oil and gas development is such a major activity on the outer continental shelf in the Gulf of Mexico, the U.S. Department of the Interior's Minerals Management Service (MMS) has supported mapping and study programs of the Flower Garden Banks since the early 1970s to determine how to mitigate environmental impacts of oil and gas exploration. Information from these studies has supported MMS's belief that lease stipulations can minimize the potential impact of discharged contaminants to reef communities in the area. One such important stipulation requires shunting of drill cuttings so that they are deposited within 10 m of the bottom and not further up in the water column (MMS, http://www.mms.gov/eppd/compliance/13089/banks.htm, accessed 6/25/04).

Furthermore, removal of the enormous platforms, which weigh thousands of tons, is nearly impossible without the use of explosive materials. Gitschlag and Herczeg (1994) conducted one of the few known observations of fish mortality following such explosive activity. They reported that one event killed as many as 51,000 fish (larvae and juveniles were not counted). Removal of structures may also decrease the availability of habitat for fish that utilize the sites as artificial reefs (Patin, 2004, http://www.offshore-environment.com/abandonment.html, accessed 6/24/04).

Other Threats

Crown-of-Thorns Starfish Outbreaks

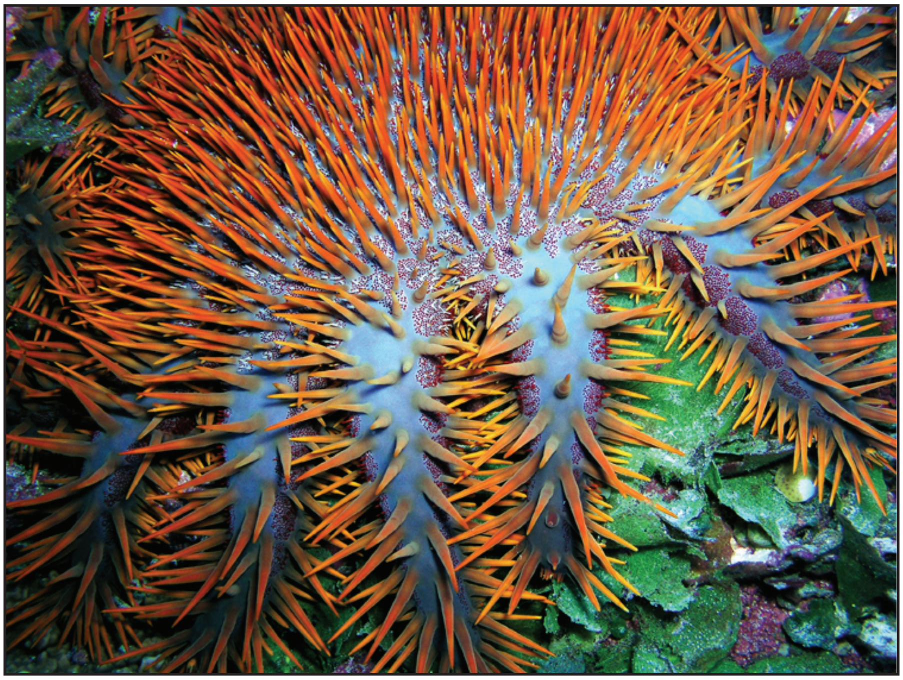

Figure 3.13. A closeup of a crown-of-thorns starfish, *Acanthaster planci*, on a reef in the PRIAs. Photo: J. Maragos.

The COTS (*Acanthaster planci*) is a species of echinoderm found throughout the Indo-Pacific region (Figure 3.13). COTS feeds on several common species of hard coral, particularly *Acropora* spp., showing a clear preference for tabular forms and those corals that are least well defended (De'ath and Moran, 1998; Pratchett, 2001). They reproduce sexually with synchronized release of gametes and have a remarkable ability to regenerate damaged parts. COTS is preyed upon by several species of fish including triggerfish (Balistidae), and pufferfish (Tetradontidae), and a few large crustaceans and mollusks. At relatively low densities, the starfish are considered to play an important role in maintaining high diversity on coral reefs (Aronson and Precht, 1995). At many locations, however, populations periodically increase to levels that result in the degradation of coral reefs. Aggregations of hundreds of thousands of individuals have been reported across the Indo-Pacific, including Australia's Great Barrier Reef, Fiji, Micronesia, American Samoa, the Cook Islands, the Society Islands, the Ryukyu Islands (Japan), Hawaii, Malaysia, the Maldives, and the Red Sea. The rate of recovery after a major outbreak is highly variable, with full recovery estimated to take decades or even many hundreds of years (Sano, 2000; Lourey, 2000).

A number of environmental factors have been considered causative in COTS outbreaks, including hurricanes, nutrient input, and overfishing (Birkeland, 1982; Ormond et al., 1991). The level of impact from human activity is still unclear since outbreaks have also been reported in remote areas with very little human activity. Nevertheless, stressors generated through human activity are likely to influence the trajectory and rate of post-outbreak recovery.

Outbreaks of other echinoderms, such as spiny sea urchins (Echinoidea), can also adversely impact coral reef ecosystems through excessive erosion of coral substratum, removal of newly settled corals, and intense herbivory (Sammarco, 1982; Carreiro-Silva and McClanahan, 2001). Damage to coral reefs due to high density populations (12-100 urchins/m^2) of urchins have been occasionally reported in U.S. waters including Hawaii, USVI, and the Marshall Islands.

Earthquakes and Volcanoes

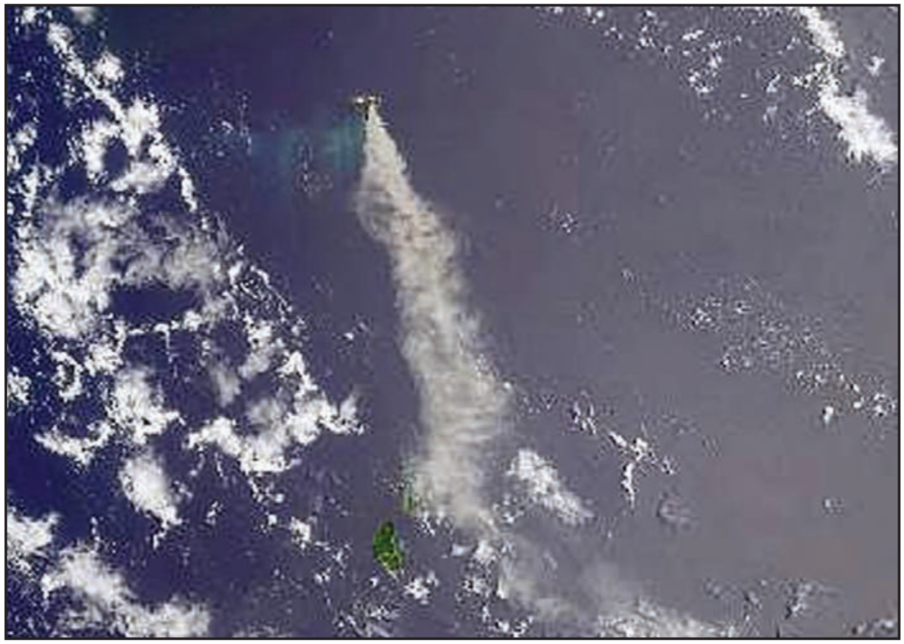

Figure 3.14. In the past few years, eruptions of the volcanic island Anatahan in CNMI have deposited tons of ash on nearby reefs and temporarily closed international airports in Saipan and Guam. The latest major cluster of eruptions occurred in April 2005. Photo: NASA, MODIS sensor.

Many islands in the Pacific and Caribbean were formed and transformed through tectonic and volcanic activity. In fact, coral reef atolls are formed through the erosion and subsidence of volcanoes and the subsequent gradual upward growth of coral reefs (Darwin, 1842). Volcanic eruptions can have important direct and indirect consequences for coral reefs. The eruption of Mt. Pagan, CNMI in 1981 resulted in extensive damage to coral communities due to scouring by lava and smothering by volcanic ash, although observation of new coral recruits indicated recovery occurring within two years of the eruption (Eldredge and Kropp, 1985). Similarly, rapid recovery was observed after high coral mortality as a result of burial by ash after the 1994 eruption of Rabaul Caldera in Papua New Guinea (Maniwavie et al., 2001). Major eruptions can also impact coral reefs many thousands of kilometers away through a complex sequence of events (Figure 3.14). For example, the 1991 eruption of Mount Pinatubo in the Philippines led to a short-term atmospheric cooling throughout the Middle East during the winter of 1992. This abnormal cooling resulted in deep vertical mixing in the Gulf of Eilat and excessive nutrient upwelling, which in turn, triggered algal blooms causing widespread coral death (Genin et al., 1995). However, cooled larva flow can also create new habitat suitable for the settlement and growth of corals and other organisms.

In 1993, an earthquake measuring 8.2 on the Richter scale caused collapse of some coral reefs around Guam and also destroyed some large coral colonies that had formed on unstable substrata (Birkeland, 1997). Earthquakes that uplift some areas while subsiding others, or even triggering catastrophic sedimentary events, are thought to be important factors in the present spatial patterns of fringing reefs in the Gulf of Aqaba, Red Sea (Shaked et al., 2004). In the Hawaiian archipelago, a high frequency of deep earthquakes combined with submergence and rising sea-level may explain the absence of coral reefs in some locations around the island of Hawaii.

Cable-laying Operations

There has been a rapid increase in the need for submarine cables, particularly fiber optic cables, to support the telecommunications industry. Cable-laying operations and the movements of unsecured cables have been found to disrupt and destabilize benthic structure (Sultzman, 2002). The impact of laying a cable on benthic habitats will depend on the location of landing points, route chosen, and installation process. In some instances, sand channels through reefs have been used, but damage has occurred where cables have been laid directly over corals. Coral transplants and artificial reef modules have been used to replace lost hard coral, yet little is known about the effectiveness of these methods. Furthermore, few restoration efforts have considered damage to non-scleractinian components of the biota.

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The State of Coral Reef Ecosystems of the U.S. Virgin Islands

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INTRODUCTION AND SETTING

Coral reef ecosystems in the U.S. Virgin Islands (USVI) consist of a mosaic of habitats, namely coral and other hardbottom areas, seagrasses, and mangroves that house a large diversity of organisms. These biologically rich ecosystems provide important ecosystem services (e.g., shoreline protection) and support valuable socio-economic activities (e.g., fishing and tourism), but they are also affected directly and indirectly by these activities. This chapter presents an assessment of the current status of coral reef ecosystems in the USVI. It provides a comprehensive review of historic and current literature and long-term datasets that describe coral reef ecosystems of the territory. It also provides data synthesized from current monitoring programs conducted by Federal and territorial organizations.

The USVI comprises three large main islands and several smaller islands (Figure 4.1). St. Croix – the largest island – is 207 km^2 in size. St. Thomas is the second largest island at 83 km^2, and St. John is the third largest at 52 km^2. The geologically dissimilar islands lie between two major island archipelagos: the older Greater Antilles to the west and the younger Lesser Antilles to the east. St. Thomas and St. John are more similar to the Lesser Antilles than to Puerto Rico with which they share an extensive shallow water platform (Adey et al., 1977). St. Croix geologically belongs to the Greater Antilles but is isolated by the Virgin Islands Trough that is over 4,000 m deep (NOAA National Geophysical Data Center, http://www.ngdc.noaa.gov/mgg/gdas/gd_sys.html, accessed: 11/2/2004). Managed areas in coastal waters of the three main islands exist to protect, maintain, or restore natural and cultural resources (Figure 4.1).

Reefs in St. Thomas and St. John generally form fringing, patch, or spur and groove formations that are distributed patchily around the islands (see Figure 4.20). The eastern and southern shores of St. Croix are protected by well-developed barrier reef systems with near-emergent reef crests that separate lagoons from off-shore bank areas (Adey, 1975; Hubbard et al., 1993). Bank reefs and scattered patch reefs occur on geological features at greater depths offshore. Recently, the National Oceanic and Atmospheric Administration (NOAA) mapped 485 km^2 of benthic habitats in the USVI to a nominal depth of 30 m. Analyses of these maps revealed that coral reef and hard-bottom habitats comprise 300 km^2 (61%), submerged aquatic vegetation covers 161 km^2 (33%), and unconsolidated sediments comprise 24 km^2 (4%) of shallow water areas (Kendall et al., 2001; Monaco, 2001; http://biogeo.nos.noaa.gov, accessed 1/19/05).

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7 National Park Service, St. Croix, USVI
8 US Geological Survey, St. John, USVI.

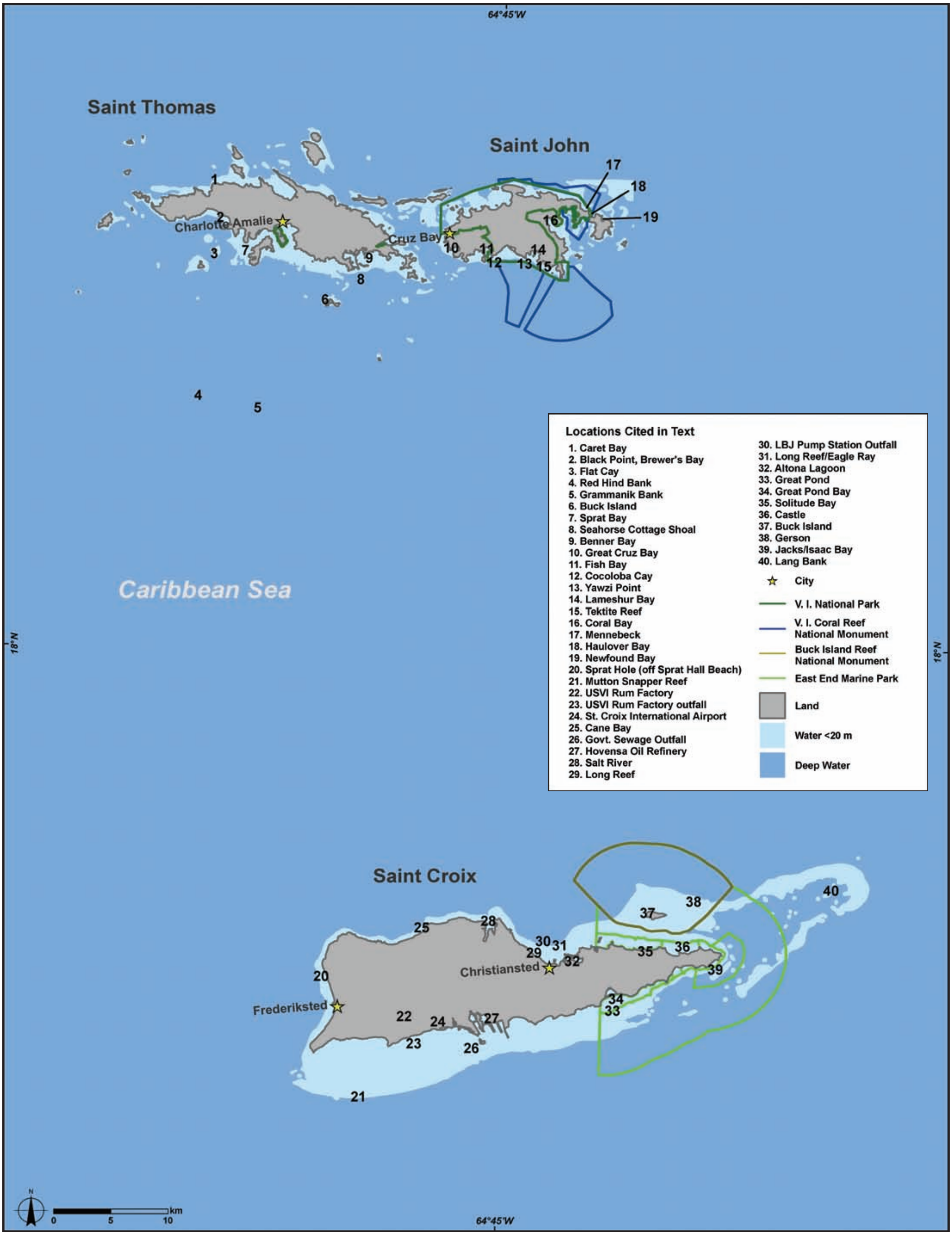

Figure 4.1. A map of the USVI showing managed areas, municipalities, and other locations mentioned in this chapter. Map: A. Shapiro.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Coral reefs in the USVI face similar pressures as reefs elsewhere in the Caribbean (Rogers and Beets, 2001). Of the 13 major coral reef stressors identified by the U.S. Coral Reef Task Force, 10 have been identified as being problematic to reef ecosystems in the territory. These stressors include climate change; diseases; tropical storms; coastal development and runoff; coastal pollution; tourism and recreation; fishing; and ships, boats, and groundings. The impacts of these stressors on USVI coral reefs are summarized in this chapter. Other stressors such as alien species, security activities, and offshore oil activities are not relevant to the USVI. Stressors are described fully in Chapter 3 of this report.

Climate Change and Coral Bleaching

Climate change refers to the trend of increasing mean global air temperature and sea surface temperatures (SST) within the last century compared with previous estimates. This warming trend is generally attributed to the atmospheric accumulation of greenhouse gases. Bleaching in the USVI has been reported since 1987 (Figure 4.2). Bleaching was most severe and had the highest reported incidence of occurrence during the Caribbean-wide event of 1998-1999. According to the U.S. National Park Service (NPS), the 1998 bleaching event coincided with the highest recorded SSTs in the USVI. Bleaching was less severe in 1999 probably because water temperatures were slightly lower (28.8ºC) during that year. The 1999 bleaching event did not result in extensive coral colony mortality because most colonies recovered within six months of being bleached (Nemeth and Sladek-Nowlis, 2001; Nemeth et al., 2003c). For both years, bleaching was most severe in St. Croix, followed by St. John, and then St. Thomas (Figure 4.2).

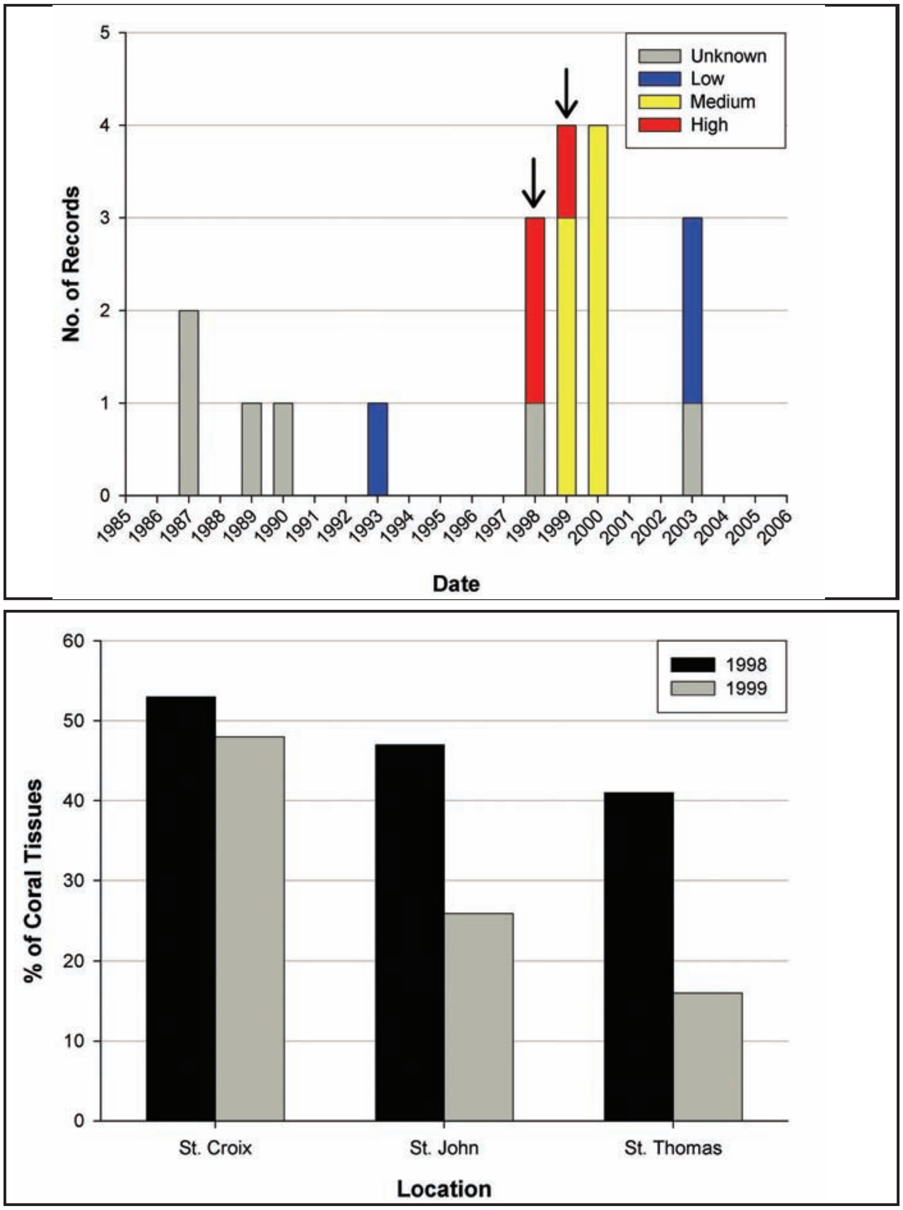

Figure 4.2. Annual trends in coral bleaching in the USVI. Upper panel shows the number of bleaching reports by year and severity. Arrows indicate the Caribbean-wide bleaching event of 1998-1999. Source: Reefbase 2003, http://www.reefbase.org, Accessed: 10/23/2003. Lower panel shows the estimated percent of coral tissues that bleached in 1998-1999. Bars represent the maximum percent of sampled coral colonies that bleached by island and year. Source: Rogers and Miller, 2001; Nemeth et al., 2003c.

Diseases

Several diseases have affected coral community structure and have degraded coral cover (Table 4.1). Between 1976 and 1989, white band disease (WBD), bleaching, and hurricanes reduced the cover of elkhorn coral (*Acropora palmata*) by as much as 85% within the Virgin Islands National Park (VINP) and the Buck Island Reef National Monument (BIRNM; Gladfelter et al., 1977; Rogers et al., 1982; Edmunds and Witman, 1991; Bythell et al., 1992; Rogers and Beets, 2001). Between December 1997 and May 2001, 14 species of

Table 4.1. Diseases affecting coral reef organisms in the U.S. Caribbean and Florida. Source: Bruckner, 2001.

DISEASE	DESCRIPTION	CAUSATIVE AGENT	NUMBER OF CORAL SPECIES AFFECTED	CORAL SPECIES AFFECTED	RATE OF INFECTION (MM PER DAY)
Aspergillosis	Irregular lesion(s) of various sizes distributed throughout the sea fan blade due to loss of tissue and skeleton. Tissue surrounding the lesion often becomes dark purple and may have nodules, both of which occur in response to a variety of stressors. Identification of this disease requires confirmation of the presence of white fungal filaments.	Fungus (*Aspergillus sydowii*)	10+ (Weil and Smith, 2003)	Common sea fan (*Gorgonia ventalina*), Venus sea fan (*G. flabellum*), and other branching gorgonians including *Pseudoterigorgia* spp.	Unknown
Black band	Crescent shaped or circular band of black filamentous material separating living, colored coral tissue from white exposed coral skeleton.	Cyanobacteria, Sulfide-oxidizing bacteria, Sulfate-reducing bacteria	20	Several soft corals and 20 hard corals including boulder star corals (*Montastraea annularis* complex) and symmetrical brain coral (*Diploria strigosa*)	1 - 20
Dark spots	Dark purple, gray, or brown circular or irregular patches of discolored tissue scattered on the surface of a colony or at the colony's margin. The discolored tissue increases in size and radiates outward as the area first affected dies. Darkened polyps often are depressed and appear smaller in size than normal polyps.	Unknown	3 or 4	Massive starlet coral (*Siderastrea siderea*), blushing star coral (*Stephanocoenia intersepta*), and *Montastraea annularis* complex	Unknown
Red band-I	Narrow band or mat of filamentous cyanobacteria that advances slowly across the surface of a coral and kills living tissue as it progresses. It is similar in appearance to black band disease, in that it forms a distinctive band that separates live coral tissue from bare white skeleton.	Cyanobacteria	14 or more	Lettuce corals (*Agaricia* spp.), boulder brain coral (*Colpophyllia natans*), cactus corals (*Mycetophyllia* spp.), blushing star coral, the common seafan (*Gorgonia ventalina*)	Unknown
Red band-II	During daylight, the filaments spread out like a net in a diffuse fashion over live tissue and bare skeleton; at night the band forms a compact balled-up mat at the interface between live tissue and exposed skeleton.	Cyanobacteria	6	*D. strigosa, C.natans, M. annularis, M. cavernosa, Porites astreoides,* and *Siderastrea radians*	Unknown
White band	Coral tissue peels or sloughs off from coral skeleton in a uniform band, from the base of the colony upwards. A second form (WBD-II) exhibits a transient zone between apparently healthy tissue and exposed skeleton that consists of bleached but intact tissue.	Unknown	3	Elkhorn and staghorn corals (*Acropora* spp.)	5
White plague complex (Types I, II, and III)	Similar to white band in that an abrupt line of exposed (white) coral skeleton separates living tissue from dead coral colonized by algae.	Plague type II is caused by a bacterium (*Aurantamonus coralicida*); the cause of Plague types I and III is still unknown	32 or more	At least 32 species including brain corals (*Diploria* spp. and *C. natans*), cactus corals (*Mycetophyllia* spp.), the elliptical star coral (*Dichocoenia stokesii*), star corals, and starlet coral (*Siderastrea siderea*)	3 - 200

Table 4.1 (con't.). Diseases affecting coral reef organisms in the U.S. Caribbean and Florida. Source: Bruckner, 2001.

DISEASE	DESCRIPTION	CAUSATIVE AGENT	NUMBER OF CORAL SPECIES AFFECTED	CORAL SPECIES AFFECTED	RATE OF INFECTION (MM PER DAY)
White pox	White circular lesions on the surface of infected colonies.	*Serratia marcescens*	1	Elkhorn coral (*A. palmata)*	250 -1,050
Yellow blotch	Pale, circular blotches of translucent tissue or a narrow band of pale tissue at the colony margin surrounded by normal, fully pigmented tissue. Infected tissue dies, and exposed skeleton is colonized by algae.	Unknown	3	Boulder star corals (*Montastraea* spp.) and the brain coral (*Colpophyllia natans)*	< 1

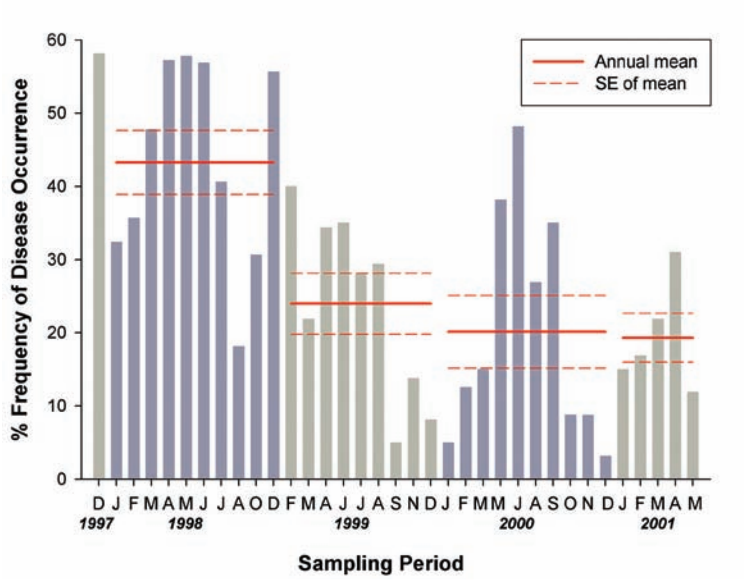

Figure 4.3. Mean monthly and annual frequency of disease occurrence on Tektite Reef, St. John, over 42 months. Source: Miller et al., 2003.

hard coral in the VINP were infected with the white plague type II, a newly identified disease (Miller et al., 2003; Weil and Smith, 2003). Miller et al. (2003) observed a new incidence of white plague type II every month, although the monthly frequency of infections decreased during the study (Figure 4.3). A disease-causing fungus, *Aspergillis sydowii*, has been isolated from air samples taken during African dust storms and has been infecting sea fans on reefs in the USVI (Garrison et al., 2003).

Tropical Storms

Tropical storms are a major force structuring coral reef communities in the Caribbean. Storms have the capacity to degrade reefs in several ways. They increase terrestrial runoff, sedimentation, and pollution affecting coral reefs, and cause extensive physical damage to the substratum. Several hurricanes have affected USVI reefs since 1979, but Hurricanes David (1979) and Hugo (1989) were the most severe and destructive (Figure 4.4). The eye of David – a category five hurricane - traveled about 160 km southwest of St. Croix; the eye of Hugo – a category four hurricane – passed directly over the island (Figure 4.4). Damage to reefs varied with storm path, strength and velocity, wave height and direction, the dominant coral species, and reef depth (Rogers et al., 1997; Bythell et al., 2000). The strongest evidence of storm damage to reefs was observed at Lameshur Bay, St. John, and Buck Island, St. Croix. Hurrincane David resulted in large stands of elkhorn coral on reef crests being replaced by mounds of dead elkhorn coral rubble at both Lameshur Bay and Buck Island (Rogers et al., 1982; Beets et al., 1986). In Lameshur Bay, Hurricane Hugo caused significant declines in total live coral cover, including star coral (*Montastrea annularis*), a dominant and slow growing coral species (Edmunds, 1991; Rogers et al., 1991). At Buck Island, Hurricane Hugo resulted in significant declines in cover of *M. annularis* and *Porites porites* at depths of 8–10 m, although *M. annularis* suffered greater mortality from predation and tissue necrosis over a two-year period than from physical damage from the hurricane (Bythell et al., 1993; Bythell et al., 2000). Hurricane Hugo also reduced areas on the south side of Buck Island to rubble pavement and moved the reef crest off the island's south side 30 m landward (Hubbard, 1991).

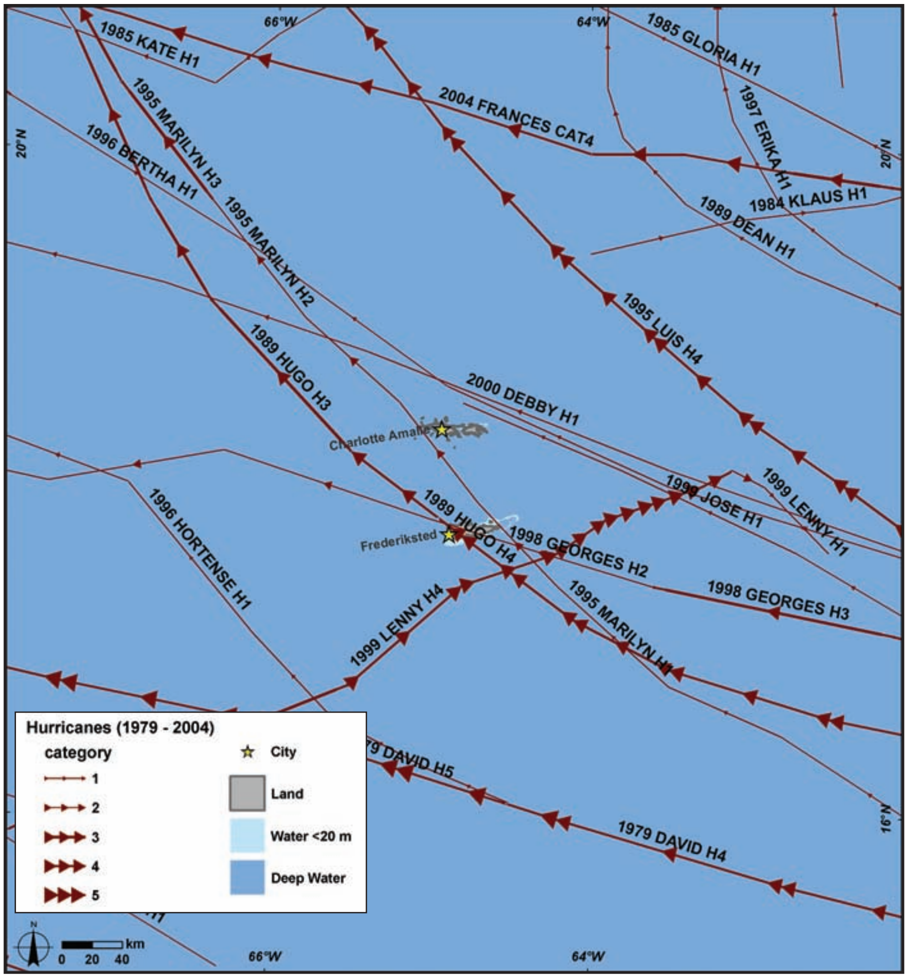

Figure 4.4. Hurrcanes that affected the coral reef ecosystems in the USVI between 1979 and 2001. Storm names are followed by year of occurrence and storm category on the Saffir-Simpson hurricane scale. H1 to H5 = Hurricane categories one through five. Arrows indicate the direction and path of the storms. Map: A. Shapiro. Source: NOAA Coastal Services Center.

Fifteen years after Hurricane Hugo, reefs in Lameshur Bay still have not shown significant increases in live coral cover (Rogers et al., 1997; C. Rogers, pers. obs.; J. Miller, pers. obs.). Exposure by Hugo of new substrates for colonization, coupled with a reduction in abundance of urchins and herbivorous fishes that consume macroalgae, may have facilitated extensive growth of macroalgae (Lessios et al., 1984; Levitan, 1988; Rogers et al., 1997). Macroalgae inhibit settlement and survival of coral recruits and growth by existing colonies, and mean benthic cover of macroalgae sometimes reaches over 30% in the affected areas (Lessios et al., 1984; Levitan, 1988; Rogers et al., 1997). At Buck Island, recovery of elkhorn coral damaged by Hurricane David was hindered by WBD and by Hurricane Marilyn in 1995 (Rogers et al., 1982; Rogers et al., 2002). Some recruitment of elkhorn coral has occurred since the 1995 hurricane (Bythell et al., 2000; Rogers et al., 2002).

Coastal Development and Runoff

Sedimentation associated with runoff from coastal development poses a serious threat to water quality in the USVI. In St. Thomas and St. John, the problem is worsened by the steep terrain of the islands (80% of the slopes exceed 30° in incline), and runoff from unpaved roads after intense rain showers is considered the largest contributor of eroded sediments to coastal waters (CH2M Hill Inc., 1979; Anderson and MacDonald, 1998; IRF, 1999). Although published data on the temporal increase and spatial extent of coastal development in the USVI are scarce, unplanned and poorly regulated development for a growing population, and a booming tourism industry may have taken a toll on coral reef ecosystems through the years (see Tourism and Recreation section). Nemeth and Sladek-Nowlis (2001) monitored the impacts of a hotel development on a nearby fringing coral reef at Caret Bay, St. Thomas (Figure 4.5) monthly for two years. The hotel construction site was on a steep hillside less than 50 m from the shoreline. The landward edge of the reef was 75-140 m from the shoreline. Rates of sedimentation, changes in water quality, and changes in the abundance and diversity of corals and other reef organisms were measured along five permanent transects from July 1997 to March 1999. Sediment loads and suspended solids were highest at ravine outlets and sheltered locations, increased during large rainfall events, and decreased after buildings and road pavements were completed. Live coral cover along the entire reef tract declined about 14% and was lowest at sites with the highest rates of sedimentation (Figure 4.6).

Figure 4.5. A large mound of dirt was excavated from a construction site located less than 100 m from the shoreline at Solitude Bay, St. Croix. Photo: C. Jeffrey.

Severe rainfall events are problematic and can overwhelm existing sewer and stormwater systems. During November 2003, a low pressure system dropped 38 cm of rain in five days throughout the territory and contributed to the formation of large sediment plumes along developed areas of the coastline. Sediment plumes resulted in a decline in water quality, elevated turbidity on nearby reefs and seagrass beds, and forced the closure of swimming beaches. Additionally, wastewater disposal and sewage systems frequently malfunction and discharge raw sewage into nearshore areas. Despite the many environmental problems associated with coastal development, major development projects adjacent to environmentally sensitive habitats are being proposed and welcomed by government officials as boosters of the economy. Such projects may exacerbate existing problems of coastal pollution and runoff, and ultimately may harm the islands' economy that is at least partly dependent on the health of their natural resources.

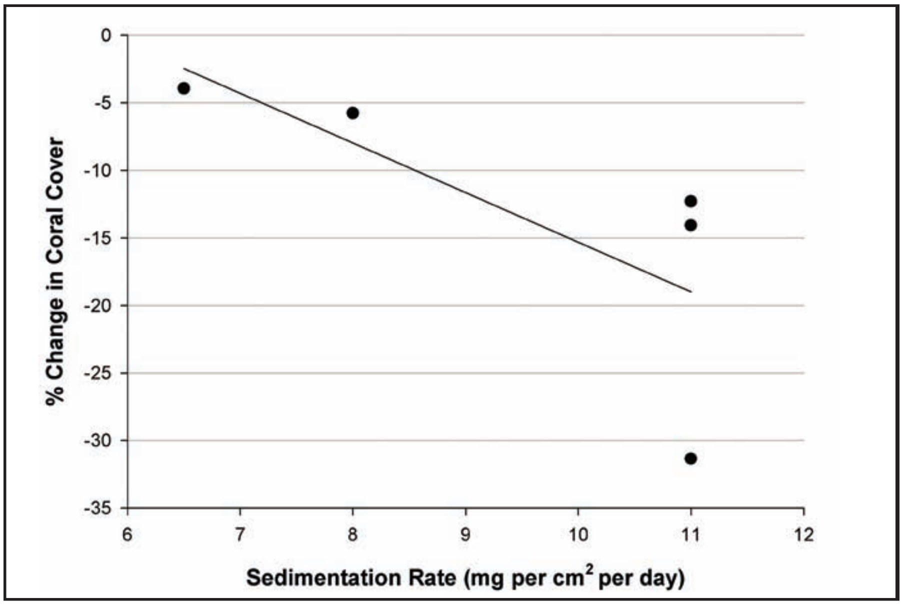

Figure 4.6. Percent change in live coral cover as a function of increasing rate of sedimentation at Caret Bay, St. Thomas. Data were collected from five permanent transects at Caret Bay Reef between July 1997 and March 1999 before, during, and after the construction of the Caret Bay Villas. The decline in live coral was significant ($p < 0.01$). Source: Nemeth and Sladek-Nowlis, 2001.

Coastal Pollution

Coastal pollution has led to several days of beach closings in the USVI. In 1999, the USVI was ranked third in the number of beach closings per year among U.S. States and Territories with 307 beach-closing days (National Resources Defense Council, http://www2.nrdc.org/water/oceans/ttw/sumvi.pdf, Accessed: 11/10/2004). Beach closings decreased to eight days in 2002, but increased tenfold to 80 days in 2003. The continued decline in coastal water quality has been linked to coastal development and runoff, as well as point and nonpoint source discharges (USVI DPNR, 2004). In St. Croix, the Virgin Islands rum manufacturing plant discharges a plume of wastewater that is visible from the discharge point to about 10 km westward along the shoreline. Biological pollution of coastal water results largely from a failing, overloaded municipal sewage system that frequently empties sewage directly into nearshore waters as well as the discharge of vessel wastes directly into the sea by boat owners. Coastal waters also become polluted when groundwater that has been contaminated by failing septic tanks, sewage infiltration, and petroleum is carried to the marine environment during flooding after intense rainfall (USVI DPNR, 2004). These pollution problems are worsened by a lack of public awareness about the importance of USVI waters, which further contributes to the degradation of marine water quality.

The USVI Department of Planning and Natural Resources (DPNR) conducts a Water Pollution Control Program to monitor all known point source discharges of pollution such as outfalls, harbors, marinas, and main recreational areas (USVI DPNR, 2004). The program also evaluates coastal water quality by monitoring nonpoint source discharges through a signed Memoranda of Agreement and Cooperation with several partner agencies, including the Virgin Islands Resource Conservation and Development Council, VI Conservation District, University of the Virgin Islands (UVI), U.S. Geological Survey (USGS), Island Resources Foundation, the NPS, and the St. Croix Environmental Association (SEA). Additionally, the NPS in St. John and UVI publish a local newsletter to inform and educate the public on nonpoint source pollution problems (USVI DPNR, 2004).

Tourism and Recreation

Historically dependent on agriculture and trade, the USVI has developed a robust tourism industry during the last 34 years, which has shifted the islands' economy to one that is mainly tourism-based. The number of tourist arrivals to St. Thomas and St. John has quadrupled between 1970 and 2000; tourist arrivals to St. Croix remained relatively unchanged during the same period (Figure 4.7). In 2000, 108,612 USVI residents were joined by 2.2 million visitors, but the annual number of tourists has remained fairly constant since then (U.S. Census Bureau, 2003, http://www.census.gov/prod/cen2000/island/VIprofile.pdf, Accessed 3/1/05; USVI Bureau of Economic Research, http://www.usviber.org, Accessed 11/7/2004).

Tourism accounts for more than 70% of the gross domestic product of the territory, and as in other tourism-dependent countries, the environmental costs of tourism are evident. Visible impacts of increased visitation include physical damage to habitats, poor treatment and control of solid waste and sewage, increased eutrophication, groundwater depletion and contamination, increased sediment loads, and displacement of traditional resource use (IRF, 1996; Bryant et al., 1998; Burke and Maidens, 2004). Snorkeling and diving are major recreational activities that could cause physical damage to reefs. For exam-

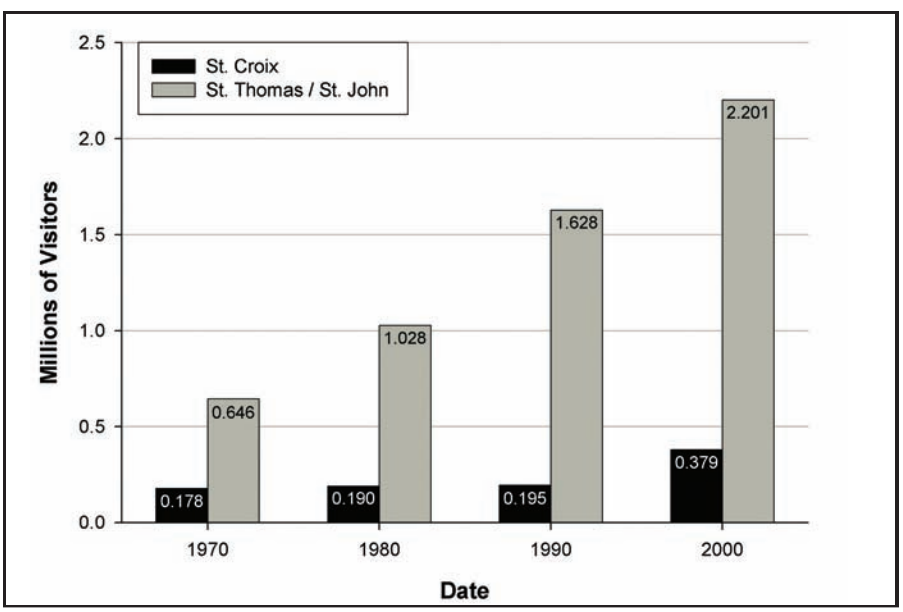

Figure 4.7. Number of visitors to St. Croix and St. Thomas/St. John between 1970 and 2000. Source: USVI Bureau of Economic Research, http://www.usviber.org, accessed 11/7/04.

ple, physical damage to corals has been observed at the BIRNM underwater snorkel trail, which attracts up to 200 visitors per day (Z. Hillis-Starr, pers. obs.). However, the more obvious impact of increased tourism has been the exacerbation of solid waste disposal problems caused by the high density of tourists and residents as well as an economy heavily dependent on high energy-consumption.

Tourists, residents, and poorly regulated development also contribute directly and indirectly to coastal pollution. For example, participation by residents and tourists in diverse marine recreational activities such as boating, fishing, diving, snorkeling, kayaking and beach camping negatively impact the marine environment in overpopulated areas. Most reported oil spills in the USVI stem from the refueling of yachts, ferries, and cruise ships (IRF, 1996). Poor lawn care practices on golf courses, in residential areas, and at tourist resorts are considered major sources of nitrate and phosphate contamination to nearshore areas through stormwater runoff (IRF, 1996). Finally, the development of major tourism facilities in coastal areas further threatens the coastal environment through increased sediment loads from the construction of buildings and roads, the operations of facilities, and stormwater runoff (IRF, 1996).

More thought and effort is now being given to promoting sustainable tourism. Dive and anchor buoys have been installed at popular dive sites to reduce the incidence of anchor damage. Environmental education and outreach is on the agenda of the national and local non-governmental organizations (NGOs), as well as territorial and Federal government agencies. For example, the NPS, UVI, SEA, and The Nature Conservancy are providing eco-hikes and other educational tours and programs for the public.

Fishing

Fishery resources have declined in the USVI since the 1960s (e.g., Appeldoorn et al., 1992). Although fishing is a visible and obvious impact to fisheries species in coral reef ecosystems, less tractable environmental threats such as habitat degradation or loss and marine pollution have also undoubtedly contributed to the decline in fisheries. Fishing has a long history in the USVI (Fiedler and Jarvis, 1932). Strongly integrated into the Virgin Islands culture, fishing provides subsistence, supplemental income, recreation, or full-time employment to the islanders. Residents and tourists consume a wide variety of marine species in relatively large quantities (i.e., about 15 kg/person/year; Swingle et al., 1979; Olsen et al., 1984). Resource managers divide the USVI fisheries into commercial and recreational fishing sectors. Presently, the bulk of information on USVI fisheries is derived from the commercial sector.

The USVI commercial fishery is artisanal in nature and consists of about 380 registered fishers – 240 on St. Croix and 140 on St. Thomas and St. John (Brownell, 1971; Brownell and Rainey, 1971; Tobias et al., 2000; CFMC, 2003; Gordon and Uwate, 2003; Kojis, 2004). Typically, fishers use small, open vessels (6 to 8 m in length) powered by outboard motors to fish with a variety of gear types and methods, although traps or fish pots are the most popular gear type (Sylvester and Dammann, 1972; Appeldoorn et al., 1992; Beets, 1997; Kojis, 2004). Scuba diving is also a common commercial method used to harvest reef fishes (by spear) and invertebrates (by hand or with snare; CFMC, 2003). In the past decade, gillnets and trammel nets used with the aid of scuba equipment have become common fishing gear on St. Croix, and annual landing from nets now exceed annual landings from traps on this island (Tobias and Toller, 2004). USVI commercial fishers must submit monthly catch records as a stipulation for permit renewal.

Recreational fishing is also very important to the USVI economy. Boat-based recreational fishing may have contributed as much as $5.9 million in fishing-related expenditures to the local economy in 2000 (UVI EEC, 2002), up from about $90,000 in 1986 (Jennings, 1992). Snappers were the most preferred species-group of fishers. Collectively, however, much of the reported fishing effort was directed towards pelagic fish species such as blue marlin, sailfish, dolphinfish, tuna, wahoo, and kingfish (UVI EEC, 2002). The recreational fishery for pelagics has been routinely monitored for over a decade but is not the subject of this review (see Adams, 1995; Mateo, 2000). Less data exist on the impact of recreational fishing to reef-associated species primarily because recreational fishers do not obtain fishing permits, and no records are kept on their population size or activity (Appeldoorn et al., 1992).

Reef Fish Fishery

Reef fish assemblages and the composition of reef fish landings have changed markedly in the USVI over the past 40 years (Appeldoorn et al., 1992; Rogers and Beets, 2001). Catanzaro et al. (2002) reviewed the lamentable collapse of the USVI fishery for Nassau groupers during the 1970s (Olsen and LaPlace, 1978) and red hind during the 1980s (Beets and Friedlander, 1992). Landings of larger individuals of snappers (Lutjanidae) and other groupers (e.g., the coney, *Epinephelus fulvus*) also declined in the 1980s (Appeldoorn et al., 1992). Although fishery-dependent monitoring data for the 1990s are still unavailable, a growing number of fishery-independent studies, primarily utilizing visual survey methods, indicate that populations of targeted grouper and snapper species have not recovered to date (Rogers and Beets, 2001; Beets and Friedlander, 2003; CCMA-BT, unpublished data; Nemeth et al., 2004). On average, fewer than eight groupers per year were observed during monitoring of reef fish assemblages at four reference sites within the VINP between 1989 and 2000 (Figure 4.8). Nassau grouper were observed in only 3% of 1,764 visual surveys conducted at the four reference sites during the entire study period (Beets and Friedlander, 2003). Of the 2,292 snappers and groupers observed during 756 visual fish surveys within the VINP and the BIRNM, less than 2% were greater than 35 cm in length (CCMA-BT, unpublished data). On nearshore reefs throughout the USVI, Nemeth et al. (2003c) also found a similar trend where snappers and groupers larger than 40 cm were mostly absent from the fish assemblage. Densities of snappers and groupers averaged five and three fish/100 m^2, respectively, with the most common size class of both families being 11-20 cm (Nemeth et al., 2003c). In contrast, the herbivorous fishes (e.g., Acanthuridae and Scaridae) dominated the fish assemblage with average densities between 10-20 fish/100 m^2.

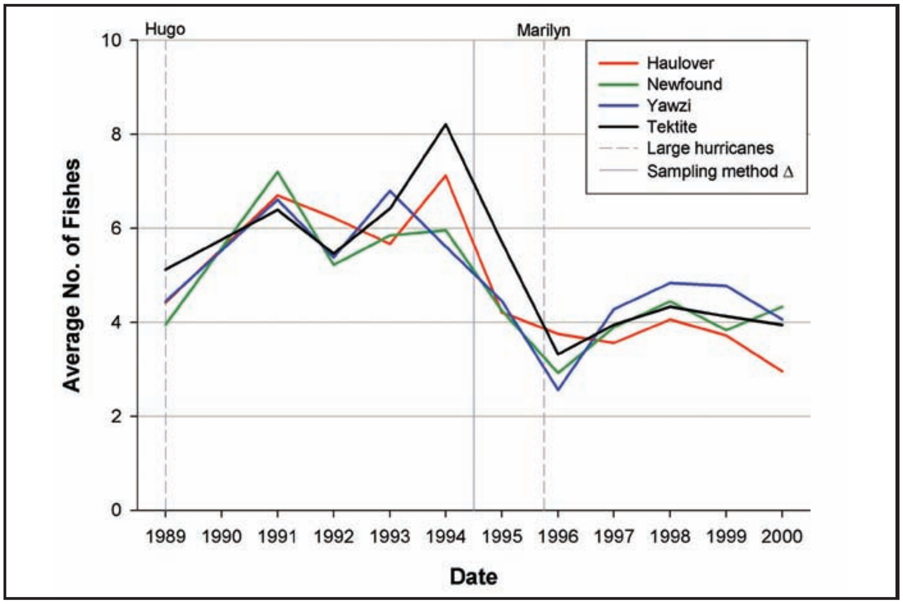

Figure 4.8. Abundance trends in groupers (Serranidae) among the four reference sites around St. John, U.S. Virgin Islands, from 1989-2000. Source: Beets and Friedlander, 2003.

Lobster Fishery

The Caribbean spiny lobster, *Panulirus argus*, is a species of tremendous commercial and recreational importance in the USVI. Spiny lobsters accounted for 6% of total reported landings in 1998-1999 (Tobias, 2000) and its commercial value probably exceeds that of any other single reef-associated species in the USVI. Although Bohnsack et al. (1991) concluded that USVI lobster populations appeared healthy, more recent studies found a 10% decrease in mean size between 1997 and 2000, which suggests that overfishing is occurring (Tobias, 2000; Mateo and Tobias, 2002). The Virgin Islands Division of Fish and Wildlife (DFW) routinely monitors commercial lobster landings (weight and carapace length) and has periodically monitored lobster recruitment around St. Thomas, where recruitment appears to be highly variable but generally low (Gordon and Vasques, in press). Limited field surveys around St. John also indicate that average lobster size and density have decreased since 1970 (Wolf, 1998).

Conch Fishery

The queen conch, *Strombus gigas*, forms an important fishery in the USVI. During the 1990s, conch accounted for about 2% of total USVI landings, with most conch landed on St. Croix (5% of total St. Croix landings) and less landed on St. Thomas and St. John (0.4% of total landings on St. Thomas and St. John; Valle-Esquivel, 2002). The value of reported USVI commercial conch landings in 1998-99 was about $340,000 (Tobias et al., 2000). In the USVI, commercial fishers harvest queen conch by hand, primarily by scuba diving, although some conch are also harvested by free diving (Rosario, 1995). Very little information exists presently on the recreational harvest of conch, but concerns about declining stocks have been voiced for over 20 years (Wood and Olsen, 1984; Valle-Esquivel, 2002). Although numerous territorial regulations were enacted in 1988 to protect conch stocks including a five-year closure of the fishery on St. Thomas and St. John, conch stocks have either not shown significant recovery or have continued to decline in the USVI (Friedlander, 1997; Gordon, 2002).

It is difficult to separate out the causal factors of fishery decline in the USVI. Overfishing, technological advances in fishery gear (larger boats, more powerful engines, and improved gear), and the deterioration of habitats may have contributed to significant changes in the community structure of reef fish assemblages and the observed decline in fishery yields. Several studies have documented the failure of existing regulations and a lack of enforcement in protecting reef fishes or reversing the declines in the abundance of preferred species such as the large groupers and snappers (Beets,1996; Wolff, 1996; Garrison et al., 1998; Rogers and Beets, 2001). Likewise, other studies have identified sedimentation and pollution as major factors in the decline of nearshore reef ecosystems, which may have contributed to the decline of fisheries species (deGraaf and Moore, 1987; Rogers and Beets, 2001).

On a more positive note, some USVI fisheries are beginning to show small signs of recovery. Since the closure of an important red hind spawning aggregation site south of St. Thomas in 1990, the average size of red hind from the St. Thomas fishery increased significantly from 26 cm to over 34 cm total length in 2003 (Nemeth, in review). Moreover, tag and release studies conducted by the UVI on a red hind spawning aggregation near a shelf-edge reef south of St. Thomas found that 78% of the fish were over 35 cm, 50% over 37.5 cm, and fish greater than 40 cm (Nemeth, unpublished data). In March 2004, scientists at UVI discovered the first evidence of a Nassau grouper spawning aggregation reestablishing itself south of St. Thomas. Underwater surveys estimated that up to 100 Nassau groupers have aggregated and showed signs of reproductive activity (Nemeth, in review). Unfortunately local fishers have targeted this unprotected reef for the past several years and fishing mortality may seriously threaten this Nassau spawning aggregation. In this same area, yellowfin grouper, tiger grouper, and cubera snapper have all been seen forming large spawning aggregations (Nemeth, in review).

Trade in Coral and Live Reef Species

The trade in coral and live species is a minor problem in the USVI and has not received as much attention as it has in other U.S. jurisdictions with coral reef ecosystems. The trade in live coral and fishes is prohibited by the USVI Endangered and Indigenous Species Act of 1990 (Title 12, Chapter 2), the purpose of which is "to protect, conserve, and manage indigenous fish, wildlife and plants, and endangered or threatened species for the ultimate benefit of all Virgin Islanders, now and in the future." Very few permits have been issued for the harvest or take of live coral and non-commercial or recreational fishes. Issued permits have been for research and education purposes only. Thus, there are very few exports of live coral (W. Coles, pers. obs.). Locally, U.S. Customs and Department of Agriculture officials have confiscated small amounts of live coral that had been recently collected by tourists departing from the territory. A much greater problem is the export of dead coral (some of which may have been collected alive) and other marine organisms. Considerable amounts of dead and dried coral, undersized conch, and shells have been confiscated at airports on the islands of St. Thomas and St. Croix and at the U.S. Postal Service inspection facility in Puerto Rico.

Ships, Boats, and Groundings

Data on the impacts of resource use within the territory are limited, and research on this topic is needed. A recent assessment of marine resource utilization identified boating as a major recreational activity in the USVI, and damage from small boats anchored in corals and seagrasses as a primary concern (Link, 1997). A total of 2,462 private and commercial boats were registered throughout the territory in 2000 (Uwate et al., 2001). To reduce anchor damage to reefs, the VINP has installed over 300 mooring and protection buoys around St. John and at the BIRNM. Another local program initiative called "Anchors Away" has recently installed 50 mooring buoys around the island of St. Croix. Additionally, funding from the NOAA Coral Reef Conservation Program has been approved for additional moorings within the East End Marine Park in St. Croix. Boat groundings are also of concern. In 1988, a cruise ship destroyed 283 m^2 of reef within the VINP, and coral recovery after 10 years has been minimal (Rogers and Garrison, 2001).

Marine Debris

Marine debris has become a problem in the USVI. Debris that washes out to sea via runoff (sewers, street litter) pollutes the water and shorelines and can be life-threatening to marine organisms and humans. Fishing line and nets, rope and other trash can wrap around animals and cause drowning, infection, or amputation, or can settle on hard bottom areas and kill coral colonies. A major landfill that exists along the coast near Sandy Point, St. Croix receives most of the solid waste from the island. Debris from this landfill – consisting primarily of fishing lines, bottles, plastic bags and other street litter – is often washed out to sea where it becomes a health hazard to marine life. The same may be true for landfills on St. Thomas and St. John. The SEA has organized several beach cleanup campaigns to increase public awareness about marine debris and reduce the amount of debris that litters the nearshore environment, but this threat is an ongoing concern.

Aquatic Invasive Species

Aquatic invasive species are not recognized as a major threat in this jurisdiction.

Security Training Activities

No security training activities currently occur in this jurisdiction.

Offshore Oil and Gas Exploration

No offshore oil and gas exploration currently occurs in the USVI.

CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

This section focuses on resource monitoring activities, data collection and analyses, and summaries of published studies and data sets to provide an assessment of the current condition of resources in coral reef ecosystems of the USVI. Information is presented to describe three functional or structural components of coral reef ecosystems: marine water quality, benthic habitats, and coral reef-associated fauna (Table 4.2). A brief summary of ongoing research and monitoring programs, methods, results and discussion, and an assessment of overall condition are presented for each ecosystem component. Locations of monitoring and research efforts are shown in Figure 4.9.

Table 4.2. Data sets selected for the description of the current condition and status of coral reef ecosystems in the USVI.

ECOSYSTEM COMPONENT	DATA SET	SOURCE AGENCY/ORGANIZATION
Water quality	2000 Water Quality Assessment for the United States Virgin Islands. 305b Report to the Environmental Protection Agency.	Department of Planning and Natural Resources, Division of Environmental Protection (USVI DPNR-DEP)
	Water Quality Assessment for the Virgin Islands National Park, St. John, 1988 to 1998.	NPS and U.S. Geological Survey, Biological Resource Division (USGS-BRD)
	Coral Bay Sediment Deposition and Reef Assessment Study. Report to the USVI Department of Planning and Natural Resources, Division of Environmental Protection (USVI DPNR-DEP), Non-Point Source Pollution Grant Program MOA# NPS-01801 by the Center for Marine and Environmental Studies (Devine et al., 2003).	University of the Virgin Islands and USVI DPNR-DEP
Benthic habitats	Coral Monitoring Program for the Virgin Islands National Park (Miller et al., 2003).	NPS and USGS-BRD
	Elkhorn Coral Monitoring Project (C. Rogers, unpublished data).	NPS and USGS-BRD
	Video monitoring assessment of coral reefs in St. Croix, USVI. Year I and Year II reports to the USVI DPNR (Nemeth et al., 2002, 2003a).	UVI-CMES
	Atlantic and Gulf Rapid Reef Assessment Program. A rapid assessment of coral reefs in the Virgin Islands, Part 1: stony corals and algae (Nemeth et al., 2003b).	UVI-CMES
	Characterization of benthic habitats in the Virgin Islands National Park and the Buck Island Reef National Monument (NOAA, unpublished data).	NOAA CCMA-BT
Associated biological communities	Characterization of reef fish in the Virgin Islands National Park and the Buck Island Reef National Monument (Kendall et al., 2003, Monaco et al., in prep.).	NOAA CCMA-BT
	Quantitative estimates of species composition and abundance of fishes, and fish species/habitat associations in St. Croix, USVI. Year II report (Nemeth et al., 2003a).	USVI DPNR-DFWS
	Temporal Analysis of Monitoring Data on Reef Fish Assemblages inside Virgin Islands National Park and around St. John, US Virgin Islands, 1988-2000. Report to USGS/BRD (Beets and Friedlander, 2003).	NPS
	Atlantic and Gulf Rapid Reef Assessment Program. A rapid assessment of coral reefs in the Virgin Islands, Part 2: fishes (Nemeth et al., 2003b).	UVI-CMES

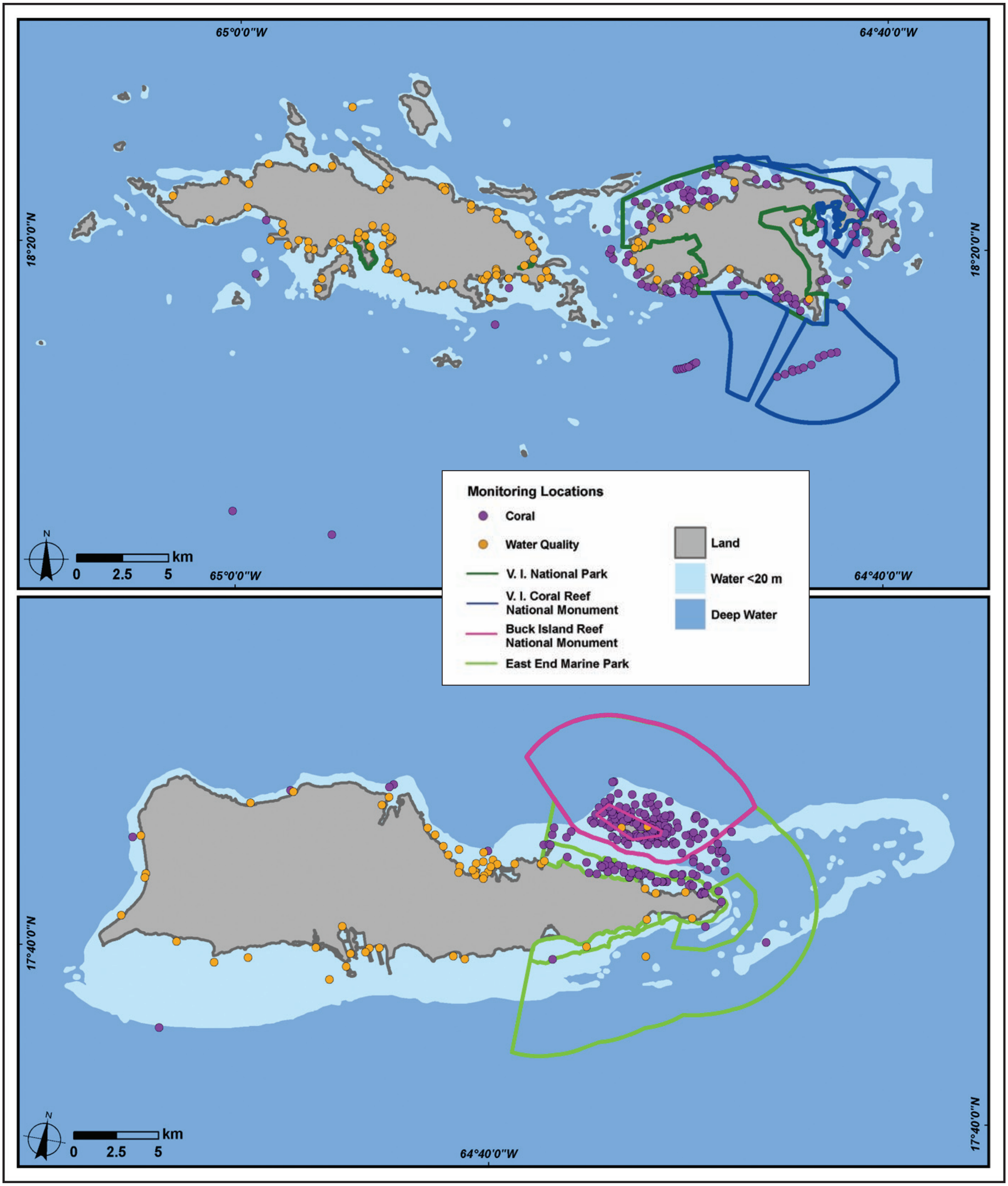

Figure 4.9. Locations of monitoring and research efforts in the USVI between 1988-2004. The boundary of the Buck Island Reef National Monument was expanded in 2001 from 880 acres to 19,015 acres. Both the original and expanded boundaries are shown. Water quality monitoring is conducted by the USVI DPNR. Coral monitoring is conducted by NOS, NPS, USGS, USVI DPNR, and UVI-CMES. Map: A. Shapiro.

WATER QUALITY

USVI DPNR/DEP Water Quality Monitoring

Methods

Water sampling in the USVI was initiated by the local health department in 1968. A network of fixed monitoring stations was selected within the bays and nearshore waters of the islands to target areas of particular concern, such as outfalls, harbors, marinas, and main recreational areas. The Division of Environmental Protection (DEP) within the USVI DPNR samples 135 sites quarterly each year (53 around St. Croix, 64 around St. Thomas, and 18 around St. John). At each monitoring site, water samples are collected at the surface to measure and record the chemical and physical parameters listed in Table 4.3. All data are uploaded into STORET, a national online database maintained by the U.S. Environmental Protection Agency (EPA, http://www.epa.gov/storet/dw_home.html, Accessed: 12/28/2004). Quarterly assessments are also complemented by periodic assessments of water quality during episodic events (e.g., a sewage bypass), when USVI DPNR-DEP collects daily samples until acceptable levels of water quality are reestablished.

Table 4.3. Water quality parameters measured by the USVI DPNR-DEP, NPS, and the U.S. Geological Survey.

PARAMETER	UNITS	COLLECTION METHOD
Temperature	˚C	*In situ* - YSI multi parameter meter: surface and near bottom
Dissolved oxygen	ml/L	*In situ* - YSI multi parameter meter: surface and near bottom
Salinity	Parts per thousand (ppt)	*In situ* - YSI multi parameter meter: surface and near bottom
pH	Scale of 1-14	*In situ* - YSI multi parameter meter: surface and near bottom
Turbidity	NTU	*In situ* - YSI multi parameter meter: surface and near bottom
Secchi disk depth	Meters (m)	*In situ* - Average depth of Secchi disk (disappearance/appearance)
Total suspended solids	mg/L	Grab near surface and send to a certified lab
Fecal Coliform / Enterococci	number of colonies/100 ml	Grab near surface and send to a certified lab
Nutrients	mg/L	Grab near surface and send to a certified lab

Results and Discussion

Data from the USVI DPNR-DEP water quality monitoring program indicate that water quality in the USVI is generally good but declining because of an increase in point and nonpoint source pollution (S. Caseau, pers. obs.). Almost all direct discharges in the USVI were traced to a failing and overloaded municipal sewage system. Moreover, sewage treatment plants malfunction as the result of human error, old equipment, or unusual conditions in the raw sewage.

Flooding is a major concern in the Virgin Islands. Watersheds have small areas, steep slopes, and increasing amounts of impervious surfaces, which in turn can result in high-volume runoff after short periods of intense rainfall. The territorial system consists of combined sewers, which are pipes designed to carry both raw sewage and stormwater. When the volume of rain becomes too great, the sewer system becomes overloaded, and untreated sewage discharge flows into nearby marine waters (Figure 4.10A). In non-urban and suburban areas, rainwater often flows directly over farms, golf courses, and lawns, washing pathogenic animal waste, fertilizers, and pesticides into the water. Failure to use effective silt-control devices during construction activities and improper discharge of waste by boat owners can result in pathogens that pollute beaches in less densely populated areas (Figures 4.10B, C).

The Virgin Islands rum manufacturing process generates wastewater that is discharged on the south coast of St. Croix. The effluent typically forms a plume visible from the discharge point to about 10 km westward along the shoreline. As a result, a strong turbidity and color gradient decreases light penetration, which could impede normal growth of submerged aquatic vegetation and corals. This effluent may be a reason for the absence of significant coral reefs within direct influence of the discharge.

Figure 4.10. Pollution of marine waters in the USVI. Left panel: Flooding of a sewer system in St. Croix after an intense rainfall. Center panel: Poor land management practices associated with accelerating coastal development in St. John. Right panel: Improper discharge of gasoline in marine waters from boating activities in St. Thomas. Source: V. Mayor, USVI DPNR-DEP.

NPS and USGS Water Quality Monitoring

Methods

The NPS and USGS conduct assessments of water quality within the VINP in St. John. Monitoring of water quality within and outside the park began in 1988. Thirty-one sites were originally identified for monitoring but were reduced to 15 in 1996. Samples are taken every three months at each site for the parameters listed in Table 4.3. Data through 2000 are available on-line at the EPA STORET website. Data from 2000 through the present are being processed and analyzed for uploading to STORET (http://www.epa.gov/storet/dw_home.html, Accessed: 12/28/2004). In June 2000, monthly sampling for *Enterococcus* spp. and fecal coliform began at three park swimming beaches.

Results and Discussion

Data collected by the NPS and USGS from 1988-1998 indicate that marine water quality in the VINP is excellent except at Cruz Bay. Horizontal visibility ranged from 10-20 m. Mean water temperature at 1m depth was 27.9°C with a range of 20.2-31.9°C. At a depth of 10 m, temperature varied from 24.5°C to 30.8°C. Average salinity was 35 parts per thousand and average conductivity was 54 siemens. Marine systems in the region experience little variation in these parameters. The extinction coefficient of photosynthetically active radiation (PAR) was approximately 0.18, which is extremely good. Dissolved oxygen over dense seagrass beds was 7-8 mg/L. Dissolved oxygen over barren, muddy substrates (e.g., Cruz Bay) averaged 6.0 mg/L and ranged between 5.0-7.1 mg/L.

Turbidity, a measure of particles in the water column, has been increasing. Additionally, turbidity was consistently higher outside the park than in waters inside the park, which may have resulted from sediment erosion caused by development of land outside the VINP. Total suspended solids (TSS) ranged from 1-15 mg/L adjacent to heavily disturbed watersheds after large rainfall events. Likewise, nutrient analyses resulted in detectable levels of micronutrients around mangroves, probably resulting from the natural production of organic nutrients and in bays adjacent to the most developed watersheds such as Coral Bay, Cruz Bay, and Great Cruz Bay. Clean, clear water is critical to maintaining healthy coral communities and seagrass beds.

UVI-CMES and USVI DPNR-DEP Coral Bay Study

Methods

The UVI Center for Marine and Environmental Studies (UVI-CMES) conducted a descriptive assessment of sediment deposition and marine water quality in Coral Bay, St. John. Nonpoint source pollution resulting from runoff contamination, sediment deposition, solid waste, and dumping of unregulated human waste is a common problem in the Virgin Islands, especially in Coral Bay.

Sediment coring and data on TSS were used to provide a rapid assessment of the state of Coral Bay. Sampling site locations were chosen based on: 1) proximity to expected inputs of terrigenous sediment and 2) achieving adequate spatial coverage throughout the bay. Sites were concentrated within Coral Harbor, the area most expected to be impacted by the recent increase in development. Sites outside of the harbor were chosen as control sites or sites at which to detect point sources of input from recent development. The assessment of water quality conditions in Coral Bay, Coral Harbor, and at other sites around St. John was based on a review of TSS data from the NPS water quality monitoring program at the VINP. Detailed descriptions of the sampling protocol are provided in Devine et al., 2003.

Results and Discussion

Devine et al. (2003) found poor water quality in Coral Bay. Vibracores and surface sediment samples indicated a seven-fold increase in the sedimentation rate and terrigenous input into Coral Bay as a direct result of development within the watershed during the last 100 years, and more probably over the past 40 years. Analyses of sediment samples also suggest that within the last 10-15 years, sedimentation rates in Coral Bay were 1) 10-20 times greater than the rate of natural sediment deposition averaged over the last 5,000 years and 2) the plantation era had a very small impact on sediment deposition. TSS was four times higher in Coral Harbor than the average for all other sampled locations in St. John. Mapping of sediment deposition and data on water chemistry indicate a growing problem within the harbor and the adjacent Coral Reef National Monument.

Coral Bay, an Area of Particular Concern (APC), is one of the largest watershed drainage areas within the territory at 1,215 ha (Hubbard et al., 1987; Devine et al., 2003). The area also has the highest recorded rate of population growth (79%) in the USVI between 1990 and 2000 (U.S. Census Bureau, 2001). The Coral Bay Watershed has steep slopes that average 18º (several greater than 35º), highly erodable soils, and very diverse land use along the shoreline (Devine et al., 2003).

Coral Bay has a protected inner harbor with critically valuable fringing mangroves and salt ponds. The area is also home to a cruising and live-aboard population of between 75-150 boats at any particular time. Many boats (i.e., 15-20) are permanently anchored to the small mangrove fringe. No pump-out facilities exist to handle vessel septic waste, no inspections are made of these vessels' holding tanks, and no regulations are enforced to protect marine resources. Along the inner harbor, commercial businesses and an undeveloped marina operate without containment for liquid spills or solid waste, paint, and dust. Residential roads, new homes, and failing septic systems contribute unmeasured amounts of pollutants to the harbor.

The tremendous growth and diverse uses of the landscape and marine resources in this watershed have visibly deteriorated marine water quality. Sedimentation and runoff are increasing in intensity and frequency, with routine sediment plumes inundating the area during the rainy season. Chronic pollution from point and nonpoint sources including the dumping of human and animal wastes, failing septic systems, and dumping of boat tank materials has resulted in high nutrient levels in Coral Bay.

BENTHIC HABITATS

NPS and USGS Coral Disease and Benthic Cover Abundance Monitoring

Methods

Long-term monitoring of coral diseases and abundance (percent cover) is conducted by the Inventory and Monitoring Program around St. John and Buck Island in St. Croix. Diseases of corals are specifically monitored using two different methods at two sites in VINP. The incidence and progression of the coral disease white plague type II in 28 tagged coral colonies is being monitoring approximately quarterly using still photography. Coral diseases are also monitored monthly with 1 m^2 quadrats along eight 10-m transects. Details of these monitoring projects, which began in 1997 and are still on-going, are given in Miller et al. (2003).

Benthic cover monitoring is conducted annually through the use of digital videography at four representative sites around St. John US Virgin Islands (three within VINP, one outside of the park); and at two sites within BIRNM in St. Croix. Monitoring of benthic cover began at two sites in 1999; four additional sites have been added since 2000 (J. Miller, pers. obs.). The benthic sampling protocol involves the selection of random (transect origin) sites, which is accomplished by using a SONAR-based mapping system (AquaMap®). Twenty 10-m transects are filmed using a digital video camera, and then the images are downloaded to a computer. Random dots are placed upon images captured from transects. The substrate underneath each dot is identified to the lowest taxonomic unit possible (e.g., coral to species, algae to genus) and entered into a database. Queries of the database produce values on the percent cover, diversity indices of species, and cover groups. Qualitative data on coral disease are also collected. A detailed description of the protocol is available online (http://science.nature.nps.gov/im/monitor/protocoldb.cfm, Accessed: 12/28/2004).

Results and Discussion

Live coral cover along disease monitoring transects decreased from 65.3% (± 7.41 standard deviation [SD]) to 43.4% (± 5.08 SD) between December 1997 and May 2001. The frequency of disease within transects ranged from 3% to 58%, and the area of disease patches ranged from 0.25 to 9,000 cm^2 within that same period. New incidences of disease were observed every month with associated loss of living coral. Increases in disease occurrence did not correlate with elevated water temperatures. The photos and observations revealed no recovery of diseased corals with all necrotic tissue being overgrown rapidly by turf algae, usually within less than one month. Most coral colonies suffered partial mortality and some colonies greater than 1.5 m in diameter were completely consumed in less than six months. Some limited recruitment (e.g., *Porites* spp., *Agaricia* spp., *Favia* spp., and sponges) has been noted on the diseased areas.

In general, reefs monitored by the NPS and USGS were dominated by dead coral with turf algae (Figure 4.11). Other benthic organisms such as gorgonians and sponges were not abundant and showed no significant temporal patterns in percent cover. In contrast, the estimates of the percent cover of macroalgae, turf algae, and abiotic substrates (sand, rubble, and pavement) varied substantially among sites and among sample periods. A total of 19 coral species were recorded throughout the study period; the number of species varied among sites and years. At Newfound Reef in St. John, the *Montastraea annularis* complex was the most abundant and most frequently observed coral, accounting for approximately 70% of live coral cover and was present in all 20 transects. The percent cover of live coral and algae was variable among sites, with Mennebeck Reef in St. John having the highest estimates of live coral cover (Figure 4.11). Mennebeck Reef and Western Spur and Groove Reef, St. Croix had more live coral than macroalgae, but live coral was twice as abundant on Mennebeck as on Western Spur and Groove (Figure 4.11). At Yawzi Reef, the opposite pattern occurred, with macroalgae being more abundant than live coral for all years (Figure 4.11). At South Fore Reef, St. Croix and Newfound Reef, mean estimates of live coral cover were similar to those for macroalgae (Figure 4.11).

Significant changes in live coral cover occurred only at Newfound Reef in St. John, where the mean percent live cover decreased by approximately 24% between 1999 and 2001 ($p<0.01$, Figure 4.11). *Porites porites* was the only coral species to increase in both mean live coral cover and frequency at Yawzi Reef. At both Yawzi and Mennebeck Reefs, *Porites* coral was consistently observed in more than 50% of belt-transects. Haulover Reef in St. John had a high abundance of live coral (22.1%) based on one year's worth of data (Figure 4.11). Fifteen species were recorded at Haulover. The *Montastraea annularis* complex comprised 84% of the live coral cover and occurred in all transects at Haulover Reef.

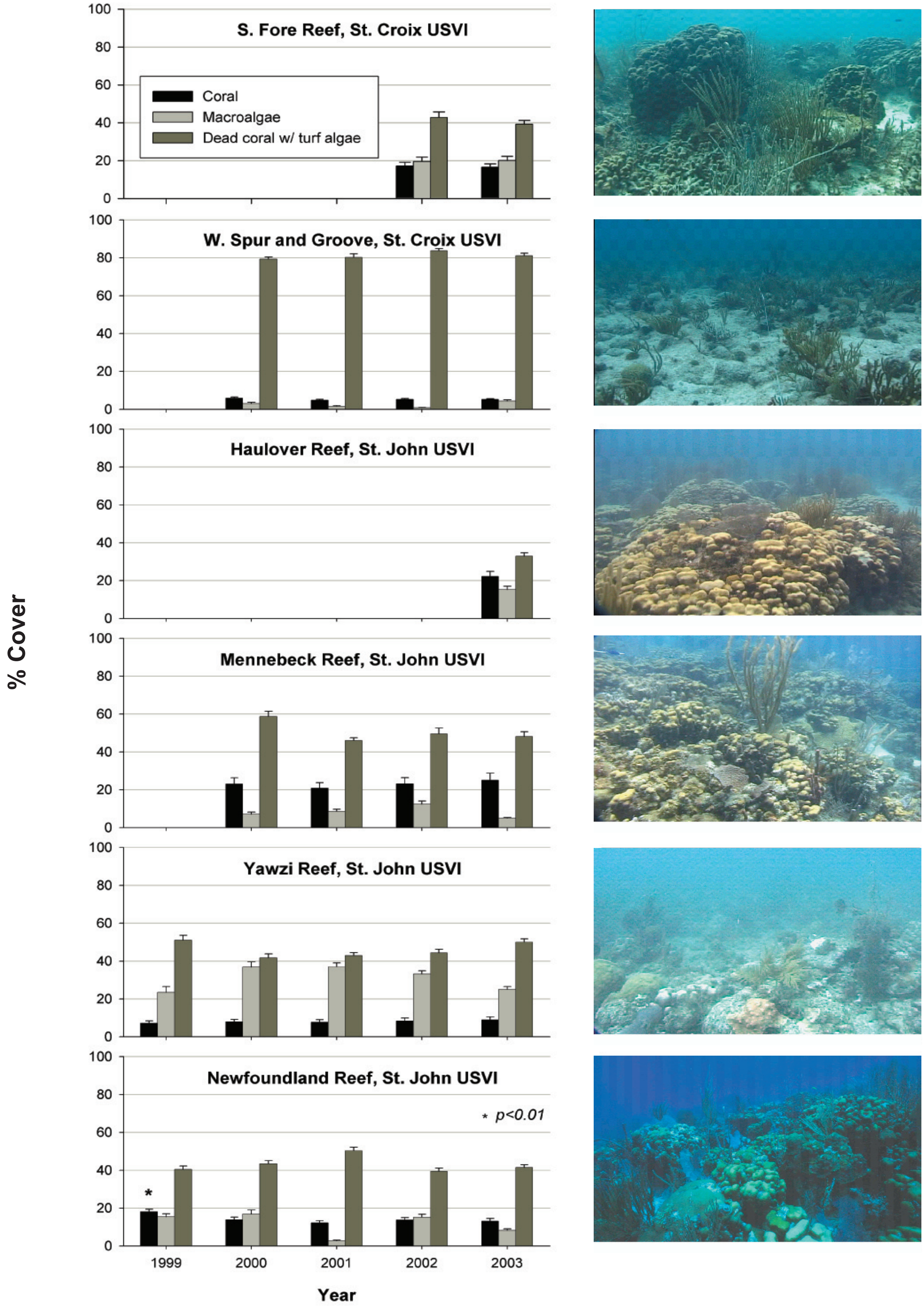

Figure 4.11. Mean percent cover (± SE) of coral, macroalgae, and dead coral with turf algae at six sites in the USVI. Data were collected according to video monitoring protocols developed by the USGS and NPS (http://science.nature.nps.gov/im/monitor/protocoldb.cfm). Specific sites or years without data were not sampled or the data are not yet analyzed. Source: J. Miller, unpublished data.

NPS, USGS, and UVI-CMES Elkhorn Coral *(Acropora palmata)* Monitoring

Methods

Researchers from the USGS, NPS, and UVI-CMES began an 18-month study of 66 tagged elkhorn coral colonies at Haulover Bay, St. John in January 2003. The geographic coordinates of the perimeter of each monitoring site and the locations of sampled elkhorn colonies are mapped onto geo-referenced aerial photographs. Data are recorded on the depth, three-dimensional size of colonies, type of substrate, percent cover of live and dead coral, presence/absence of specific diseases and lesions, and counts of damselfish territories and predators (snails – *Coralliophila abbreviata* and *C. caribaea*; and fireworms – *Hermodice* spp.).

Results and Discussion

Observations of 66 tagged corals over an 18-month period showed that 17% died, 74% had disease, and 30% suffered physical breakage, most likely from careless snorkelers (Table 4.4). Although 92% showed new growth throughout the study period, 15% of the new growth later lost 90-100% of their tissue. White pox disease was the most significant cause of coral mortality, however white pox lesions can heal. Forty-eight percent of the white pox lesions healed completely, mostly within three months. The onset of a severe disease outbreak coincided with increasing sea surface temperatures. Both the number of corals with white pox and the total number of disease lesions started to rise in September and continued increasing into November, tracking the trend in SST.

Table 4.4. The results of a study on the health and condition of *Acropora palmata* colonies (N=67). Data were collected through videography and *in situ* observation by the USGS Caribbean field station since February 2003 at Haulover Bay, St. John, USVI. Source: Rogers and Muller, unpublished data.

	NUMBER OF CORALS AFFECTED (N=67)		
	6 Months	**18 Months**	**22 Months**
New Growth	40	61	61
New White Pox	15	49	57
Healed White Pox	5	28	32
Snails Present	15	29	30
Physical Breakage	6	20	23
Complete Mortality	3	11	11
Unidentified Lesions	2	2	2
White Band	1	3	3
Bleached	0	1	1
Damselfish Territory	1	1	1

UVI-CMES Video Assessment of Benthic Substrates

Methods

UVI-CMES researchers used digital videography along belt-transects to characterize and monitor benthic cover at permanent and rapid assessment sites in St. Croix and St. Thomas. The maximum width and height and the percent of diseased coral cover were estimated from the videos for all coral colonies greater than 10 cm in diameter that were located directly under the transect lines. Data on diseases and bleaching were not collected at rapid assessment sites. In St. Croix, divers filmed three to six permanent 10-m transects at 10 long-term and two rapid assessment sites between April 2001 and March 2003. In St. Thomas, digital video transects were conducted at six coral reef sites between August 2002 and September 2003. The St. Thomas reefs were placed into three categories based upon their location along the insular platform: nearshore reefs (5-30 m deep, <2 km from the shoreline); mid-shelf reefs (5-30 m deep, 2-10 km offshore; and shelf-edge reefs (>30 m deep, 10-50 km offshore). Detailed video sampling methods are discussed in Nemeth et al. (2002). Results are reported separately here for St. Croix and St. Thomas.

Results and Discussion

St. Croix

The percent cover of living coral was variable among sites and ranged from 4.4% to 39.1%. Coral was the most abundant component at only one site. Turf algae covering dead coral comprised 50% or more of the substrata and was dominant at most sites (Figure 4.12A, B). Dead coral included both long dead and recently killed coral covered with a layer of turf algae. The percent cover of macroalgae ranged from 3.2% to 34.9% (Figure 4.12C). Percent cover of living coral was similar among years but a significant increase in turf algae and a corresponding decrease in macroalgae were observed at Buck Island between years (Figure 4.12 B, C). These trends were reversed at Sprat Hole, where an increase in macroalgae corresponded with a decrease in turf algae (Figure 4.12B, C). Significant increases in macroalgae also occurred at Long Reef (Figure 4.12C). It is unlikely that the significant changes observed in the abundance of macroalgae between years at Buck Island and Sprat Hole were caused by urchins (*D. antillarum*) because macroalgae were very rare at those sites. Sponges and gorgonians each comprised less than 10% of the benthic cover at all sites (Figure 4.13D, E). Sand was the only non-living substrate type found at the sites, ranging from 0.0% to 9.5% (Figure 4.13F). No significant changes occurred for sponges, gorgonians, or sand cover between years at any site.

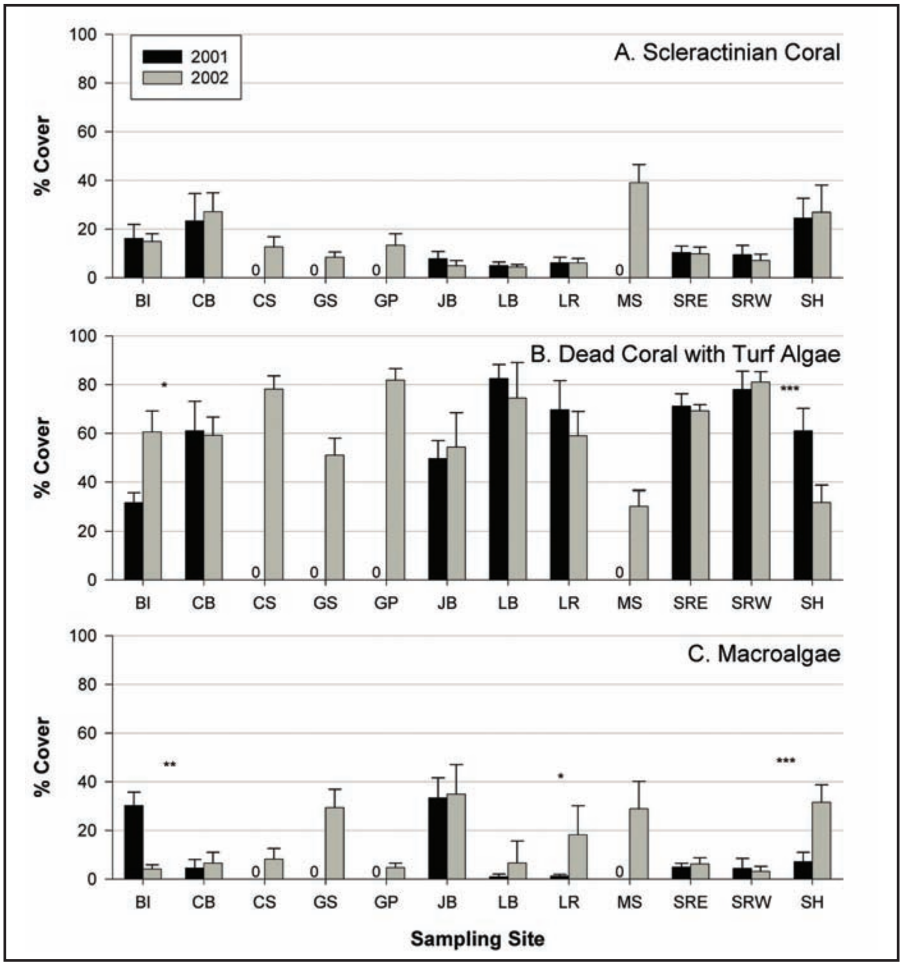

Figure 4.12. Annual mean percent of (A) scleractinian corals, (B) dead coral with turf algae, and (C) macroalgae for 12 sampling sites in St. Croix. Site codes are: BI=Buck Island, CB=Cane Bay, CS=Castle, GS=Gerson, GP=Great Pond, JB=Jacks Bay, LB=Lang Bank, LR=Long Reef/Eagle Ray, MS=Mutton Snapper, SRE=Salt River East Wall, SRW=Salt River West Wall, SH=Sprat Hole. Error bars represent standard deviation. Asterisks denote significant differences: *=p<0.05; **=p<0.01; ***=p<0.0001. Source: Nemeth et al., 2002, 2003a.

The composition of the coral community was similar among sites, with 10 species representing 95% of the coral community (Figure 4.14). *Montastraea* spp. were the most dominant corals except at Castle where *Porites porites* was most abundant, at Great Pond where *Porites astreoides* was most abundant, and at Gerson and Lang Bank where *Diploria strigosa* was most abundant. Coral diversity ranged from a Shannon-Weaver diversity index (H') of 1.50 at Great Pond to 2.40 at Salt River West Wall (Figure 4.15).

Coral condition varied greatly among sites. The incidence of coral disease and bleaching ranged from 0-17% at several sites and 0-22% at Lang Bank. Diseases and bleaching were observed among eight dominant coral species, with *Siderastrea siderea* having the highest incidence of disease (50% of colonies) and bleaching (80% of sampled colonies). Divers observed white plague, dark spots disease, yellow blotch/band disease, and white spots that were classified as disease, but were unidentifiable to a specific disease.

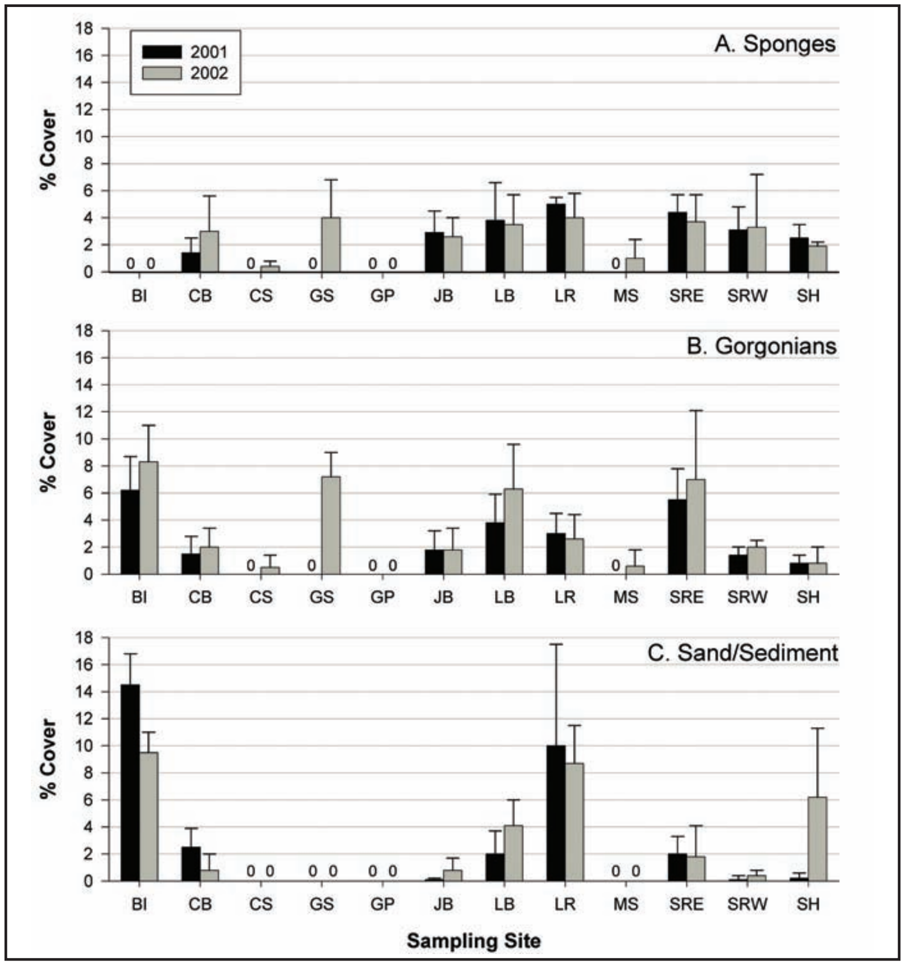

Figure 4.13. Annual mean percent of (A) sponges, (B) gorgonians, and (C) sand/sediment for 12 sampling sites in St. Croix. Site codes are: BI=Buck Island, CB=Cane Bay, CS=Castle, GS=Gerson, GP=Great Pond, JB=Jacks Bay, LB=Lang Bank, LR=Long Reef/Eagle Ray, MS=Mutton Snapper, SRE=Salt River East Wall, SRW=Salt River West Wall, SH=Sprat Hole. Error bars represent standard deviation. Asterisks denote significant differences: *=p<0.05; **=p<0.01; ***=p<0.0001. Source: Nemeth et al., 2002, 2003a.

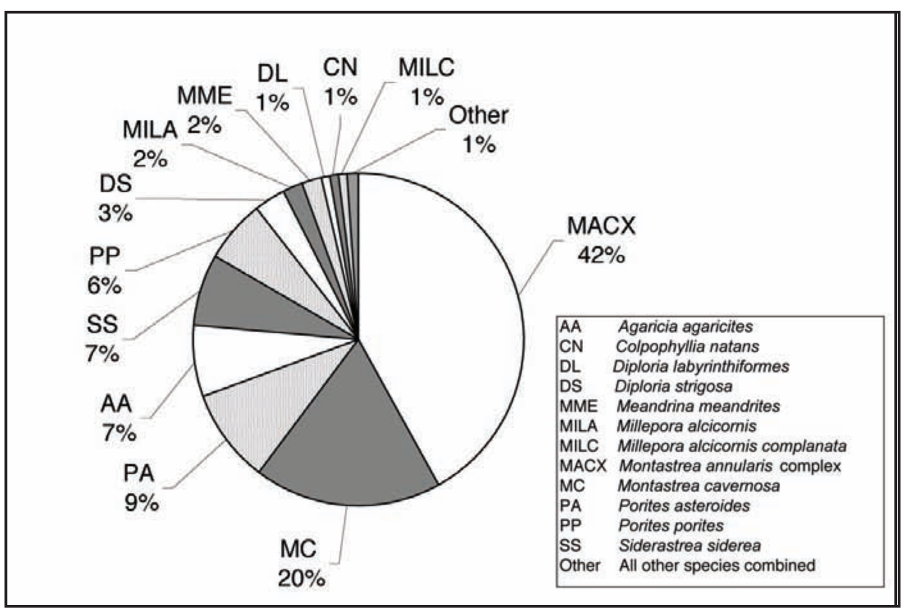

Figure 4.14. Percentage coral species composition at all sampled sites in St. Croix. 'Other' denotes percent of all other coral species combined: *Stephanocoenia michelinii, Eusmilia fastigiata, D. clivosa, Madracid decactis, M. mirabilis, Mussa angulosa, Mycetophyllia danaana, M. ferox, M. aliciae, Dichocoenia stokesii, Manicina areoloata*, and *P. divaricata.* Source: Nemeth et al., 2002, 2003a.

St. Thomas

The percent cover of living coral ranged from a low of 8.3% at Benner Bay to a high of 42% at Grammanik Bank (Figure 4.16A). The percent cover of dead coral covered with turf algae ranged from 15% at Seahorse Cottage Shoal to 45.6% at Benner Bay (Figure 4.16B). The percent cover of macroalgae ranged from 13.8% at Black Point to 42.7% at Seahorse Cottage Shoal (Figure 4.16C). Sponges and gorgonians each comprised less than 10% of the benthic cover at all sites (Figure 4.17D, E). No gorgonians were observed on the shelf-edge sites. The percent cover of sand/sediment ranged from 3% at the Grammanik Bank to 28% at Black Point (Figure 4.17F). Almost all of the substrate at Black Point was covered by sediment, whereas the substrates at other sites were predominantly sandy areas mixed with vertical reef structures.

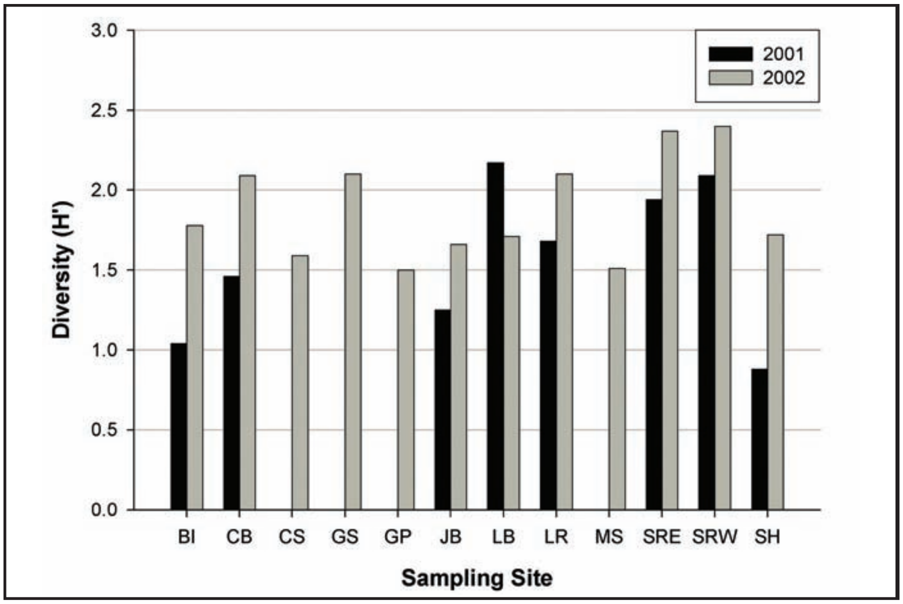

Figure 4.15. Annual diversity index (Shannon-Weaver H') for corals at 12 sites in St. Croix. BI=Buck Island, CB=Cane Bay, CS=Castle, GS=Gerson, GP=Great Pond, JB=Jacks Bay, LB=Lang Bank, LR=Long Reef/Eagle Ray, MS=Mutton Snapper, SRE=Salt River East Wall, SRW=Salt River West Wall, SH=Sprat Hole. Source: Nemeth et al., 2002, 2003a.

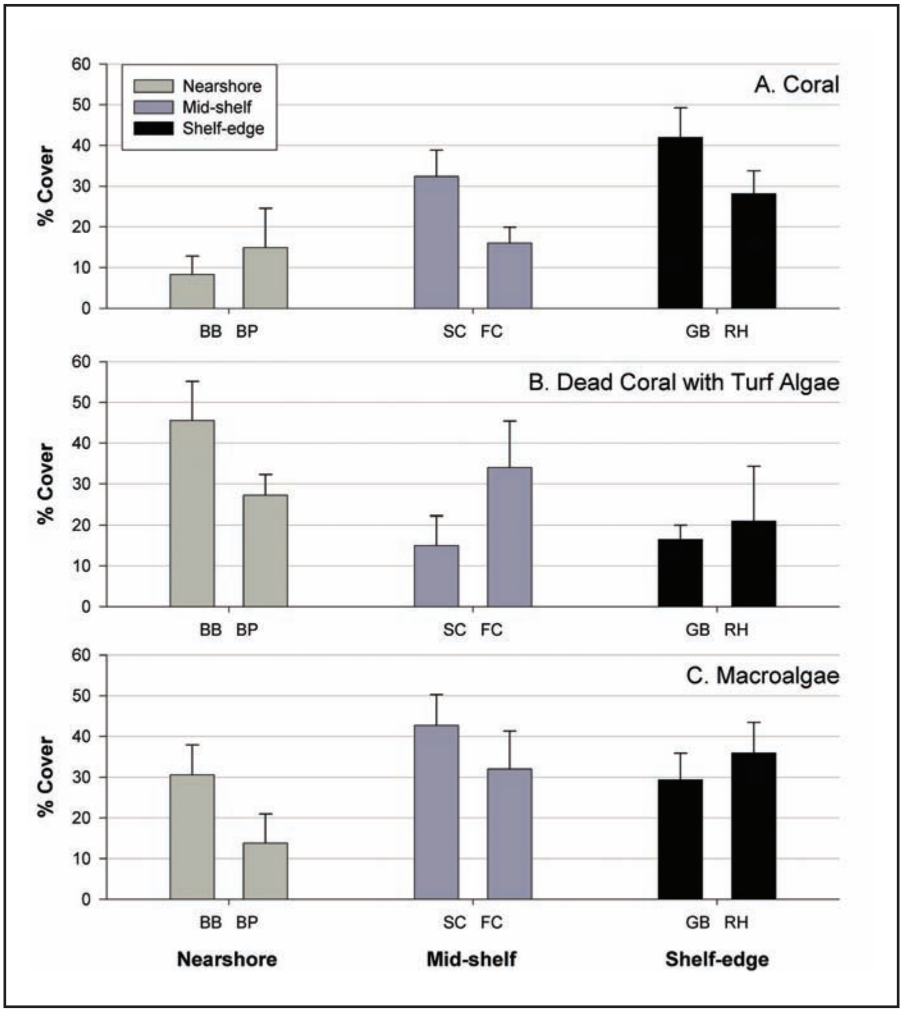

Figure 4.16. Mean percent cover of benthic organisms in St. Thomas at: BB=Benner Bay, BP=Black Point, SC=Seahorse Cottage Shoal, FC=Flat Cay, GB=Grammanik Bank, RH=Red Hind Bank. BB and BP are nearshore sites; SC and FC are mid-shelf sites; GB and RH are shelf-edge sites. n=6 transects for all sites. Error bars represent standard deviation. Source: S. Herzlieb, unpublished data.

Nearshore sites tended to have lower percent cover of living coral and higher percent cover of dead coral covered with turf algae than mid-shelf and shelf-edge sites (Figure 4.18). Also, nearshore sites tended to have lower percent composition of corals within the *M. annularis* complex and higher percent composition of the stress tolerant corals *P. astreoides* and *S. siderea* than mid-shelf and shelf-edge sites (Figure 4.18). The coral reefs of St. Thomas were generally dominated by coral species in the genus *Montastraea* (Figure 4.18). The Shannon-Weaver Diversity Index (H') for coral ranged from a high of 2.26 at Flat Cay to a low of 1.20 at Grammanik Bank. In general, deeper shelf-edge sites (Seahorse Cottage, Grammanik Bank, and Red Hind Bank) had lower diversity than the shallow sites (Figure 4.19).

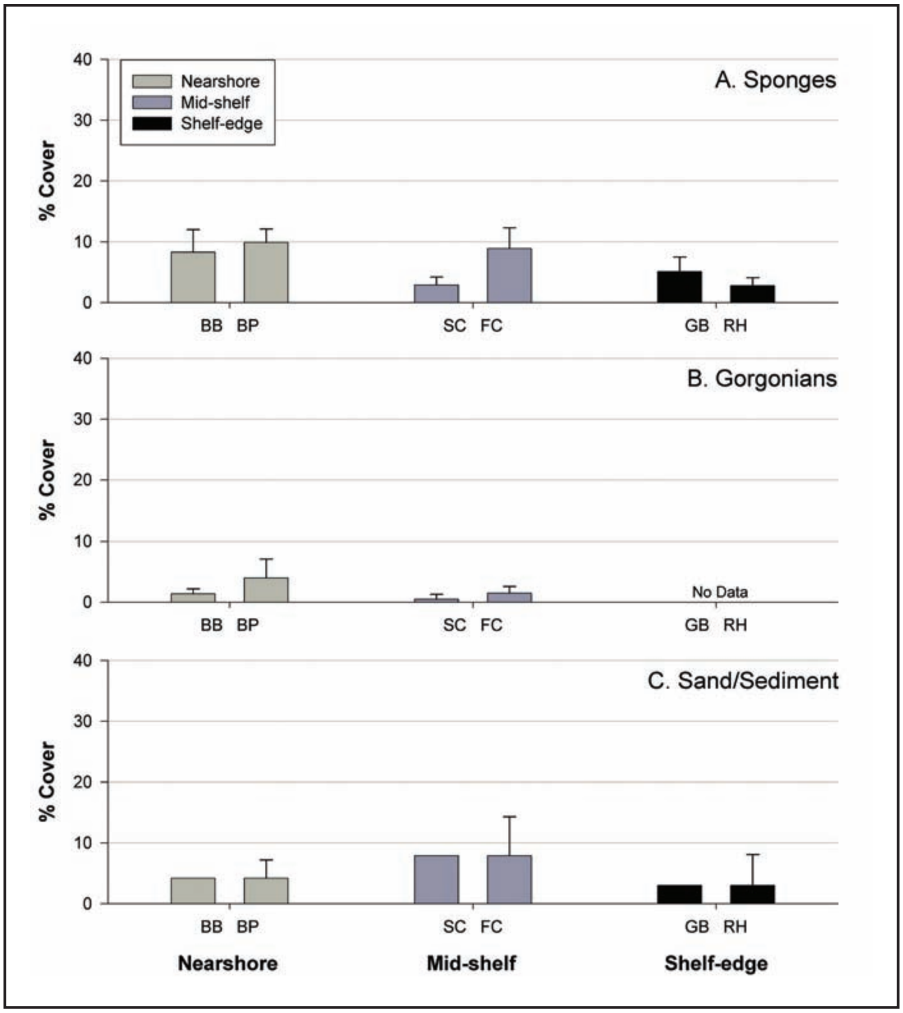

Figure 4.17. Mean percent cover of A. sponges, B. gorgonians, and C. sand/sediment in St. Thomas: BB=Benner Bay, BP=Black Point, SC=Seahorse Cottage Shoal, FC=Flat Cay, GB=Grammanik Bank, RH=Red Hind Bank. BB and BP are nearshore sites, SC and FC are mid-shelf sites, and GB and RH are shelf-edge sites. n=6 transects for all sites. Error bars represent standard deviation. Source: S. Herzlieb, unpublished data.

Since most research and monitoring in the Virgin Islands in have generally been concentrated on nearshore fringing reefs, mid-shelf and shelf-edge sites were chosen to fill gaps in the knowledge of other reef systems, as well as to establish an experimental design to test hypotheses involving differences between reefs located at different points along the insular platform off the coast of St. Thomas. The close proximity of nearshore fringing reefs to human populations and their relatively shallow depths, increases the susceptibility of these reefs to both harmful human activities (overfishing, sedimentation, nutrient enrichment, and physical damage) and the effects of natural disturbances (storm wave damage, high SSTs, and high irradiance).

Due to their similar depths but greater distance from shore, mid-shelf reefs are less susceptible to the human-induced stresses listed above, but are exposed to levels of natural impacts similar to nearshore reefs. Thus, the mid-shelf reefs provide an ideal control for measuring the effects of human-induced stresses on nearshore reefs. Deep reefs located along the edge of the insular platform are largely free from human induced stresses (excluding fishing and anchoring) and natural impacts because of their greater distance from human populations and their greater depths. The shelf-edge deep reefs are quite extensive, but largely unstudied. Monitoring of these systems will contribute greatly to an understanding of coral reef resources in the Virgin Islands. Cross-shelf patterns in benthic composition in St. Thomas warrant special attention because they suggest that overall reef quality is lower at nearshore sites compared with sites further offshore. However, only two reefs of each reef type were surveyed, thus robust comparisons between reef types are difficult. Future monitoring efforts involving a greater number of St. Thomas reefs will help to elucidate these and any further differences among the near-shore, mid-shelf, and shelf-edge reef systems.

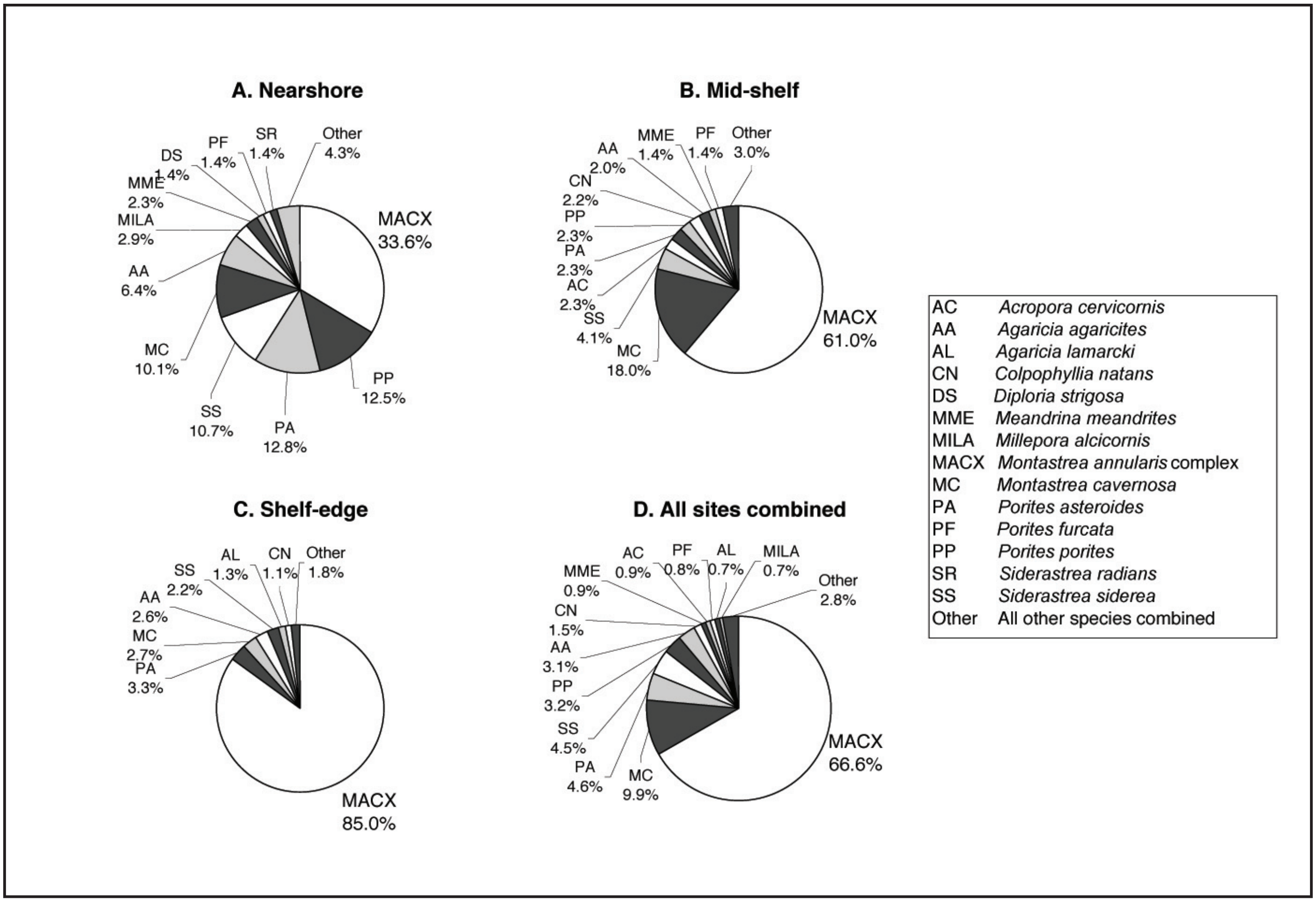

Figure 4.18. Percentage of coral species composition at nearshore sites, mid-shelf sites, shelf-edge sites and all sites combined for St. Thomas. ‘Other’ denotes percent of all other coral species combined and includes: *Agaricia grahamae, A. humilis, Dendrogyra cylindrus, Diploria clivosa, D. labyrinthiformis, Eusmilia fastigiata, Manicina areolata, Mycetophyllia aliciae, M. danaana, M. lamarckiana, P. divaricata, Solenastrea bournoni, S. hyades,* and *Stephanocoenia michelinii*. Source: S. Herzlieb, unpublished data.

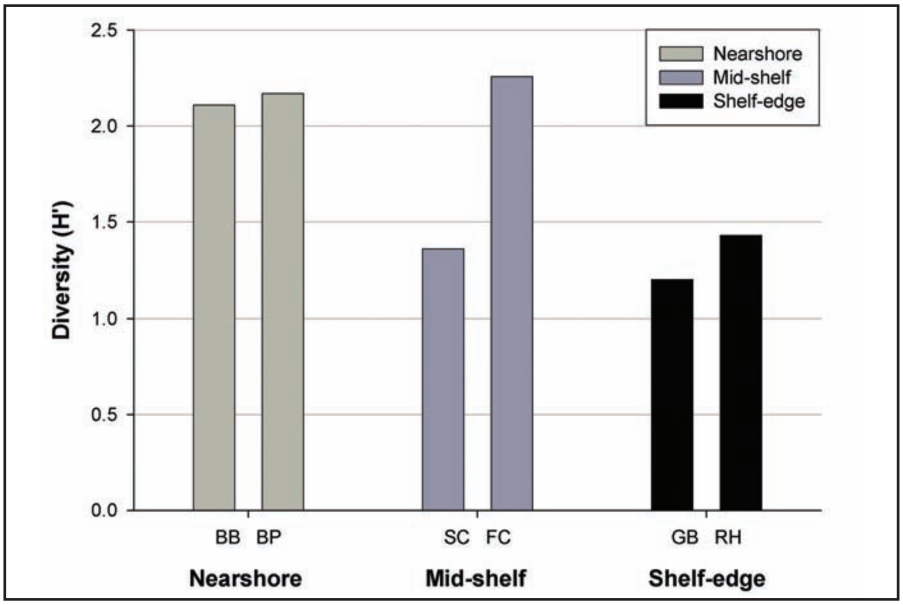

Figure 4.19. Shannon-Weaver Diversity Index (H’) for corals at eight monitored sites in St. Thomas: BB=Benner Bay, BP=Black Point, SC=Seahorse Cottage Shoal, FC= Flat Cay, GB=Grammanik Bank, RH=Red Hind Bank. BB and BP are nearshore sites, SC and FC are mid-shelf sites, and GB and RH are shelf-edge sites. n=6 transects for all sites. Error bars represent standard deviation. Source: S. Herzlieb, unpublished data.

UVI-CMES AGRRA Assessments of Benthic Substrates

Methods

Between May 1998 and August 2000, 16 sites within the USVI were surveyed (Nemeth et al., 2003a) using the Atlantic and Gulf Rapid Reef Assessment protocol (AGRRA; Version 2.0). The AGRRA protocol focuses on three aspects of benthic reef communities: coral condition, algae abundance, and sea urchin density along a 10-m transect. To assess coral condition, the dimensions of 50-100 coral colonies, occurring directly beneath the transect line were measured. Coral colonies >25 cm in diameter were inspected for signs of disease, predation, and overgrowth. The percent of old or recent tissue mortality was also estimated for each coral colony from a planar view. Along these same transects, the point intercept method was used to estimate percent coral cover, and the number of *Diadema antillarium* sea urchins occurring within 1 m of each side of the transect line were counted. Finally at least 50 quadrats (0.25 m^2) were placed along the transect lines to estimate the percent cover and height of macroalgae, turf algae, and coralline algae, and to count the number of coral recruits <2 cm in diameter.

The assessment sites included eight reefs on St. John, five reefs on St. Thomas and three reefs on St. Croix. The data were summarized by depth (< 5.5 m and > 6 m) and geographic region (St. Thomas/St. John and St. Croix). St. Croix was considered a unique geographic region because of its isolation from the northern Virgin Island Archipelago, its unique geology (sedimentary/carbonate), and its location completely within the Caribbean Sea. St. Croix sites included Cane Bay, Salt River East Wall, and Long Reef. St. Thomas and St. John were grouped as the northern Virgin Islands because of their close proximity, similar geographic origins and topography (high volcanic islands), and exposure to both Atlantic waters from the north and Caribbean waters from the south. Reefs around St. Thomas included Brewer's Bay, Buck Island, Caret Bay, Flat Cay and Sprat Bay. Reefs around St. John included two sites in Great Lameshur Bay (Tektite, Yawzi Point) and two sites in Fish Bay (outer east and west). Shallow reefs <5.5 m on St. John included two sites in Great Lameshur Bay (Donkey Bight and VIERS) and two sites in Fish Bay (inner east and west). The AGRRA protocol is described in detail in Ginsburg et al. (1996).

Results and Discussion

The percent cover of living coral ranged from 10% to 35% in the Virgin Islands. Average cover of living coral on reefs deeper than 6 m was very similar between St. Thomas/St. John and St. Croix, but was significantly lower on the shallow reefs of St. John (Table 4.5; Nemeth et al., 2003a). Large stony corals that were individually surveyed were numerically dominated by the *Montastraea annularis* species complex in the shallow and deeper reefs around St. Thomas/St. John whereas similar reefs in St. Croix were dominated by *M. cavernosa*. The second most common taxon was *Siderastrea siderea*. The differences in the AGRRA data for St. Croix and the video assessment data presented above most likely resulted from differences in methods used (AGRRA only assessed colonies greater than 25 cm whereas the video method included colonies of all sizes). Moreover, the three sites surveyed for AGRRA were located on the north coast of St. Croix, whereas the larger number of sites (n=12) assessed for the video method were distributed around the entire island.

Table 4.5. Summary data for corals from AGRRA assessment of USVI reefs around St. John, St. Thomas, and St. Croix and the shallow reefs <5.5 m around St. John. Source: Nemeth et al., 2003b.

SITE NAME	DEPTH (m)	COLONIES (#)	CORAL COVER (%)	MORTALITY (%)			BLEACHED CORALS (%)	DISEASED CORALS (%)	CORALS W/ FISH BITES (%)
				New	Old	Total			
St. John (shallow)	4.5	407	12.4	3.4	43	46.4	28.5	4.5	17.3
St. John	9.5	419	22.4	0.8	27	27.8	21.6	8.3	2.8
St. Thomas	10.8	553	20.8	1.7	27.8	29.5	16.6	7.4	8.5
St. Croix	14.3	301	20.2	0.8	33.5	34.3	48.2	2	6.8

Between 1998 and 2000 the condition of coral colonies varied among island groups. Coral bleaching was recorded at all sites with the highest average values occurring on St. Croix, the lowest occurring around St. Thomas, and moderate levels around St. John (Table 4.6). Alternatively, incidence of disease was lowest on St. Croix and the shallow reefs of St. John but higher on the deeper reefs of the northern Virgin Islands. Divers were able to recognize four general disease types: black band, yellow blotch, white plague, and dark spots. The coral species most susceptible to disease included *M. faveolata, M. franksi, M. cavernosa, M. annularis, Colpophyllia natans,* and *Siderastrea siderea*. The high percentage of coral colonies with fish bites contributed to the elevated level of recent tissue mortality on shallow reefs of St. John. These shallow nearshore reefs were also affected by sedimentation especially those outside the boundaries of the VINP (i.e., Fish Bay) that had high levels of old tissue mortality.

Table 4.6. Summary data for algae (macro, turf, crustose coralline) and coral recruitment from AGRRA assessment of reefs around St. John, St. Thomas, and St. Croix and the shallow reefs <5.5 m around St. John. Source: Nemeth et al., 2003b.

SITE NAME	DEPTH (m)	QUADRATS (#)	MACRO ALGAL HEIGHT (cm)	ALGAE RELATIVE ABUNDANCE (%)			CORAL RECRUITS #/0.0625 m²	DIADEMA #/100 m²
				Macro	Turf	Crust		
St. John (shallow)	4.5	219	2.8	41.8	47	11.2	4.4	11.5
St. John	9.5	214	1.5	42.6	46.3	11.1	9.8	0.3
St. Thomas	10.8	232	2.5	50.9	31.4	17.7	8.2	1.8
St. Croix	14.3	170	1.2	16	74	10	10.3	1.3

Stony coral recruitment varied considerably from site to site, but on average, it was similar among reefs greater than 6 m depth (Table 4.6). Coral recruitment on the shallow reefs of St. John was about 50% of that on deeper reefs. With the exception of *S. siderea*, coral recruits were dominated by species that brood their larvae. The five most abundant taxa - *S. siderea* (23%), *Agaricia* spp. (17%), *Porites astreoides* (15%), *P. porites* (13%) and *S. radians* (6%) - comprised 70% to 80% of the recruits on all islands (Nemeth et al., 2003b). The relative abundance of macroalgae was significantly lower on St. Croix compared with the northern Virgin Island reefs and the shallow reefs of St. John, which had over two times the number of *Diadema* spp. urchins than deeper reefs (Table 4.6).

NOAA CCMA-BT Benthic Habitat Mapping

NOAA's Center for Coastal Monitoring and Assessment-Biogeography Team (CCMA-BT) completed a nearshore benthic habitat mapping project for the USVI in 2002. Aerial photographs were collected by a NOAA citation jet in 1999 and used to delineate habitat polygons in a geographic nformation system (GIS). The habitat polygons were defined and described according to a hierarchical habitat classification system consisting of 26 discrete habitat types. The project mapped approximately 490 km² of nearshore habitat in the islands including coral reefs, mangroves, seagrass beds, and other tropical marine bottom types. A series of 55 maps are now available via a CD-ROM, and on-line (http://biogeo.nos.noaa.gov/products/benthic. Accessed 1/19/05). Major habitat types are depicted in Figure 4.20.

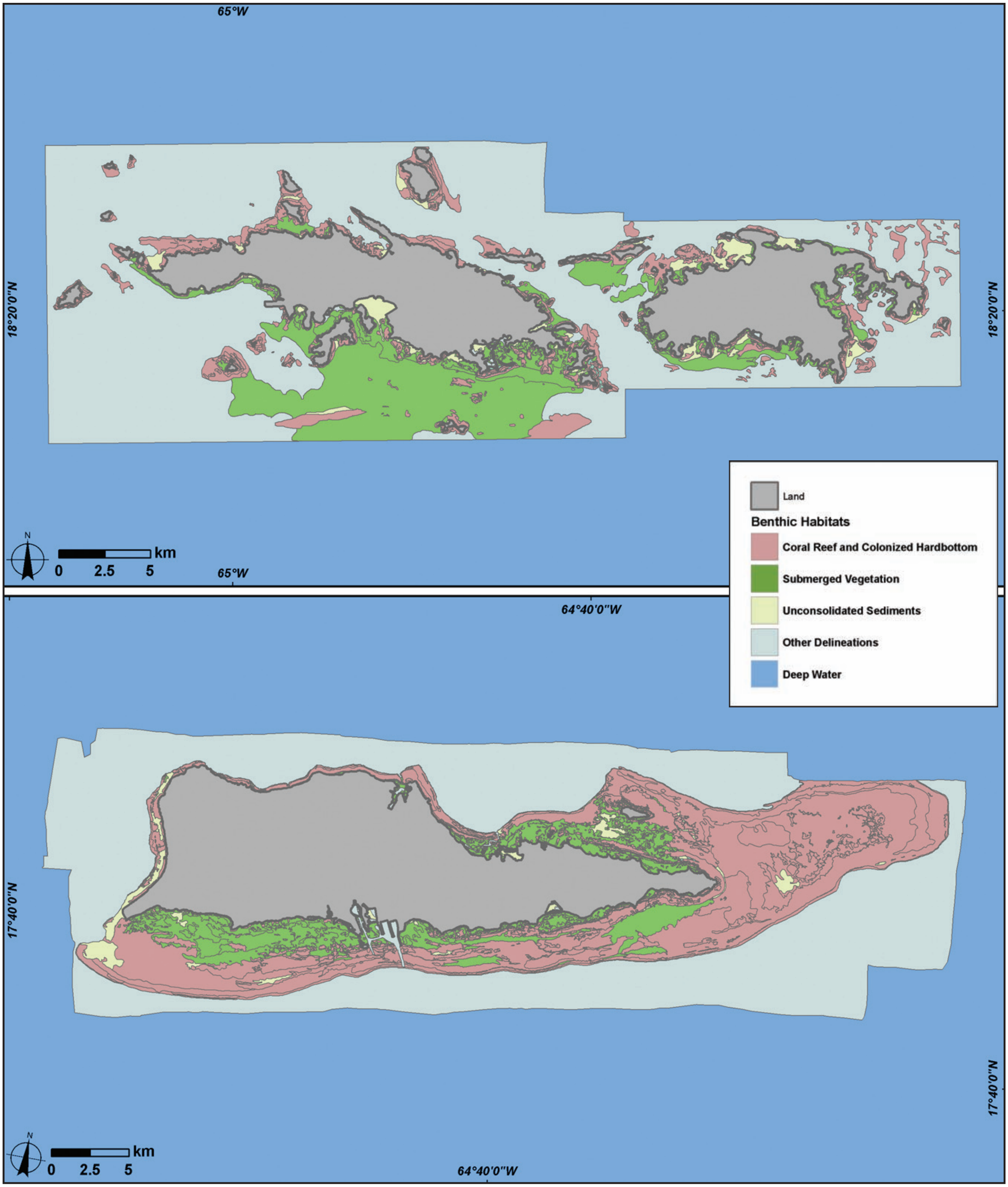

Figure 4.20. Nearshore benthic habitat maps were developed in 2001 by CCMA-BT based on visual interpretation of aerial photography and hyperspectral imagery. For more info, see: http://biogeo.nos.noaa.gov. Map: A. Shapiro.

ASSOCIATED BIOLOGICAL COMMUNITIES

Data from four monitoring and assessment programs were used to characterize community structure, biomass, trophic structure, and the size frequency distribution of fish assemblages in the USVI. Mean estimates of standard reef fish assemblage variables were determined from each data set. Species richness is the total number of species observed per sample. Abundance is the mean number of individuals per sample. Biomass is the estimated live wet weight of individuals per sample. Live wet weight (W) of each fish was estimated from the mean visually estimated fork-length (FL) with the equation: $W = a(FL)^b$, where a and b are known parameters of the length-weight relationship for each species (Randall et al., 1967; Froese and Pauly, 2000; http://fishbase.org., Accessed 12/28/2004). For species not in these databases, estimates from available literature on the species or congeners were used. The biomass of all fishes recorded in all censuses was obtained by multiplying the mean live wet weight for each size class for each species by the total number of individuals observed in that size class.

NPS Long-term Monitoring of Reef Fish Assemblages

Methods

Annual trends in total species richness, fish abundance, and biomass were analyzed and are presented separately for the NPS long-term reef fish monitoring dataset. NPS has been monitoring reef fish populations monthly at four reference sites in the VINP on St. John for 12 years (1988-2000). This data set represents one of the longest time series data sets on reef fishes for the territory. An investigation to study the monthly variation in reef fish assemblages was initiated in November 1988 and continued through May 1991 (Beets and Friedlander, 1990; Beets, 1993). The study was conducted at two sites (Yawzi Point Reef and Cocoloba Reef) using the stationary visual census technique developed by Bohnsack and Bannerot (1986). Following Hurricane Hugo in September 1989, NPS initiated reef fish sampling at several reef sites (n=18) around St. John in addition to the monthly sampling at the two sites in the southern portion of the VINP. The NPS used a modified visual census technique that was developed and used in the Dry Tortugas National Park in 1987 (Kimmel, 1992). Monitoring at the sites established in 1989 (originally 18 reef sites were selected with a few omitted and added among years) continued each June/July until 1994 using the modified method. In 1995, the standard stationary visual census technique (Bohnsack and Bannerot, 1986) was employed to continue long-term monitoring at four established reference sites, representing topographically complex, speciose sites including areas selected for monitoring other resources (coral, macroalgae, water quality). The goals of this monitoring project were to 1) establish a baseline of information on reef fish assemblages around St. John; 2) conduct sustained monitoring on representative high-diversity reefs; 3) collect data on reefs with known or potential environmental degradation; 4) compare fish assemblages among selected reefs; and 5) determine trends in reef fish assemblages over time. The four permanent reference sites (Yawzi Point Reef, Tektite Reef, Newfound Bay West Reef, and Haulover Bay West Reef) were monitored annually from 1989-2000 (except in 1990). Yawzi Point Reef was monitored monthly from 1988-1991.

Results and Discussion

In most tropical fisheries, many changes go relatively unnoticed and undocumented. Data acquisition and monitoring programs are frequently initiated following large resource changes. While this is true for the USVI, the area has fortunately received much scientific investigation at other times as well. A comparison of historical data (1958-1961) and more recent monitoring data (1989-2000) provides a view of changes in reef fish abundance over 60 years.

NPS reef fish monitoring data documented numerous significant declines in the abundance of several reef fish over a 12-year period (Beets and Friedlander, 2003; Figure 4.21). However, numerous species that were historically common in landings, such as the Nassau grouper, demonstrated no significant trend over the monitoring period (Figure 4.21). This may be because their abundance is presently too low to show significant trends, assuming that a decline in abundance has occurred. Furthermore, large declines in abundance for species, such as the Nassau grouper, may have occurred before monitoring projects were initiated.

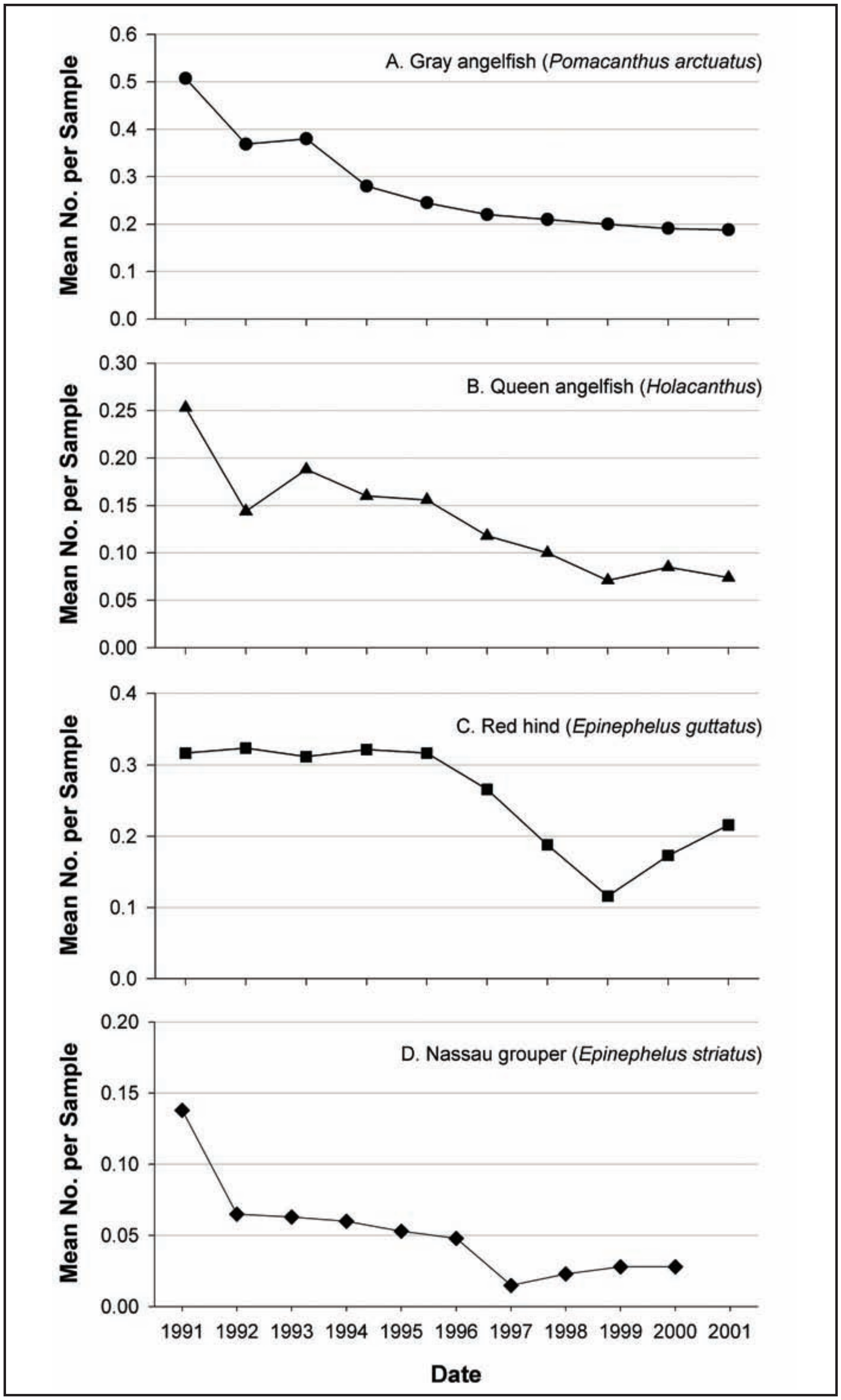

Figure 4.21. Significant (A-C) and non-significant (D) declines in abundance of four commercially-targeted species observed in visual monitoring data from four reefs around St. John, US Virgin Islands from 1991-2000. Source: Beets and Friedlander, 2003.

Historical data collected by previous investigators provide comparative information, although comparative abundance data frequently are not available. For example, Randall (1967) collected many species of fish for his landmark studies of Caribbean reef fishes around St. John from 1958-1961. Although few were quantitative, Randall's studies provided relative abundance and size structure of species. Large groupers frequently captured by Randall in 1958-61 were in very low relative abundance in the 1989-2000 monitoring data (Figure 4.22). The two smaller-sized groupers, red hind and coney, were much more common in the recent monitoring data. These long-term comparisons suggest that large changes have occurred in Virgin Islands fisheries, similar to patterns observed throughout the Caribbean. Over-exploitation by fisheries certainly has been a strong contributor to the observed declines.

The most apparent temporal signal in reef fish assemblage characteristics around St. John over the 12-year monitoring period resulted from the influence of large storm events (Beets and Friedlander, 2003). The Virgin Islands have been greatly influenced by numerous large storms since 1988. Data were separated into two periods (1989-1994 and 1996-2000) representing the post-storm recovery periods following the two major storms affecting St. John (Hurricane Hugo, Sept. 1989; Hurricane Marilyn, Sept. 1995). As data for 1995 were collected just prior to Hurricane Marilyn, those data were excluded from analysis. Assemblage characteristics (species richness, abundance, and biomass) showed statistically significant increases during the five-year period following Hurricane Hugo (1989, Figure 4.23). While species, number of individuals, and biomass all increased following Hurricane Marilyn (1995), none of these trends were significant for the

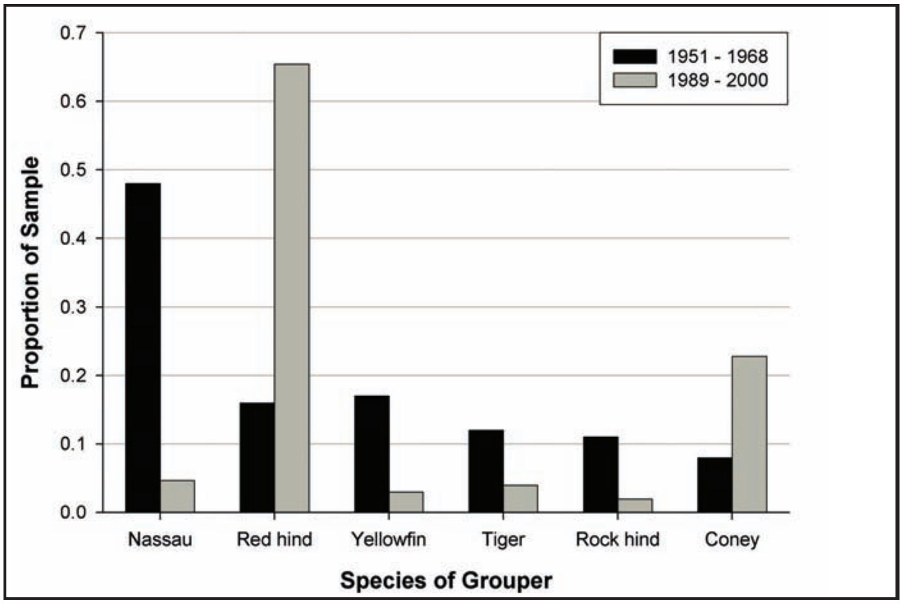

Figure 4.22. Comparison of the relative abundance of groupers collected by Randall from 1958-1961 and groupers sampled during 1989-2000 around St. John. Source: Beets and Friedlander, 2003.

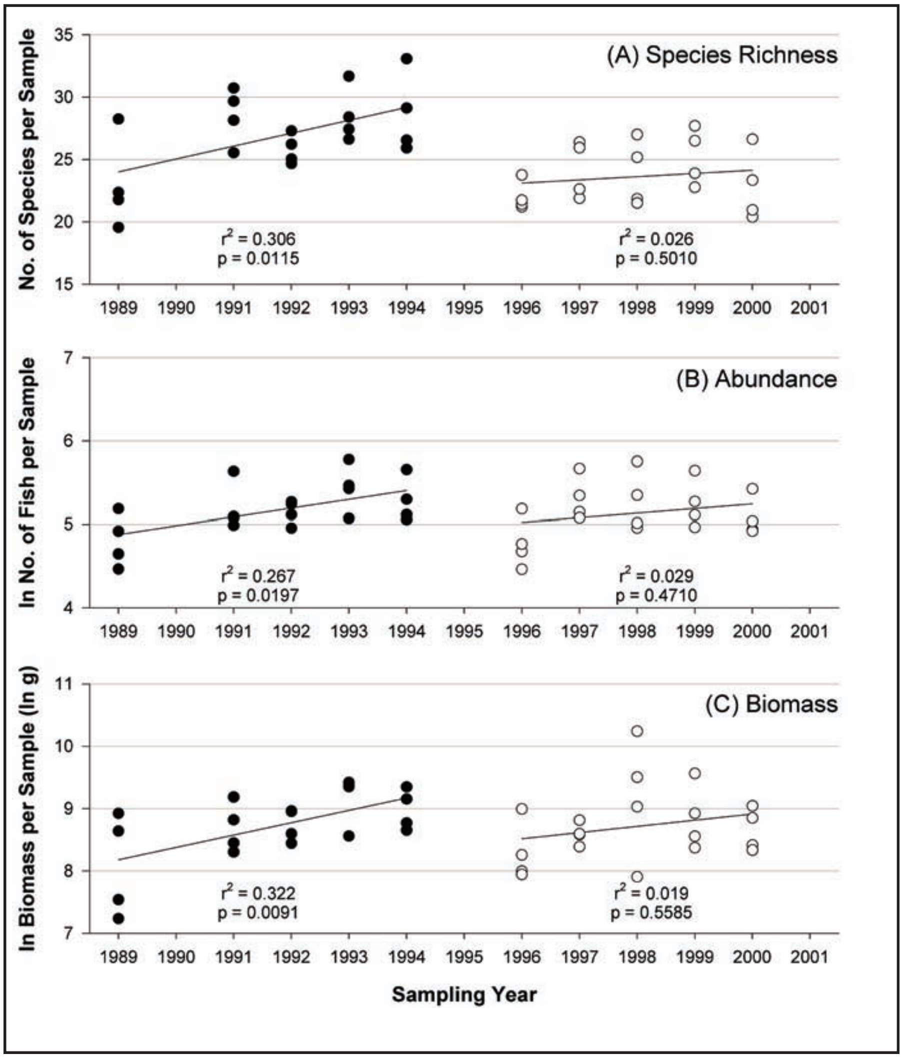

Figure 4.23. Trends in assemblage characteristics during the five years following two hurricanes which affected St. John (Hugo, Sept. 1989; Marilyn, Sept. 1995). Average values for each of the four reference sites are represented by circles for each year. Regression lines and coefficients were obtained from linear regression analysis. Data for 1995 were excluded from these analyses. Source: Beets and Friedlander, 2003.

five-year period following the storm (Figure 4.23). Large storms that passed near the USVI in 1998 and 1999 may have had a significant negative impact on reef fish assemblage recovery, as lower values in assemblage characteristics were noted for 2000. Without long-term consistent data, the ability to evaluate such events is limited.

Current Status of Reef Fish Assemblages in the USVI

Methods

The current status of reef fish assemblages in the USVI was determined from the CCMA-BT, DFW, and UVI-CMES reef fish monitoring programs. These programs present the most recent data on the status of reef fishes in the USVI. In 1998, UVI-CMES joined the Caribbean-wide effort to assess reef fish assemblages at 16 sites throughout the USVI. Since 2001, CCMA-BT has surveyed reef fishes semi-annually for three years at 309 and 128 hard bottom sites in St. Croix and St. John, respectively. Most recently, the DFW conducted 80 visual surveys and collected 120 trap samples at eight permanent hard bottom areas in St. Croix during spring and fall of 2002.

Table 4.8. Species of commercially important snappers (Lutjanidae) and groupers (Serranidae) for which estimates of mean biomass density (g/m^2) were calculated for the Virgin Islands National Park, St. John and the BIRNM, St. Croix. Source: Appeldoorn et al., 1992.

FAMILY	SPECIES	COMMON NAME
Lutjanidae (snapper)	*Lutjanus analis*	mutton snapper
	Lutjanus apodus	schoolmaster
	Lutjanus griseus	gray snapper
	Lutjanus jocu	dog snapper
	Lutjanus mahogoni	mahogany snapper
	Lutjanus synagris	lane snapper
	Ocyurus chrysurus	yellowtail snapper
Serranidae (grouper)	*Epinephelus cruentatus*	graysby
	Epinephelus fulvus	coney
	Epinephelus guttatus	red hind
	Epinephelus morio	red grouper
	Mycteroperca tigris	tiger grouper

Mean biomass density of 12 commercially important species of groupers and snappers (Table 4.8), the trophic biomass ratio of three broad feeding guilds (Table 4.9), and the size frequency distribution of selected species were calculated for each site. Biomass density is the live wet weight of groupers and snappers observed per area (m^2) sampled. Trophic biomass ratio is the proportion of live wet weight of fishes in one of three feeding guilds. Fishes were assigned to trophic guilds according to Randall (1996). However, Randall's trophic classification was reduced to three trophic groups to simplify the interpretation of the results. Randall's "mobile invertebrate feeders/piscivores" were integrated into the group "piscivores"; herbivores were not reclassified; all other trophic groups ("detritivores", "sessile invertebrate feeders", "zooplanktivores", and "omnivores") were combined into one category called 'generalized carnivores' (Table 4.9). Size class frequency is the proportion of individuals of a species belonging to one of eight size classes. Size classes were based on visual estimates of fork length (FL). Size class frequency was estimated for three commercially important species - red hind grouper (*Epinephelus guttatus*), coney (*E. fulvus*), and red band parrotfish (*Sparisoma aurofrenatum*) - and the bluehead wrasse (*Thalassoma bifasciatum*), a commonly occurring species with no commercial importance. These assemblage and species variables were chosen because they can provide a relative index of the condition of coral reef fish assemblages. Current estimates of these assemblage variables will be used as a baseline for comparison with estimates from future monitoring data to determine how reef fish assemblages are changing over time.

Table 4.9. Trophic guilds used to determine trophic biomass ratio of fishes in the USVI. Source: Randall, 1967.

TROPHIC GUILD	FOOD TYPE	EXAMPLE TAXA
Herbivores	Marine plants	Damselfishes, parrotfishes, surgeonfishes
Piscivores, mobile invertivores/piscivores	Other fish, crabs	Red hind, other groupers, snappers
Mobile invertivores, sessile invertivores, zooplanktivores, generalized carnivores	Crustaceans, corals, zooplankton, etc.	Spanish hogfish, wrasses, gobies, filefish, butterflyfish, blennies, cardinal fishes, angelfishes, squirrel fishes, goatfishes, scadblennies, cardinal fishes

NOAA CCMA-BT

Since August 2000, NOAA's CCMA-BT has led a collaborative effort to monitor coral reef ecosystems throughout the U.S. Caribbean, including the USVI. This regionally-integrated monitoring effort explicitly links observed fish distributions to shallow (<30 meters) benthic habitats recently mapped by CCMA-BT and its many partners (Kendall et al., 2001). Objectives of this work include: 1) developing spatially-articulated estimates of the distribution, abundance, community structure, and size of reef fishes, conch, and lobster; 2) relating this information to *in situ* data collected on associated habitat parameters; 3) using this information to establish the knowledge base necessary to implement and support "place-based" management strategies for coral reef ecosystems of the Caribbean; and 4) quantifying the efficacy of management actions.

This regional monitoring program has been conducted in partnership with the UVI, NPS, USGS, and DPNR, and provides standardized monitoring data for portions of the entire U.S. Caribbean. Since the inception of this effort, over 600 surveys of reef fish populations and associated benthic habitats have been conducted in southwestern USVI (see Figure 4.9). The foundation of this work is the nearshore benthic habitats maps created by CCMA-BT in 2001. Using ArcView© GIS software, the benthic habitat maps are stratified to select monitoring stations along a cross-shelf depth gradient. Because the program was designed to monitor the entire coral reef ecosystem, CCMA-BT and its partners survey seagrass meadows, mangroves, sand flats, as well as various coral reef formations. Survey sites are selected at random within each habitat stratum to ensure complete coverage of the study region. At each site, fish, conch, lobster, and benthic habitat information is collected using standard visual survey techniques (Christensen et al., 2003). Since 2003, CCMA-BT has also been collecting water quality and oceanographic characteristic data at each survey location. These water quality data are not yet available, but will be provided in a future report.

By correlating monitoring data to the habitat maps, CCMA-BT and its partners are able to map and model (predict) species and community level parameters throughout the seascape. Furthermore, by integrating this work with other studies being conducted concurrently by its partners on fish migration patterns, home range size, fish dispersal, and recruitment, CCMA-BT is in a unique position to answer questions about marine zoning strategies (e.g., placement of marine protected areas [MPAs]), and evaluate management efficacy through long-term monitoring.

USVI-DPNR-DFWS

Surveys of reef fishes were conducted by divers from the DFW. Surveys occurred during fall of 2003 at eight permanent long-term monitoring sites surveyed annually by researchers from UVI-CMES. The permanent sites were selected because they were considered representative of the reefs around St. Croix (Nemeth et al., 2002). Sites were hard-bottom, less than 15 m in depth, and considerably varied in the composition of benthic flora and fauna (Nemeth et al., 2002).

A 60 m^2 rectangular transect was used to assess reef fish assemblage structure (Nemeth et al., 2003c). Visual fish counts were conducted along 10 replicate transects at each site. During fish transects, transect width and fish lengths (measured in 5-cm increments up to 35 cm) were measured with a 1 m t-bar marked in 5 cm increments. Using transects as replicates, the average density (no./100m^2) and size (cm) of each species and family were calculated for each site.

The DFW also conducts independent fisheries monitoring of reef fishes with fish traps and hand-lines through the Southeast Area Monitoring and Assessment Program for the Caribbean (SEAMAP-C; Tobias et al., 2002). SEAMAP-C is a cooperative program among NOAA Fisheries, the Puerto Rico Department of Natural Resources, and DFW. SEAMAP-C was implemented to collect data needed to assess the status of marine resources of the U.S. Caribbean and to monitor any changes in status (Tobias et al., 2002). Briefly, 12 baited fish traps and three hand-lines (each with three hooks) were used to sample reef fishes in a 52 km^2 area northeast of St. Croix on 10 sampling missions between January 2001 and April 2002 (Figure 4.9). Traps were placed randomly at two depth strata (0-18 m and 19-36 m). Total trap soak time was 59 hours and total hand-line fishing time was also 59 hours. A detailed description of the SEAMAP-C sampling methods is provided in Tobias et al. (2002).

UVI-CMES

Between May 1998 and August 2000 16 sites within the USVI were surveyed (Nemeth et al., 2003b) with the AGRRA protocol (Version 2.0; Ginsburg et al., 1996). Visual fish counts along at least 10 60-m^2 transects were conducted at each site. On St. Croix, additional surveys were conducted at Cane Bay (n=3), Long Reef (n=5) and Salt River (n=6). Transect width and fish lengths (measured in 5-cm increments up to 35 cm) were estimated using a 1 m wide t-bar constructed of pvc. Using transects as replicates, the average density (no./100 m^2) and size (cm) of each species and family were calculated for each site and island group (see below). Parrotfish and grunts less than 5 cm were counted and identified to species when possible at all sites except St. Croix. Sites were identical to those listed in the UVI-CMES AGGRA Assessments of Benthic Substrates section of this chapter.

Results and Discussion

Despite the variation in sampling techniques, spatial extent, and temporal coverage, analysis reveals patterns in the abundance and assemblage structure of reef fishes that were consistent among the data sets. These patterns are described below.

The biomass of commercially important groupers and snappers was very low for all monitoring programs. Mean biomass density of groupers and snappers was 5.67 ± 0.55 g/m^2 (CCMA-BT) and 8.76 ± 1.17 g/m^2 (UVI-CMES). Furthermore, the NPS long-term reef fish data show clearly that the average number and frequency of occurrence of groupers decreased at reference sites during 12 years of sampling (Figure 4.22). Low estimates of biomass also reflect low abundance of groupers and snappers in USVI waters, and indicate a lack of recovery of local grouper populations to fishable levels. Intense fishing pressure, degradation of coral reef habitats, and tropical storm events have contributed to the demise of several large-sized grouper and snapper species such as the Nassau grouper, *Epinephelus striatus* and the dog snapper, *L. jocu* in the USVI (Olsen and LaPlace, 1978; Beets and Friedlander, 1992; Rogers and Beets, 2001). Now, the abundance of smaller-sized groupers (e.g., red hind, *E. gutatus*; coney, *E. fulvus*; graysby, *E. cruentatus*) that have replaced the decimated fisheries are so low that they too are rarely caught in recreational or commercial fisheries (W. Tobias, pers. comm.). Continued monitoring of grouper/snapper biomass density would provide an easy way to assess the future trends and health of USVI reef fish assemblages.

Overfished reef fish assemblages typically are characterized by a higher proportion of herbivores and fewer piscivores compared with unfished assemblages. Many large-bodied predatory species (e.g., groupers and snappers) usually are the primary targets of fishers, which results in the depletion of the largest and most valuable fishes from reef fisheries. As the abundance of these larger species decrease to unfishable levels, fishers are forced to switch to smaller and more undesirable fishes, a phenomenon known as "serial overfishing" (see Ault et al., 1998). Assuming a reduction in fishing pressure may result in an increase in the abundance of predators, monitoring temporal changes in the trophic structure could provide another way to determine the status of USVI reef fish assemblages. The three trophic categories were well represented among most of the data sets. Piscivores comprise 25% (CCMA-BT), 2% (DFW), and 6% (UVI-CMES) of fish biomass at sampled locations (Figure 4.24). Herbivores comprised 43% (CCMA-BT), 3% (DFW), and 18% (UVI/CMES) of

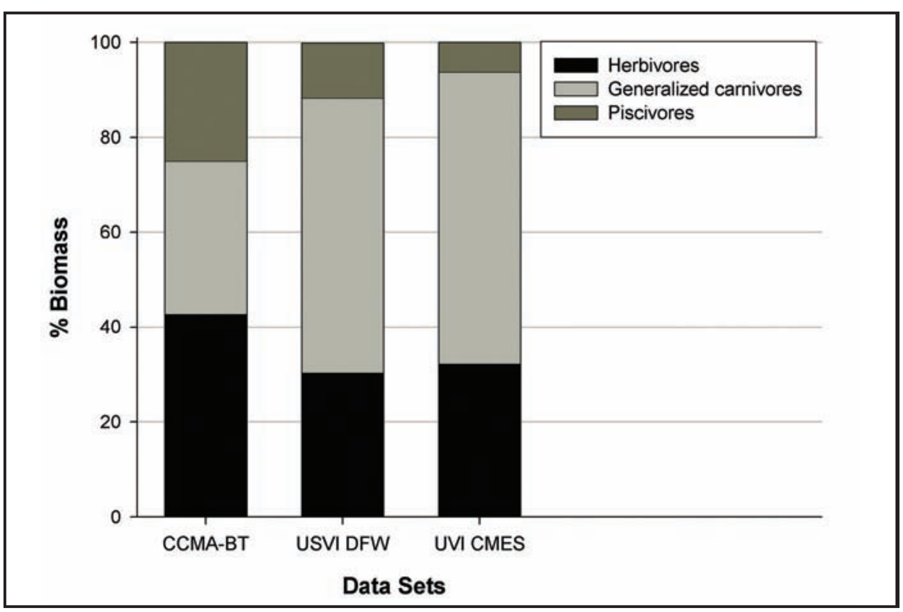

Figure 4.24. Percent biomass of piscivores, herbivores, and omnivores based on data collected by three monitoring and assessment programs: CCMA-BT, USVI DFW, and UVI CMES. Sources: Kendall et al., 2001; Nemeth et al., 2003a,c.

fish biomass. Other trophic guilds accounted for 38% (CCMA-BT), 67% (DFW), and 64% (UVI-CMES) of the observed biomass. Comparisons of current baseline data with future estimates of trophic biomass ratios could indicate whether fishing pressure on UVSI reef fish assemblages is increasing or decreasing.

The size frequency distributions of groupers suggest that grouper populations in the USVI consist predominantly of small-sized individuals. The average adult size of a red hind grouper ranges from 25-38 cm, with a maximum known length of 61 cm (Humann and Deloach, 2002). The coney is smaller with an average adult size ranging from 15-25 cm and a maximum length of 40 cm (Humann and Deloach, 2002). Eighty-three percent of the 909 red hind and coney groupers observed by CCMA-BT were smaller than 25 cm in size (Figure 4.25A). DFW caught 513 red hind and 46 coney groupers during trap and hand-line fishing in St. Croix. Of these, 89% were smaller than 25 cm in size (Figure 4.25B). UVI-CMES divers observed 30 red hind and 72 coney groupers, 94% of which were smaller than 30 cm in size (Figure 4.25C).

Most redband parrotfish observed in the USVI were smaller than the average size of an adult. The average adult-sizde redband parrotfish ranges from 15-25 cm (Humann and Deloach, 2002). A total of 3,043 redband parrotfish were observed during 373 CCMA-BT surveys (Figure 4.25D). Thirty-four percent (1,035 individuals) were 0-5 cm in length. The number of individuals decreased consistently as size-class increased, and only 21% were larger than 15 cm in length. DFW divers observed 590 red band parrotfish grouped into four size-classes, and 93% were less than 20 cm (Figure 4.25E). UVI-CMES reported 721 redband parrotfish grouped into five size-classes, with 82% being less than 20 cm in size (Figure 4.25F). The size frequency distribution

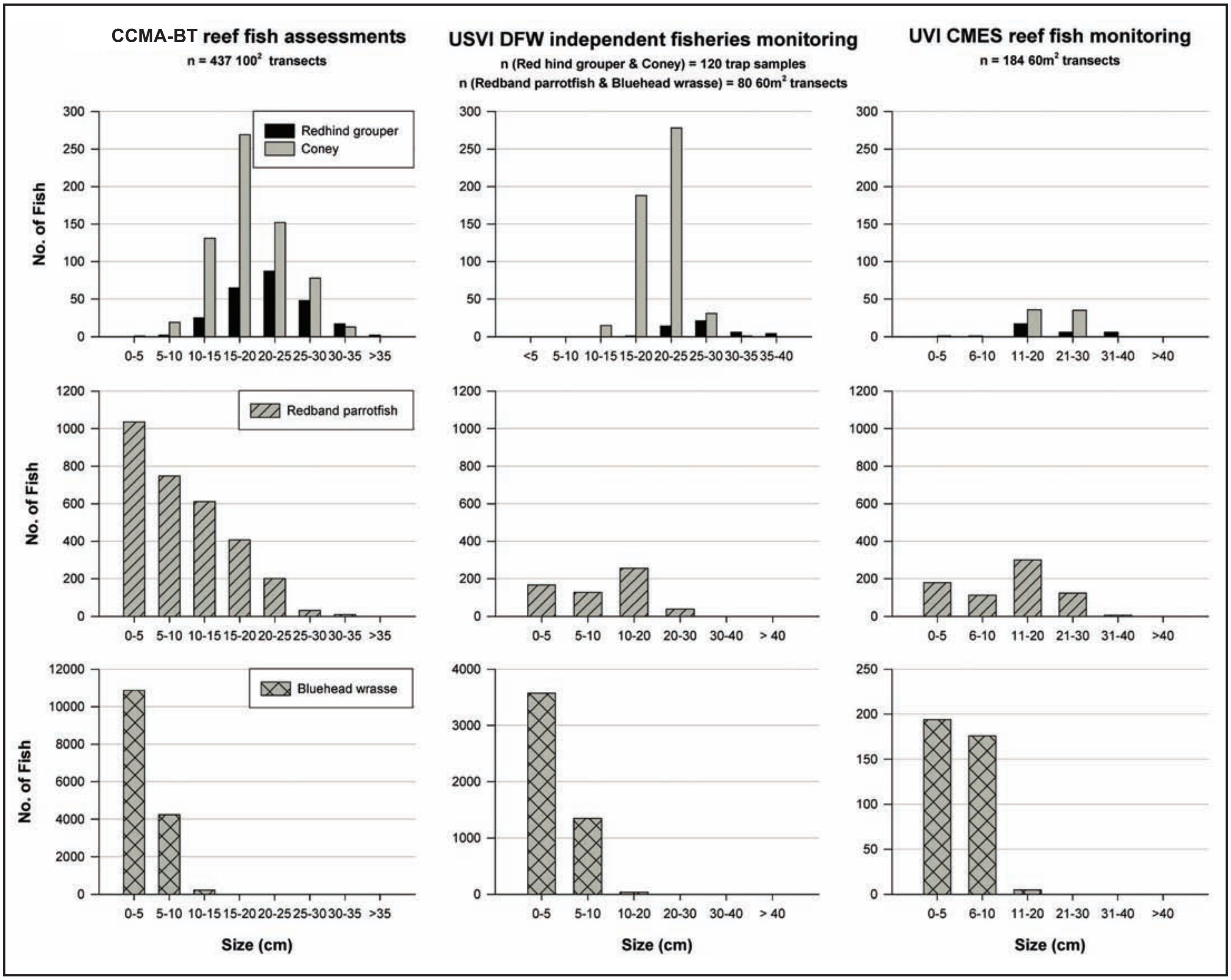

Figure 4.25. Size frequency histograms for four reef fishes based on data collected by three monitoring and assessment programs: CCMA-BT, USVI DFW, and UVI CMES. Sources: Kendall et al., 2003; Nemeth et al., 2003a,c.

indicates that redband parrotfish populations in the USVI generally consisted of immature individuals.

Bluehead wrasse populations in the USVI also consisted primarily of individuals smaller than the average adult size (10-13 cm; Humann and Deloach, 2002). CCMA-BT divers observed 15,337 bluehead wrasse on 398 of 437 surveys (Figure 4.25G). Most (98.5%) were less than 10 cm in length. DFW divers observed 4,959 bluehead wrasse in three size-classes and 99% were less than 10 cm in length (Figure 4.25H). UVI-CMES reported 375 bluehead wrasse grouped into three size-classes, and 98% were smaller than 10 cm in size (Figure 4.25I). The size frequency distribution of the bluehead wrasse indicates that the USVI populations consist primarily of juveniles and immature adults.

In summary, fish species composition on reefs and in fisheries catch has shifted to more herbivorous species since 1988. Additionally, there has been a decline in the number of grouper and snapper species as well as the average size of fishes observed on reefs during field surveys. Commercially important species such as large grouper and snapper species, that once abounded on USVI reefs during the 1950s and 1960s are currently of low abundance in fisheries landings. Continued monitoring of the status of reef populations and reef fisheries as well as commercially important macroinvertebrates (e.g., conch and lobster) is important.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

The U.S. Department of the Interior (DOI), U.S. Department of Commerce (DOC), and Virgin Islands Territorial Government all have jurisdiction in overlapping sections of submerged lands within the USVI (Table 4.10). These agencies have conducted several research and monitoring activities to aid in the management of USVI coral reef ecosystems. Both Federal and territorial agencies in the USVI use a variety of management tools to address issues such as fishing, recreational use, and land-based sources of pollution to protect the marine resources of the territory.

Table 4.10. Authorities with jurisdiction over waters and submerged lands with coral reefs in the USVI.

GOVERNMENT AGENCY	JURISDICTION
Department of Interior, Minerals Management Service	Leasing responsibility for Federal submerged lands within 200 nmi of shore.
NPS	Buck Island Reef National Monument, Salt River Bay National Historical Park and Ecological Preserve, Virgin Islands National Park, Virgin Islands Coral Reef National Monument
NOAA	3-200 nmi
Virgin Islands Territorial Government	All other waters and submerged lands from the shoreline to 3 nmi.

Mapping

In 2000, an extensive seafloor mapping project around the USVI was completed by NOAA, local partners, and the U.S. Coral Reef Task Force. For this project, much of the insular shelf of the USVI from the shoreline to a depth of approximately 20 m was mapped using visual interpretation of aerial photographs, a 26-category classification scheme, and a minimum mapping unit (MMU) of 1 acre (NOAA, 2001). Completed maps cover approximately 490 km^2 of benthic features including mangroves, seagrass, and coral reefs. These maps have been used for a wide variety of research and management applications, including stratification of sampling effort in reef fish monitoring projects, distribution and abundance surveys for elkhorn coral and lobster populations, and an inventory of cryptic fish. Mapping projects since 2000 have primarily covered smaller areas of particular interest in the USVI, focused on specific bottom types, and had smaller MMUs. Aerial photos have been used recently to map Buck Island and Salt River, St. Croix at a finer scale (100 m^2 MMU) than was done previously by CCMA-BT and NPS. These activities are focused on providing a more refined inventory of habitat types in the national parks located at those sites.

Automated computer analysis of historical and current aerial photos was recently completed to detect changes in seagrass beds northeast of St. Croix (Kendall et al., 2004). This information is currently being used to establish records of this critical habitat in a location where anchor damage has historically been a problem. Lidar has also been collected by USGS northeast of St. Croix and around St. John for fine-scale bathymetry and habitat mapping. Several groups at NOAA are using satellite data to map benthic cover and bathymetry. LandSat has been used to map bathymetry around the USVI (EarthSat), with cover mapping currently underway. IKONOS is being used by CCMA-BT to map bathymetry and bottom types around Buck Island, St. Croix.

Several sonar-based projects have also been completed or are underway in the region. These projects cover areas too deep or too turbid to map with either aerial or satellite-based sensors. Side scan sonar has been used by the Caribbean Fishery Management Council and DPNR to map the marine conservation district south of St. Thomas along with some nearby areas to aide fisheries management. An upcoming project by CCMA-BT and partners will use multi-beam sonar to map bottom features below 20 m around the BIRNM, St. Croix and along the mid-shelf reef south of St. John and St. Thomas. The cumulative result of these and future projects will be continuous map coverage of benthic cover and bathymetry from the shoreline to deep water areas beyond the insular shelf.

Marine Protected Areas

MPAs are used as management tools to protect, maintain, or restore natural and cultural resources in coastal and marine waters. They have been used effectively both nationally and internationally to conserve biodiversity, manage natural resources, protect endangered species, reduce user conflicts, provide educational and research opportunities, and enhance commercial and recreational activities (Salm et al., 2000).

Many different types of MPAs have been established throughout the USVI to provide different levels of protection for resources based on their size, management goals, and intended purpose (Table 4.11). Over the years, the number and size of these protected areas have grown steadily, thereby providing protection to a greater proportion of coral reef ecosystems. Recently, additional marine areas have been set aside for protection through Federal and local legislation.

The BIRNM is a large coral reef national park located off the island of St. Croix. The monument, originally established in 1962 by Presidential Proclamation, included a tropical dry forest island (0.7 km^2) and 2.9 km^2 of submerged land. Created to protect the island's elkhorn coral (*Acropora palmata*) barrier reef, the original park boundaries did not fully encompass all essential coral reef habitats or the unique "haystack" formations along the north side of the reef.

When the USVI was highlighted by the U.S. Coral Reef Task Force in 1999, the Secretary of the Interior actively sought to improve protection for coral reef areas under DOI jurisdiction. In 2001, this effort resulted in two Presidential Proclamations, one expanding BIRNM by adding over 75 km^2 acres of submerged lands, and another creating the Virgin Islands Coral Reef National Monument (VICRNM) on St. John. The VICRNM contains 48.9 km^2 of marine waters adjacent to the VINP, including bank shelf and spur-and-groove reef formations, mangrove shorelines, hardbottom habitat, and seagrass beds. VICRNM is almost entirely a no-take area (fishing for baitfish and blue runner in a specified zone is allowed) and anchoring is prohibited. The BIRNM expansion not only added many of the missing and essential coral reef habitats (seagrass, sand, shallow and deep shelf-edge reefs, and deep pelagic areas), but it also made the entire park a no-take area. Anchoring at BIRNM requires a permit.

BIRNM and VICRNM are two of the four units in the National Park System that contain fully-protected marine reserves. The parks were given two years to develop new general management plans and a vessel management plan, but the expansion of BIRNM and new regulations prohibiting all extractive uses were legally challenged by the USVI territorial government. To determine if the President had the right to expand BIRNM and create VICRNM, the Virgin Islands' delegate to Congress requested that the U.S. General Accounting Office review the Presidential Proclamations. The review, which took almost 18 months, found that the Proclamations were valid. The regulations for both monuments went into effect on May 5, 2003.

Table 4.11. USVI Marine Managed Areas (MMA) and their management agencies.

TYPE OF PROTECTION	ST. THOMAS	ST. JOHN	ST. CROIX	MANAGING JURISDICTION
MPAs, Reserves and No-Take	*Cas Cay/Mangrove Lagoon Reserve*	*Small Pond at Frank Bay Wildlife and Marine Sanctuary*	*St. Croix East End Marine Park* established 2003, in early stages of implementation	USVI Government
	St. James Reserve		*Salt River Bay National Historical Park and Ecological Preserve* established 1992, expanded 1975 and 2003 by Presidential Proclamations	NPS
	Compass Point Marine Reserve and Wildlife Sanctuary			
National Monuments		*Virgin Islands Coral Reef National Monument* established 2001 by Presidential Proclamations	*Buck Island Reef National Monument* established 1962, expanded 1975 and 2001 by Presidential Proclamations	NPS
National Parks		*Virgin Islands National Park* established 1956, expanded marine portions added in 1962	*Salt River Bay National Historical Park and Ecological Preserve* * established 1992, expanded 2002 * jointly with territorial government	NPS
Spawning Aggregations	*Red hind Closure* - closed year round		*Red hind Closure* - closed December 1 - February 28	USVI
			Mutton snapper Closure - closed March 1 - June 30	Joint Federal and Territorial Government
Restricted Areas			*Altona Lagoon and Great Pond* shrimp management area, restricted gear use	Territorial Government

The most recent addition to the existing network of protected areas is the St. Croix East End Marine Park, the first territorial park designated by the USVI Legislature in January 2003. With this designation, the USVI Legislature opened the way for the establishment of a territorial network of marine parks. The St. Croix East End Marine Park is not yet functional, but an advisory committee – comprised of stakeholders from the community – developed a management plan and will be involved in the implementation and management of the park.

By far, one of the most compelling reasons for the implementation of MPAs in the USVI has been their potential use as fisheries management tools. To this end, one permanent and two temporary closures exist to protect spawning aggregations of red hind grouper and mutton snapper in St. Thomas and St. Croix (Table 4.11). These closures were prompted by the drastic decline of grouper populations in the USVI primarily caused by heavy fishing pressure during spawning season, when the groupers and snappers form large aggregations. The Red Hind Bank Marine Conservation District south of St. Thomas, USVI was closed permanently in 1999 following nine years of seasonal protection covering the red hind spawning period. Recent data indicate that enforcement of these closures have been successful because the size and numbers of fish spawning within the aggregations have increased, as have the size of fish caught in the fishery (Nemeth, in review). The implementation of the MPA resulted in a reversal of the trend of declining red hind size (Figure 4.26) and a dramatic increase in the biomass of spawning individuals (Figure 4.27).

The NPS Sea Turtle Research Program is in its 18th year of operation (2005). This critical program provides for long-term monitoring, research, and conservation of nesting hawksbill (*Eretmochelys imbricata*), green (*Chelonia mydas*), leatherback (*Dermochelys coriacea*), and loggerhead (*Caretta caretta*) turtles at BIRNM.

In 2003, the Marine Managed Area (MMA) Inventory was completed for the territory through the collaborative efforts of the NOAA, DOI, and USVI Coastal Zone Management Program. The USVI inventory is part of a U.S.-wide MMA inventory. It is currently under review and will be accessible on-line at: http:/www.mpa.gov. The database contains detailed information on each MMA and can be queried for geographic location, management characteristics, resources, level of protection, and specific restrictions.

Other Management Tools

The DFW has deployed several fish aggregating devices (FADs) in territorial waters and the adjacent Exclusive Economic Zone in order to take fishing pressure off the reefs and promote a shift to pelagic fishes (Tobias, 2001). Six FADS are currently deployed around St. Croix and three around St. Thomas. Efforts are underway to increase these numbers during 2004.

Mooring buoys have been installed throughout the territory by Federal and territorial agencies as a management tool to decrease recreational impacts on coral reefs and related ecosystems. Mooring buoys are well used by dive operators, recreational fishers and boaters. Funding has been secured by the territorial government to increase the number of mooring buoys throughout the territory, especially within the St. Croix East End Marine Park.

Outside of managed areas, fishing is regulated under Federal and territorial rules and regulations. Size restrictions exist for whelks, conch, and lobster. The harvest of goliath grouper (*E. Itajara*) and Nassau grouper (*E. striatus*), as well as the commercial harvest of billfish is prohibited. Other restrictions are in place. The territorial fishing rules and regulations are currently under review and will be revised in the near future.

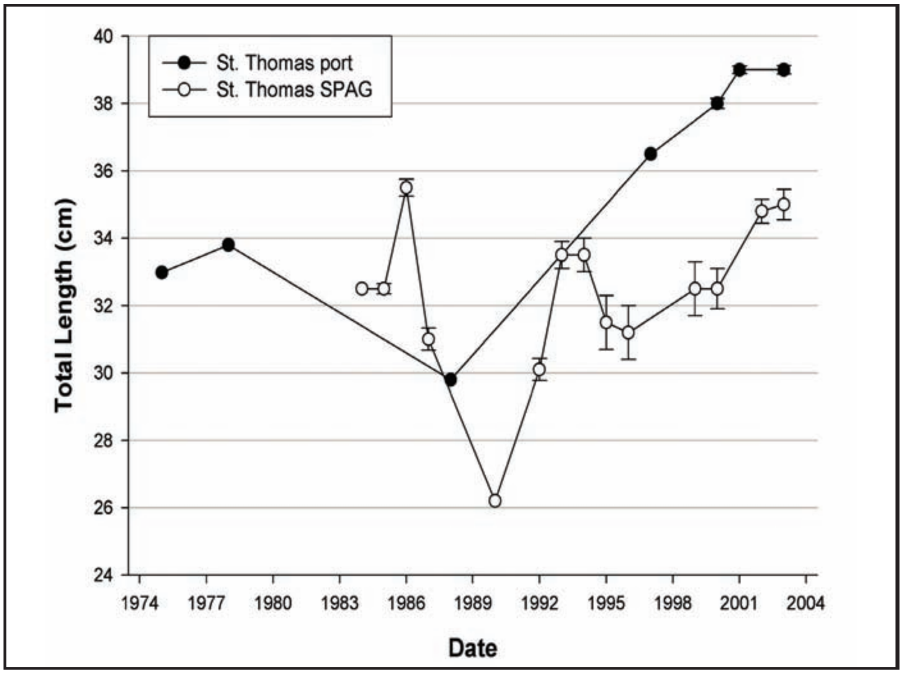

Figure 4.26. Length of red hind from fishery port surveys conducted over 30 years and from red hind spawning aggregation (SPAG). Modified from Nemeth (in review).

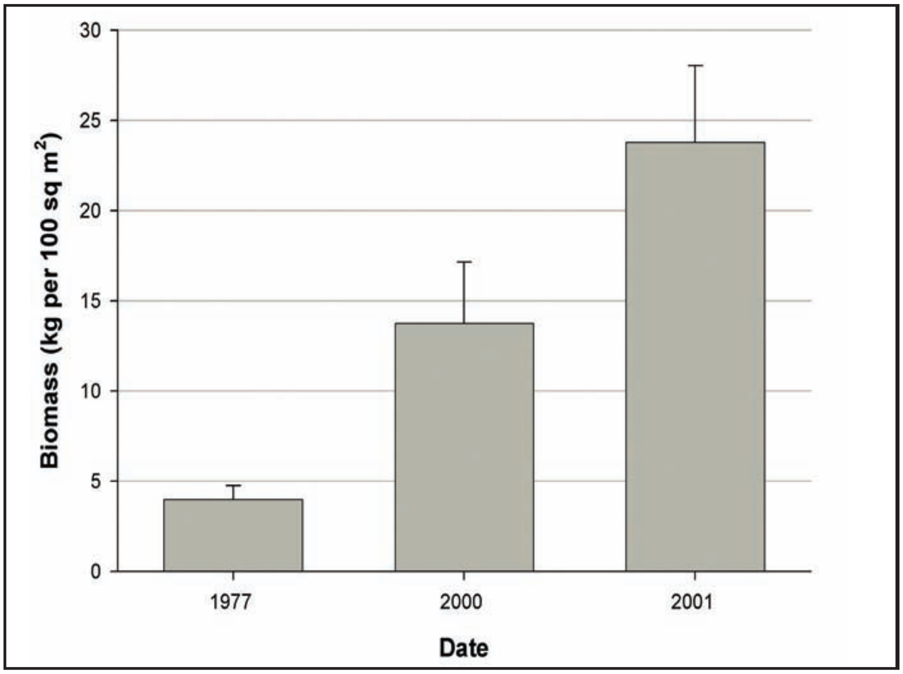

Figure 4.27. Biomass of spawning red hind at the Marine Conservation district south of St. Thomas USVI. Source: 1997 data: Beets and Friedlander (1999); 2000-2001: Nemeth (in review).

OVERALL CONCLUSIONS AND RECOMMENDATIONS

This report has identified several threats facing coral reef ecosystems in the USVI. Current assessments indicate that water quality is generally good, but it is declining because of an increase in point and nonpoint source discharges into the marine environment. Coral diseases remain abundant and epidemic, and the percent cover of coral remains low, while macroalgae abundance on reefs remains high. Dense stands of elkhorn coral that occurred on reefs during the 1960s and 1970s have not recovered to date. Likewise, populations of large-sized grouper and snapper species, which were abundant on reefs and were common in fisheries landings 40 years ago, have not rebounded. Notwithstanding, the size and numbers of groupers and snappers spawning within some enforced MPAs may be increasing, which is very encouraging. Due to the existence of several MPAs, current coral reef ecosystem conditions could improve with: 1) a reduction in the number and intensity of the major threats affecting reefs; 2) enforcement of existing MPAs and laws governing resource use and extraction; and 3) increased environmental education and awareness among residents and visitors. Furthermore, coral reef ecosystems would benefit substantially from stronger coordination and collaboration among Federal and territorial agencies and NGOs that have an interest in marine conservation in the USVI.

Gaps, Problems, and Recommendations

Although the importance of MPAs has been recognized and much effort has been put into their establishment by government agencies and NGOs, a lack of enforcement of MPAs is a major problem. Minimal enforcement stems from a lack of management capacity caused by understaffed teams and limited project funding. The establishment of MPAs is meaningless unless rules and regulations governing those areas can be properly enforced. This is also true for territorial and Federal fishing regulations, which are not enforced because enforcement offices are understaffed. This issue must be addressed before additional or stricter regulations can be proposed and enacted.

Another problem caused by a lack of capacity is the absence of a flow of information between research and management programs within and among management agencies. For instance, monitoring programs have collected several years' worth of data, but analyses of these data have been delayed. Limited human resources caused by a lack of funding are a primary reason why the results and recommendations from data analyses sometimes are not available to local managers in a timely manner. Thus, management decisions concerning resource issues usually are not proactive. Additionally, research and management programs run by territorial agencies are supported mainly through funding from Federal agencies (EPA, NPS, NOAA and USGS) rather than through funding from the territorial government. Consequently, the direction and emphasis of research programs in the USVI are often directed by the programmatic mandates of non-territorial funding agencies rather than by specific resource issues that affect the territory.

The fact that several jurisdictions are involved in resource management has led to conflicts in the past. Approaches are very different among management agencies and jurisdictions, and conflicts have arisen where jurisdictions overlap. Whereas the territorial government tried to involve stakeholders and communities, the establishment of monuments and national parks has been a top-down approach. This approach has led to conflicts between managers of monuments and territorial management agencies, such as when objections were raised, and are still being raised to the 2001 presidential proclamation that expanded the BIRNM. The territory is also in need of management plans for all designated APC. As of now, these areas exist only on paper and are useful only for supporting permit decisions for coastal development. Along with efforts to address the issues here, the following actions would be very valuable in helping to manage and protect resources in the USVI. These actions include the following:

1. Establishing acceptable limits of change or carrying capacity for protected areas;
2. Training judges on adjudication of environmental issues and concerns;
3. Hiring trained environmental prosecutors (as environmental crimes are currently of low priority in the territory);
4. Shifting toward eco-tourism and increased support and promotion of sustainable and ecologically sound coastal development by the territorial government; and
5. Establishing pollution control criteria.

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The State of Coral Reef Ecosystems of the Commonwealth of Puerto Rico

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INTRODUCTION AND SETTING

Puerto Rico, the smallest of the Greater Antilles, is located in the north central Caribbean, between the U.S. Virgin Islands (USVI) to the east and the Dominican Republic to the west (Figure 5.1). Puerto Rico is an archipelago comprised of the main island; the oceanic islands of Mona, Monito, and Desecheo in the Mona Passage; Caja de Muertos Island on the south coast; Vieques Island; Culebra Island; and a series of smaller islets or cays known as the "Cordillera de Fajardo." The total area of the Puertorrican archipelago is 8,929,468 km^{2}.

The geological, climatological, and oceanographic features that affect growth and development of coral reefs vary markedly among insular shelf segments (García-Sais et al., 2003). The north and northwest coasts are narrow (<3 km) and shallow communities are subject to strong wave action during winter as large swells from the north Atlantic reach the Caribbean Antilles. The north and west coasts also receive substantial sediment and nutrient loading from the discharge of the largest rivers of Puerto Rico. Sand dunes are abundant along the north coast, some of which are now submerged eolianites. Others fringe the coastline, forming rocky beaches with rich intertidal communities. The northeast coast has a wider shelf, partially protected from wave action by a chain of emergent rock reefs (Cordillera de Fajardo) aligned east-west between the main island and the island of Culebra. The northeast coast is upstream from the discharge of large rivers, resulting in more appropriate conditions of light penetration for coral reef development. The east coast between Fajardo and Vieques is characterized by extensive sand deposits that provide unfavorable substrates for coral growth. However, scattered rock formations within this shelf section have been colonized by corals.

The south coast is an environment of relatively low wave energy and the insular shelf is generally wider than the north coast. Rivers with smaller drainage basins discharge on the southeast coast and only small creeks discharge on the southwest coast, which has been classified as a semi-arid forest. The south coast also features a series of embayments and submarine canyons (Acevedo and Morelock, 1988). Small mangrove islets fringe the south coast and many of these provide hard substrate for coral development. The shelf-edge drops off at about 20 m with an abrupt, steep (almost vertical) slope in many sections. At the top of the shelf-edge lies a submerged coral reef which gives protection to other reefs, seagrass and mangrove systems of the inner shelf (Morelock et al., 1977).

The southwest coast is relatively wide and dry, with many emergent and submerged coral reefs that provide adequate conditions for development of seagrass beds and fringing mangroves. Toward the central west coast lies Mayaguez Bay, one of the largest estuarine systems of the island and partially influenced by wave action from North Atlantic swells during winter. Coral reefs off Mayaguez Bay show a marked trend of deterioration toward the coastline, but the shelf-edge reef systems are in good condition. Farther north along the west coast is Rincón and coral reef systems are established throughout the relatively narrow shelf off Tres Palmas, including an elkhorn coral (*Acropora palmata*) biotope fringing the coastline that is probably the largest remaining stand in Puerto Rico. A series of patch reefs are distributed throughout the Rincón mid-shelf and there is a "spur-and-groove" coral reef formation at the shelf-edge. Off the northeast coast of Aguadilla, several small marginal coral reef systems are associated with rock outcrops at depths between 15-25 m. These reefs are strongly affected by intermittent river discharge (Culebrinas River) and wave action. East of Aguadilla, the influence of large river plumes, a prominent feature of the coastline, constrains coral reef development, but hard ground and rock reefs with live corals are present throughout.

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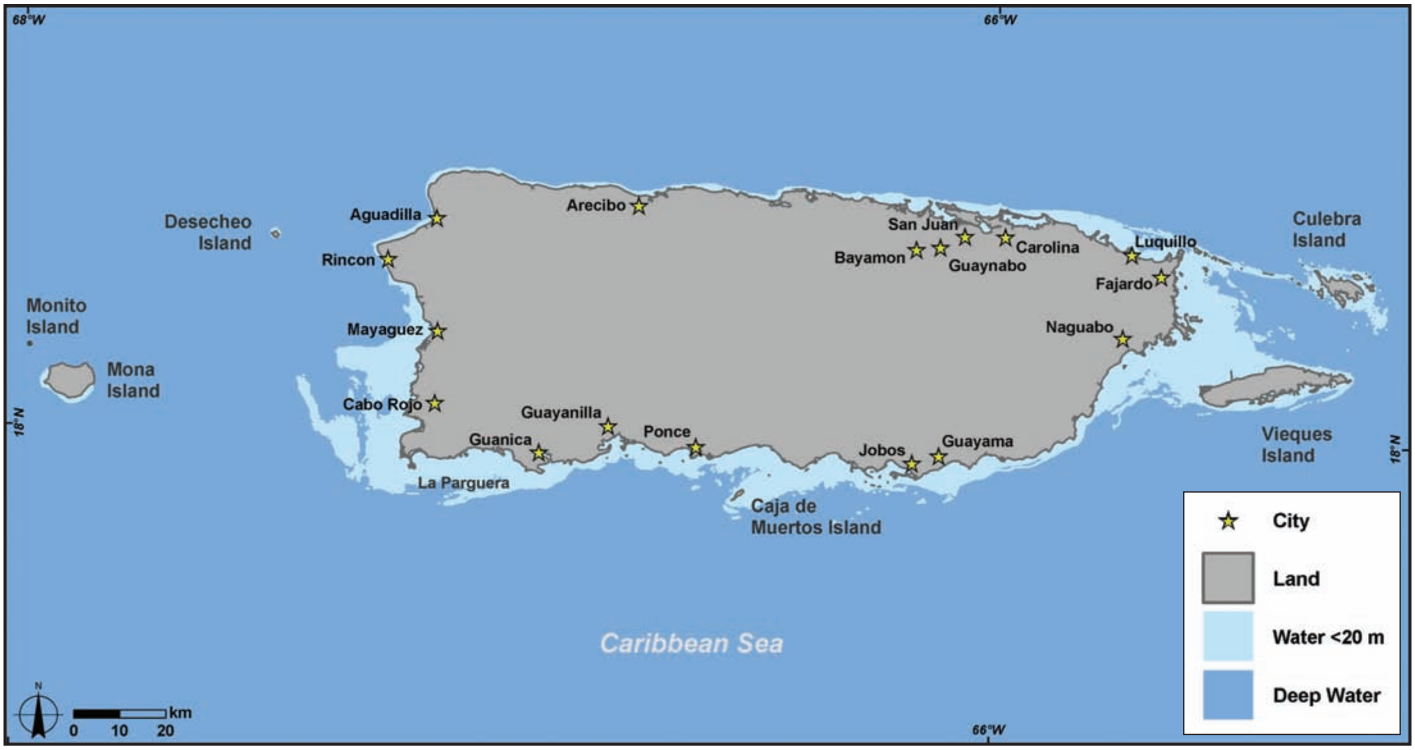

Figure 5.1. A map of Puerto Rico showing locations mentioned in this chapter. Map: A. Shapiro.

Mona and Desecheo are oceanic islands in the Mona Passage that belong to Puerto Rico. The northern sections of the islands are strongly impacted by wave action and their insular platforms are narrow, whereas the southern coastal sections of these islands are more protected and have wider platforms where coral reefs develop. There are no rivers on either of the islands, which are surrounded by waters of exceptional transparency (Cintrón et al., 1975). In Desecheo, the coral reef system is impressive at depths between 20-30 m with live coral cover exceeding 70% in many sections. The coral reef system off Puerto Canoas at Desecheo Island extends down to a depth of 40 m (García-Sais et al., 2004).

Modern shelf-edge reefs formed in Puerto Rico some 8,000 years ago (Adey, 1978). Inner reefs, formed on top of submerged banks and sandy bottoms of the flooded shelf are believed to be about 5,000 years old (Adey, 1978). The rise in sea level associated with the last Pleistocene glaciation (Wisconsin) flooded the lower limestone ridges of the shelf, providing appropriate sites for coral growth and subsequent reef development (Goenaga and Cintrón, 1979). Cross-shelf seismic profiles provided by Morelock et al. (1977) support the theory of Kaye (1959), which states that reefs on the southwest coast developed on drowned calcarenite cuestas formed as eolianite structures parallel to the coastline during the Wisconsin glacial period. Proper substrate, depth, and water transparency conditions in the southwest coast allowed for extensive development of coral reefs during the mid-Holocene period (Goenaga and Cintrón, 1979). At least three major types of reefs (rock reefs, hard ground reefs, coral reefs) are recognized within the Puertorrican shelf (García-Sais et al., 2003) although different coral reef formations have been reported (Goenaga and Cintrón, 1979; Hernández-Delgado, 1992; Morelock et al., 1977).

Rock reefs are submerged hard substrate features of moderate to high topographic relief with typically low to very low coral cover, mostly colonized by turf algae and other encrusting biota (Figure 5.2). Coral colonies are abundant in some cases (e.g., *Diploria* spp., *Siderastrea* spp., *Montastrea cavernosa*, *Porites astreoides*) but grow mostly as encrusting forms, providing minimal topographic relief. These types of reefs fringe the west and northwest coasts and are believed to be the main components of deep reef systems beyond the shelf-edge. Rock reefs are important habitats for fishes and macroinvertebrates since they are usually the only available structure providing underwater topographic relief in these areas. Some have developed atop of submerged rocky headlands and are characterized by the development of coralline communities adapted for growth under severe wave action and strong currents.

There are deep basaltic rock reefs; an extensive and complex system of slabs, boulders, crevices; and vertical walls associated with the insular slope. The most extensive deep reef formation is the great southern Puerto Rico fault zone (Glover, 1967; Garrison and Buell, 1971), a submerged section of the Antillean Ridge that extends across the entire Mona Passage. The ridge rises from a mean depth of 4,600 m and includes the islands of Mona, Monito and Desecheo, as well as submerged seamount peaks that rise to depths of less than 100 m, such as Bajo de Cico and Bajo Esponjas

Hard ground reefs are mostly flat platforms ranging in depth from 5-30 m and largely covered by turf algae, encrusting sponges, and scattered patches of stony corals (Figure 5.2). Coral colonies are typically encrusting forms, an adaptation to the extremely high wave energy that prevails seasonally on the north coast. Many of the encrusting coral colonies grow over vertical walls in crevices among the hard ground. The barrel sponge, *Xestospongia muta*, is usually abundant in hard ground reefs, where it represents one of the main features contributing topographic relief. Low-relief sand channels aligned perpendicular to the coast cut through the hard ground platform in many areas and provide topographic discontinuities. The sand is generally coarse and mostly devoid of biota, reflecting short deposition times and highly dynamic movements across the shelf due to the high wave action. These systems are found off the north central and northeast coastlines (García-Sais et al., 2003).

Coral reefs are mostly found as fringing, patch, and shelf-edge formations in Puerto Rico. Fringing coral reefs are by far the most common. These are located throughout most of the northeast, east, and southwestern coastlines associated with erosional “rocky” features of the shelf. In most instances, coral is not the main constituent of the basic reef structure, but its development has significantly contributed to topographic relief, influencing the sedimentation of adjacent areas and providing habitat for a taxonomically diverse community that is consistent with a coral reef system (García-Sais et al., 2003). On the south coast, coral reefs fringe many small islands or keys, and are found as extensive coral formations associated with the shoreline at the mouths of coastal embayments. In some instances, coral growth has been primarily responsible for the formation of emergent island reefs, or keys, such as the reefs off La Parguera (García-Sais and Sabater, 2004). Fringing reefs are also found off the northeast coast, mostly on the leeward section of the islets off Fajardo (in the Cordillera de Fajardo Natural Reserve).

Shelf-edge reefs are the best developed (but least studied) coral reef systems in Puerto Rico. An extensive reef formation is found at the shelf-edge off the southwest coast in La Parguera. This reef displays the typical “spur-and-groove” growth formation with sand channels cutting through the shelf perpendicular to the coastline (Figure 5.2). Also, the reef formations at the shelf-edge of Ponce (Derrumbadero), Guánica, and Desecheo and Mona Islands are characterized by structurally and taxonomically complex communities. The shelf break on the north coast is characterized by a more gentle slope than on the south coast and the substrate is generally sandy or a flat, hard ground with low relief. Scattered rock reefs occur throughout many sections of the north coast. Some are present down the insular slope and represent the main substrate for deep reef communities with live hermatypic and ahermatypic corals providing important physical habitat.

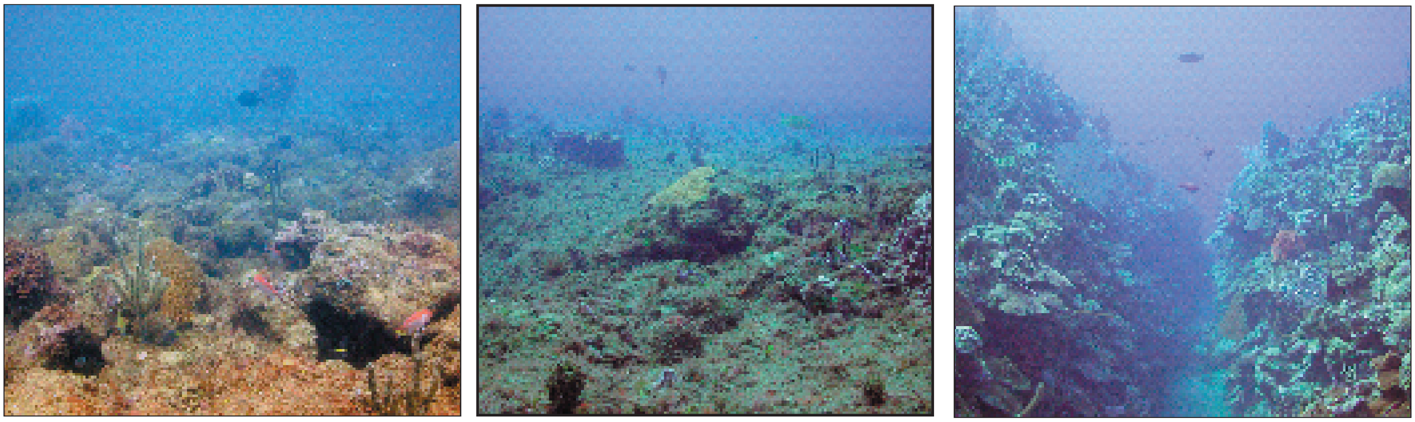

Figure 5.2. Left photo depicts rock reef habitat in the Aguadilla shelf, northwest coast. Center photo shows hard ground reef habitat in Arecibo, north coast. Right photo depicts a “spur and groove” coral reef formation in La Parguera, southwest coast. Photos: J. Sabater.

The Coral Reef Monitoring Program for Puerto Rico, which is sponsored by the National Oceanic and Atmospheric Administration (NOAA) and administered by the Puerto Rico Department of Natural and Environmental Resources (DNER), is now fully implemented and has achieved its initial goals in collaboration with Federal and local governmental agencies and marine scientists from research institutions. This chapter provides an assessment of the status of coral reef systems in Puerto Rico. A synopsis of scientific research undertaken in characterization of coral reefs is included, along with an evaluation of temporal and spatial trends of reef community structure and health, as suggested by the data emerging from ongoing monitoring programs. Quantitative baseline characterizations of sessile-benthic and fish communities at natural reserve sites and other sensitive coastal areas represent the basis for this assessment of Puertorrican coral reefs. Inferences derived from basic research on coral diseases, coral bleaching, mass mortalities and potentially relevant environmental and anthropogenic stressors, such as global warming, storms, eutrophication, fishing, sediment runoff, dredging activities and others are also presented. A description of the major ongoing programs on coral reef community characterizations and monitoring is included, along with a database on percent cover and taxonomic composition of live corals and fishes from reefs surveyed around Puerto Rico. Conservation management strategies that include active marine protected area (MPA) programs and revisions to fishing laws are presented and evaluated. Preliminary conclusions about the status of coral reefs and recommendations for management are also included in this chapter.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

Bleaching has been reported on Caribbean reefs since the 1940s (Goreau, 1964) and has been associated with localized events including marked changes in salinity, turbidity and extreme low tides (Winter et al., 1998). During the summer of 1987, a massive coral bleaching event was observed in Puerto Rico (Goenaga et al., 1989; Williams et al., 1987) and throughout the Caribbean (Williams and Bunkley-Williams, 1988).

Goenaga et al. (1989) reported extensive bleaching of zooxanthellate cnidarians from forereef environments in La Parguera that included scleractinians, zoanthids, encrusting and arborescent gorgonians, anemones and hydrocorals. A total of 64 species of coral reef photosymbiotic hosts were affected (Williams and Bunkley-Williams, 1989). Goenaga et al. (1989) associated the bleaching event to exceptionally calm seas coupled with high water transparency and increased water temperature. Vicente (1994b) found 22% of 326 corals monitored at Cayo Enrique Reef in La Parguera bleached in 1987 and 44% of those showed tissue necrosis. Goenaga et al. (1989) also found that bleaching was unrelated to depth and that the Boulder star coral, *Montastrea annularis*, had been most affected by the bleaching event in Cayo Enrique, La Parguera. Lingering effects of the 1987 mass bleaching of corals in La Parguera that lasted until late 1988 were reported by Bunkley-Williams et al. (1991). Williams and Bunkley-Williams (1990b, 2000) argued that beyond the initial damage, corals do not have sufficient time to recover between closely spaced major bleaching events and therefore the damage may be cumulative and ever increasing.

Velasco et al. (2003) tagged and observed 386 specimens of 23 species of corals off southwestern Puerto Rico after a bleaching event in 1998. They found 99% of coral colonies recovered from bleaching after three years, including the 15% that bleached again in 1999 (Velasco et al., 2003). Wilkinson (2003) and Williams and Bunkley-Williams (2000) suggested that the 1998 event in the northern Caribbean consisted of widespread, but only low to moderate bleaching. Wilkinson (2003) suggested that most susceptible corals had been killed by previous bleaching.

A number of bleaching studies have been conducted around Puerto Rico (e.g., Bunkley-Williams et al., 1991; Goenaga and Canals, 1990; Goenaga et al., 1989; Goreau et al., 1992; Hall et al., 1999; Hernández-Delgado and Alicea-Rodriguez, 1993; Velasco et al., 2003; Vicente, 1989, 1990, 1994a,b; Williams and Bunkley-Williams, 1988, 1989; Williams et al., 1987; Winter et al., 1998; Woodley et al., 1997). The nearshore reefs seem to have been damaged more by bleaching and have recovered less than the shelf-edge reefs in southwestern Puerto Rico (Williams and Bunkley-Williams, unpublished data). Many former inshore coral reefs have deteriorated to algal reefs. The reefs at Mona Island appear to have been damaged more than those on the main island of Puerto Rico, but this seems to be due more to diseases than bleaching, although bleaching may have had a precursor effect (Williams and Bunkley-Williams, unpublished data).

Winter et al. (1998) compared coral reef bleaching events at La Parguera to a 30-year (1966-1995) record of sea surface temperature (SST) for that location and found that the annual temperature indices of maximum daily SST, days >29.5°C, and days >30°C all predicted the years of severe coral bleaching in La Parguera corresponding to 1969, 1987, 1990, and 1995. However, no one simple predictor of the onset of a bleaching event within a single year may be applicable according to Winter et al. (1998).

Diseases

Coral disease, specifically black band disease (BBD), was first reported on reefs surrounding mainland Puerto Rico in 1972 (Antonius, 1981), with sporadic observations by other researchers over the last three decades (Williams and Bunkley-Williams, 1990b). A coral disease monitoring program established in 1994 has documented outbreaks of BBD in selected locations near La Parguera, Rincón, and Aguadilla, with isolated cases observed in other locations including the offshore islands of Desecheo and Mona (Bruckner, 1999). The prevalence of BBD has declined since Hurricane Georges (1998), although localized outbreaks in previously unaffected locations continue to occur. A recent Caribbean-wide survey reported an unusually high prevalence of BBD (6.8%) on Desecheo Island (Weil et al., 2002). On Mona Island, BBD has affected 1-11% of the brain corals (*Diploria strigosa* and *D. clivosa*) in reef crest and backreef environments since the mid-1990s, with infections occurring sporadically (<1%) among other massive (*M. faveolata, C. natans* and *S. siderea*) and plating (*Agaricia* spp.) corals in deeper forereef environments.

An outbreak of white plague was reported on reefs near La Parguera in 1997 (Bruckner and Bruckner, 1997), and again in 2003 at shelf edge localities which affected at least 16 species (Weil, unpublished data). An outbreak of white plague was also observed in 1999 on Mona Island that affected 14 species, with the highest prevalence among small, massive corals (*D. strigosa, D. stokesii*) many of which died within one to two weeks. Culebra Island's *Montastraea* spp. populations have also been affected by white plague since 2002, with the most recent outbreak observed in April 2004 (E. Herndandez-Delgado, pers. comm.).

White band disease (WBD), the leading cause of mortality to Caribbean acroporid populations, was first reported by Goenaga in the early 1980s with 20-33% of the *A. palmata* colonies affected on one reef near La Parguera (Davis et al., 1986). Isolated cases of WBD were observed between 1995-2003, including an outbreak that affected 15% of the standing colonies on a reef off the east coast of Mona Island (Bruckner and Bruckner, in press). WBD has also been observed among *A. cervicornis* populations near La Parguera in shallow nearshore locations and deeper shelf-edge reefs. A more virulent form of WBD was first documented among *A. cervicornis* colonies throughout Culebra in 2003, affecting 45% of all colonies on seven reefs (AGRRA, 2003). More recently, this has been reported among inshore *A. cervicornis* nurseries and in reef environments around Culebra (E. Hernandez-Delgado, pers. comm). Other conditions that have increased in abundance since 1999 on reefs near La Parguera, Desecheo and Mona Islands include yellow band disease (YBD) among *M. faveolata* and *M. annularis* and dark spots disease on *S. siderea* and other species (Bruckner, unpublished data; Weil, 2004).

The prevalence of diseases has been monitored annually on Mona Island since 1995, with emphasis on YBD. YBD was absent from these reefs in 1995 and was observed for the first time in 1996 among four colonies of *M. faveolata*. In 1999, YBD affected up to 50% of all *M. annularis* (species complex) colonies within permanent sites, including many of the largest (2-3 m diameter and height) and presumably oldest colonies. The highest prevalence of disease was recorded in shallow depths (3-10 m) off the protected west coast while fewer colonies were affected in deeper water (15-25 m) off the south coast. Measured rates of disease spread and tissue mortality has been slow (5-15 cm/year) compared to other diseases, although spatial, seasonal, and annual differences were observed. Individual colonies with a single YBD lesion have exhibited multiple infections on the colony surface over time. With exception of those colonies with YBD that died, most corals first affected by YBD between 1999 and 2001 were still affected in 2003, with colonies losing 50-100% of their tissue over this period. The prevalence of YBD progressively increased in deeper sites over the last four years and this disease is the greatest threat affecting the survival of *Montastraea* spp. populations.

Tropical Storms

Hurricanes are natural catastrophic events that have caused massive mortalities to coral reef and other coastal marine communities in Puerto Rico (Figure 5.3). In particular, hurricanes appear to be the main factor for the large-scale decimation of elkhorn coral (*Acropora palmata*) biotopes in Puertorrican reefs. The intense wave action, surge, and sediment abrasion stress associated with hurricanes cause the mechanical detachment and mortality of many benthic reef organisms, including corals in shallow reef zones. Coastal communities are also impacted by high sediment and nutrient loads from rainfall runoff during and several days after the pass of hurricanes.

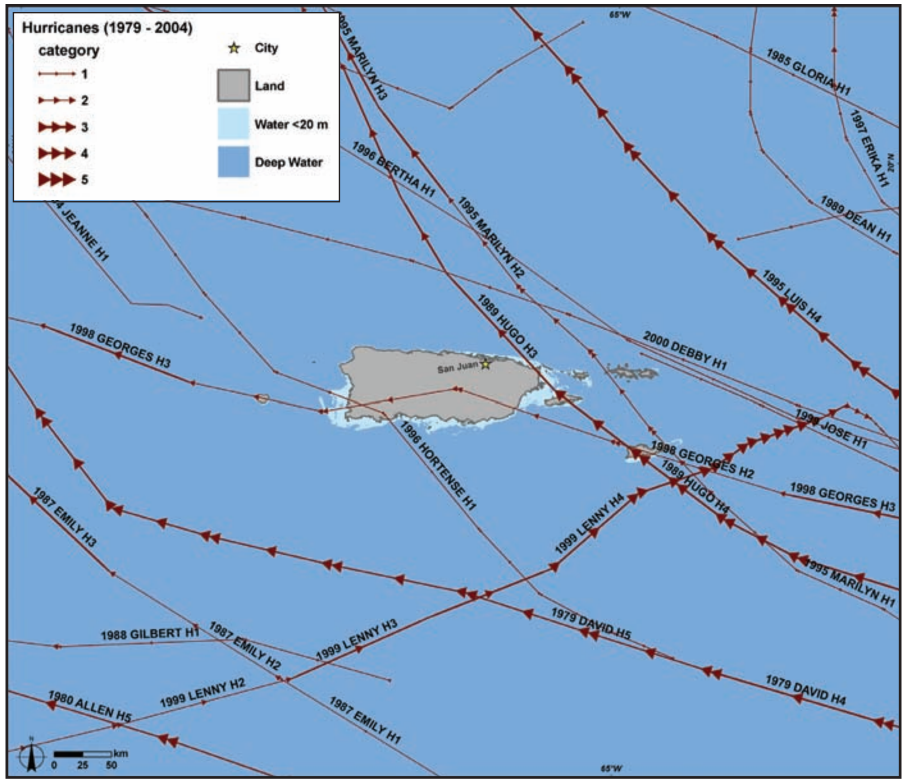

Figure 5.3. The path and intensity of hurricanes passing near Puerto Rico between 1979 and 2004. Year of storm, Hurricane name and storm strength on the Saffir-Simpson scale (H1-5) are indicated for each. Map: A. Shapiro. Source: NOAA Coastal Services Center.

The effects of Hurricane Edith (1963) on the shallow reefs of La Parguera were documented by Glynn et al. (1964). In addition to the massive mortality of reef benthic invertebrates and algae, destruction of the elkhorn coral biotope to the extent of 50% mortality was noted on inner reefs by Glynn et al. (1964). Based on aerial photoanalysis, Armstrong (1981) described the large-scale detachment and deposition of coral fragments, mostly elkhorn coral (*A. palmata*), finger coral (*Porites porites*), and fire coral (*Millepora* spp.) on the forereef of Cayo Enrique, La Parguera, after Hurricane David passed 340 km south of Puerto Rico during August 1979. The fringing red mangrove (*Rhizophora mangle*) also suffered significant damage from Hurricane David due to uprooting and scalding of the leaves (Armstrong, 1981). Extensive mass mortalities of benthic algae down to a depth of 17 m were reported by Ballantine (1984) after the pass of Hurricanes David and Allen one year later (in August 1980). Matta (1981) also noted a drastic decline in abundance and species richness of macroalgae in Cayo Turrumote, one of La Parguera's outer reefs.

Massive destruction of elkhorn coral biotopes off the northwest coast of Vieques Island reefs was reported by García-Sais et al. (2001d). These reefs appear to have been impacted by a high magnitude mechanical force, probably Hurricane Hugo in 1989. Large broken arms and other smaller coral fragments have been overgrown by benthic algae and other encrusting biota. This catastrophic phenomenon was highly significant for the north coast reef communities of Vieques in particular because of the relatively extensive area of the reef crest in relation to deeper reef physiographic zones. Re-colonization and growth of *A. palmata* colonies, as inferred from observations at La Parguera and Vieques reefs appears to be occurring at a very slow pace.

At a broader scale, hurricanes can change the biogeochemistry and productivity of coastal regions due to their influence upon river discharge and loading of sediments, nutrients, organic matter and other materials that affect phytoplankton primary productivity. Using a time series of remotely sensed imagery to analyze changes in ocean color, Gilbes et al. (2001) showed that after the pass of Hurricane Georges (September 21-22, 1998), phytoplankton biomass increased by at least two orders of magnitude, extending from coastal to adjacent oceanic regions more than 37 km offshore. Based on U.S. Geological Survey (USGS) stream flow measurements at 55 stations in 15 drainage basins, Gilbes et al. (2001) estimated that more than 1,000 metric tons of nitrate were discharged to the coastal waters of Puerto Rico during September 20-25, 1998 and concluded that this massive pulse of nutrients significantly increased phytoplankton productivity, generating a signal that was prominent in the SeaWiFS imagery.

Coastal Development and Runoff

Puerto Rico has a population of approximately 3.8 million people. The capitol city of San Juan is the main population center with 434,000 people, or 11.4% of the total population (2001 Census; http://www.censo.gobierno.pr/Centro_Datos_Censales.htm, accessed 1/20/05). Bayamón (224,000), Ponce (186,000), Carolina (186,000), Arecibo (100,000), Guaynabo (100,000), and Mayaguez (98,000) are the other main population centers. With the exception of Guaynabo, the remaining six cities (which combine for 1.23 million people or 32% of the total population) are located on the coast (Figure 5.1). San Juan, Bayamón, Carolina, and Arecibo are located on the north coast, where no significant development of coral reefs occurs. These are coastal areas with a narrow insular shelf that experience heavy wave action during the winter and are under the influence of major river runoff. Most coral reef systems in Puerto Rico are located in areas upstream of major rivers and away from population centers and terrestrial inputs, such as those in Cordillera de Fajardo, Vieques, Culebra, and the oceanic islands of Desecheo and Mona. Extensive coral reefs also exist along the protected southwest coast, from Guayanilla to La Parguera and Cabo Rojo.

Important coral reef systems are found along the Mayaguez and Ponce sections of the insular shelf. Coral reefs on these coastal sections developed under the influence of moderate (Ponce) to high (Mayaguez) seasonal runoff from river discharge and have experienced significant degradation, particularly in systems located close to the shoreline. These two cities share a history of coastal development that has been detrimental to coral reefs. Both are cities where dredging activities have been required to allow large ship traffic within the bays. Primary sewage was discharged inshore close to reef systems via submarine outfalls for several decades. Organic discharges from tuna factories were dumped through submarine outfalls in both bays for more than 20 years. Benthic habitats have been subjected to sedimentation caused by resuspension during ship docking activities and navigation within the bays. The result has been the loss of coral reefs within the inner shelf and a major shift of benthic community structure on mid-shelf sections, where soft corals have colonized hard ground benthic habitats (García-Sais and Castro, 1995). However, outer shelf reef systems at both bays, such as Tourmaline Reef in Mayaguez Bay and Derrumbadero Reef in Ponce Bay, rank among the best developed coral reefs in Puerto Rico, with live coral cover exceeding 40% at both sites.

Significant water quality restoration initiatives have been implemented during the last decade to prevent further deterioration of the marine habitats at both bays. In Mayaguez Bay, secondary treatment was mandated by the U.S. Environmental Protection Agency (EPA) for both domestic sewage and tuna factory discharges into the bay. At Ponce, the primary treated submarine sewage outfall was relocated to discharge at a depth of 150 m down the insular slope below the pycnocline. The tuna factory finished operations and moved out of Ponce Bay, but the proposed expansion of the Ponce port into the Megaport of the Americas poses relevant challenges to avoid further deterioration of coral reefs in the bay. Sediment re-suspension by large cargo ships and dredging represents the major threats to coral health. Concerns have also been raised in relation to potential impacts of the Ponce megaport operations on downstream coral reef systems at Guayanilla, Guánica and La Parguera. Guayanilla Bay is an important port that supported large scale industrial (petrochemical) operations between the 1960s and 1980s, and still harbors two large thermoelectric power plants (i.e., Costa Sur and EcoEléctrica) and several smaller coastal industries. As with Ponce and Mayaguez Bays, the inner coral reefs have been severely impacted, but those at the outer shelf appear to be in better condition. The coral reefs off Guánica Bay are mostly associated with the bay's entrance and the shelf-edge. Inside the enclosed bay, conditions are estuarine and unfavorable for coral reef development.

Coastal Pollution

Most industrial discharges are connected to Regional Waste Water Treatment Plants (RWWTP), which are administered by the Puerto Rico Aqueducts and Sewers Authority (PRASA). Five RWWTPs discharge disinfected (chlorinated) primary-treated effluent via submarine outfalls to the marine environment in compliance with the Federal Clean Water Act, Section 301(h). These include the five RWWTPs of Carolina, Bayamón-Puerto Nuevo, Arecibo, Aguadilla and Ponce. The location of these outfalls is shown in Figure 5.9 and discussion of the results of monitoring activities at outfall sites can be found in the 'Water Quality' section of this chapter.

Another potentially relevant source of pollution to the coastal waters of Puerto Rico results from the operation of thermoelectric power plants as large volumes of seawater are used to cool the machinery. The plants of San Juan (in San Juan Bay), Palo Seco (in San Juan), Aguirre (in Jobos Bay, Guayama), and Costa Sur (in Guayanilla Bay) are administered by the Puerto Rico Power Authority, whereas the EcoEléctrica Power Plant is privately owned. The power plants of Aguirre and EcoEléctrica have seawater cooling towers and do not discharge heated effluents to coastal waters. All power plants have to comply with EPA-mandated demonstration studies in compliance with Federal Clean Water Act, Section 316(a) to evaluate the effect of thermal discharge upon marine communities, including zooplankton entrainment and impingement of small fishes and invertebrates. An initial evaluation of thermal and entrainment impact by the Costa Sur power plant in Jobos Bay was prepared by the Puerto Rico Nuclear Center (PRNC, 1972). Significant impacts of the thermal effluent upon mangrove root and seagrass communities were observed within the mangrove fringed coastal lagoon in the immediate vicinity of the thermal discharge, also known as the "thermal cove" (PRNC, 1972). Entrainment of zooplankton affected mostly estuarine populations of copepods and larval stages of benthic invertebrates and fishes. Taxonomic assessments of fishes and invertebrates entrained by the power plant were not provided in the study by the PRNC (1972). Coral reef systems located in the outer bay section were not directly affected by thermal pollution associated with thermoelectric power plant operations in Jobos Bay. Potential indirect effects of larval mortality and/or recruitment failure of reef organisms with mangrove-related developmental stages were not quantitatively evaluated.

As part of the environmental baseline studies for establishment of the EcoEléctrica power plant in Guayanilla Bay, García-Sais et al. (1995) studied the taxonomic composition and temporal abundance patterns of zooplankton, including ichthyoplankton in the vicinity of the proposed plant's intake and outfall structure locations in the bay. Clupeiform (including anchovies and sardines) and Gobioidei (mostly Gobiidae) larvae and other estuarine types were the numerically dominant assemblage of larval fishes and zooplankton present within the inner- and mid-sections of Guayanilla Bay. Coral reef fish larvae, including snapper (Lutjanidae) and grunts (Haemulidae), were collected from the deeper sections of the mid- and outer-bay shelf-edge, where a submarine canyon connects the inner-bay (estuarine) environment with the outer bay's fringing reefs and adjacent offshore waters. The information on larval reef fish distributions was pursued with the objective of locating intake structures in areas that would minimize entrainment of reef fish larvae. An EPA-mandated monitoring program of reef benthic populations and zooplankton entrainment is ongoing in Guayanilla Bay.

Tourism and Recreation

The effect of tourism activities upon coral reef systems in Puerto Rico is not well known. According to the Puerto Rico Tourism Company (PRT, 2002), a total of 2.5 million rooms in hotels and "paradores" were occupied throughout the island during 2001-2002. The total room occupancy maintained a gradually increasing rate from 1992 to 2000 (1.08-2.63 million), and then declined slightly (2.51 million) during 2001 (Figure 5.4). Approximately 58% of the total room occupancy has been concentrated within the San Juan metropolitan area, where coral reefs do not occur. However, tourists staying in San Juan often travel to the northeast, south and southwest coasts to participate in scuba diving charters and other marine recreation activities. There is a generalized perception that passive recreational diving has minimal impact

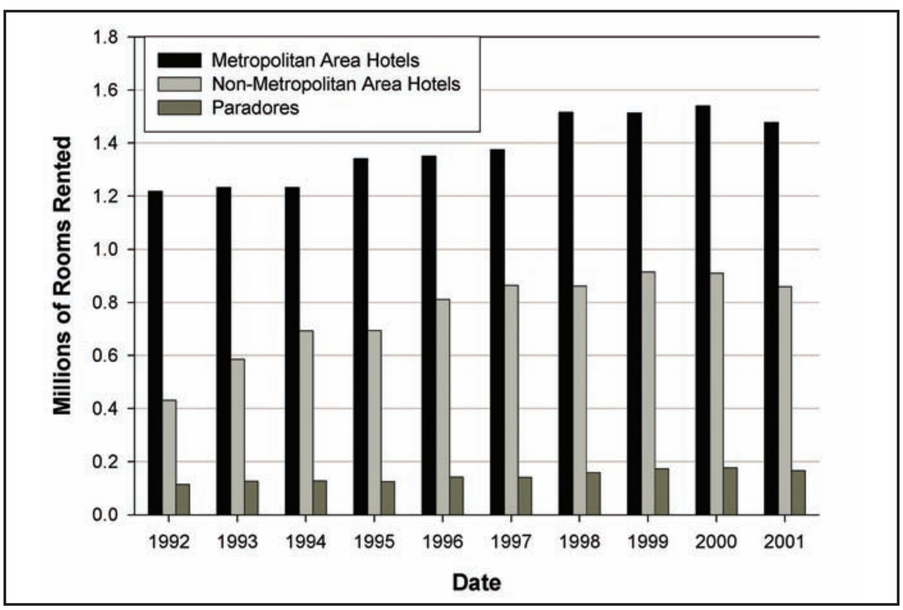

Figure 5.4. Annual occupancy rates for hotels and paradores in Puerto Rico from 1992-2001. Source: Puerto Rico Tourism Company, 2002.

upon coral reef systems. The diving charter industry is at the forefront in terms of coral reef protection policies and is active and highly visible in many activities organized for coral reef protection. In most instances, diving charters do not allow spearfishing during diving expeditions and emphasize coral reef protection. The effect of anchoring by relatively large diving vessels was a problem that has been significantly improved by the installation of mooring buoys by the DNER in the most heavily visited dive sites.

One of the main concerns regarding the ecological health of coral reefs in Puerto Rico is the unknown recreational carrying capacity of these systems. There has been an increasing trend of utilization of coastal resources by local and non-local tourists without consideration of the maximum level of resource utilization that the system can withstand. Between 1996-2003, the total number of boats registered in Puerto Rico increased almost 28%, from 44,050 units in 1996 to 60,911 units in 2003 (Figure 5.5). Coral reef areas are favorite destinations for recreational boat users because of the protected waters they create on the leeward side of reefs. For example, on holidays, over 200 boats can be anchored on a small reef in La Parguera. Concerns over reef health include many activities that are usually undocumented, such as the extra fishing pressure, damage of corals and seagrass during anchoring and propeller groundings, trampling on corals and seagrass during snorkeling activities, and the contamination of the water by garbage, engine fuel, and other substances.

There is a critical need to establish a maximum capacity of boats allowed per reef and orientation guidelines for best utilization of reef resources, including illustrative presentations of the underwater life and prepared underwater trails for recreational snorkeling that minimize damage and optimize resource utilization (García-Sais and Sabater, 2004).

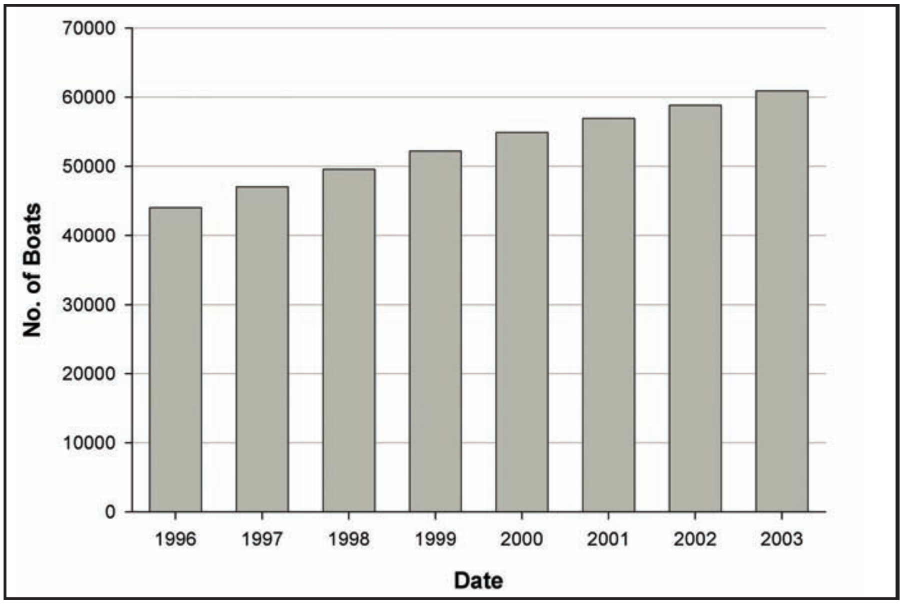

Figure 5.5. Number of boats registered in Puerto Rico between 1996 and 2003. Source: Matos-Caraballo et al., 2002.

Fishing

Reef fish are under intense pressure in Puerto Rico from a variety of user groups, including commercial fishers, recreational anglers, as well as ornamental organism collectors and exporters. Reef fisheries have plummeted during the last two decades and show the classic signs of overfishing: reduced total landings, declining catch per unit effort (CPUE), shifts to smaller fish, and recruitment failures. Commercial fish landings reported between 1979 and 1990 fell by 69% (Appeldoorn et al., 1992).

The latest commercial fishery census (Matos-Caraballo, 2002) reported 1,163 commercial fishers in Puerto Rico for 2002, a reduction of 38% since 1982 (Figure 5.6). The 2002 commercial fisheries data includes 956 fishing vessels, 10,372 fish traps,

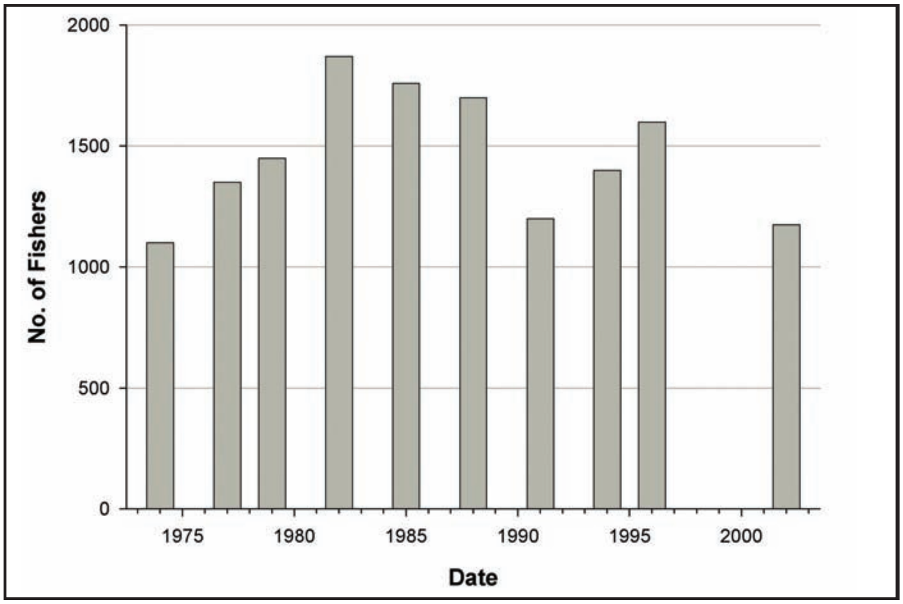

Figure 5.6. Number of active fishers in Puerto Rico since 1974. Source: Matos-Caraballo, 2004.

2,774 lobster pots, 147 beach seines, 993 gill nets, 391 trammel nets, 1,267 cast nets and 12,310 fishing lines of different types. Among the different fishing techniques, 385 fishers practice skin diving and 225 practice scuba diving. An average of 3.07 million pounds of fish and shellfish per year were captured from 2001-2003 by the commercial fishery (Matos-Caraballo, 2004). Yellowtail, silk, lane, and mutton snapper were the four main species, collectively representing 32.2% of the total fish catch between 2001 and 2003 (Table 5.1). Landings of conch and lobster averaged approximately 574,000 pounds between 2001-2003, or 18.7% of the total commercial fisheries landings.

Reef associated fisheries represented 82% of the total commercial landings between 2001 and 2003, whereas deep water snappers (silk, queen, wenchman) and groupers (misty) represented 11.3% of the total catch. Large pelagic species, including dolphinfish, tunas, and wahoo, were 6.6% of the total landings. Between 2001 and 2003 notable catch reductions were observed for most reef fishes, particularly for mutton and yellowfin snappers which declined 72.6% and 46.3%, respectively (Table 5.1). The catch of silk snapper also declined markedly, from 291,722 pounds in 2001 to 169,826 pounds in 2003.

Until 2000, the only fishery statistics available in Puerto Rico relied on data collected by the commercial fishing industry. In January of 2000, NOAA Fisheries' Marine Recreational Fisheries Statistics Survey (MRFSS) reinitiated data collection in Puerto Rico, and has greatly increased the understanding of recreational fishing pressure on reef fish populations (Lilyestrom and Hoffmaster, 2002). On average, the angler population is comprised of approximately 200,000 residents and 40,000 non-residents.

Table 5.1. Total reported commercial fisheries landings (in lbs.) by species in Puerto Rico during 2001-2003. Source: Matos-Caraballo, 2004.

COMMON NAME	CATEGORY	2001	2002	2003	MEAN
Yellowtail snapper	Reef	328,998	291,024	176,569	265,530
Silk snapper	Slope	291,722	198,028	169,826	219,859
Lane snapper	Reef	186,225	184,630	123,150	164,668
Mutton snapper	Reef	291,722	91,842	79,980	154,515
Grunts	Reef	156,641	147,100	107,566	137,102
Queen snapper	Slope	107,671	110,058	126,999	114,909
Cero mackerel	Reef	84,711	117,869	80,897	94,492
Dolphinfish	Oceanic	111,075	100,622	64,848	92,182
Parrotfishes	Reef	99,255	107,543	69,590	92,129
Trunkfishes	Reef	77,814	79,110	58,596	71,840
Red hind	Reef	69,098	81,206	48,045	66,116
Hogfish	Reef	68,843	68,578	55,957	64,459
Ballyhoo	Reef	60,905	68,045	41,094	56,681
Mullets	Reef	61,129	57,023	42,846	53,666
Triggerfishes	Reef	60,929	56,694	35,998	51,207
Bar jack	Reef	50,845	63,137	37,085	50,356
King mackerel	Reef	101,572	28,053	16,946	48,857
Unid. groupers	Reef	54,180	46,837	31,709	44,242
Barracudas	Reef	19,888	53,546	41,997	38,477
Sharks	Reef	45,169	38,437	25,210	36,272
Skipjack tuna	Oceanic	38,391	38,443	30,655	35,830
Rays	Reef	3,637	53,326	35,624	30,862
Unid. jacks	Reef	38,168	30,117	23,074	30,453
Blackfin tuna	Oceanic	25,286	27,107	34,196	28,863
Vermilion snapper	Reef	44,891	23,135	15,835	27,954
Unid. snappers	Reef	60,114	9,495	9,943	26,517
Yellowfin tuna	Oceanic	35,392	19,303	23,467	26,054
Porgies	Reef	37,031	24,558	11,276	24,288
Snooks	Reef	11,830	37,836	20,900	23,522
Mojarras	Reef	19,445	20,995	17,411	19,284
Sardines	Reef	25,398	28,053	16,946	19,062
Goatfishes	Reef	22,475	19,004	12,785	18,088
Unid. tunas	Oceanic	26,147	11,055	14,818	17,340
Nassau grouper	Reef	18,706	18,708	10,217	15,877
Little tunny	Reef	20,323	14,486	11,704	15,504
Coney	Reef	16,091	19,038	11,002	15,377
Squirrelfishes	Reef	18,313	16,086	10,701	15,033
Wenchman	Slope	7,731	6,197	7,233	7,054
Misty grouper	Slope	6,222	5,679	5,861	5,921
Horse-eye jack	Reef	6,607	4,823	4,188	5,206
Yellowfin grouper	Reef	3,708	6,916	4,893	5,172
Wahoo	Oceanic	8,344	1,095	2,012	3,817
Tarpon	Reef	2,193	4,421	2,436	3,016
Yellow jack	Reef	3,934	3,215	827	2,659
TOTAL FISHES		**2,887,686**	**2,689,338**	**1,921,936**	**2,499,653**
Lobster	Reef	285,018	300,753	242,583	276,118
Conch	Reef	328,467	235,608	188,020	250,698
Octopus	Reef	33,939	28,561	26,476	29,659
Other shellfish	Reef	14,241	12,092	8,127	11,487
Land crabs	Reef	6,322	6,460	1,619	4,800
TOTAL SHELLFISH		**671,338**	**583,474**	**466,825**	**573,879**
TOTAL LANDINGS		**3,559,024**	**3,272,812**	**2,388,761**	**3,073,532**

Total annual fishing trips varied from a high of 1,411,943 in 2001 to a low of 1,098,420 in 2002. Total angler participation dropped from 249,869 to 216,861 in 2003. Trends in the recreational fishery indicate a decline in the use of traps and nets due to their high costs and relatively low yield, and an increase in the use of lines and scuba gear. The largest percentage (58-64%) of recreational fishing trips were made by shoreline anglers. Private boat trips accounted for 35-40% of trips and the remainder (1-3%) was charter fishing trips. Reef fish comprised 16-29% of the total catch. Most of the reef fish were caught by private boat anglers. Total recreational catch from 2000 to 2002 varied between 4,601,748 lbs. and 2,413,878 lbs (Lilyestrom and Hoffmaster, 2002). Overall CPUE declined an average of 40% per year over this same period. As for the commercial fisheries landings, consistent declines were noted in the catch of lane snapper, mutton snapper and silk snapper.

In an effort to convert the collapsing fishery into one which will be sustainable over time, the DNER has enacted new fishing regulations which will require recreational fishing licenses, prohibit recreational spearfishing with scuba gear, eliminate beach seines within three years, establish size limits and daily quotas on several species, require species-specific permits for high-value and sensitive species (i.e., spiny lobsters, queen conch, and land crabs), and create MPAs around Mona, Monito, and Desecheo Islands and the Condado Lagoon, among other measures. Compatibility with Federal fisheries management measures has been achieved to a high degree with these regulations.

Trade in Coral and Live Reef Species

According to Sadovy (1992) export of marine organisms from Puerto Rico for the aquarium trade began in the early 1970s with approximately 50 species. From the available data, reef fishes and motile megabenthic invertebrates comprise the bulk of the aquarium trade. The most commonly captured and exported fish species is the royal gramma (*Gramma loreto*), followed by yellowhead jawfish, blue chromis, redlip blenny and rock beauty, although over 100 species have historically been exported (Mote Environmental Services, Inc., 2002). Table 5.2 presents a list of the main fish and invertebrate species in the aquarium trade in Puerto Rico. There are approximately 12 ornamental organism collectors in Puerto Rico, and three main exporters who exported over 37,000 royal gramma and over 8,400 yellowhead jawfish between 1998 and 2000.

Approximately 113 marine invertebrates have also been historically exported, with the top five species in terms of numbers exported being *Condylactis* spp. anemones, blue legged hermit crabs, feather dusters, serpent stars and turbo snails. A total of 7,500 blue legged hermit crabs and 3,600 *Condylactis*

Table 5.2. Reef fish and invertebrate species exported in largest quantities from Puerto Rico for the aquarium trade during 1998-2000. Source: LeGore and Associates, 2002.

FISHES	
Common Name	**Species**
Royal gramma	*Gramma loreto*
Yellowhead jawfish	*Opistognathus aurifrons*
Blue chromis	*Chromis cyanea*
Redlip blenny	*Ophioblennius atlanticus*
Rock beauty	*Holacanthus tricolor*
Greenbanded goby	*Gobiosoma multifasciatum*
Blue tang	*Acanthurus coeruleus*
Horned blenny	*Hysoblennius exstochilus*
Bluehead wrasse	*Thalassoma bifasciatum*
Pygmy angelfish	*Centropyge argi*
Spanish hogfish	*Bodianus rufus*
Flame cardinal	*Apogon maculatus*
Redtail trigger	*Xantichthys ringens*
French angelfish	*Pomacanthus paru*
Neon wrasse	*Halichoeres garnoti*
INVERTEBRATES	
Blue leg hermit crab	
Pink tip anemone	
Turbo snail	
Serpent starfish	
Feather duster worm	
Rock anemone	
Curly cue anemone	
Flame scallop	
Sea cucumber	

spp. were exported in the first five months of 2002. In addition to the quantified exports, there are unquantified sales to local aquarium shops and private collections for home aquariums. Efforts are underway to estimate the number of private marine ornamental organism collectors in Puerto Rico through the MRFSS telephone survey. A proposal has been submitted to provide a stock assessment and design management strategies for aquarium trade target species in Puerto Rico (Le Gore and Associates, 2002).

Ships, Boats, and Groundings

Since 2001 there have been seven reported ship groundings off Puerto Rico and the associated islands involving substantial coral reef injuries as well as a number of additional unreported incidents. Relatively few of these involved significant restoration efforts, although local scientists and volunteers have performed coral rescue operations to stabilize broken coral. The largest effort was undertaken in Vieques after a ferry grounding in November 2002, which involved reattachment of over 100 coral fragments using cement.

One of the largest restoration efforts undertaken in Puerto Rico to date is in response to the *M/V Fortuna Reefer* ship grounding. On July 24, 1997, the *Fortuna Reefer* ran aground on a fringing reef located off the southeast coast of Mona Island (18°02'N; 67°51'W), 65 km from Puerto Rico. The 326-foot freighter remained grounded for eight days within the island's largest remaining elkhorn coral (*Acropora palmata*) stand.

The grounding and subsequent removal of the *Fortuna Reefer* impacted 6.8 acres of shallow forereef. The reef substrate was crushed and fractured, and entire colonies of *A. palmata* and *D. strigosa* were dislodged and fractured along the direct path of the vessel, and hundreds of additional *A. palmata* branches were sheared off by the cables used to remove the vessel. Coral fragments (n=1,857) were reattached to the reef substrate or standing dead colonies using wire within three months of the grounding, and fragment survivorship and patterns of recovery have been monitored twice per year since 1999. More than half (57%) of the fragments were alive two years after the restoration effort, while the remainder died (26%) or were detached and removed from the site (17%; Bruckner and Bruckner, 2001).

Six years after the restoration, 20.3% (377) of the restored fragments were living (Figure 5.7). Many of these (58%) had produced new branches and 30% (114) had reattached to the substrate. Fragments had an average of 60% live tissue, although 33% had little or no mortality and 22% showed signs of re-sheeting over previously denuded skeleton. Each fragment had developed an average of four new 21 cm branches (maximum of 30 branches, up to 73 cm long per fragment), and branching patterns had the typical tree-like morphology seen on adult colonies. The most significant sources of mortality include overgrowth by boring *Cliona* spp. sponges, predation by *Coralliophila abbreviata* gastropods, and WBD, with partial mortality associated with algal interactions (primarily *Dictyota* and *Halimeda* spp.) and damselfish (*Stegastes planifrons*) algal lawns (Figure 5.8). In 2003, an outbreak of WBD affected 15% of the standing colonies within the grounding site and surrounding area, with a lower prevalence (4%) among restored colonies.

Reef fish communities appear to be recovering within the *Fortuna Reefer* grounding site, with an increase in abundance, species richness and diversity over the last four years. Mean fish abundance per transect (total area 60 m^2) has increased from 13.9 (± 5.17 standard error [SE]) to

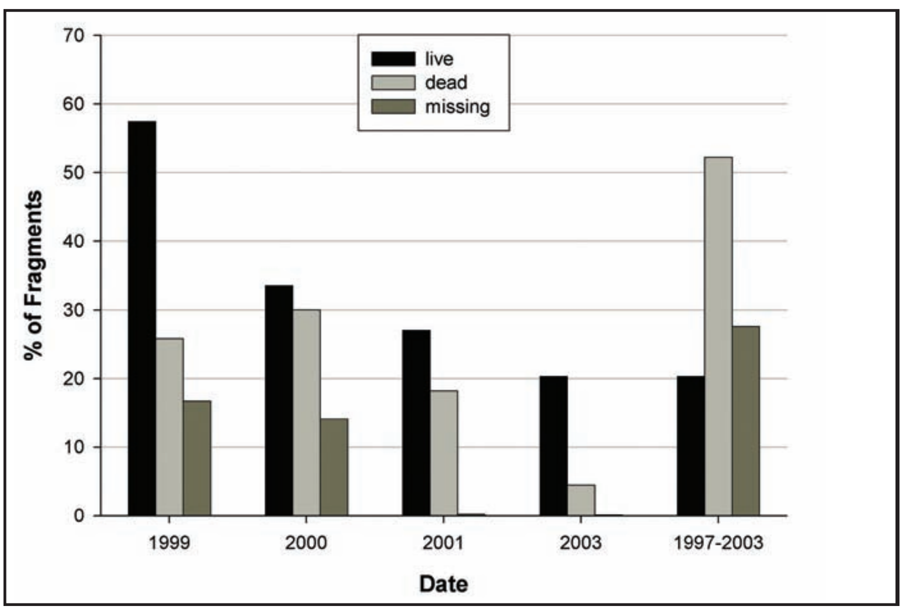

Figure 5.7. Status of restored fragments at the *Fortuna Reefer* site. Source: Bruckner and Bruckner, in press.

32.3 (± 4.8 SE) and the number of species has increased from 2.5 (± 0.54 SE) to 7.3 (± 0.332 SE). While the number of species per transect is similar inside and outside the grounding site, abundance outside of the site is nearly three times as high (mean=90.6). This difference in abundance may be due in part to the presence of large schools of acanthurids observed outside the grounding area.

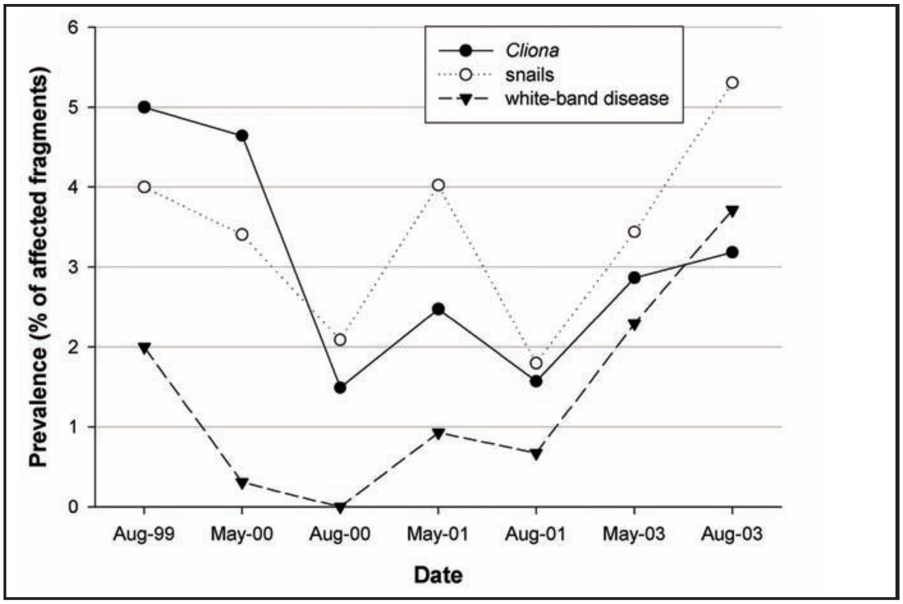

Figure 5.8. Sources of fragment mortality at the *Fortuna Reefer* site. Source: Bruckner and Bruckner, in press.

Marine Debris

Marine debris is has not been reported to be a significant problem affecting Puertorrican reefs.

Aquatic Invasive Species

A number of freshwater non-native/invasive/alien species have been introduced into Puerto Rico (Bunkley-Williams and Williams, 1994; Bunkley-Williams et al., 1994; Williams and Sindermann, 1992; Williams et al., 2001b). The Mozambique tilapia, *Oreochromis mossambicus* (Cichlidae), dominates in local brackish waters, but has not invaded coral reef areas. This species is known to utilize coral reefs in the Pacific and the reasons for its current limited distribution in the Caribbean are not known (Williams and Bunkley-Williams, unpublished data). The introduced jellyfish, purple sea mane (*Drymonema dalmatinum*) experienced a major population explosion in Puerto Rico in 1999 (Williams et al., 2001a) and a minor one in the Virgin Islands in 2003 (Williams and Bunkley-Williams, unpublished data). These outbreaks are not known to have caused much damage, but the potential for greater problems exists.

Williams and Bunkley-Williams (1990b; 2000) suggested that the 1983-1984 mass mortalities of the black long-spined sea urchin, *Diadema antillarum* Phillipi (Echinometridae), and later die-offs (Williams et al., 1991) were caused by a virus introduced from the Pacific region. These events changed the ecology of the reefs throughout the region, and neither the urchins nor the reefs have ever recovered. In addition, Juste and Cortés (1990) reported the presence of non-native clams including southern quahog (*Mercenaria campechiensis*), northern quahog (*M. mercenaria* and *M. mercenaria notata)* from five localities around Puerto Rico. The non-native clams are not considered a major threat to coral reefs.

Whitfield et al. (2002) reported red lionfish, *Pterois volitans* (Scorpaenidae) established along the Atlantic coast of the U.S. and in Bermuda. This species was recently observed in Puerto Rico (Williams et al., unpublished data), but it is not known if a reproductively viable population has been established. Widespread rumors of the escape and establishment of Indo-Pacific clownfishes (Pomacentridae) in Puertorrican waters (Williams et al., 1994a) are unconfirmed.

Williams et al. (1994a) suggested that the euryhaline leech, *Myzobdella lugubris* (Rhynchobdellida: Piscicolidae) was introduced from the continental U.S. to eastern Puerto Rico along with mariculture animals. It also occurs in western Puerto Rico (Williams and Bunkley-Williams, unpublished data).

Security Training Activities

The islands of Vieques, Culebra, and Desecheo have served as training ranges for the U.S. Navy since the 1940s. There is no published information regarding the impact of such training activities in Culebra and Desecheo Islands. Rogers et al. (1978) reported severe destruction of coral reefs in Vieques Island caused by bombing activities during military training. For the last two decades, there have been no reliable monitoring records for Vieques' easternmost coral reefs, although 8% to 50% declines in coral cover from coral reefs located within maneuver areas in Vieques have been reported (Antonius and Weiner, 1982). Decline in coral cover has been attributed to hurricanes, concluding that the impact of bombing in the coral reef was negligible (Antonius and Weiner, 1982). Unfortunately, deep reef sections that are typically unaffected by hurricanes have not been included in the assessment of bombing effects. Efforts to include the coral reef systems within the shooting range of eastern Vieques as part of the National Coral Reef Monitoring Program of NOAA have not been successful to date. However, a large biological baseline data set is now available for 11 reefs outside the shooting range in Vieques (García-Sais et al., 2001d).

Offshore Oil and Gas Exploration

There are currently no offshore oil and gas exploration activities occurring in Puerto Rico.

CORAL REEF ECOSYSTEMS- DATA GATHERING ACTIVITIES AND RESOURCE CONDITION

Puertorrican coral reefs were initially described in terms of their taxonomic composition by Almy and Carrión-Torres (1963). This initial survey identified a total of 35 species of scleractinian corals from La Parguera, on the southwest coast of Puerto Rico. Later surveys were reported by Rogers et al. (1978), Armstrong (1980), Goenaga and Boulon (1991), Hernandez-Delgado (1992, 1994a,b), and Hernandez-Delgado and Alicea-Rodriguez (1993a,b).

Goenaga and Cintrón (1979) prepared the first geographical inventory of Puertorrican reefs. This work, along with subsequent qualitative surveys of reef geomorphology and community structure (Cintrón et al., 1975; Canals and Ferrer, 1980; Canals et al., 1983), established criteria for designation of marine areas with coral reef development as natural reserves by the government of Puerto Rico.

During the last decade, coral reef research in Puerto Rico has largely focused on community characterization and monitoring programs, benthic habitat mapping, marine reserve feasibility studies, environmental impact assessments, coral diseases, and mitigation programs. As part of the U.S. Coral Reef Initiative Program for Puerto Rico (NOAA), a series of coral reefs located in natural reserves were recently selected as priority sites for characterization and monitoring programs. Other initiatives have included characterization efforts in support of the coral reef systems occurring within the Rio Espiritu Santo Natural Reserve (Hernández-Delgado,1995), Isla de Mona Natural Reserve (Canals et al.,1983; Hernández-Delgado, 1994a) and La Cordillera de Fajardo Natural Reserve (Hernández-Delgado, 1994b).

The purpose and priorities of the Coral Reef Monitoring Program for Puerto Rico were initially presented by the DNER to NOAA's U.S. Island Coral Reef Initiative in 1997. The main objectives of the program were to map the spatial distribution of coral reefs, produce a baseline characterization of priority reef sites and establish a monitoring program targeting selected high-priority reef sites. The monitoring program would provide information needed for effective resource management and public awareness, while contributing to a scientific database for long-term analysis of the coral reefs in natural reserves of Puerto Rico.

The DNER has identified the natural reserves of Mayaguez Bay, Desecheo Island, Rincón, La Parguera, Bahía de Jobos, Ponce Bay, Cordillera de Fajardo and the islands of Culebra and Vieques as high-priority monitoring sites. Baseline characterizations for these reef systems were prepared by García-Sais et al. (2001 a, b, c, d). The baseline characterization and monitoring for the Culebra Marine Reserve was prepared by Hernández-Delgado (2003). The baseline characterization of the newly-established MPA at Tres Palmas Reef in Rincón is ongoing. This report includes monitoring data from a total of 12 reef sites under the U. S. Coral Reef Monitoring Program funded by NOAA and two additional reef sites monitored since 1999 as part of EPA's 301(h) studies associated with operations of the submarine outfalls of the RWWTPs at Arecibo and Aguadilla, on the north and northeast coasts, respectively. La Parguera, on the southwest coast of the island, is the monitoring site within Puerto Rico for the Caribbean Coastal Marine Productivity Program (CARICOMP). The CARICOMP data base is available on-line at http://www.caricomp.com.

Additional quantitative and qualitative characterizations of reef communities were included as part of environmental impact studies related to the submarine outfall discharges of RWWTPs of PRASA from 11 sites around Puerto Rico (Figure 5.9; García-Sais et al., 1985). Other characterizations of coral reef communities were performed in relation to operations of thermoelectric power plants with thermal outfalls in Jobos Bay (Szmant-Froelich,1973), San Juan Bay (García-Sais and Castro,1995), and Guayanilla Bay (Castro and García-Sais,1996; García-Sais and Castro,1998). Table 5.3 provides a list of reef sites for which quantitative baseline characterizations were performed, along with geographic references and depths. Mass mortalities of corals and related reef organisms have also received research attention in Puerto Rico. Vicente and Goenaga (1984) reported on the mass mortality of the black sea-urchin, *Diadema antillarum*, around the coastline of Puerto Rico and provided a general description of dying specimens from direct observations in the field. A series of reports of massive coral bleaching in the waters of Puerto Rico were produced in the late 1980s (Bunkley-Williams and Williams, 1987; Williams and Bunkley-Williams, 1989; Goenaga et al., 1989; Williams and Bunkley-Williams, 1990a,b). These studies highlighted the permanent damage of the bleaching phenomena on reef corals and associated the periodic bleaching events to elevated SSTs.

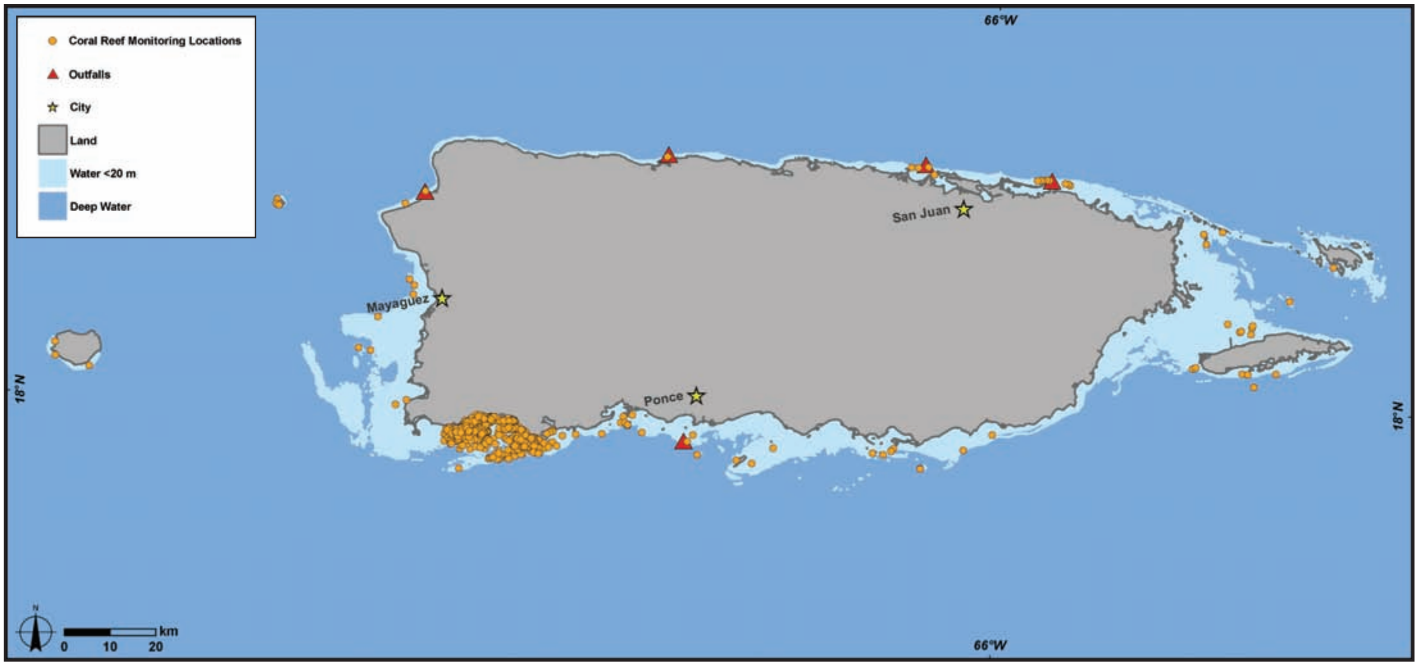

Figure 5.9. Coral reef monitoring sites around Puerto Rico. Map: A. Shapiro. Source: Garcia-Sais, pers. obs.; CCMA-BT, unpublished data.

Table 5.3. Geographic references, dates, and depths of reef habitats surveyed during baseline characterization and monitoring programs. Source: Garcia-Sais, pers. obs.

	DATES		GEOGRAPHIC REFERENCES		
REEF - SITE	**Baseline**	**Monitoring**	**Latitude**	**Longitude**	**DEPTH (m)**
Bajíos - SJ	1994	none	18° 27.900' N	066° 07.800' W	6.7
Guayanilla - GY	1995	none	17° 58.600' N	066° 45.800' W	3.6-5.5
Caja de Muertos 1 - PON	May-99	2001	17° 53.341'N	066° 29.810' W	9.1
Boca Vieja - SJ	93-94	none	18° 28.700' N	066° 09.800' W	6
Río - TAY	1995	none	17° 58.800' N	066° 44.700' W	3
Unitas - GY	1995	none	17° 57.900' N	066° 46.100' W	10.6
Media Luna - MAY	Jun-99	2001	18° 06.079' N	067° 18.731' W	10.6
Caribe 1 - JOB	Sep-96	none	17° 55.400' N	66° 12.300' W	4.0-6.0
Manchas Grandes- MAY	1997	none	18° 12.500' N	067° 12.100' W	10
Berberia - PON	May-99	2001	17° 55.190' N	066° 27.190' W	7.6
La Barca - JOB	Sep-96	2001	17° 54.635' N	066° 13.564' W	10
Manchas Ext. 2 - MAY	1997	none	18° 14.300' N	067° 12.600' W	10
Caribe 2 - JOB	Sep-96	2001	17° 55.094' N	66° 12.595' W	10
Caja de Muertos 2 - PON	May-99	2001	17° 53.701' N	066° 31.703' W	7.6
Cayo Coral - GUA	Jun-99	2001	17° 56.173' N	066° 53.303' W	7.6
Pta. Maguey - CUL	n/d	none	18° 17.600' N	065° 18.100' W	5.0-6.0
Manchas Int 2 - MAY	1997	none	18° 13.600' N	067° 12.000' W	10
Pta. Ventana 2 - GY	Jun-99	2001	17° 56.500' N	066° 48.400' W	12
Las Coronas - MAY	Jun-99	2001	18° 05.836' N	067° 17.225' W	10
Pta. Ballena - GUA	Jun-99	2001	17° 56.380' N	066° 51.633' W	10
Fanduco - GY	1995	none	17° 57.900' N	066° 45.600' W	6.1
Isla Palominitos - FAJ	Jul-99	none	18° 20.142' N	065° 33.944' W	10.6 - 7.6
Cayo Diablo - FAJ	Jul-99	2001	18° 21.602' N	065° 31.942' W	10.6
Media Luna - LP	1996	none	17° 56.200' N	067° 03.200' W	10
Turrumote - LP	1996	none	17° 56.100' N	067° 01.100' W	10
Tourmaline - MAY	Jun-99	2001	18° 09.794' N	067° 16.418' W	10.6
Pta. Maguey - CUL	n/d	none	18° 17.600' N	065° 18.100' W	5.0-6.0
Manchas Int 2 - MAY	1997	none	18° 13.600' N	067° 12.000' W	10
Isla Palomino - FAJ	Jul-99	2001	18° 21.333' N	065° 34.267' W	10.6
North Reef - DES	Jun-00	2001	18 ° 23.416' N	067° 29.229' W	11
Pto. Botes - DES	Jun-00	2001	18° 22.895' N	067° 29.316' W	17

Table 5.3, (continued). Geographic references, dates, and depths of reef habitats surveyed during baseline characterization and monitoring programs. Source: Garcia-Sais, pers. obs.

	DATES		GEOGRAPHIC REFERENCES		
REEF - SITE	Baseline	Monitoring	Latitude	Longitude	DEPTH (m)
Pto. Canoas - DES	Jun-00	2001	18° 22.699' N	067° 29.026' W	18
El Palo - CRO	May-00	2001	18° 00.034' N	067° 12.670' W	3
Resuellos - CRO	May-00	2001	17° 59.470' N	067° 13.987' W	8.2
South of Margarita Reef - LP	May-00	none	17° 52.068' N	067° 06.017' W	8.2
La Boya (Shelf edge) - LP	May-00	none	17° 53.304' N	066° 59.877' W	18.1
South of Turrumote - LP	Jul-00	none	17° 53.949' N	067° 01.108' W	13
Arrecife Las Mujeres - MON	Jun-00	none	18° 04.302' N	067° 56.215' W	18
Pajaros - MON	Jun-00	none	18° 03.168' N	067° 51.995' W	13.6
Carmelitas - MON	Jun-00	none	18° 05.923' N	067° 56.300' W	8.5
Boya 2 - PON	Aug-01	none	17° 55.815' N	066°37.814' W	16.1
Bajo Derrumbadero - PON	Aug-01	none	17° 54.237' N	066° 36.516' W	16.7
Bajo Tasmania - PON	Aug-01	none	17° 56.564' N	066° 37.147' W	9.1
Maria Langa Veril 50' - GY	Aug-01	none	17° 57.563' N	066° 45.255' W	15.2
Maria Langa 30' - GY	Aug-01	none	17° 57.630' N	066° 45.256' W	10
Tallaboa 35' - GY	Aug-01	none	17° 56.759' N	066° 43.480' W	10.6
Las Mareas 55' - GMA	Sep-01	none	17° 53.093' N	066° 08.956' W	16.7
Las Mareas 70' - GMA	Sep-01	none	17° 53.057' N	066° 08.947' W	21.2
Cayos de Barca 35' - GMA	Sep-01	none	17° 54.830' N	066° 14.866' W	10.6
Arrecife Guayama 45' - ARO	Sep-01	none	17° 55.353' N	066° 03.675' W	13.6
Punta Guilarte Shoal 33' - ARO	Sep-01	none	17° 57.219' N	066° 00.112' W	10
West Caballo Blanco - VIE	May-01	2004	18° 10.297' N	065° 28.126' W	4.5
Arrecife Mosquito - VIE	May-01	2004	18° 09.804' N	065° 29.632' W	10.6
Arrecife Comandante - VIE	May-01	none	18° 09.465' N	065° 28.227' W	5.5
Boya 6 - VIE	May-01	none	18° 10.711 N	065° 31.148' W	10.6
Arrecife Coronas - VIE	May-01	2004	18° 09.896' N	065° 29.454' W	10.6
North Caballo Blanco - VIE	May-01	none	18° 10.563' N	065° 28.029' W	3
Black Jack - VIE	May-01	2004	18° 03.319' N	065° 27.794' W	30.3
Canjilones Reef - VIE	Feb-01	2004	18° 05.380' N	065° 35.413' W	15.2
Puerto Ferro Reef - VIE	Feb-01	none	18° 04.845' N	065° 25.057' W	12
Pirata Reef - VIE	Feb-01	2004	18° 05.512' N	065° 35.011, W	15.2
Boya Esperanza Reef - VIE	Feb-01	2004	18° 04.832' N	065° 29.277' W	9.1
Capitan Reef - VIE	May-01	none	18° 04.766' N	065° 28.572' W	13
Bajo Holiday - VIE	May-01	none	18° 13.500' N	065° 23.500' W	18.2
Arecibo - AA1	Oct-99	2000-2004	18° 29.478' N	066° 40.878' W	16.1
Arecibo - AA2	Oct-99	2000-2004	18° 29.460' N	066° 40.974' W	21.2
Aguadilla - AGS2	Oct-99	2000-2004	18° 24.780' N	067° 10.878' W	13.9
Aguadilla - AGS3	Oct-99	2000-2004	18° 23.256' N	067° 13.350' W	10.9
Bayamon - B15	1999	2000-2004	18° 28.728' N	066° 10.632' W	11.5
Bayamon - B14	1999	2000-2004	18° 28.788' N	066° 08.538' W	11.5
Carolina - CC3	1999	2000-2004	18° 26.892' N	065° 50.934' W	9.1
Carolina - CC4	1999	2000-2004	18° 27.018' N	065° 51.156' W	9.7
Carolina - CC5	1999	2000-2004	18° 27.078' N	065° 51.534 ' W	9.7
Carolina - CC6	1999	2000-2004	18° 27.426' N	065° 53.514' W	7.3
Carolina - CC7	1999	2000-2004	18° 27.468' N	065° 53.826' W	10.3
Carolina - CC8	1999	2000-2004	18° 27.432' N	065° 54.294' W	10.3
Carolina - CC9	1999	2000-2004	18° 27.426' N	065° 54.552' W	10
Carolina - CC10	1999	2000-2004	18° 27.402' N	065° 55.002' W	9.7

WATER QUALITY

Water quality monitoring is conducted by several organizations in Puerto Rico and is under the official purview of the DNER. Most of its monitoring data were not available for inclusion in this report, but the data should be analyzed and incorporated in the next reporting effort.

Data analyzed in this section primarily comes from monitoring of industrial discharges associated with RWWTPs administered by PRASA. Five RWWTPs discharge disinfected (chlorinated) primary-treated effluent via submarine outfalls to the marine environment under EPA 301(h) waiver compliance programs. These include the RWWTPs of Carolina, Bayamón-Puerto Nuevo, Arecibo, Aguadilla, and Ponce, as shown in Figure 5.9.

Methods

Water quality monitoring of the effluent and receiving waters has been in effect for all of the above mentioned RWWTPs since 1999. The receiving water monitoring program analyzes of 171 water and sediment chemistry parameters including nutrients, suspended sediments, trace metals, pesticides, and bacteriology (CSA/CH2MHILL, 1999). Sampling is performed quarterly or biannually within the discharge zone, at one reference station, and at upstream and downstream far-field stations. Water samples are taken at 10%, 50% and 90% of the total station depth. Supporting data on ocean currents and biological assessments of infaunal and epibenthic invertebrates, fish, and coral reef communities are also included as part of the 301(h) monitoring programs for receiving waters of the RWWTPs (CSA/CH2MHILL, 1999). Secondary treatment plants discharge via submarine outfalls in the vicinity of Humacao, Barceloneta, Manatí, and Mayaguez Bay. All of the submarine outfalls discharging disinfected primary-treated effluent are located in the immediate vicinity of a large river.

Results and Discussion

In general, sediment and nutrient loading to the marine environment by RWWTPs submarine outfalls represents a small fraction of the river discharge. For example, the mean loading of total suspended solids (TSS) by the Aguadilla RWWTP submarine outfall from 2000 to 2002 was approximately 1.35% of the Culebrinas River loading for the same period (Table 5.4). Likewise, dissolved inorganic nitrogen (DIN) and total phosphorus (TP) loading by the RWWTP was 0.5% and 1.49% of the loading by the Culebrinas River, respectively. In terms of fecal coliform contamination of coastal waters, the RWWTP input was less than 1% (<0.1%) of the Culebrinas River input to Aguadilla Bay (Table 5.4). A similar pattern has emerged for other submarine outfalls in the north coast of Puerto Rico (CSA/CH2MHILL, 2000-2003), suggesting that rivers still represent the main pathways of sediment, bacteria and nutrient loading into Puerto Rico's coastal waters.

Table 5.4. Total suspended sediment (TSS), nutrient, and bacterial loadings from the Aguadilla RWWTP outfall, and the Culebrinas River into the coastal waters of Aguadilla. Source: CH2MHILL, 2000-2003; USGS hydrological data, http://waterdata.usgs.gov/nwis.

PARAMETER	2000		2001		2002		MEAN	
	RWWTP	River	RWWTP	River	RWWTP	River	**RWWTP**	**River**
Total Suspended Solids (10^6 kg/yr)	1.328	99.52	0.84	46.07	0.259	34.4	**0.81**	**60**
$NO_2 + NO_3 - N$ (10^6 g/yr)	0.67	250.54	0.69	219.59	1.07	207.61	**0.81**	**225.91**
Dissolved Inorganic N (DIN) (10^6 g/yr)	0.71	258.19	1.26	235.05	1.69	219.53	**1.22**	**237.59**
Total Phosphorus (TP) (10^6 g/yr)	0.38	60.59	0.81	42.33	0.93	39.77	**0.71**	**47.56**
Fecal Coliforms (10^{12} col./yr)	273.5	52505	15.05	44690	1.43	110549	**96.66**	**69.23**

BENTHIC HABITATS

U.S. National Coral Reef Monitoring Program in Puerto Rico

Methods

Quantitative assessments of sessile-benthic reef communities were performed on at least 79 reefs around Puerto Rico between 1985 and 2003 (Table 5.5). Scientists utilized various techniques to collect information on the percent cover by reef substrate (sessile-benthic) categories, including: continuous measurements along 10 m linear transects using chain links (CARICOMP, 1996), video-transects (CSA/CH2MHill, 1999), and 1 m^2 standard quadrat techniques (CSA/CH2MHill, 1999). Data on reef community structure and coral taxonomic composition were separated into three relative depth strata: shallow (1-5 m), intermediate (6-14 m) and deep (15-25 m), representing different reef types and physiographic zones within each reef. Mean percent substrate cover was calculated from replicate line transects or quadrat surveys (n=4 or 5) for each reef.

Results and Discussion

Percent cover by sessile-benthic substrate categories at shallow reefs (1-5 m) is presented in Figure 5.10. Benthic algae was the dominant substrate type in terms of percent cover in seven of the nine shallow reefs surveyed, ranging in substrate cover between a minimum of 31.8% at Algodones Reef in Naguabo, and a maximum of 82.1% at Punta Bandera Reef in Luquillo (García-Sais et al., 2003). The mean cover of algae on shallow reefs was 65%. Live coral at shallow reefs varied between a maximum of 48.9% at Algodones Reef and a minimum of 3.7% at Punta Bandera Reef (Figure 5.10). Mean live coral cover was 15.5%. The two shallow reefs with live coral cover of 20% or higher were both from the southeast coast (Algodones and Punta Fraile), whereas reefs with live coral cover below 10% were all from the northeast coast, including Vieques Island. The taxonomic composition of stony corals at shallow reefs was characterized by a mixed assemblage of species (Figure 5.11). Between four and 10 species of corals were intercepted on linear transects at each reef. The *Porites astreoides, P. porites, Siderastrea radians,* and *S. siderea* assemblage represented more than 50% of the total coral cover at shallow reefs surveyed. *Porites astreoides* and *Siderastrea radians* were present at all reefs surveyed in the 1-5 m depth range. Other common taxa included *Diploria* spp. and the hydrocorals, *Millepora* spp. The encrusting octocoral, *Erythropodium caribaeorum*, was present in five of eight reefs surveyed, with maximum cover (44%) at Gallito Beach Reef in Vieques. Zoanthids, particularly the encrusting, colonial form *Palythoa* spp., and sponges were the other main biotic components of the shallow reef benthos. Abiotic cover (sand, holes, overhangs, etc.) averaged 8% at shallow reefs (García-Sais et al., 2003).

In the intermediate depth range (6-14 m), live coral cover varied from 0.6% to 51.9% at surveyed reefs (n=52). Mainland reefs from the north and northeast coastlines (Mameyal, Bajíos, Morrillos, Boca Vieja and Cerro Gordo) contained very low coral cover (<5%) (Figure 5.10). Las Cabezas Reef in Fajardo was the only mainland reef from the northeast coastline with live coral cover above 10%, ranking 19th among reefs studied at intermediate depths. Hard ground and rock reef communities of the north coast are subject to very strong wave action and heavy loads of sediment from large river plumes. Reefs from the south coast located close to shore in Ponce Bay (e.g., Hojitas) and Guayanilla Bay (e.g., Guayanilla, Cayo Río, Cayo Unitas) also exhibited very low live coral cover (<5%). These are inshore coral reefs in an advanced state of degradation. An increasing pattern of live coral cover associated with distance from shore was observed in Mayaguez Bay, where a series of dead coral reef structures, such as Algarrobo Reef and other submerged patch reefs (not included in this survey), are found close to shore. Mid-shelf reefs in Mayaguez Bay varied in live coral cover between 10.6% at Media Luna and 29.3% at Las Coronas (Figure 5.10). Tourmaline Reef on the outer shelf of Mayaguez Bay showed the highest live coral cover of all reefs studied with a mean of 51.9%. Turrumote and Media Luna Reefs in the southwest coast (near La Parguera); Cayo Diablo and Isla Palominitos Reefs from the northeast island chain (Cordillera de Fajardo Reefs); and Comandante, Mosquito and Boya Esperanza Reefs from North Vieques all presented live coral cover higher than 35% (Figure 5.10). In the case of the reefs of the Cordillera de Fajardo and Vieques, this may be related to their level of exposure and distance from river discharges. Both areas are subject to strong wave action during winter, but are located up-current from major rivers, and thus, do not receive large sediment loads. Well-developed coral reef communities exist along the protected (leeward) sections of the chain of islets.

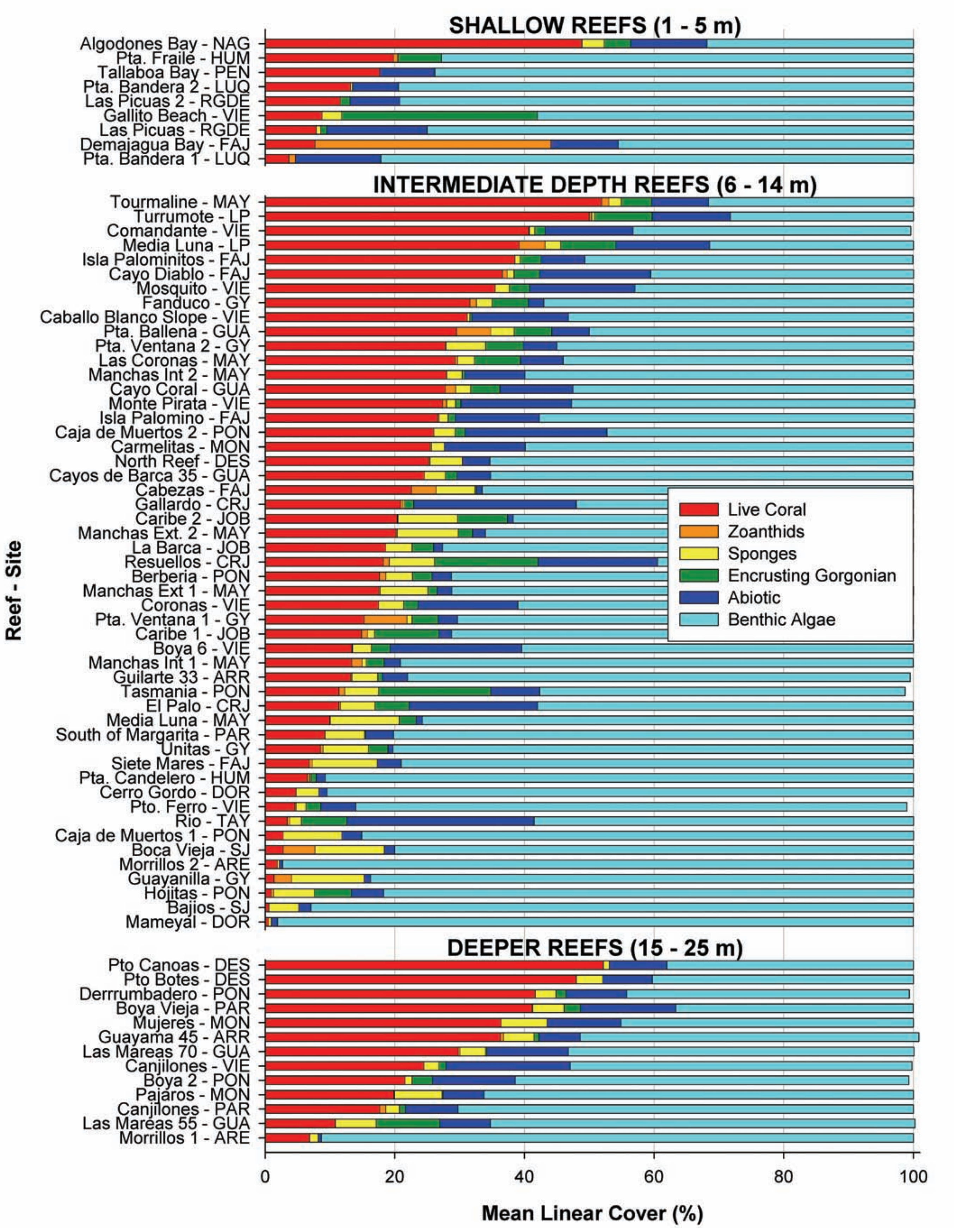

Figure 5.10. Mean linear cover by sessile-benthic substrate categories for various reef depths. Total cover may not equal 100% due to rounding within categories. Source: Garcia-Sais et al., 2003; Garcia-Sais et al., 2001d.

Benthic algae was the dominant substrate on 47 of the 52 reefs studied at intermediate depths, ranging in cover from 28.2% in Turrumote to 98% at Mameyal Reef (Figure 5.10). A mixed assemblage of short filamentous algae forming an "algal turf" was the most common type of algal cover, although substantial fleshy algae was observed at La Barca and Cayo Caribes Reefs from Jobos Bay, as well as at Mameyal and Cerro Gordo Reefs in Dorado. Calcareous algae, (mostly *Halimeda opuntia*) was an important component of the algal cover at Cayo Rio and Guayanilla Reef. The encrusting octocoral, *Erythropodium caribaeorum*, was observed in variable percent cover at most reefs surveyed from intermediate depths (6-14 m). The highest cover was observed in the Tasmania Reef in Ponce (17.3%). Conversely, encrusting gorgonian was mostly absent from the high energy hard ground and rock reef communities of the north coast. Zoanthids (*Palythoa* spp.) and sponges were the other main biotic components of the reef benthos at intermediate depths. Abiotic cover (e.g., sand, holes, overhangs) ranged from 0-26.8%.

The taxonomic composition of corals at reefs of intermediate depth (6-14 m) is presented in Figure 5.11. *Montastrea annularis* was the dominant scleractinian coral in 19 of the 22 reefs with highest live coral cover and was absent from 12 of the 13 reefs with lowest live coral cover among the 52 reefs surveyed. *Montastrea cavernosa* and *Porites astreoides* occurred in more reefs than any other coral taxa and were the main components of the live coral assemblage of highly degraded reefs, such as Mameyal, Cayo Río, Morrillos, and Guayanilla Reef.

Live coral cover from the deeper reefs studied (15-25 m) was highest at Puerto Canoas and Puerto Botes Reefs in Desecheo Island (in the Mona Passage) with 52.2% and 48.8%, respectively (Figure 5.10). Puerto Canoas had extensive reef sections where live coral cover exceeded 80% and featured some of the largest live coral colonies of the Puertorrican coral reefs. Live coral cover at Puerto Canoas Reef peaked at depths between 22-25 m. The reef extended down the insular slope to a maximum depth of 40 m. Further down the insular slope, live coral cover declined sharply with increasing depth and sponges became the dominant sessile-benthic invertebrate taxa (García-Sais et al., 2003). Derrumbadero Reef in Ponce presented the third highest live coral cover among reefs studied in the 15-25 m depths with a mean of 41.8%. Derrumbadero Reef is a submerged seamount with a spectacular "spur-and groove" coral reef formation fringing the southern edge of the seamount top. The spurs rise about 5-6 m from their coralline sandy base and are colonized with corals and other encrusting biota on their top and at the walls, forming ledges and overhangs at the shelf-edge.

Among coral reefs associated with the mainland shelf-edge, La Boya Vieja Reef in La Parguera presented the highest live coral cover with a mean of 41.2% (Figure 5.10). Shelf-edge reefs in the south and eastern sections of the mainland (e.g., Boya 2 near Ponce, Maria Langa near Guayanilla, Las Mareas near Guayama) presented generally lower live coral cover (<30%). The shelf-edge reef at La Parguera, located in the southwest coast, is farther offshore and farther away from river plumes than shelf-edge reefs of the south and southeast coasts which are influenced by estuarine conditions that inhibit light penetration. Wave energy appears to be another relevant factor in the structural development of shelf-edge coral reefs in Puerto Rico. For example, the shelf-edge reef at Pájaros, located on the southeast coast of Mona Island, had a mean live coral cover of 19.9%, whereas the shelf-edge reef at Mujeres on the southwest coast averaged 36.4%. Likewise, the shelf-edge reefs established on the southwest coast of Desecheo Island (e.g., Puerto Botes, Puerto Canoas) had much higher live coral cover (48.0-52.2%) than at North Reef (on the north coast) which averaged 25.3% (Figure 5.10). The southwest coast is protected from the seasonally large swells that pound the north coast of Puerto Rico during the winter and from the extreme southeasterly swells generated by hurricanes traveling across the Caribbean Basin.

Montastrea annularis was the dominant coral in terms of substrate cover at reefs studied in the 15-25 m depth range (Figure 5.11). In general, the variability of live coral cover for the reefs studied within this depth range was associated with the variation in cover by *M. annularis*. As for reefs studied in the 6-14 m depth range, the deeper reefs with highest live coral cover consistently showed a high relative substrate cover for *M. annularis*. For example, *M. annularis* represented more than 55% of the total cover by stony corals in seven reefs with greatest live coral cover. Conversely, in the seven reefs with lowest overall coral cover (with the exception of Canjilones Reef in Vieques), *M. annularis* contributed less than 45% of the total coral cover. It has been reported that with increasing depth below the shelf-edge down to at least 70 m, the occurrence of *M. annularis* becomes increasingly dominant to the point that it may represent more than 90% of the total

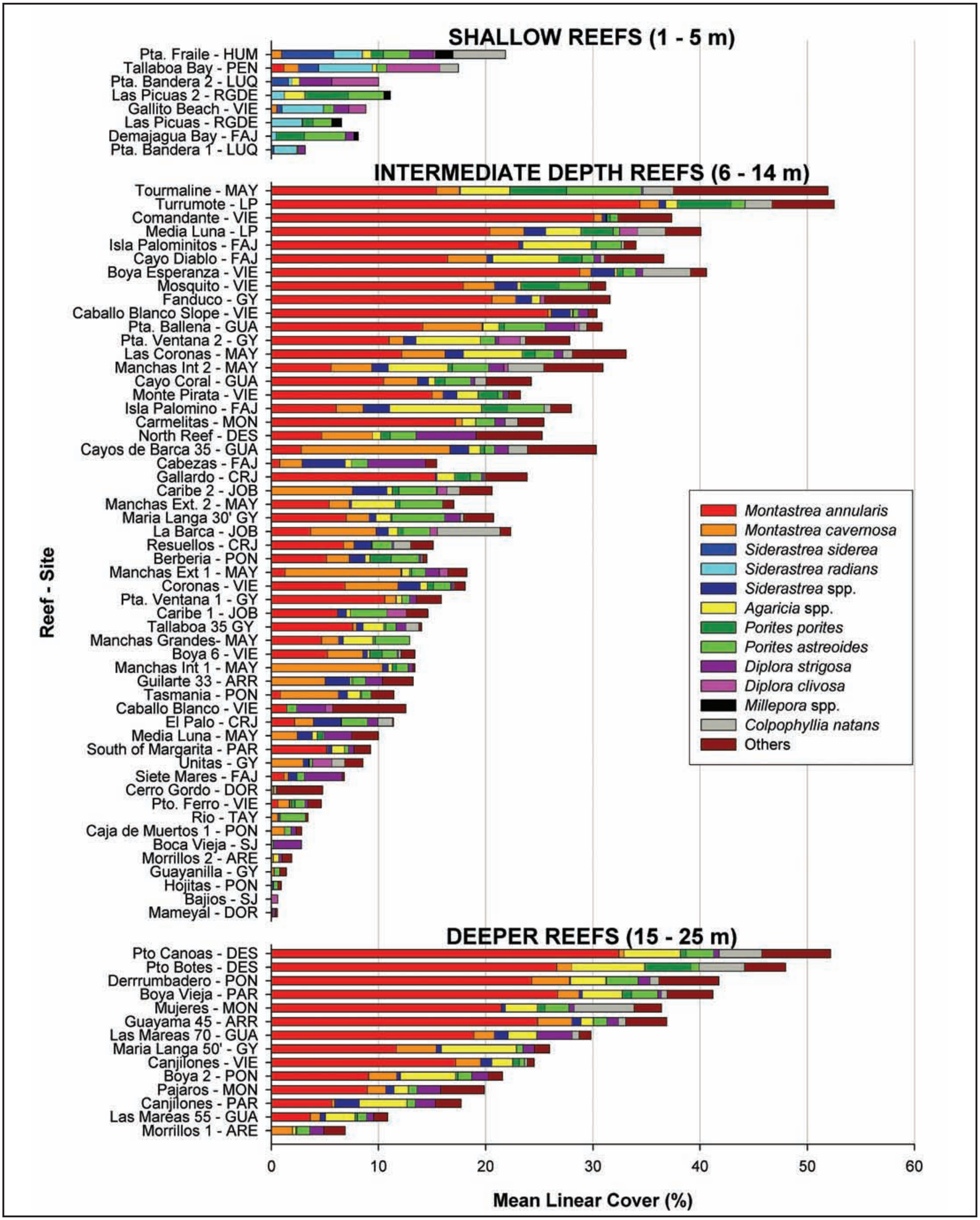

Figure 5.11. Mean linear cover by species for reefs at various depths. Source: Garcia-Sais et al., 2003; Garcia-Sais et al., 2001d.

substrate cover by live corals (García-Sais et al., 2004; R. Armstrong, pers. comm.). Other less prominent species of scleractinian corals present on the deeper reefs studied include *M. cavernosa*, *Porites astreoides,* and *Agaricia* spp. (Figure 5.11).

U.S. National Coral Reef Monitoring Program in Puerto Rico (NOAA), Natural Reserves

A series of coral reef systems located in natural reserves in Puerto Rico were selected as priority sites for biological characterization under the U. S. Coral Reef Initiative Program for Puerto Rico (NOAA) in 1999-2000. These included reef sites at Desecheo and Mona Islands, Fajardo, Guanica, Guayama, Guayanilla, La Parguera, Mayaguez, Arroyo, Cabo Rojo, Caja de Muertos, Ponce, and Vieques. Figure 5.9 shows the location of coral reef monitoring sites.

Methods

Quantitative and qualitative baseline characterizations of the reef community at these sites were reported by García-Sais et al. (2001a, b, c, d). Monitoring efforts by personnel from the DNER began on these reefs in 2001. Table 5.5 presents a summary of the quantitative data gathered during the 2001 monitoring effort for reefs included in the National Coral Reef Monitoring Program.

Table 5.5. Mean percent substrate cover by benthic categories for 18 monitored reefs. Source: DNER, unpublished data.

BENTHIC CATEGORIES	REEF SITES																	
	Caribe-Guayama	Barca-Guayama	Coral-Guanica	Ballena-Guanica	Ventana-Guayanilla	Tourmaline-Mayaguez	Coronas-Mayaguez	Media Luna-Mayaguez	West-Caja de Muertos	Windward- Caja de Muertos	Berberia- Caja de Muertos	Norte-Desecheo Island	Botes-Desecheo Island	Canoas-Desecheo Island	Palominos-Fajardo	Diablo-Fajardo	El Palo-Fajardo	Resuellos-Cabo Rojo
Live Coral	14.9	18.7	19.4	29.2	23.4	59.7	30.4	8.8	24.9	2	17.6	23.1	45.3	52.5	26	36.8	12.8	21.5
Gorgonian	3.2	2.3	4	13.4	6.1	2.5	8.7	4	2.1	0.1	6.3	0.1	0	0	2.7	3.7	10.5	31.8
Turf Algae	54.9	34.9	55.1	42.5	50.3	22.6	40.2	78	59.7	83.6	31.5	29.8	29.1	12.9	57.7	41.1	52.2	33.6
Fleshy Algae	6.7	25.3	0	0	1	0	0.8	0.1	0.2	3.4	17.1	37.3	15	24.6	4.8	1.5	0.6	0
Encr. Algae	1	1.5	0.9	2.1	6.4	1.8	0.2	0.3	0.1	1.2	1.4	2.8	2.2	3	0.5	3	0.4	0.3
Calcareous Algae	8.8	5.1	1.8	0.5	2.6	2.8	12.7	0	0.2	1.5	20.6	0	0.2	0	0	0	4	0
Sponges	6.9	4.2	1.4	4.7	7.2	1.9	1.4	7.8	2.3	7.2	1.8	4.5	3.2	3.3	0.4	1.6	2.8	4.2
Zoanthids	0.7	0	1.1	3.7	0	0.7	0.1	0.1	0	0	0.4	0	0	0	0.2	0.3	0	0
Tunicates	0	0	0.1	0	0.1	0.1	0.2	0.1	0	0.4	0	0	0.2	0	0	0	0	0
Sand	0.1	2.8	3.8	1.7	0.9	0.2	1.4	0.7	1.2	0.5	0	2.2	0.7	1.1	1.2	7.5	0.9	0.3
Gravel / Rubble	0.5	0	4.6	0	0	0	0	0	0	0	0	0	0	0	0.4	0	0	0
Dead Coral	0.2	0	0	0	0	3.6	0.4	0	2.3	0.2	0	0	0.1	0.1	0	0	0	0
Overhangs	2.2	5.2	7.6	2.2	1.9	3.9	3.2	0	7	0	3	0.2	4.1	2.3	5.9	4.5	15.4	8.3

Results and Discussion

At most sites, the percent cover of stony corals remained within 3% of baseline levels (Figure 5.12). Exceptions included the decline in coral cover at Cayo Coral in Guánica and at Cayo Caribes in Guayama. These changes may be related to small scale localized disturbances, since adjacent reefs (Ballena Reef in Guánica and Barca in Guayama) appeared relatively stable and varied very little from the baseline data. In addition, increases in coral cover that were detected at Tourmaline Reef were not detected at any other surveyed reefs within Mayaguez Bay (i.e., Coronas and Media Luna), which remained within 2% of the baseline data.

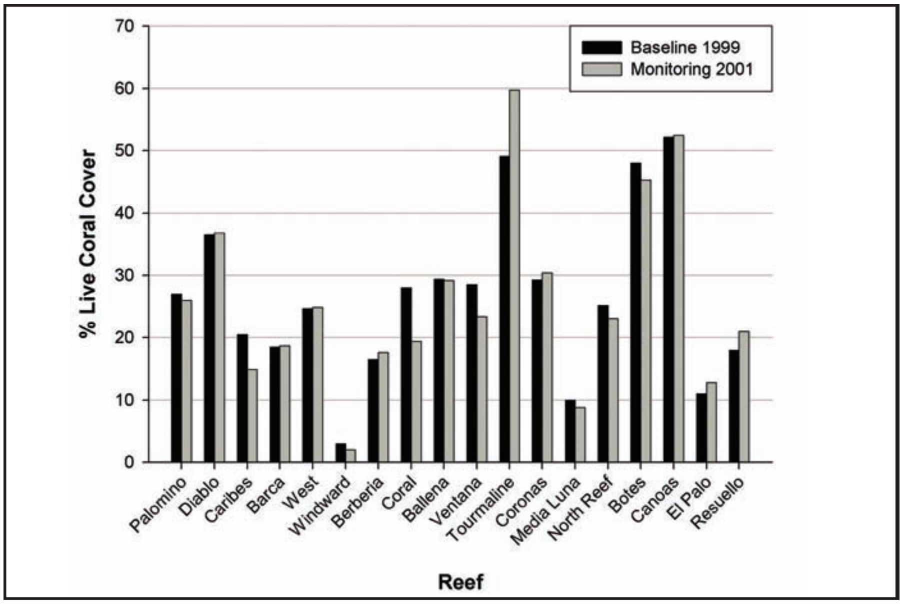

Figure 5.12. Comparison of percent live coral cover at 18 sites between baseline characterization in 1999 and first monitoring event in 2001. Source: DNER, unpublished data.

Caribbean Coastal Marine Productivity Program

The Caribbean Coastal Marine Productivity Program (CARICOMP) is a Caribbean-wide coral reef monitoring program established to examine changes in the ecological health of coral reefs and associated ecosystems (e.g., fringing mangroves, seagrass beds) across a network of laboratories and marine reserves, including the Puertorrican site of La Parguera (CARICOMP,1996). This program is directed in Puerto Rico by the University of Puerto Rico (UPR), Department of Marine Sciences and has been active since 1994. Dr. Ernesto Weil is currently the site director for the CARICOMP program in Puerto Rico. The CARICOMP Data Management Center is based in Kingston, Jamaica. Only limited CARICOMP monitoring results have been incorporated in this report, but should be included in the next reporting effort.

Methods

Monitoring methods can be found in Woodley et al., 1996.

Results and Discussion

Baseline characterization and early coral reef monitoring records for the site of La Parguera were presented at the 8th International Coral Reef Symposium in Panama (Woodley et al., 1996). The CARICOMP coral reef monitoring database includes available data for Media Luna Reef from Puerto Rico (CARICOMP, http://www.ccdc.org.jm/caricomp.html, Accessed: 12/29/04). Figure 5.13 shows the annual variation of mean cover by live corals at Media Luna Reef (10 m depth).

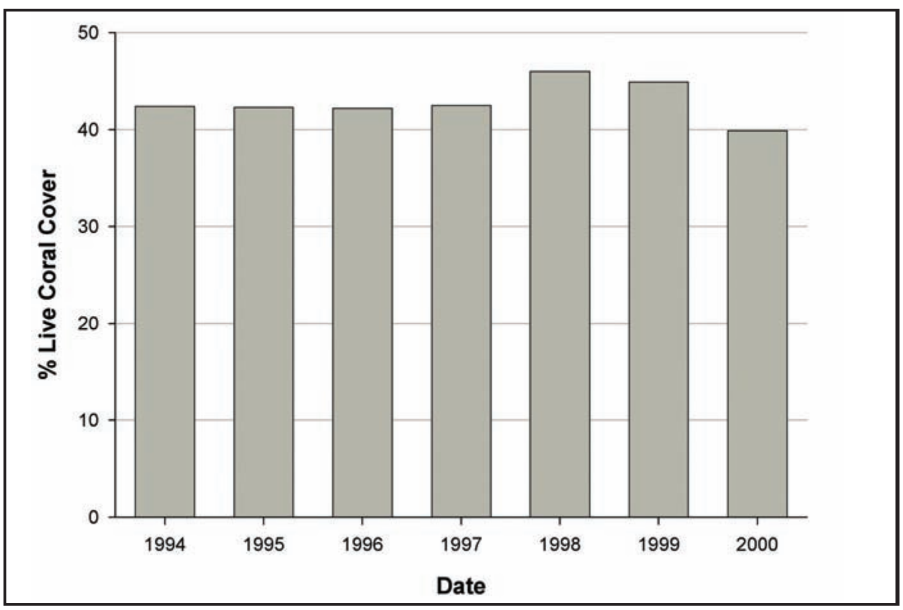

Figure 5.13. Annual variation of mean percent live coral cover (10 m depth) at Media Luna Reef in La Parguera, Puerto Rico from 1994-2000. Source: CARICOMP, unpublished data.

NOAA's Coral Reef Ecosystems Study

In 2002, NOAA's Coastal Ocean Program initiated a five-year program to address the continued decline of coral reef ecosystem health. Based at UPR-Mayaguez, the Coral Reef Ecosystems Study (CRES) is a collaborative research program involving five universities, one non-government organization (NGO), and two Federal agencies. The CRES program was developed to:

- Identify and evaluate factors critical to the decline of coral reefs;
- Evaluate effective management approaches;
- Develop tools to assist resource managers;
- Evaluate socio-economic concerns vital to management plans; and
- Integrate environmental studies, socioeconomic impacts, and modeling into a comprehensive ecological study.

The overall strategic assessment will address four major research focus areas: 1) relationships between watershed activities and coral reefs; 2) causes of ecological stress; 3) coral reef ecosystem integrity; and 4) evaluation and linkages of MPAs. The principal study area is the reef system off La Parguera, with additional work being conducted in conjunction with the Luis Peña Channel Marine Fishery Reserve (LPCMFR) on Culebra Island and the National Park on St. John, USVI. Figures 5.14 and 5.15 show preliminary results identifying watershed sources of sedimentation to the coastline in the natural reserve at La Parguera, Lajas.

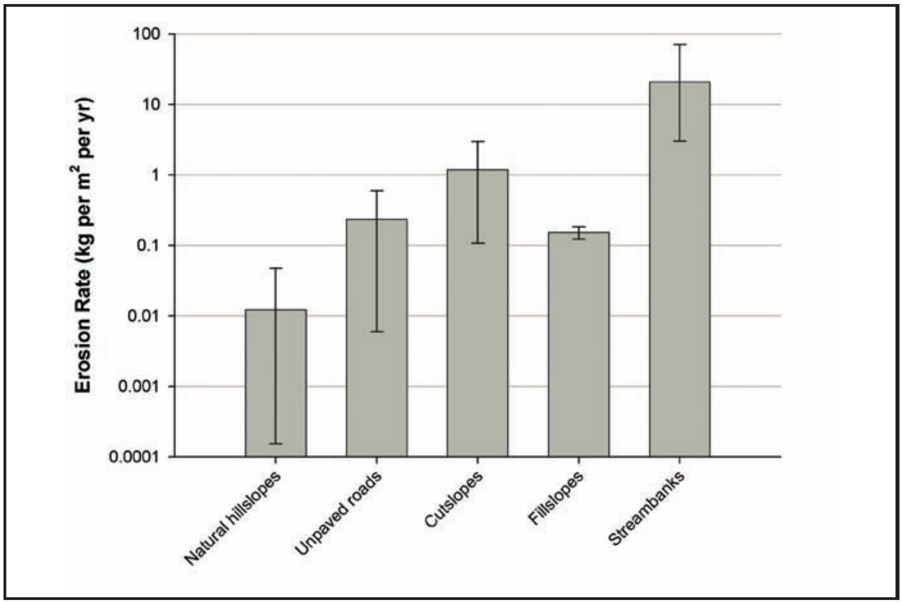

Figure 5.14. Measured erosion rates for different sediment sources in the watershed of La Parguera. Source: C. Ramos, unpublished data.

The CRES project has conducted only one full year of sampling, yet certain trends have become apparent. Detailed seasonal sampling has shown that the reef system is very dynamic, with large changes occurring over short periods of time. Some of these seem to be associated with seasonal variations (e.g., temperature, rainfall) while others may be indicative of increased nutrient stress (e.g., cyanobacterial overgrowths in La Parguera and Culebra).

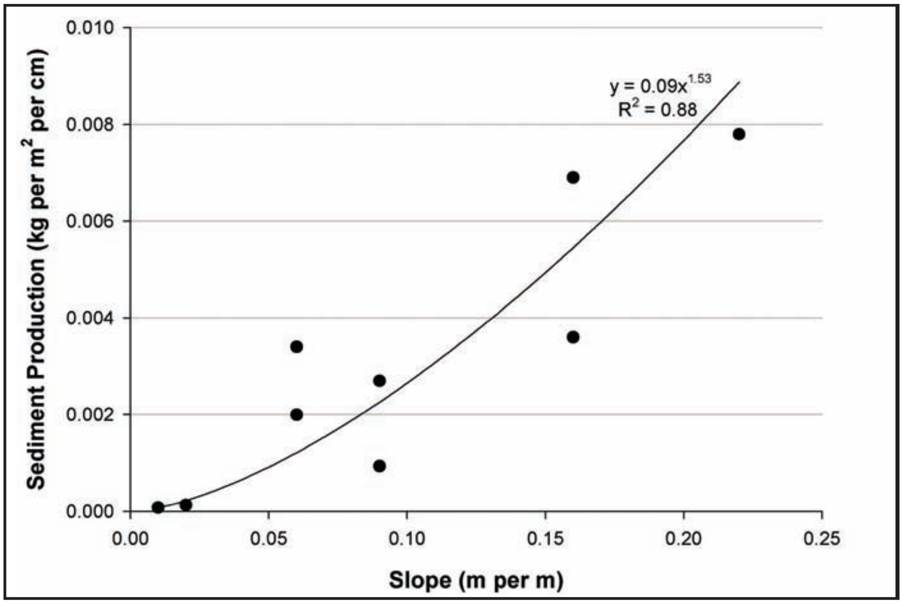

Figure 5.15. Rate of sediment production as a function of slope in disturbed areas of La Parguera watershed. Source: C. Ramos, unpublished data.

Coastal development, especially in hilly areas, is often a major cause of increased sedimentation. The unique environmental signal resulting from the intense rain event in November 2003 provided an opportunity to study the transport of nutrients and sediments into the La Parguera system. These studies showed the process to be complex and result from both nearshore and upstream processes that differentially act at various locations across the shelf. A combination of techniques (permanent data loggers, sediment traps, high spatial and temporal sampling) is necessary to fully understand how the system operates.

Diseases and bleaching continue to be a problem, with the worst bleaching event since 1988 occurring in 2003. While some progress has been made in identifying potential pathogens, new diseases were observed (e.g., of coralline algae) and the potential for disease reservoirs suggests that the causes and cycles of disease infection may be more complex that previously thought.

Luis Peña Channel Marine Fishery Reserve Monitoring (LPCMFR)

The Luis Peña Channel Marine Fishery Reserve (LPCMFR) was established on the west coast of Culebra by the government of Puerto Rico in May 1999. The main objective of this project is to monitor benthic organisms and fish at permanent stations within and outside of the reserve in order to determine the impact of protection.

Methods

Monitoring methods can be found in Hernández-Delgado, 2003

Results and Discussion

As in past years, fish biomass within the reserve has increased since closure. The most striking results are illustrated in Figure 5.16.

At one site within the LPCMFR, the data showed a decline in coral cover over time and then a more recent stabilization. This result may have followed the delayed but eventual increase in herbivores observed since the reserve was closed. The opposite trend to that of corals would represent the change in percent algal cover. However, as Figure 5.16 illustrates, the recorded increase in algae was due almost entirely to an increase in cyanobacteria. This strongly suggests that the increase in herbivorous fishes has mostly impacted fleshy macroalgae, while an increase in nutrient loading into the reserve (a trend supported by observed changes in nearby land use, resulting in runoff and increased turbidity) has allowed cyanobacteria to colonize the open space.

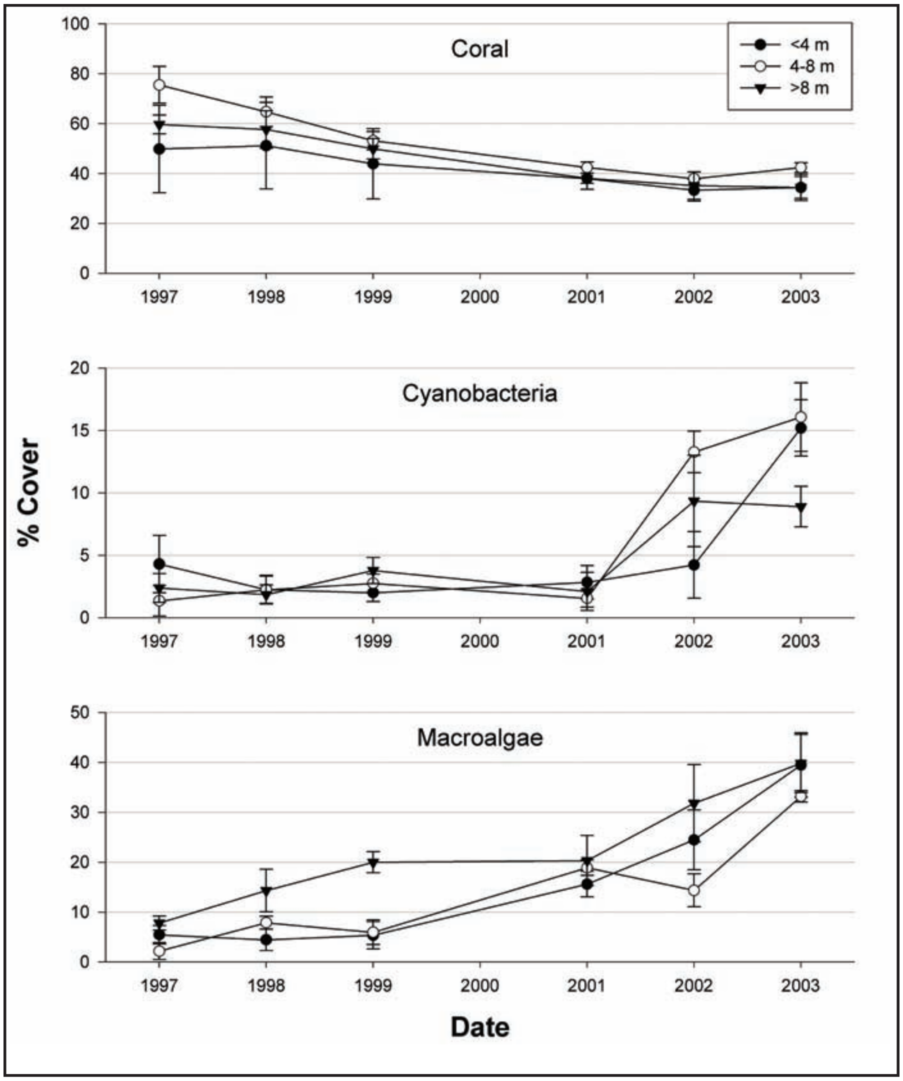

Figure 5.16. Decline in coral cover and increase in cyanobacteria cover within the Luis Peña Channel Marine Fishery Reserve, Culebra. Source: Hernández-Delgado, 2003.

PRASA Submarine Outfall Studies-301h Waiver Demonstration

Another ongoing, long-term monitoring of reef communities in Puerto Rico is associated with EPA's 301(h) waiver demonstration studies for the submarine outfalls of the PRASA RWWTPs. The location of these submarine outfalls in the north and south coasts of Puerto Rico are shown in Figure 5.9. Initial baseline characterization studies of marine communities in the vicinity of these submarine outfalls were prepared by García-Sais et al. (1985). Monitoring studies of water quality and currents, sediment chemistry, infaunal benthic communities, fish and epibenthic invertebrate communities, and coral reef communities started in October 1999 and have continued to the present at the RWWTPs of Carolina, Bayamón-Puerto Nuevo, Arecibo, Aguadilla, and Ponce. The 301(h) monitoring program for the Arecibo RWWTP submarine outfall includes monitoring of coral communities to assess whether effluent discharge has had any measurable impact on the maintenance of balanced indigenous populations of corals and associated fish and epibenthic invertebrate communities. Included in this report are summarized results for the RWWTPs of Arecibo and Aguadilla, which are being monitored by UPR-Department of Marine Sciences under the direction of Dr. Jorge (Reni) Garcia-Sais.

Methods

Sampling protocols and EPA-approved quality assurance/quality control manuals for the monitoring program were prepared by CSA Group/CH2MHill (1999). With the exception of Ponce, which is an ocean outfall 150 m deep, all other outfalls discharge within the insular shelf at depths ranging between 15-40 m on the north coast of Puerto Rico. From these sites, true coral reef systems are only present in the vicinity of the RWWTP submarine outfall in Aguadilla, but coral communities associated with rock and hard ground reefs are included in the monitoring program for all RWWTP submarine outfalls.

Two coral community monitoring stations were studied in the vicinity of the Arecibo outfall. Stations AA1 and AA2 were established on a hard ground reef habitat, located approximately 1 km and 0.8 km due east of the outfall, respectively. The insular shelf section located to the west of the outfall is under the direct influence of the Rio Grande de Arecibo plume and impractical for monitoring benthic communities due to the prevailing high turbidity of the water. Both coral stations AA1 and AA2 are sections of an extensive hard ground reef habitat found off the Arecibo coastline. Coral monitoring stations were located at similar distances due east of the outfall, but at different depths. AA1 reef was studied at a depth of 16 m, whereas AA2 was surveyed at a depth of approximately 21 m. The geographic coordinates of the alternative coral community stations are included in Table 5.3.

Monitoring of coral reef communities within the Arecibo RWWTP 301(h) program has followed a winter and summer cycle with sampling efforts usually occurring in February and July. The two Arecibo coral monitoring stations are located within a general area subject to extended periods of high wave energy (from October to March) and the influence of the Rio Grande de Arecibo plume.

Two coral community monitoring stations were established to the east and west of the Aguadilla RWWTP outfall. Aguadilla station AGS2 was established on a hard ground reef habitat, located approximately 0.93 km northeast of the outfall. Station AGS3 was established on a coral reef area approximately 4.26 km southwest of the outfall. The location of sampling stations is shown in Figure 5.9. Coral community monitoring stations were established at locations that characterized the typical reef communities present in the vicinity of the outfall. Station AGS2 is a submerged patch hard ground habitat that rises from a depth of approximately 18 m to a fairly even platform at 14 m. This station is close to the outfall and also under the influence of the Culebrinas River plume. Station AGS3 is located in a zone of abundant rock outcrops farther offshore than AGS2 and also farther from the influence of both the outfall and the Culebrinas River plume. The coordinates of the alternative coral community stations are included in Table 5.3.

Results and Discussion

Summarized monitoring data of coral benthic community structure for the Arecibo Reefs AA1 and AA2 are presented in Figure 5.20. As can be inferred from the percent cover of biota at these reefs, it is evident that benthic algae (both turf and fleshy growth) represent the dominant biological assemblage colonizing hard substrate at AA1 and AA2, and sponges represent the most prominent invertebrate taxa of the reef community. Live corals represent minor components of the reef community structure at both Arecibo sites and occur mostly as encrusting forms, providing low topographic relief and scarce habitat for fishes and other reef biota. The poorly developed state of these hard ground reefs is related to the strong wave and surge energy seasonally

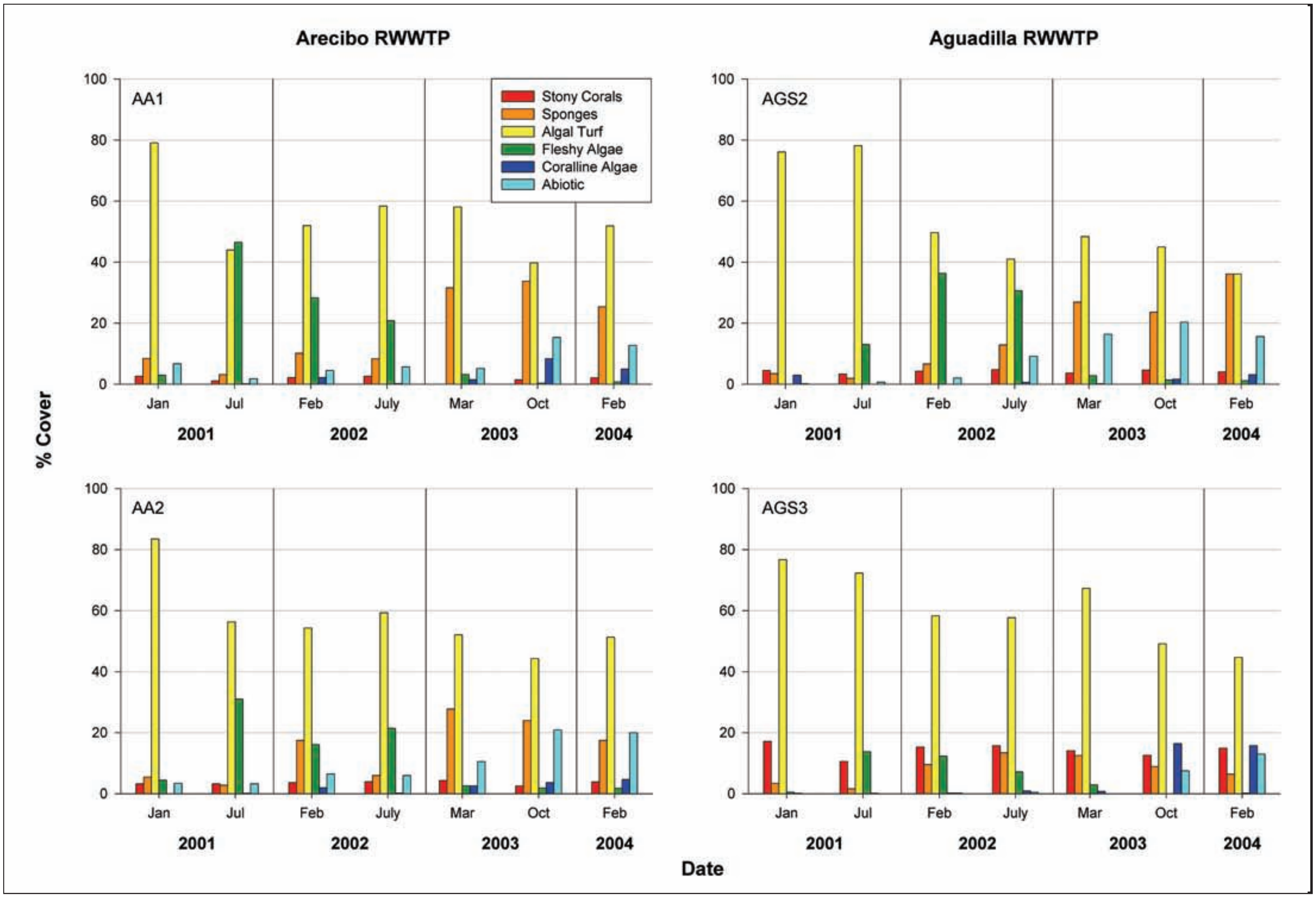

Figure 5.17. Percent cover by substrate categories at coral communities in the vicinity of the Arecibo and Aguadilla RWWTP outfalls, from 2001-2004. Source: EPA 301(h) Waiver Demonstration Monitoring Program.

affecting the north coast of Puerto Rico and the localized effect of large river plumes.

Summarized monitoring data on percent cover by substrate categories at Aguadilla reef community stations AGS2 and AGS3 also appear in Figure 5.17. Coral stations in Aguadilla are located in a high-energy environment and evidently under the estuarine influence of the Culebrinas and Guayabo River plumes. Coral communities in the study area are representative of the typical hard ground reef habitat that prevails on many sections of the north coast of Puerto Rico (e.g., AGS2), and of sparse and relatively small patch reef systems that have developed on top of rocky promontories (e.g., AGS3).

The higher taxonomic complexity and percent cover of live corals at AGS3, as compared to AGS2, may be related to a combination of factors, including the higher exposure to river runoff and associated sedimentation stress at AGS2; the deeper location of the reef at AGS2, with its implications for lower light availability for corals; differences of sediment types at the base of reefs between both stations; and the higher separation of the reef at AGS3 from the unconsolidated substrate at its base. The two latter differences have implications for higher propensity of AGS2 to sediment re-suspension effects, as compared to AGS3. The higher number of fish species and abundance at AGS3 are probably associated with the higher topographic relief (habitat heterogeneity) and availability of live coral habitats.

It is difficult to make an assessment of what has been the effect, if any, of the Aguadilla RWWTP discharge on coral reefs in this region due to the confounding effects of sedimentation stress, both from the strong wave and surge action and from the massive river runoff from the Culebrinas and Guayabo Rivers. Nevertheless, the hard ground coral community at AGS2 does not show any structural evidence of previous coral reef development, nor does AGS3 show any evidence of significant degradation of its standing coral structures. Records from permanent photoquadrats show that an active coral growth and recruitment process is taking place at the Alt-AGS3 reef station.

Benthic Habitat Mapping Project

NOAA's Center for Coastal Monitoring and Assessment, Biogeography Team (CCMA-BT), completed a nearshore benthic habitat mapping project for Puerto Rico in 2001.

Methods

Map development was based on visual interpretation of aerial photographs, which were used to delineate habitat polygons in a geographic information system (GIS). Habitat polygons were defined and described according to eight geomorphologic zones and a hierarchical habitat classification system consisting of 21 discreet habitat types within five major habitat categories. A detailed description of methods can be found in Kendall et al. (2001).

Results and Discussion

The mapping project was completed in 2001 and resulted in a series of maps encompassing 1,599 km^2 of nearshore habitat in Puerto Rico. The maps are currently being distributed on a CD-ROM and on-line at http://biogeo.nos.noaa.gov/products/benthic/. A summary map (Figure 5.18), where polygons have been aggregated into five major habitat categories, depicts the geographical distribution of reefs and other types of benthic habitats on the Puertorrican shelf (Kendall et al., 2001).

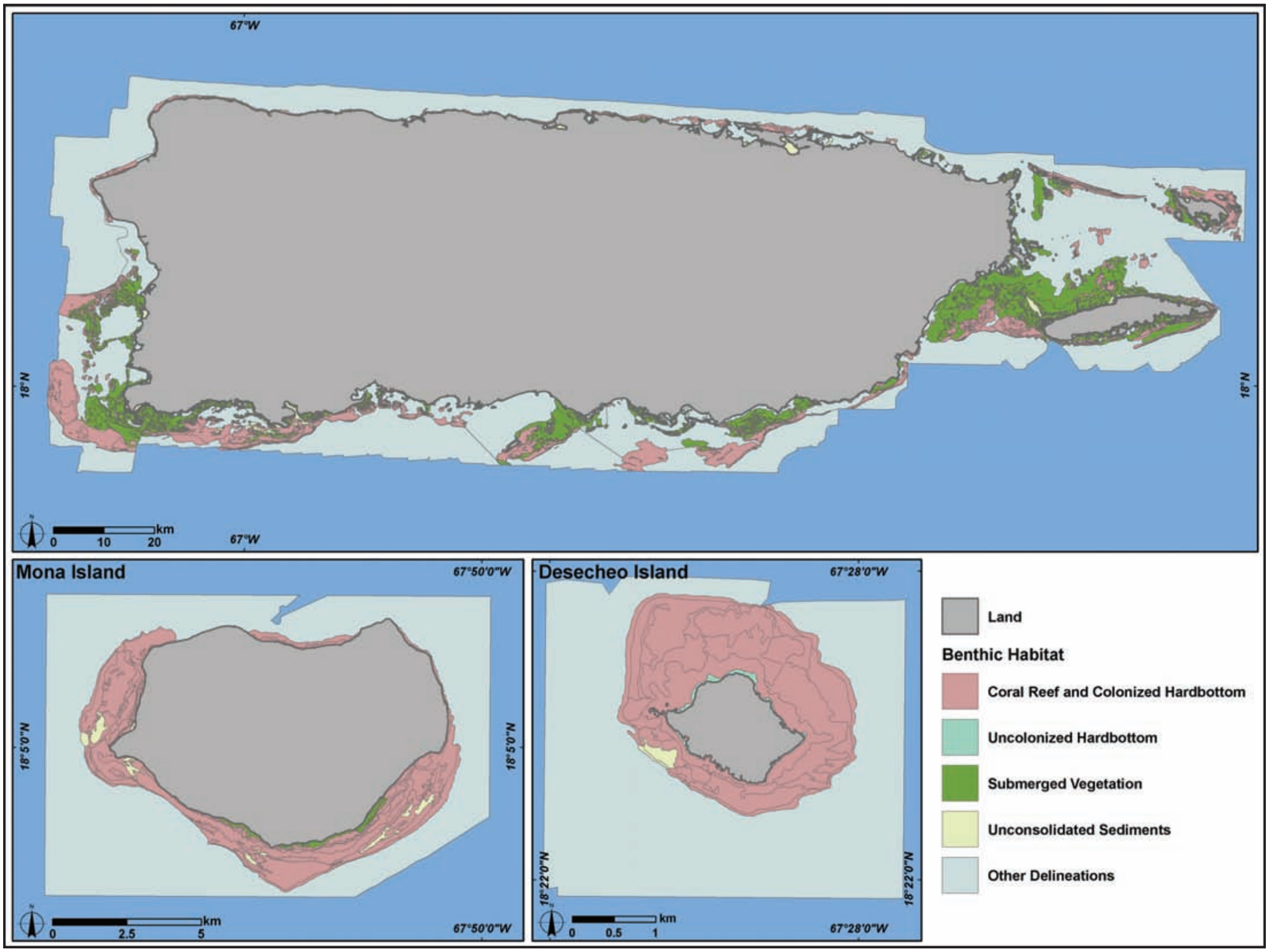

Figure 5.18. Nearshore benthic habitat maps were developed in 2001 by CCMA-BT based on visual interpretation of aerial photography and hyperspectral imagery. For more info, see: http://biogeo.nos.noaa.gov. Map: A. Shapiro. Sources: García et al., 2004; Kendall et al., 2001.

ASSOCIATED BIOLOGICAL COMMUNITIES

U.S. National Coral Reef Monitoring Program in Puerto Rico (NOAA), Reef Fish Monitoring

Methods

Quantitative and qualitative surveys of diurnal, non-cryptic reef fishes have been included as part of the biological baseline characterizations and monitoring of coral reef communities in Puerto Rico. Reef fishes were surveyed using a belt-transect technique. Transects 10 m long and 3 m wide (30 m^2 survey area) centered over the linear transects were used to characterize the reef benthic community. A total of five belt-transects were surveyed at each reef station.

Results and Discussion

The mean abundance of fishes ranged from 241.4 per 30 m^2 at Puerto Botes Reef at Desecheo Island to 22.0 per 30 m^2 at El Palo Reef in Boquerón (Table 5.6). Number of species was highest (29 per 30 m^2) at Puerto Canoas Reef in Desecheo and lowest (10 per 30 m^2) at Caña Gorda and Ballena Reefs in the Guánica area. The highest number of diurnal, non-cryptic fish species observed was also from Puerto Canoas Reef at Desecheo Island with a total of 54 species. The highest fish abundance was found at offshore island sites separated from the main island of Puerto Rico. Puerto Canoas and Puerto Botes at Desecheo Island were the only reefs surveyed with an average of 25 or more (non-cryptic) fish species per transect. Highest abundance (96.9 per 30 m^2) and number of species (22 per 30 m^2) of fish among the mainland reefs surveyed were found at Turrumote Reef in outer Mayaguez Bay.

Table 5.6. Mean abundance and species richness of reef fishes present within belt transects during baseline characterization surveys in 1999-2000. Source: Garcia-Sais et al., 2003; Garcia-Sais, unpublished data.

REEF/ SITE	MEAN ABUNDANCE / 30 m^2	TOTAL # SPP. / 150 m^2	MEAN SPP / 30 m^2
Puerto Botes - DES	241.4	49	25
Puerto Canoas - DES	208.6	54	29
Derrumbadero - PON	161.4	47	25.2
Playa Mujeres - MON	133	48	23
SE Cayo Diablo/99 - FAJ	128	49	21
North Reef - DES	127.4	38	21
Tourmaline - MAY	96.8	42	22
Playa de Pájaros - MON	89	40	19
Las Carmelitas - MON	86	42	22
La Barca - JOB	84.6	30	15.2
Maria Langa 15m - GUY	82.2	46	23
Cayo Puerca West - JOB	71	32	14.8
La Boya - PAR	70.4	38	24
Caribes - JOB	70.2	38	20.4
Boya Esperanzan - VIE	63.4	46	20
Corona - VIE	63.4	37	18
West Reef/99 - CMU	61.8	45	21
Mosquito - VIE	60.8	34	17
Punta Ventana/99 - GUA	60.4	34	16
Comandante - VIE	56	41	19
North Palomino/99 - FAJ	55	31	18
Palominos/01- FAJ	55	31	18
Cayo Puerca East - JOB	54.8	25	10.4
SE Palominitos/99 - FAJ	54.6	29	14
Tallaboa - GUY	50	38	17
Puerto Ferro - VIE	49.2	46	19
Punta Colchones West - JOB	48	24	12.8
Boya 2 - PON	47.8	34	17
Bajo Gallardo - BOQ	46.6	36	17
Canjilones - PAR	44	31	19
Media Luna/99 - MAY	43.2	26	13

Table 5.6 (continued). Mean abundance and species richness of reef fishes present within belt transects during baseline characterization surveys in 1999-2000. Source: Garcia-Sais et al., 2003; Garcia-Sais, unpublished data.

REEF/ SITE	MEAN ABUNDANCE / 30 m^2	TOTAL # SPP. / 150 m^2	MEAN SPP / 30 m^2
Boya 6 - VIE	43	40	19
Punta Colchones East - JOB	42.6	27	14.2
Maria Langa 10m - GUY	40.4	42	17
Monte Pirata - VIE	38.6	38	17
Canjillones - VIE	36.8	43	17
Windward Reef - CMU	36.8	19	13
Punta Ballena - GUA	36.5	20	10
Las Coronas - MAY	34.8	30	15
Margarita Hard Ground - PAR	33.4	27	15
Caballo Blanco Reef Crest - VIE	32	22	13
Caña Gorda - GUA	31.8	20	10
Berberia - CMU	28.8	26	11
Caballo Blanco Reef Slope - VIE	28.4	26	11
Resuellos - BOQ	28	32	15
Cayo Coral/99 - GUA	26.8	29	14
El Palo - BOQ	22	24	11
Tasmania - PON	16.2	21	16.2

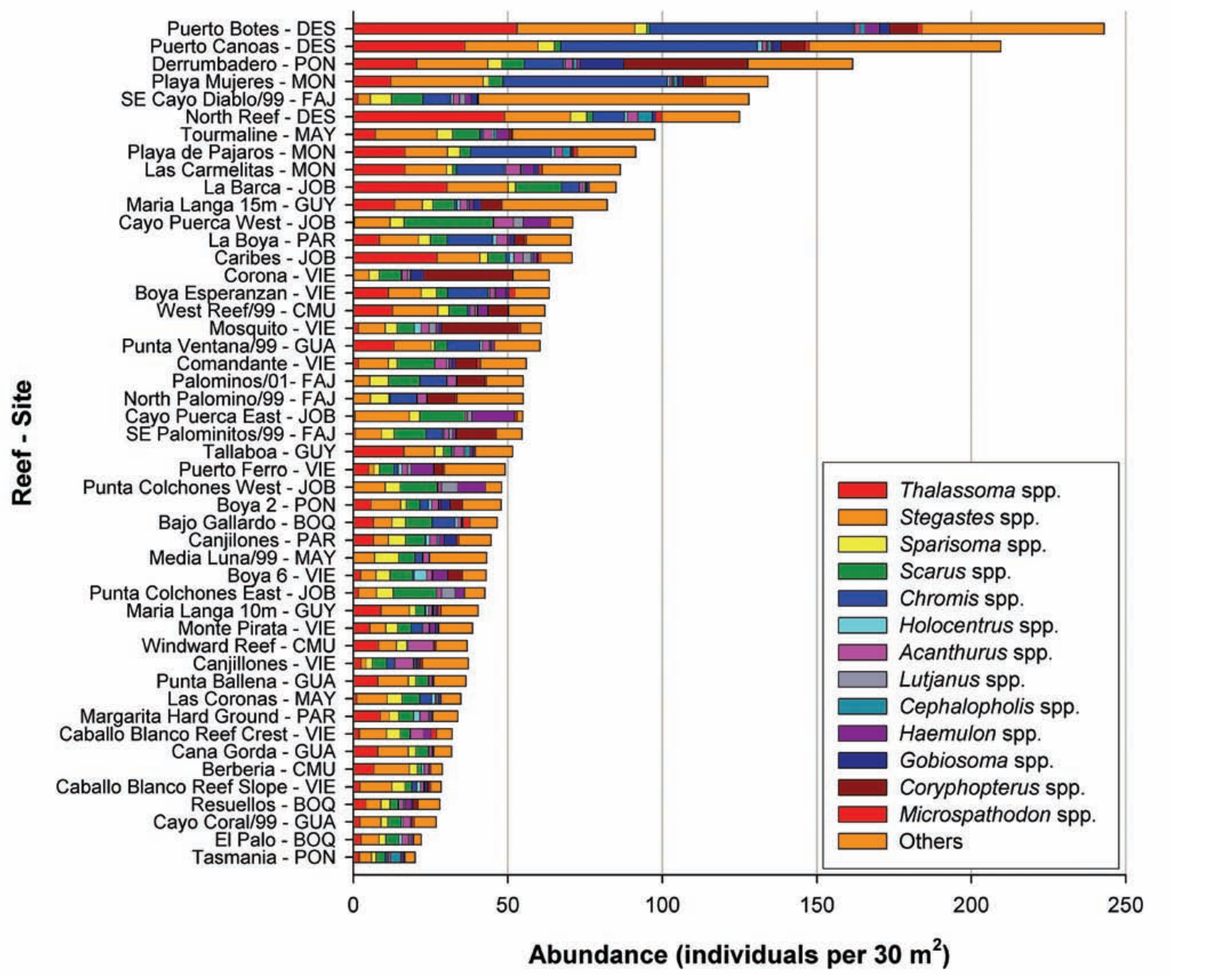

Figure 5.19. Taxonomic composition and abundance of numerically dominant fish taxa from belt-transect surveys performed during the USCRI-NOAA baseline characterization studies of Puertorrican reefs (1999-2001). Source: Garcia-Sais et al., 2003; Garcia-Sais, unpublished data.

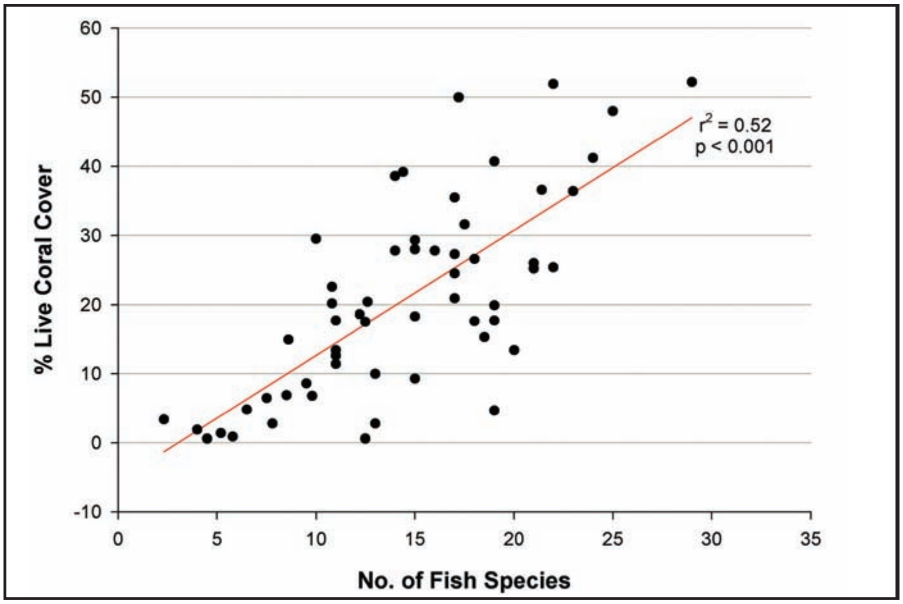

Figure 5.20. Positive correlation between fish species richness (no. of spp per transect) and percent of live coral cover on reefs surveyed around Puerto Rico. Source: Garcia-Sais et al., 2003; Garcia-Sais, unpublished data.

Fish assemblages at offshore island reefs, particularly those surveyed at Desecheo and Mona Islands, were characterized by a high abundance of zooplanktivorous fishes, such as *Chromis* spp., creole wrasse (*Clepticus parrae*), bicolor damselfish (*Stegastes partitus*) and juvenile stages of Spanish hogfish (*Bodianus rufus*) (Figure 5.19). High live coral cover was associated with high abundance of the sharknose goby (*Gobiosoma evelynae*) and peppermint goby (*Coryphopterus lipernes*) that live on top of large coral colonies. Number of fish species was positively correlated ($p<0.01$) with live coral cover on reefs surveyed around Puerto Rico (Figure 5.20) and explained more of the variability than did rugosity. Reefs with low live coral cover and high benthic algal cover exhibited less diverse fish communities, typically with a high abundance of dusky damselfish (*Stegastes dorsopunicans*).

NOAA's Center for Coastal Monitoring and Assessment, Biogeography Team (CCMA-BT)

Since August 2000, NOAA's CCMA-BT has led a collaborative effort to monitor coral reef ecosystems throughout the U.S. Caribbean, including Puerto Rico. This regionally-integrated monitoring effort explicitly links observed fish distributions to shallow (<30 m) benthic habitat types recently mapped by CCMA-BT and its many partners (Kendall et al., 2001). Objectives of this work include: 1) developing spatially-articulated estimates of distribution, abundance, community structure, and size of reef fishes, conch, and lobster; 2) relating this information to in situ data collected on associated habitat parameters; and 3) using this information to establish the knowledge base necessary to implement and support "place-based" management strategies (e.g., MPAs) for coral reef ecosystems of the Caribbean, as well as to quantify the efficacy of management actions.

This regional monitoring program has been conducted in partnership with the UPR, U.S. National Park Service (NPS), USGS, and the Virgin Islands Department of Planning and Natural Resources, and provides standardized monitoring data for portions of U.S. Caribbean. Since the inception of this effort in August 2000, 628 surveys of reef fish populations and associated benthic habitats have been conducted in southwestern Puerto Rico (Figure 5.9). The foundation of this work is the near shore benthic habitat maps created by CCMA-BT in 2001. Using ArcView© GIS software, the benthic habitat maps are stratified before monitoring stations are selected along a cross-shelf depth gradient. Because the project was designed to monitor the entire coral reef ecosystem, CCMA-BT and its partners survey seagrass meadows, mangroves, and sand flats, in addition to coral reefs.

Methods

Survey sites are selected at random within each habitat stratum to ensure spatially comprehensive coverage of the study region. At each site, fish, conch, lobster, and benthic habitat information is collected using standard visual survey techniques (Figure 5.21; Christensen et al., 2002). Since 2003, CCMA-BT has also been collecting data on water quality and oceanographic characteristics at selected survey locations. These water quality data are not yet available, but will be provided in the next reporting effort.

Results and Discussion

By relating monitoring data to the habitat maps, CCMA-BT and its partners are able to map and model (predict) species and community level parameters throughout the seascape. Furthermore, by integrating this work with other concurrent studies on fish migration patterns, home range size, fish dispersal, and recruitment being conducted by partner groups, the program is in a unique position to answer questions about marine zoning strategies (e.g., placement of MPAs), and will be in a position to evaluate management efficacy as long-term monitoring continues.

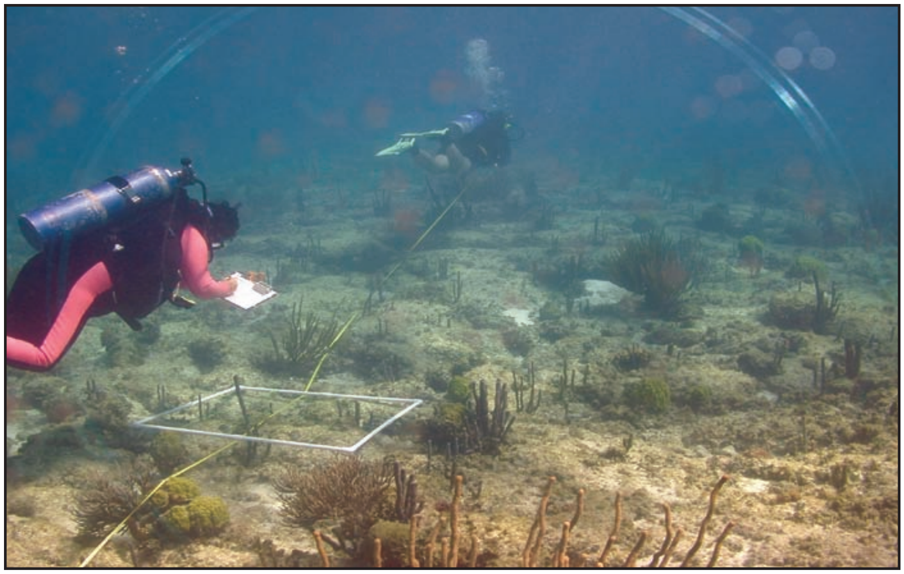

Figure 5.21. Divers collect data on fish communities and benthic habitat cover along a transect according to established protocols used by CCMA-BT scientists throughout the Caribbean. Photo: M. Kendall.

Since August 2000, a total of 628 locations in southwestern Puerto Rico have been surveyed, resulting in abundance estimates for over 200 species of fishes, 50 species of coral, and 100 species of algae. The highlights of this section are the relationships observed between fish species and the habitats they occupy throughout their life histories, as well as changes in the observed patterns since the last reporting effort in 2002.

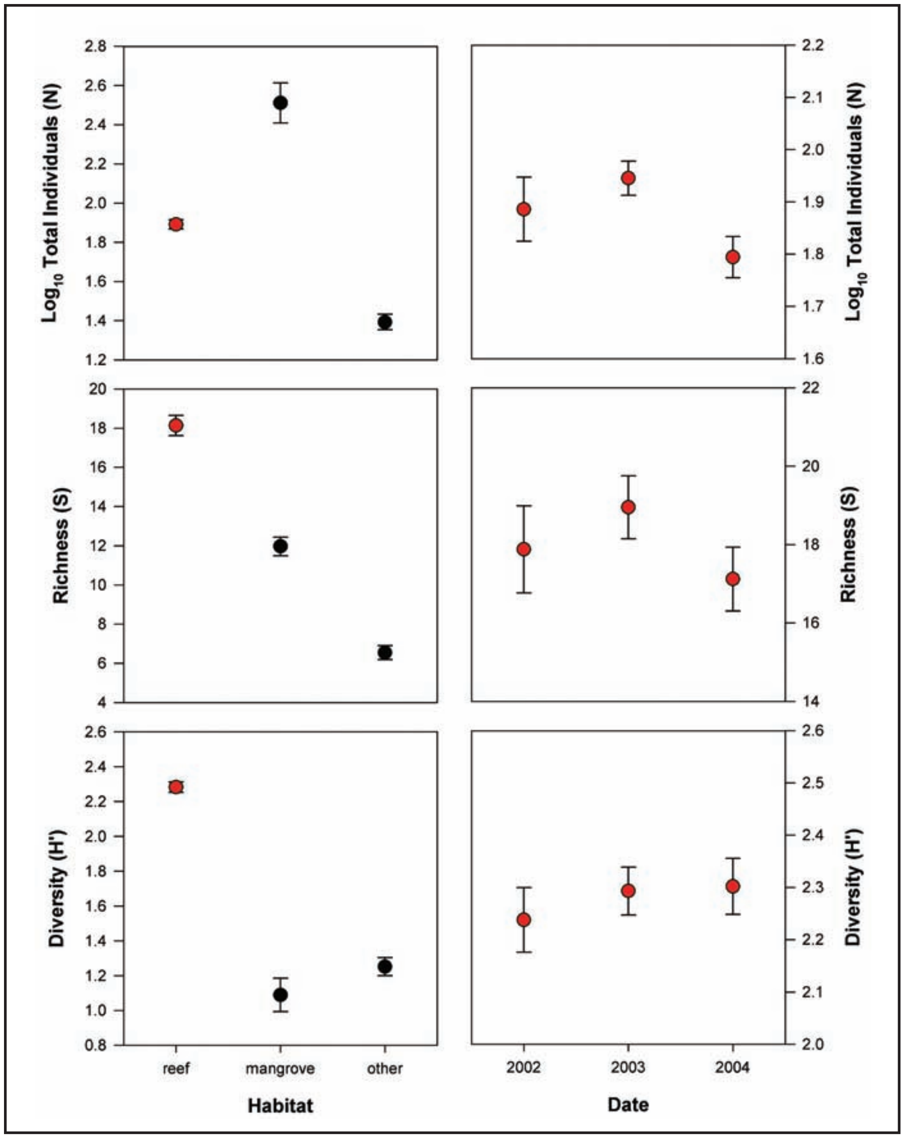

Figure 5.22. Comparison of fish community structure estimates by habitat type (left panels). Data collected in reef habitat is broken out by year (right panels). Source: CCMA-BT, unpublished data.

Measures of fish community structure (abundance, species richness, and species diversity) were markedly different among the habitat types sampled (reef, mangrove, and other substrates), with reefs exhibiting highest overall species diversity (r^2=0.50, p<0.0001) and richness (r^2=0.53, p<0.0001). Mangroves exhibited highest mean log-transformed abundance when compared to all other habitat types (r^2=0.42, p<0.0001), with relatively low average species diversity (Figure 5.22). When measures of community structure were compared among years for all coral surveys, no statistically significant differences were observed. The average total number of individuals per reef census, however, has declined since 2002, while species diversity during this same period has increased (Figure 5.22). This may indicate that the declining abundances of several once numerically dominant reef species (e.g., grunts; Figure 5.23), coupled with a relatively stable level of species richness, has resulted in increased diversity.

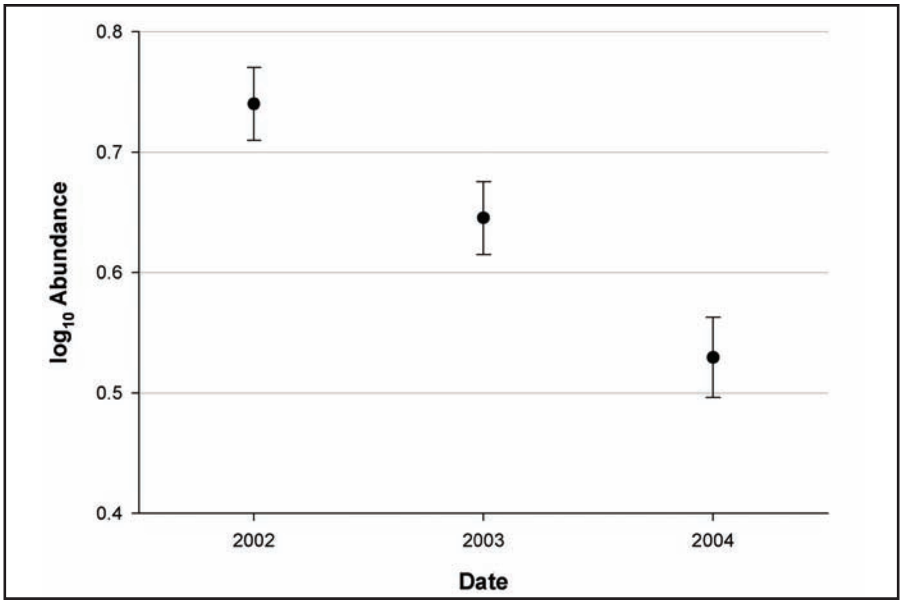

Figure 5.23. Comparison of log-transformed abundance of grunts (family Haemulidae) among years. Model is significant (p=0.02), with abundances in 2003 and 2004 lower than in 2002. Source: CCMA-BT, unpublished data.

Results of the CCMA-BT monitoring activities clearly indicate that fish community structure is different among the various habitats that comprise the coral reef ecosystem in southwestern Puerto Rico, and further corroborate findings by Christensen et al. (2002). It is important, however, to understand that many species in the region require several habitat types throughout their life-histories for growth and reproductive success. Furthermore, these data suggest that preserving a mosaic of habitats is critical to managing significant numbers of fish species that are associated with coral reefs as adults. An analysis of frequencies (correspondence analysis/reciprocal averaging) using data collected since 2002 indicated that many snapper (family Lutjanidae), grunt (family Haemulidae), and wrasse (family Labridae) species exhibit clear ontogenetic shifts in patterns of habitat utilization. For example, lane snapper (*Lutjanus synagris*) less than5 cm fork-length disproportionately inhabit seagrass meadows, and then move into the cover provided by mangrove prop roots (from 5-15 cm). *L. synagris* larger than 15 cm subsequently move from this refuge to reef sites along the entire shelf (Figure 5.24). This is just one of many examples that underscores the need for continued monitoring of reef fish populations in all component habitats of the coral ecosystem.

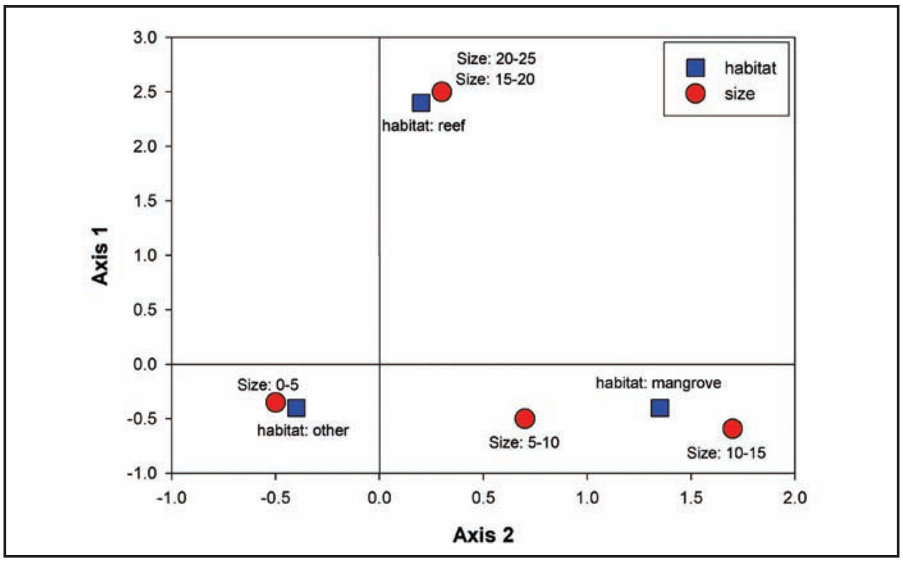

Figure 5.24. Results of correspondence analysis of lane snapper size class distributions among habitats monitored in southwestern Puerto Rico, 2002-2004. Source: CCMA-BT, unpublished data.

Coral reefs exhibited the highest number of species and the highest average diversity among all of the habitat types monitored. Measures of habitat characteristics, particularly topographic complexity (measured as rugosity) and percent live coral cover, were important determinants of fish abundance, richness, and diversity. Figure 5.25 shows the relationships between fish community structure and percent live coral coverage. Each parameter exhibited a statistically significant relationship (log_{10} abundance, r^2=0.48, p<0.0124; richness, r^2=0.69, p<0.0008; diversity, r^2=0.70, p<0.0044), with reef sites characterized by higher live coral cover having significantly higher parameters of fish community structure. It is important to note that the average percent live coral cover measured at 151 reef sites since 2002 is 3.22%, and has not changed significantly since then. A second component of reef habitat that appears to impact estimated parameters of fish community structure is rugosity. Figure 5.26 shows this strong correlation, which indicates that rugose (i.e., more structurally complex) reefs support more fish species (r^2=0.69, p<0001).

CCMA-BT coral reef ecosystem monitoring activities in southwestern Puerto Rico since 2002 indicate that parameters of fish community structure have not changed significantly over the past three years; however, several species of reef fishes have exhibited a decline in abundance (e.g., Haemulids). Community structure is significantly different among habitats within the seascape, and many species require one or more habitats for successful recruitment, growth, and reproductive success. As such, it is critical to consider the entire mosaic of habitats when managing coral ecosystems in Puerto Rico.

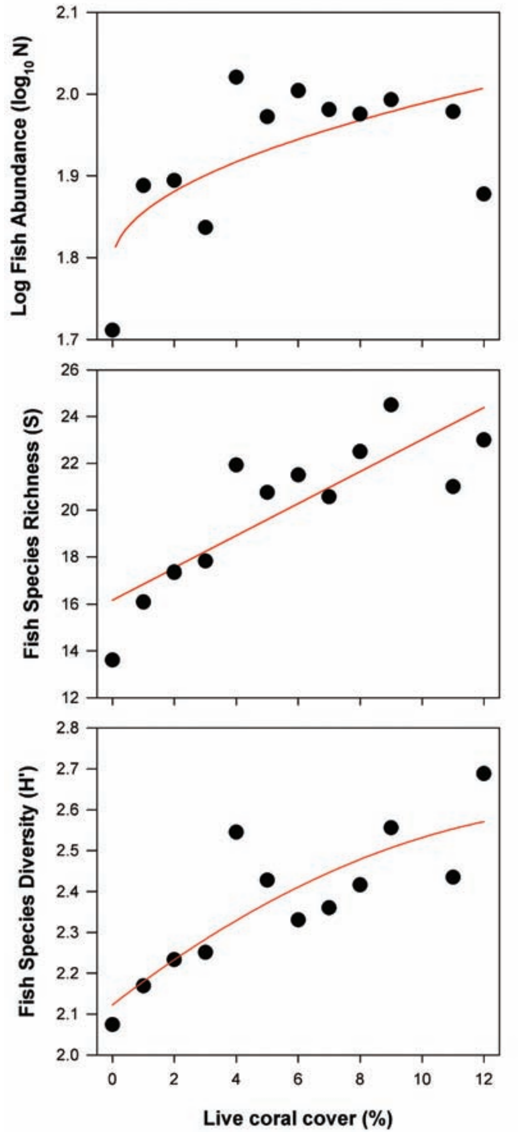

Figure 5.25. Comparison of log-transformed fish abundance, species richness, and diversity among reef sites classified by percent live coral cover, 2002-2004. Source: CCMA-BT, unpublished data.

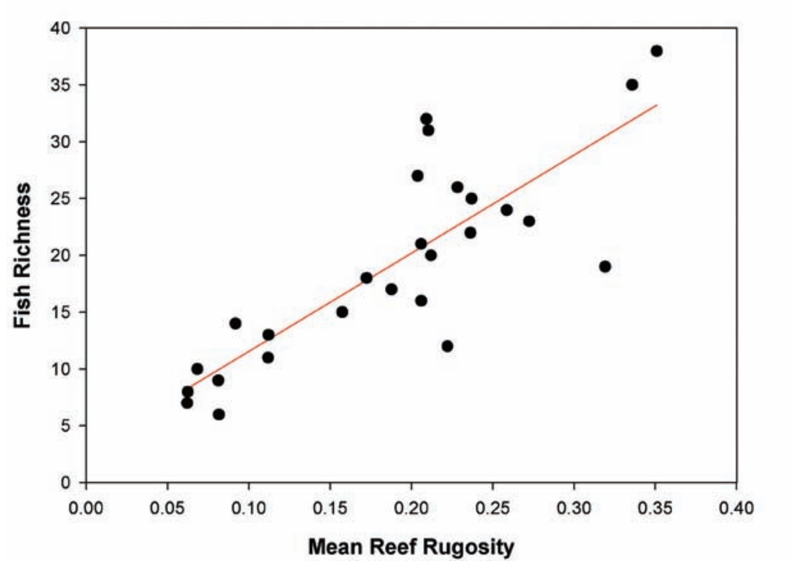

Figure 5.26. Results of regression between mean reef fish richness and mean reef rugosity, 2002-2004. Source: CCMA-BT, unpublished data.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

The purpose and priorities of the Coral Reef Monitoring Program for Puerto Rico were initially presented by the DNER to the U.S. Island Coral Reef Initiative of NOAA in 1997. The main objectives of the program were to map the geographical distribution of coral reefs, produce a baseline characterization of priority reef sites, and establish a monitoring program targeting a selection of high-priority reef sites. The monitoring program would provide information needed for effective resource management and public awareness, while constructing a scientific data base for long-term analysis of the coral reefs in natural reserves of Puerto Rico.

The benthic habitat maps of Puerto Rico and the USVI developed by NOAA in 2001 provided a valuable information source on the geographical distribution of Puertorrican reefs and other benthic habitats of the insular shelf. A more detailed physical assessment of benthic habitats using side-scan sonar technology has been produced for the reef system of La Parguera (Prada, 2002). These works corroborated and expanded upon an initial geographical inventory of Puertorrican reefs by Goenaga and Cintrón (1979). The initial work of Goenaga and Cintrón (1979) combined with studies on reef physiography and community structure (Cintrón et al., 1975; Canals and Ferrer, 1980; Canals et al., 1983) established criteria for designation of marine areas with coral reefs as natural reserves by the government of Puerto Rico. Still, there is a need for more specific physical and biological characterization of hard ground features of the insular shelf, preliminarily those classified as "linear reefs" and other hard ground habitat designations by NOAA (2000).

DNER has identified the natural reserves of Mayaguez Bay, Desecheo Island, Rincón, La Parguera, Bahía de Jobos, Ponce Bay, Cordillera de Fajardo and the islands of Culebra and Vieques as high-priority monitoring sites. Baseline characterizations for these reef systems were prepared by García-Sais et al. (2001a, b, c) and are available online at http://www.coralpr.net/index.php. The baseline characterization and monitoring for the LPCMFR was prepared by Hernández-Delgado (2003). The baseline characterization of the Tres Palmas Reef in Rincón is underway. This report includes monitoring data from a total of 12 reef sites under the U.S. Coral Reef Monitoring Program funded by NOAA and two additional reef sites monitored since 1999 as part of U.S. EPA 301(h) studies associated with operations of the submarine outfalls of the RWWTPs at Arecibo and Aguadilla, on the north and northeast coasts, respectively. La Parguera, on the southwest coast, is a CARICOMP monitoring site. The CARICOMP database is available online (CARICOMP, http://www.ccdc.org.jm/caricomp.html, Accessed: 12/29/04).

Public awareness and outreach programs focused on the ecological and socioeconomic value of Puerto Rico's coral reef systems have started in the form of special television presentations transmitted by the government television channel, WIPR, through the series "Geoambiente". An interagency committee directed to promote public awareness on the importance of coral reefs has prepared a local action strategy (LAS) to convey basic knowledge about coral reefs to secondary level students in the public education system. The plan integrates municipal governments and the tourism industry in an effort to promote awareness of human activities that negatively affect coral reef health. UPR's Sea Grant Program has played an important role in disseminating information geared toward the general public and local fishers based on scientific research regarding the ecological health of coral reef systems and associated fisheries in Puerto Rico. Educational brochures on marine life at highly impacted recreational reef sites at La Parguera and the LPCMFR have been produced and distributed.

The Caribbean Fisheries Management Council (CFMC) and the NOAA Fisheries office in Puerto Rico have collaborated with DNER scientists and management to significantly revise Puerto Rico's fisheries law. The new law is directed to protect the integrity of coral reef systems by regulating fishing activities through the implementation of catch quotas, establishment of no-take areas within three natural reserve sites (Culebra, Desecheo and Rincón) and seasonal fishing closures for overexploited species including red hind (*Epinephelus guttatus*), mutton snapper (*Lutjanus analis*) and queen conch (*Strombus gigas*).

Designations of coastal areas with extensive coral reef development as natural reserves by the DNER represents a first step towards conservation of Puertorrican coral reef resources. Natural reserves in Puerto Rico are regulated by restrictive zoning designations to protect the marine ecosystem from detrimental effects of activities occurring upstream in the watershed, such as the increased rates of terrestrial sediment runoff associated with soil movement during construction work. DNER has assigned personnel to enforce regulations applicable to the commercial and recreational utilization of marine resources within natural reserves.

The ever increasing pressure to develop the coastline into urban, industrial and tourist centers has dramatically influenced the modification of initial watershed zoning designations pertaining to many natural reserves in Puerto Rico. The trend is towards less restrictive zoning designations that allow for increased urban development within the watershed and open rural areas to tourism and commercial development. The effects have been a decrease in water quality due to increased sediment runoff and an exponential increase in the recreational utilization of marine resources. Water quality monitoring programs have been implemented to focus specifically on effects of submarine outfalls in the vicinity of Arecibo, Aguadilla, Carolina, San Juan and Ponce and thermoelectric power plant thermal discharges in the vicinity of San Juan, Guayanilla and Guayama.

Other activities underway include an evaluation of the status of organism collecting for the aquarium trade.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

The benthic habitat mapping effort by Kendall et al. (2001), in conjunction with the initial inventory of coral reefs by Goenaga and Cintrón (1979) and the most recent work by Prada (2002) in La Parguera, have provided important data on the geographical location of coral reefs and other benthic habitats in Puerto Rico. Continued field validations of this preliminary work will lead to more specific and accurate classification of the benthic habitats. A comprehensive baseline characterization of the main Puertorrican coral reefs has been produced. The database includes quantitative assessments of substrate cover by benthic categories and abundance estimates of fishes and motile megabenthic invertebrates from 28 reefs in Puerto Rico. Permanent transects allow for prospective quantitative monitoring of these reefs.

Reefs with the highest substrate cover of live corals were generally found at the leeward side of oceanic islands (e.g., Desecheo, Mona); at offshore islands within the Puertorrican shelf (e.g., Vieques, Culebra, Cayo Diablo); and associated with the mainland shelf-edge in the south (e.g., Derrumbadero), southwest (e.g., La Boya Vieja) and west coasts (e.g., Tourmaline). Boulder star coral, *Montastrea annularis,* is the dominant coral species in terms of substrate cover in reefs with relatively high coral cover. Great star coral, *Montastrea cavernosa, Siderastrea* spp., and *Porites astreoides* constitute the main coral assemblage of degraded reefs.

Year-round high water transparency and protection from extreme wave action are the main factors associated with healthy coral reef systems in Puerto Rico. Rivers represent the main sources of material loading to coastal waters of Puerto Rico, including pollutants in the form of suspended sediments, biological oxygen demand, chemical oxygen demand, fecal coliforms, heavy metals, and pesticides. Coral reef monitoring programs associated with the 301(h) RWWTP submarine outfall study in Aguadilla show that no major changes of live coral cover have occurred during the last four years of observations. The first monitoring cycle of reefs through NOAA's U.S. Coral Reef Monitoring Program in 2001 did not detect any major shifts in community structure, nor live coral cover in 16 of the 18 reefs studied. The second monitoring cycle (2004) is currently in progress. The marked decline of live coral cover from the reefs at the LPCMFR, combined with the outbreak of cyanobacterial colonization of reef substrate, was unprecedented and deserves further monitoring and evaluation.

A positive correlation exists between species richness of reef fishes and the percent of live coral cover in reefs around Puerto Rico. Coral reefs with high live coral cover generally exhibit relatively high abundance and a diverse assemblage of zooplanktivorous fishes (*Chromis* spp., *Clepticus* spp., *Stegastes partitus*), whereas coral reefs with low live coral cover numerically dominated by dusky damselfish (*Stegastes dorsopunicans*). Large, commercially important reef fishes have virtually disappeared from shallow reefs around Puerto Rico. Preliminary findings from the LPCMFR suggest that commercially important reef fishes are increasing in size and abundance within reserve boundaries.

Public awareness and outreach programs that educate the Puertorrican community about coral reef systems, the role they play in our society, and how they can be most effectively managed and utilized are underway by several organizations, including an interagency (DNER, CFMC, NOAA Fisheries, Sea Grant) effort to develop LASs and a weekly television program from the government channel, WIPR, entitled 'Geoambiente.'

The initial objectives of the U.S. Coral Reef Initiative Program for Puerto Rico, such as the mapping of benthic habitats (including coral reefs), the baseline quantitative characterization of coral reef communities, training of DNER personnel for coral reef monitoring, monitoring of reef sites, and the launching of a coral reef public awareness and outreach program have been fully addressed and achieved to a significant level due to the combined effort from local government, Federal agencies, public and private universities, and NGOs. It is time for evaluation of new priorities and re-definition of program goal objectives.

Recommendations

Recommendations for future management activities include defining and implementing a long-term coral reef monitoring program focused on a selected group of eight reef sites where baseline characterizations and previous monitoring is already available. The recommended sites include reefs within no-take MPAs (e.g., Desecheo, Tres Palmas, LPCMFR), shelf-edge reefs (Tourmaline, Boya Vieja, Derrumbadero), representative mid-shelf/coastal reefs that can be monitored cost-effectively (Media Luna, Caribes, Barca), and representative island reefs with high recreational potential (La Cordillera de Fajardo, Vieques) that are currently unprotected. Proposed coral reef monitoring sites and the region in which they are located include:

- Puerto Canoas/Puerto Botes Reefs - Desecheo
- Tourmaline Reef – Mayaguez Bay
- Boya Vieja/Media Luna Reefs – La Parguera
- Derrumbadero Reef – Ponce
- Caribes/La Barca Reefs – Guayama
- LPCMFR Reefs – Culebra
- Comandante/Esperanza/Mosquito Reefs – Vieques
- Tres Palmas Reef – Rincón
- La Cordillera Reefs – Fajardo

Field validation and classification of selected reef habitats as they appear in the benthic habitat map of Puerto Rico (Kendall et al., 2001) are required. The priority is to refine the classification of reefs as coral reef, hard ground, or rock reef habitats in order to validate area estimates of benthic habitats and their distribution within the Puertorrican shelf.

In addition, exploratory surveying, mapping, and monitoring of deep coral reef systems within the 30-50 m depth range is needed. Preliminary surveys indicate that deeper water reefs exhibit exceptionally high live coral cover and rich biological communities, particularly within deep sections of the eastern and western shelf of Puerto Rico.

Management activities must also be supported with an increased effort to raise public awareness and develop outreach activities on coral reef ecology and resource conservation, focusing on fishers and communities adjacent to natural reserves. It is also recommended that the topic of coral reef ecology and resource conservation be incorporated into the science curriculum at all educational levels in Puerto Rico. Guidelines for recreational use of coral reefs and associated ecological systems within natural reserves are needed and should be widely disseminated.

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The State of Coral Reef Ecosystems of Navassa Island

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INTRODUCTION AND SETTING

Navassa Island is a small, uninhabited, oceanic island approximately 50 km off the southwest tip of Haiti (Figure 6.1). It is under the jurisdiction of the U.S. Fish and Wildlife Service (USFWS) as one component of the Caribbean Islands National Wildlife Refuge (NWR). Based on some preliminary quantitative surveys in 2000, and because of its isolated and uninhabited status, Navassa has been presumed to provide a relatively pristine end member for reef status in the Caribbean (Miller and Gerstner, 2002). Local land-based anthropogenic pollution and recreational uses are essentially absent. Thus, Navassa reefs may provide valuable insight regarding Caribbean coral reef structure and function. However, there is substantial but unquantified fishing activity at Navassa by transient Haitians and their impact has been suggested to be substantial (Collette et al., 2003) and potentially rapidly increasing (Miller and Gerstner, 2002).

Navassa is a raised dolomite plateau ringed by vertical cliffs. For most of the Island's circumference, these cliffs reach straight down to approximately 25 m depth where a submarine terrace slopes out gradually. In limited areas around the northwest point and at Lulu Bay, the island has small shoulders of shallow reef habitat (10-15 m). The primary reef habitats are: 1) reef walls (formed by the cliffs); 2) large boulders that have been dislodged from the cliffs; 3) scattered patch reefs and hardbottom areas on the 25-30 m terrace; and 4) deeper reef slopes (>30 m) farther offshore that have not been well described. Navassa's oceanic position in the Windward Passage exposes it to substantial physical energy. The East Coast bears the brunt of persistent swells and regular storms and hurricanes. The Island does not exhibit typical Caribbean patterns of reef zonation; inshore and backreef habitats including mangroves, sandy beaches, and seagrasses (important in the life history of several reef fish groups) are largely absent at Navassa.

Despite its status as a NWR, regulations are currently not enforced and fishing activity is unmanaged with no quantitative catch or effort data available. Substantial fishing activities are, however, undertaken by transient Haitian subsistence fishers and appear to have been ongoing since at least the 1970s. Qualitative observations suggest that rapid depletion of Navassa fishery resources is underway.

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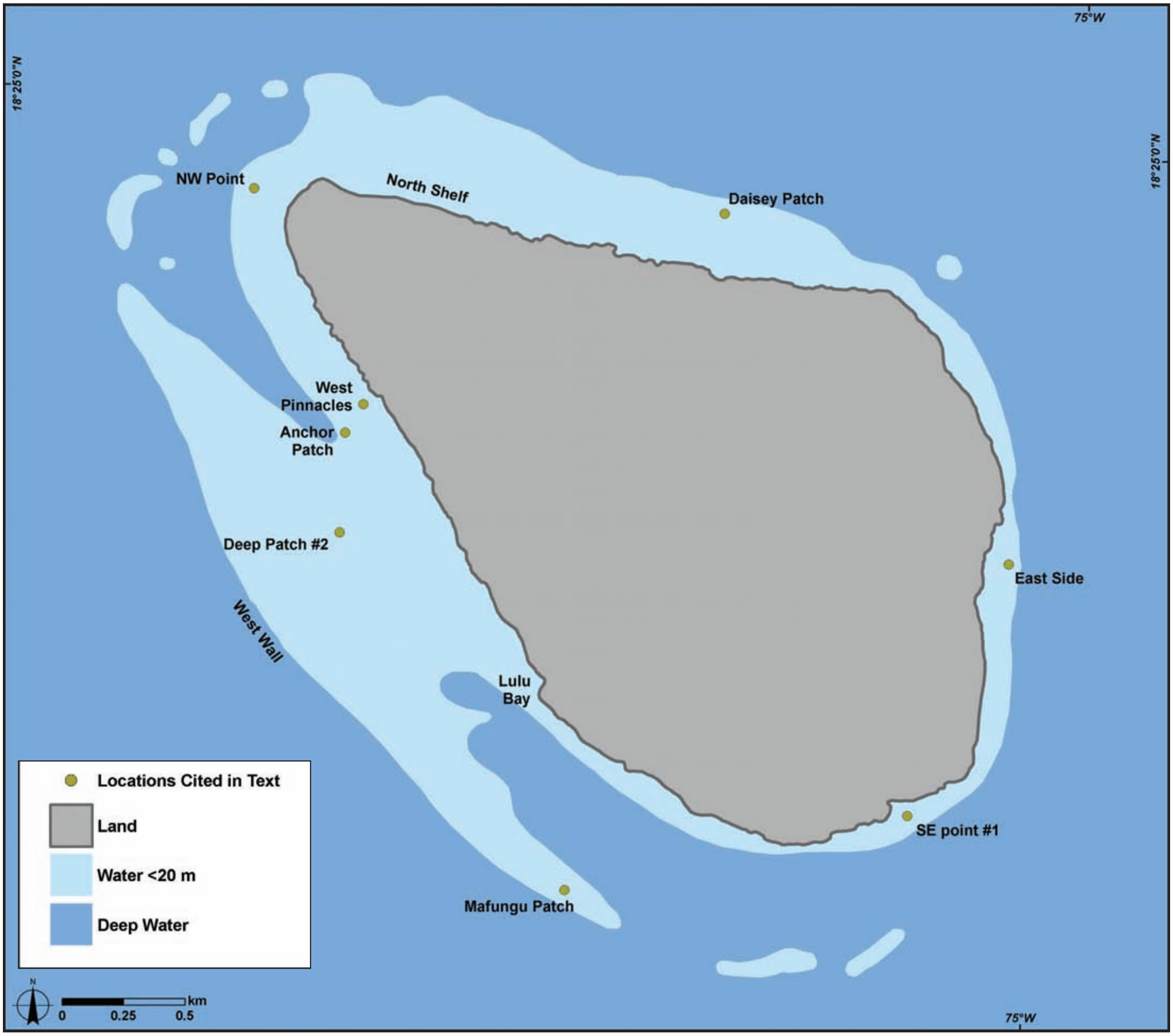

Figure 6.1. A map of Navassa Island showing locations referenced in this chapter. Map: A. Shapiro.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

No historic observations are available that are suitable for the evaluation of effects of climate change or episodes of coral bleaching. Much of the high coral-cover habitat, however, is in deep (18-30 m) waters exposed to strong currents and surge. This may provide some protection from elevated water temperatures.

Diseases

No diseased corals were noted in quantitative surveys that observed a total of 985 colonies at six shallow-water sites (<20 m). An unknown disease with an appearance similar to white plague, however, was observed on brain corals at some deeper reef sites. The quantitative surveys found an average of over 4% of coral colonies affected by predation and over 14% affected by competitive overgrowth by algae and sponges.

Tropical Storms

Navassa's oceanic position in the Windward Passage exposes it to substantial physical energy. The East Coast, in particular, bares the brunt of persistent swells, regular storms, and occasional hurricanes (Figure 6.2). However, no quantitative studies have been done on the effects of a particular storm.

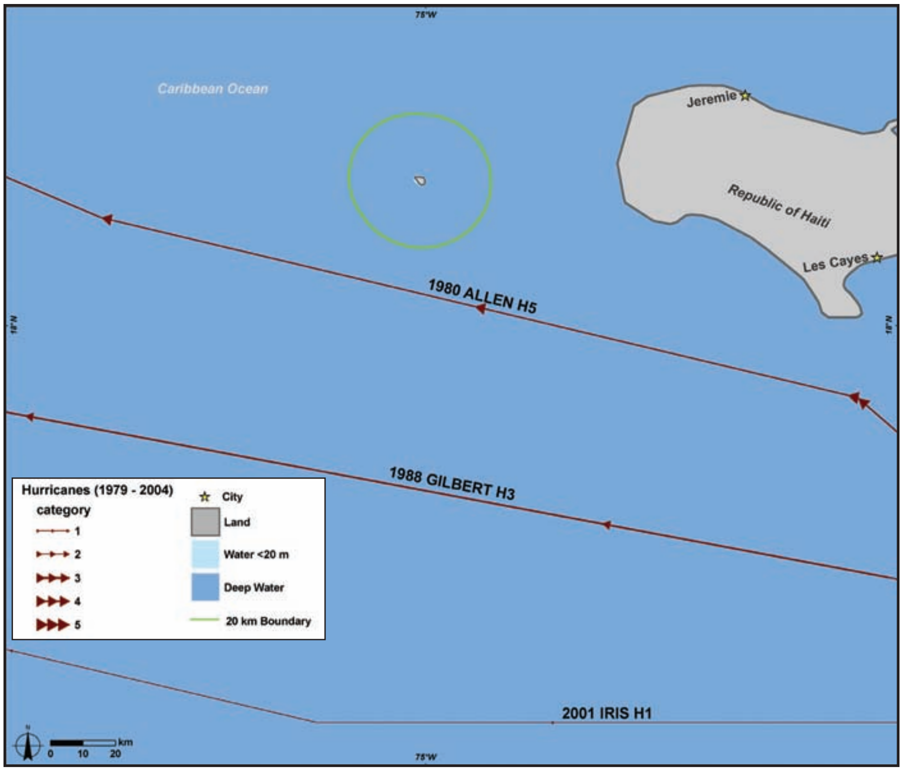

Figure 6.2. The path and intensity of hurricanes passing near Navassa Island. Year of storm, Hurricane name and storm strength on the Saffir-Simpson scale (H1-5) are indicated for each. Map: A. Shapiro. Source: NOAA Coastal Services Center.

Coastal Development and Runoff

Navassa is uninhabited, although Haitian squatters frequent the Island. With the exception of an old abandoned lighthouse building and cistern, there is no development on Navassa. Approximately 200 acres were burned in 2000 by transient Haitians and 5-7 acres were planted in corn, squash, and watermelon. Native vegetation is not fire adapted, so recovery rates are very slow.

Though there is no activity presently, there was an active terrestrial mining operation (guano and/or other phosphorus-rich deposits) on Navassa from the late 1800s through the turn of the century. The Navassa Phosphate Company acquired the Island in 1864 and invested $50,000 to establish a small town which had grown to include two dozen small buildings by 1889, although none remain today. It was estimated that one million tons of phosphate-bearing materials were removed from the Island by the mining operations subsequent to burning and vegetation removal to facilitate access to the mined material.

Coastal Pollution

Navassa is uninhabited.

Tourism and Recreation

There is no tourism or recreational use at Navassa. A Special Use Permit from the USFWS is required for entry.

Fishing

Despite its status as a NWR, fisheries at Navassa are effectively unmanaged as regulations are not well publicized and enforcement is nonexistent. Fishing activities are undertaken by migrant Haitian artisanal fishers, and these activities have been ongoing since at least the 1970s. Anecdotal evidence suggests that some technological escalation in Navassa fisheries occurred between 1997 and 2000. While no motors were observed in 1997, all of the vessels observed during the 2000 expedition had 10-15 h.p. motors. Quantification of catch or effort has not been undertaken for the Navassa fisheries, although deliberate qualitative observations were made during scientific expeditions in April 2000 (Miller and Gerstner, 2002) and November 2002 (Miller et al., 2003).

Fishing boats observed were wooden, 6-9 m in length, and manned by three to six fishers (Figure 6.3). In 2000, hook-and-line and Antillean Z-traps were observed whereas in 2002, the additional use of nets was observed. The adoption of net fishing corresponded with exploitation of new species, particularly queen conch (*Strombus gigas)* and Hawksbill sea turtles (*Eretmchelys imbricata).* Finfish catch appeared unselective and included predominantly small (<30 cm, most <20 cm) fishes including trunkfish, ocean triggerfish, surgeonfish, and bar jack (Miller et al., 2003). Ancillary effects of this artisanal fishing include a system of makeshift moorings and rock anchors which are deployed at Lulu Bay, one of three sites around the island with an extensive stand of elkhorn coral (*Acropora palmata;* Figure 6.4).

Figure 6.3. Typical Haitian boat and fishers, fishing with hook-and-line at Navassa in 2002. Photo: M. Miller.

The extent to which larger commercial fishing vessels operate in Navassa waters is not known. Observations of larger Cayman- and Dominican-flagged fishing vessels as well as a recreational vessel from Florida have been made at Navassa (J. Schwagerl, pers. obs.).

Trade in Coral and Live Reef Species

No such trade is known to occur on Navassa.

Ships, Boats, and Groundings

No vessel groundings are known or suspected around Navassa. However, it does lie in an exposed position in the Windward Passage, so future threat from shipping is not implausible.

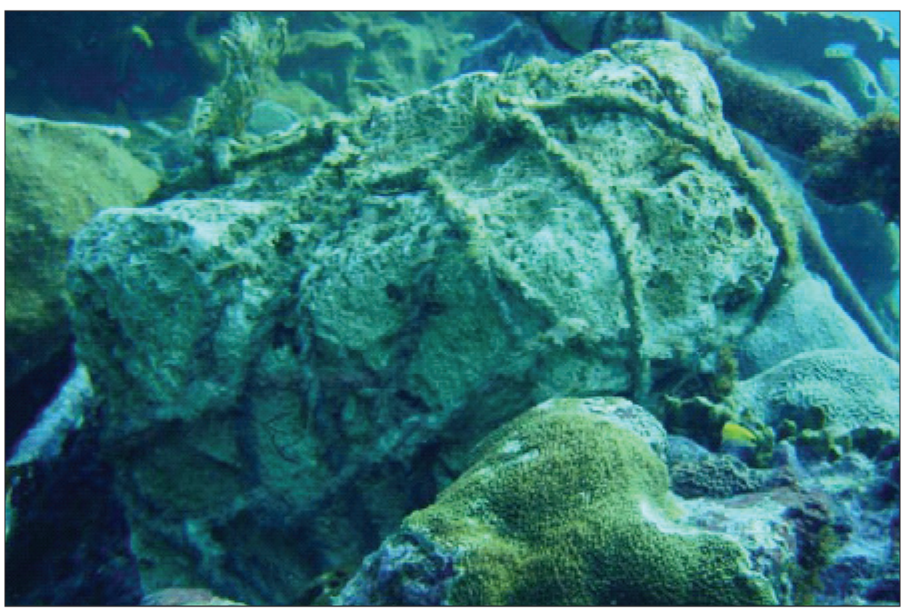

Figure 6.4. An example of a rock 'anchor' used by Haitian fishers. Photo: M. Miller.

Marine Debris

There is a small amount of marine debris (large tanks, metal debris) leftover from earlier mining activities on the Island (Figure 6.5) as well as from more recent fishing activities at Lulu Bay, the only landing site on the island. It is not known to what extent fish traps are lost and continue "ghost fishing" or are broken up, as no comprehensive survey of the mid-depth shelf (25-35 m) has been made. Whatever debris is present is likely to impose relatively large impacts given Navassa's high-energy environment and frequent exposure to storms.

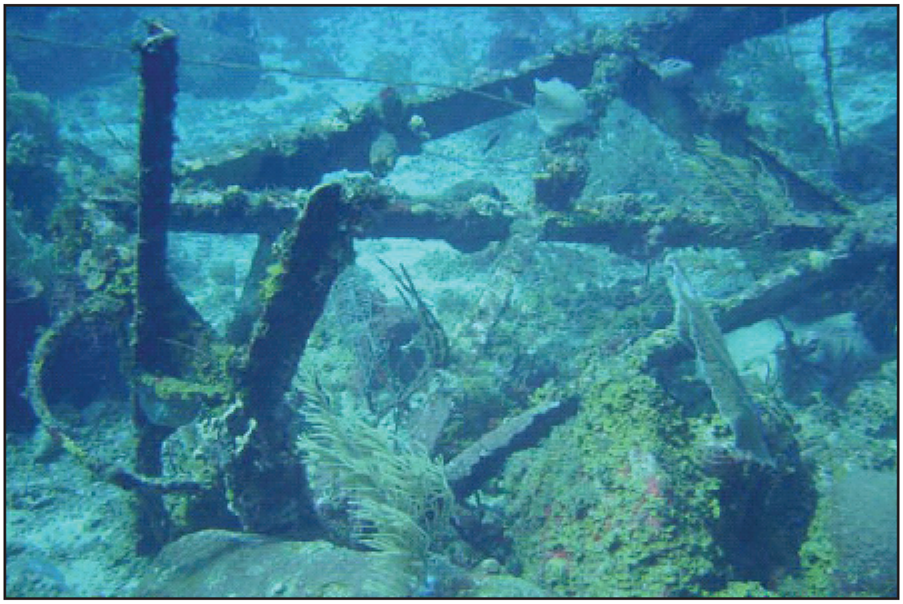

Figure 6.5. Debris remains of a former mining operation, circa 1900. Photo: D. McClellan.

Aquatic Invasive Species

No aquatic invasive species are known to occur at Navassa.

Security Training Activities

No military activities are undertaken at Navassa.

Offshore Oil and Gas Exploration

No oil and gas exploration activities occur at Navassa.

CORAL REEF ECOSYSTEM MONITORING EFFORTS AND RESOURCE CONDITION

Description of Local Coral Reef Monitoring Programs

There is no formal reef monitoring program for Navassa. The only quantitative reef status information available for Navassa has been obtained on individual cruises. Specifically, a cruise in April 2000 funded by the Center for Marine Conservation (now the Ocean Conservancy) in partnership with the John G. Shedd Aquarium, National Oceanic and Atmospheric Administration (NOAA) Fisheries, USFWS, and academic researchers focused on building a taxonomic inventory and conducting some limited reef assessments. More extensive assessments (as reported here) were performed in October and November 2002 during a cruise funded by NOAA Fisheries Southeast Fisheries Science Center, in partnership with U.S. Fish and Wildlife Service and academic researchers (Miller, 2003). The extent of data obtained in the 2002 cruise was greatly enhanced by the availability of nitrox diving (i.e., using a gas mixture different from compressed air) which allows extended bottom times for work in the mid- and deep-shelf habitats around Navassa (Figure 6.6).

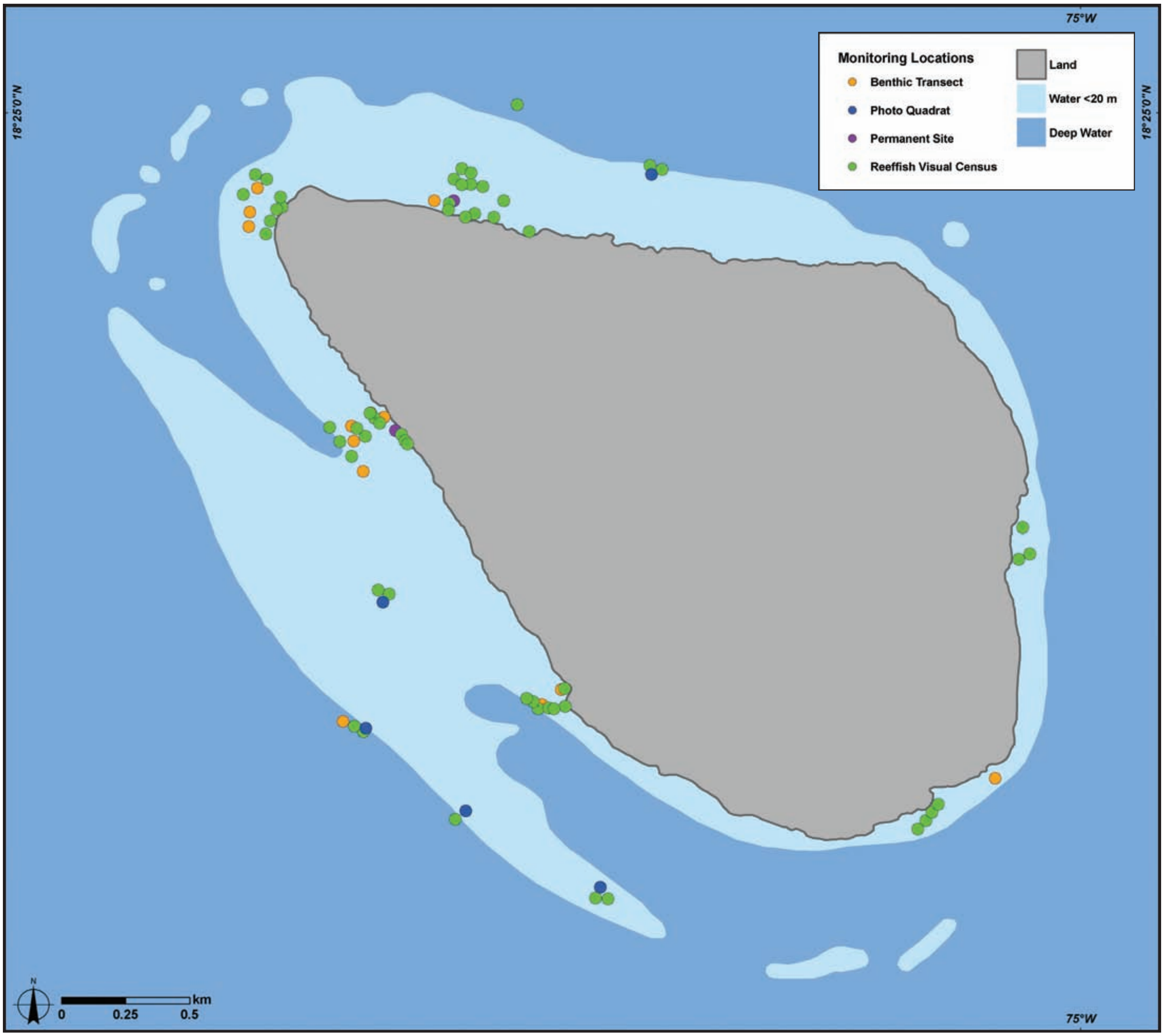

Figure 6.6. A map of the monitoring locations visited during recent scientific expeditions to Navassa. Map: A. Shapiro.

WATER QUALITY

There is neither data nor targeted monitoring regarding water quality at Navassa. Qualitatively, Navassa's oceanic position appears to afford it extremely high water clarity as well as strong currents and swells. Zooplankton density sampled in November 2002 was substantially lower than that measured in other Caribbean reef areas (Sandin, 2003). Also, a few targeted water samples taken in and around a small underwater cave during the April 2000 cruise suggested that at least some natural high nutrient input, perhaps a groundwater seep, was occurring on Navassa reefs (Figure 6.7).

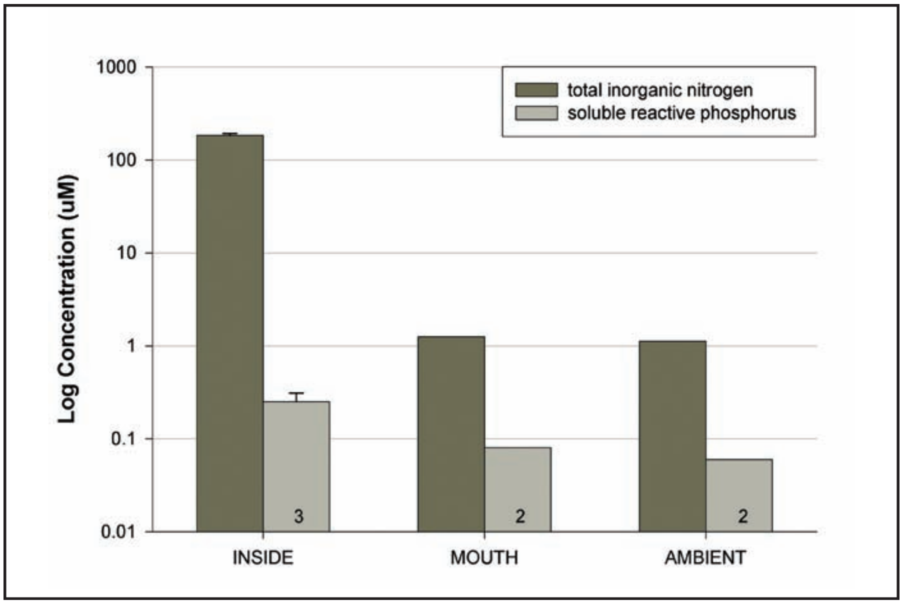

Figure 6.7. Dissolved inorganic nutrient concentrations (note log scale) in and adjacent to a cave along the western cliff of Navassa measured in 2000. Number of replicate analyses given in bars. Source: M. Miller, unpublished data.

BENTHIC HABITATS

Methods

Standard line intercept transects (15 m x one point sampled each 15 cm) were primarily used to estimate cover of primary community components (scleractinian corals, macroalgae, octocorals, sponges). In addition, a 1 m swath around this transect was used to estimate size and condition of coral colonies (diameter, height, presence of predators, disease, competitive damage) (Miller et al., 2003). Special attention was paid to crustose coralline algae and voucher specimens were collected for species level identification (Begin and Steneck, 2003). In deeper habitats (>20 m) where *in situ* transect sampling was not feasible due to bottom time constraints, ten haphazard 1 m^2 photo quadrats were taken and percent cover was later analyzed by superimposing dots on the image.

During the 2002 cruise, permanent monitoring quadrats were established to quantify scleractinian recruitment and survivorship. At each of two sites (15 m and 20 m depth), 15 1 m^2 permanent quadrats were marked with stakes and numbered tags. Photographs and *in situ* maps were made to indicate location of juvenile corals within quadrats. The *in situ* maps were used to annotate the photographs that will be used in subsequent surveys to assess persistence and growth of individual colonies.

Lastly, settlement plates (15 x 15 cm) were deployed (as part of a Caribbean-wide study by R. Steneck) to examine coral settlement in relation to colonization by crustose coralline algae.

Results and Discussion

The 2002 assessment included extensive survey of deeper shelf reef habitats (20-30 m). The percent cover by the dominant benthic groups for all sites is given in Figure 6.8.

Macroalgae (predominantly *Lobophora variegata* and *Dictyota* spp.) comprise the dominant benthic group overall, and a breakdown by genus is provided in Table 6.1. At several sites, however, (e.g., shallow shelf at Lulu Bay and several deep patch reefs), live coral cover was equal to or exceeded the cover of macroalgae. Live coral cover was highest (up to 46%) at the deep sites (25-30 m) including patch reefs and one site on the deep southwest dropoff. In shallower habitats (10-20 m), live coral cover was in the range of 10-20%. Live coral less than 10% (coinciding with extremely high macroalgal cover) was observed in sites with apparently intense disturbance regimes, including the East Coast; apparently scoured deep hardbottom habitats; and the "avalanche zone" observed at the North Shelf.

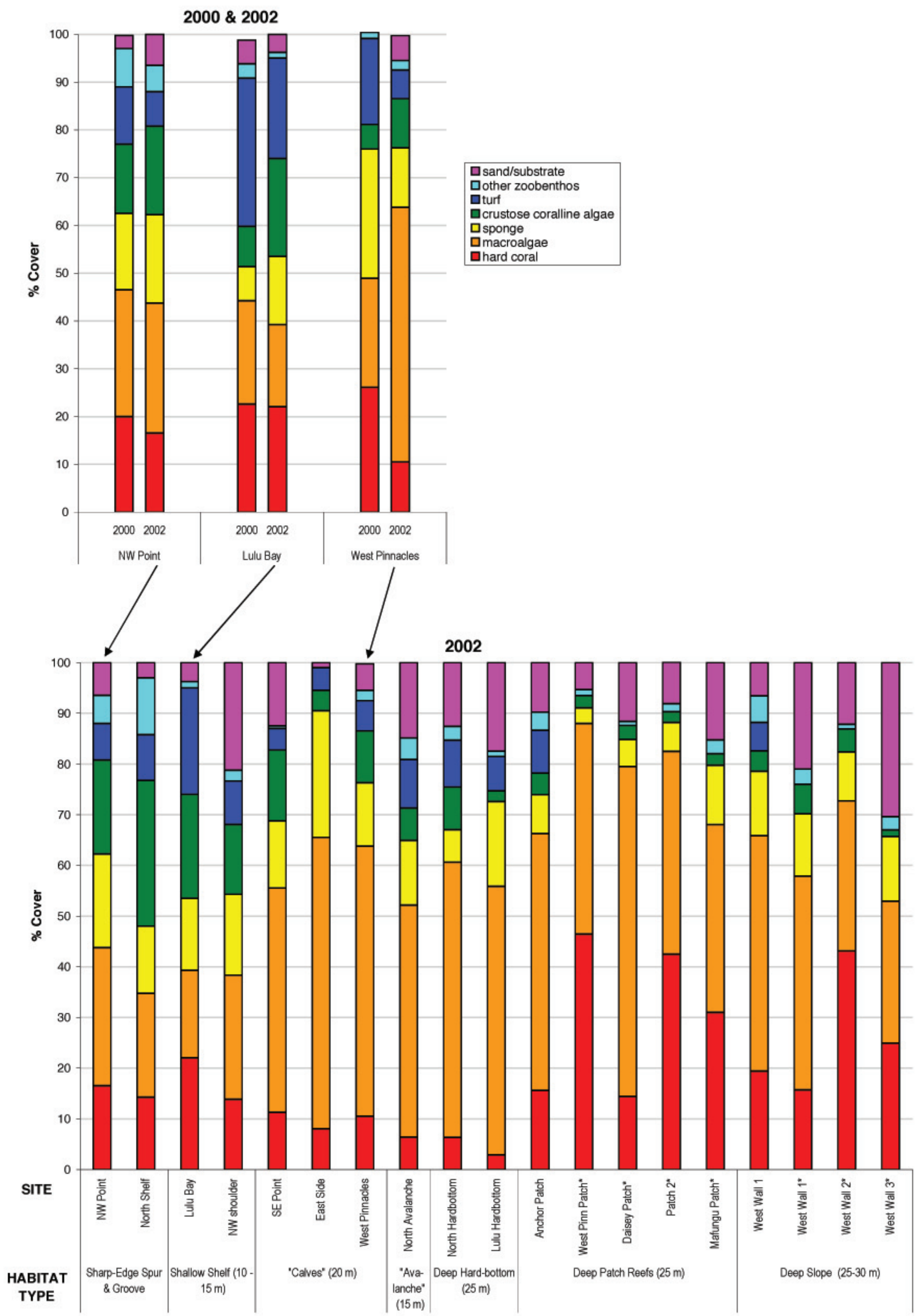

Figure 6.8. Lower panel: Community composition for all sites surveyed at Navassa in November 2002. Sites along the bottom axis with asterisk were surveyed by haphazard photo quadrats (n=8-15); others were surveyed *in situ* via point intercept transects (n=2-4 per site). Algal turfs were not resolvable from photographs. The "avalanche zone" is located on the north shelf, but is treated as a different habitat due to the level of disturbance. "Calves" are blocks of fallen rock from sea cliffs. Categories along the bottom axis indicate a priori habitat type classified according to depth and topography. Upper panel: Comparison with sites that were surveyed in April 2000. Source: Miller et al., 2003.

Table 6.1. Mean ± one standard deviation (SD) percent cover by genus for macroalgae at the six sites sampled by *in situ* line intercept transects. The first three sites are deeper sites (~20 m) while the last three sites are shallow reefs (<10 m) on the 'shoulders' of Navassa. All are n=4 transects except for the East Side, where n=2 transects. Source: M. Miller, unpublished data.

GENUS	EAST SIDE	SOUTHEAST PT.	WEST PINNACLES	LULU BAY	NORTHWEST PT.	NORTH SHELF
Halimeda	4	4.3(1.3)	15.5(6.8)	8.5(3.9)	9.8(4.5)	5.5(1.9)
Dictyota	35	15.8(6.2)	14.5(7.0)	5.8(1.7)	11.0(1.2)	12.0(4.1)
Lobophora	8.5	13.3(3.9)	22.3(8.0)	1.5(1.7)	6.0(3.5)	1.3(2.5)
Sargassum	6.5	8.5(10.4)	0.3(0.5)	0	0	0.3(0.5)
Stypopodium	3	1.3(1.0)	0	1.5(2.4)	0.5(1.0)	0.8(1.0)
TOTAL	**57**	**43**	**52.8**	**17.3**	**27.3**	**19.8**

Sponges covered 10-20% of the reef area at most sites. *Agelas spp.* was the dominant sponge taxa across habitats. Gorgonian density was relatively low (averaging <2 colonies per m^2 for the four shallow sites sampled) and a total of 21 spp. were observed.

At one site, algal cover had increased by 100% from 2000 to 2002 (25-50% cover), but was similar at two other re-sampled sites (Figure 6.8). It is not clear if this increase is attributable to seasonal effects (fall vs. spring). Little other change in benthic community structure was observed.

The relative composition of the coral community at deeper (>25 m) sites is given in Figure 6.9. The dominant coral taxa at these sites were *Montastraea* spp., *Agaricia* spp. and *Porites porites*. Overall, *Agaricia* spp. was the dominant component of the coral community in shallower sites.

The relative incidence of various coral conditions for a subset of shallow and mid-depth sites (10-25 m) is given in Table 6.2. A total of 985 colonies were examined for conditions including disease, impact of predators, and impact by competition with adjacent organisms. The most common condition was algal overgrowth where coral tissue was clearly affected was algal overgrowth, which was strongly correlated with overall macroalgal abundance among sites (r^2=0.55, n=6). A weaker relationship was found between sponge cover and incidence of sponge overgrowth damage on corals (r^2=0.27, n=6). Just over 4% of colonies on average showed signs of predation by snails, fire worms, or fish (Table 6.2). No colonies in this sample were observed with active disease although substantial impact of disease on brain corals (*Diploria* spp. and *Colpophyllia natans*) was observed in deeper sites.

Elkhorn coral (*Acropora palmata)* appears to be increasing in abundance. Substantial populations were observed at all three shallow reef sites (Lulu Bay, Northwest Point, and North Shelf) compared to the April 2000 observations when substantial *A. palmata* development was confined to Lulu Bay. Interestingly, genotyping of *A. palmata* colonies from all three sites indicates that asexual reproduction is absent at Navassa while sexual recruitment is effective (Baums, 2004). Also, the range of sampled colony sizes indicates that successful sexual recruitment is occurring repeatedly. In contrast, staghorn coral, *A. cervicornis*, remains rare and in poor condition.

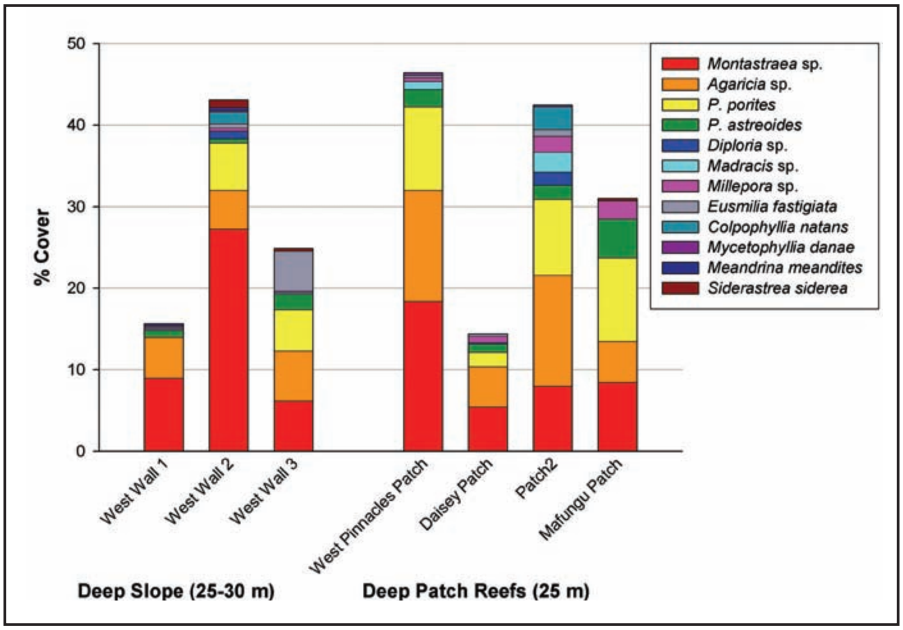

Figure 6.9. Coral species composition for deeper sites (>25 m) sampled via photo quadrats. Source: Miller et al., 2003.

Table 6.2. Percent of scleractinian coral colonies (>4 cm diameter) surveyed at subset of shallow sites (<20 m) that displayed various conditions. Overgrowth was designated only in cases where visible tissue damage was evident on the colony margins. "% w/snails" indicates the presence of corallivorous snail *Coralliophila abbreviata*; "% w/other predation" includes the presence of fishes and the fireworm, *Hermodice carunculata*. The only bleaching observed was mild (pale or splotchy appearance). Source: Miller et al., 2003.

SITE	# COLONIES	% W/ SNAILS	% W/ OTHER PREDATION	% W/ ALGAL OVER-GROWTH	% W/ SPONGE OVER-GROWTH	% W/ CORAL OVER-GROWTH	% W/ DISEASE	% W/ BLEACHING/ DISCOLORATION
NW Pt	185	0.5	1.6	5.4	1.6	0	0	2.2
North shelf	201	2.5	0	10.4	5	2	0	1.5
Lulu Bay	177	5.6	0	6.8	4.5	2.8	0	1.7
East Side	69	4.3	2.9	27.5	8.7	1.4	0	1.4
SE	179	2.8	0.6	7.8	4.5	2.2	0	1.7
West side	174	4	0	14.9	4.6	0	0	4
TOT/MEAN	**985**	**3.28**	**0.85**	**12.1**	**4.82**	**1.4**	**0**	**2.08**

Current threats to live coral include predation by the snail, *Coralliophila abbreviata*; invasion by the eroding sponge, *Cliona* sp.; and the presence of an unidentified disease affecting mainly brain corals (*Diploria* spp. and *Colpophyllia natans*). Densities of coral juveniles are similar to other areas in the northern Caribbean (e.g., United States Virgin Islands, Florida Keys, Jamaica). The crustose coralline algal flora is characteristic of one that is highly grazed (Begin and Steneck, 2003). Extended depth distributions were observed across diverse groups including elkhorn coral, benthic foraminifera (Williams, 2003), and crustose coralline algae (Begin and Steneck, 2003), with shallow water species being observed at much greater depths than typically observed for the Caribbean. This pattern is seemingly attributable to consistently clear waters surrounding Navassa.

ASSOCIATED BIOLOGICAL COMMUNITIES

Methods

Data on reef fish assemblages were collected using two complimentary methods (McClellan and Miller, 2003; Sandin, 2003). First, a stationary point sampling technique was used (Bohnsack and Bannerot, 1986). This fishery independent sampling and habitat characterization method, referred to here as the Reeffish Visual Census (RVC) approach, has been used extensively in the Florida Keys National Marine Sanctuary, Dry Tortugas National Park, and Biscayne National Park to provide baseline information and multispecies stock assessments of reef fishes (Ault et al., 1998, 2001, 2002). At each point, divers recorded fishes observed in five minutes within an imaginary cylinder extending from the surface to the bottom with a radius of 7.5 meters from the observer. Fish fork lengths (average, maximum, and minimum for each species) were estimated in centimeters by comparing fishes to a ruler attached perpendicular to the end of a scaled PVC rod. The observer also recorded new species to the sample, including rare or cryptic species, that were observed after the initial five minutes, along with estimates of length for selected species. Water temperature and visibility, presence or absence of fishing gear and artifacts, habitat characteristics, and numbers of marine turtles, spiny lobster (*Panulirus argus*), queen conch (*Strombus gigas*), and long-spined urchin (*Diadema antillarum*) were recorded if present in the sample area. For details, see McClellan and Miller (2003).

A second census technique was designed to accurately estimate the size distributions and standing crop biomass of the fish community, and to provide information on the reproductive and harvest potential from the location (Sandin, 2003). Thirty-seven 5 x 2 m quadrats were sampled between 10-30 m depths across Navassa. During a 12-minute sampling interval, one diver recorded the species and length of all site-attached fish present in a quadrat. Length was estimated to the nearest centimeter by sight and corroboration with direct measurement of nearby landmarks.

Mobile species were counted three times throughout the sampling interval, with counts taken each six minutes. The diver left the quadrat for one minute prior to the count, then recorded a scan sample of all fish in the column of water above the quadrat. Fast-moving fish were counted individually, noting species identity and length estimate. Lengths of fish were converted into biomass estimates based on published length-mass relations (available online at http://www.fishbase.org). The simple allometric function $M = \alpha L^{\beta}$ was used, where M is the mass of the fish, L represents fish standard length, and β and α are species-specific constants. Although this functional form is not ideal for estimating all size classes of a fish species, it provides an efficient size-specific mass scaling for this analysis. For species lacking specific allometric constants, parameters from a closely related, similarly shaped species were used. Final quadrat biomass estimates were calculated as the sum of all site-attached fish plus one third of the biomass of each fish counted in each of the three transient fish counts. The transient fish mass estimates thus were averaged across the three replicate scan samples. Fish densities and size-frequency distributions were equivalently computed as this weighted sum of resident and transient fish. This technique minimizes the overrepresentation of mobile species in long duration counts, yet still allows a reasonably efficient means to account for all types of fish on the reef.

Density of the long-spined sea urchin, *Diadema antillarum*, was quantitatively sampled in benthic transects described above. Lastly, population structure (size structure and sex ratio) of the corallivorous snail, *Coralliophila abbreviata*, was described based on animals collected haphazardly from a range of host coral species.

Results and Discussion

Navassa reef fish assemblages were numerically dominated by planktivores, which comprised 71% of all individual fishes in both census methods, and large size fish were virtually absent from the population structure of all species. This expedition added an additional 35 fish species to the 237 Navassa Island fish species reported by Collette et al. (2003).

One hundred and ten RVC samples were collected from around the Island (McClellan and Miller, 2003), and because of depth and bottom time constraints, only two samples could be taken per site. A total of 20,901 fishes representing 110 (and one unidentified) species (45 families) were recorded from these 110 stationary samples. The most abundant fish species, comprising 59.1% of the total number, were the blue chromis *Chromis cyanea* (n=4,912), creole wrasse *Clepticus parrae* (n=3,050), bluehead wrasse *Thalassoma bifasciatum* (n=2,950), and bicolor damselfish *Stegastes partitus* (n=1,449). Species with the highest frequency of occurrence from all of the samples were the blue tang *Acanthurus coeruleus* (88.2%), followed by the princess parrotfish *Scarus taeniopterus* (86.4%), redband parrotfish *Sparisoma aurofrenatum* (86.4%), bluehead wrasse (86.4%), bicolor damselfish (86.4%), and black durgon *Melichthys niger* (80.9%).

Only 12 individuals of larger grouper species (Graysby, red hind, yellowmouth, yellowedge, and tiger; no Nassau) were observed and 109 individuals of commercially important snappers were counted (8.6% of total biomass). Average size and density of grouper, snapper, and parrotfishes were substantially less in the more extensive 2002 survey than observed in 2000 at a subset of shallower habitats (Miller and Gerstner, 2002). Average length in the exploitable phase (>12 cm) of several fish families is given in Figure 6.10. Based on the second fish survey technique (weighted surveys of 37 5 x 2 m plots, Sandin, 2003), it was estimated that overall reef fish density was 5.6 ± 0.4 m^2 and overall fish biomass was 49.3 ± 4.6

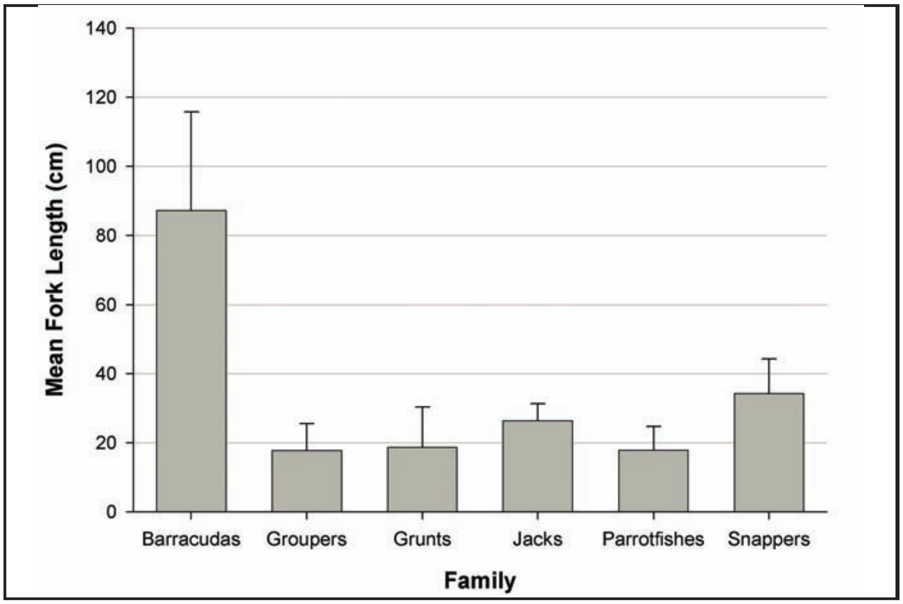

Figure 6.10. Mean lengths of selected families (in exploitable phase) observed in RVC samples. Family groups do not include individuals <12 cm that are too small to be captured with the fishing gear used (i.e., hook-and-line, traps, and nets). Source: McClellan and Miller, 2003.

g/m². For comparison, sampling via the same method in the Netherlands Antilles yielded biomass estimates ranging from 114-185 g/m² on heavily fished reefs.

Within the censused quadrats, most fish were planktivores (70.8%), followed distantly by herbivores (17.8%). The remaining trophic groups each accounted for less than 5% of the community density. In units of biomass, planktivores were the dominant contributors to reef community (36.3%). Piscivores and herbivores were the next most massive guilds (28.9% and 24.7%, respectively). Browsers composed 7.8% of community mass, and the two groups of invertebrate feeders each composed less than 2% of the total biomass (Figure 6.11). Guild-specific length-frequency distributions help to reconcile the disparity between guild contributions to density and biomass (Figure 6.12). Across all sampled fish, the average total length (TL) was 4.6 cm and only 11 individual fish (of the 1,227 counted in this approach) were larger than 24 cm standard length. Microinvertivores, planktivores, and macroinvertivores were each smaller than the community mean, averaging 3.5, 4.1, and 4.1 cm TL, respectively. Herbivores, browsers, and piscivores were each larger than the overall mean length (5.1, 8.6, and 17.7 cm TL respectively).

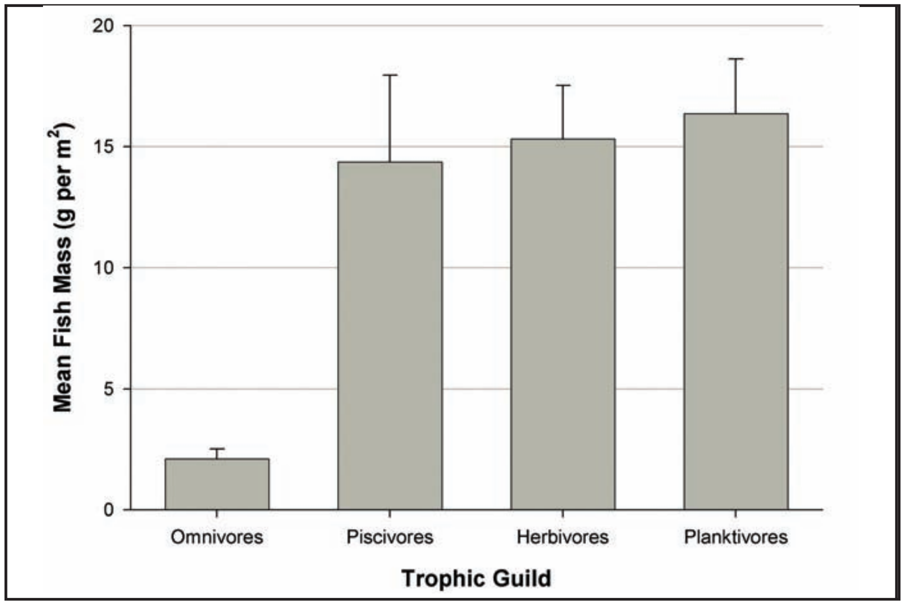

Figure 6.11. Diurnal fish biomass across trophic guilds. Averages and standard error (SE) were calculated from 37 10 m² quadrats. Fish were partitioned into trophic guilds based on the dominant food items consumed by adults. Source: Sandin, 2003.

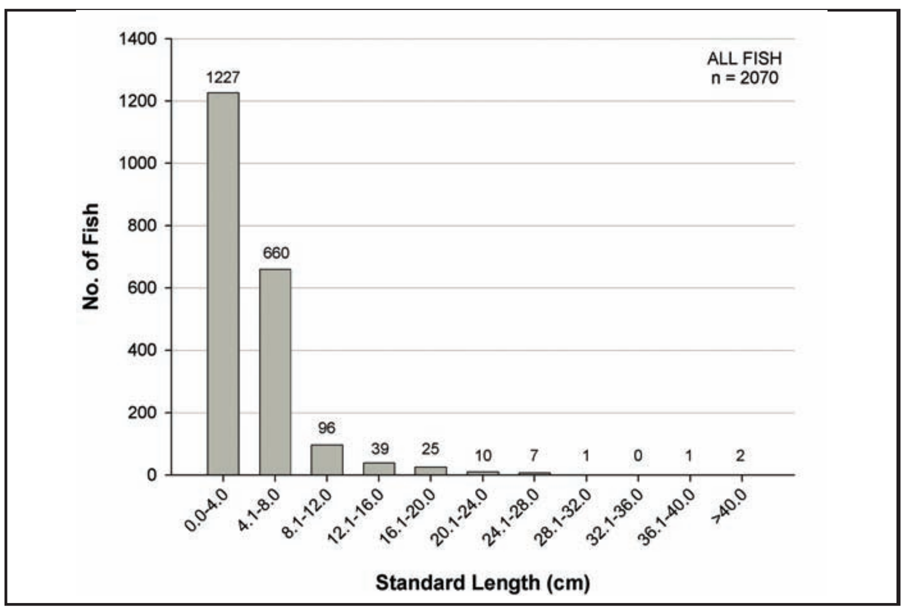

Figure 6.12. Fish community size frequency distribution observed via the weighted biomass surveys. Source: Sandin, 2003.

Quantitative transect surveys of *Diadema antillarum* at three shallow sites (7-10 m) and three mid-depth sites (17-25 m) showed they were present at mid-depth (0.16 ± 0.24 m²) and much rarer in the shallow reefs (0.02 ± 0.02 m²; Begin and Steneck 2003). A total of 18 *D. antillarum* were observed in the 110 five-minute RVC surveys across all habitat types (McClellan and Miller, 2003).

Table 6.3. Survey of the corallivorous snail, *Coralliophila abbreviata,* and its host corals: *Agaricia* spp., *Montastraea annularis* complex, and *Diploria* spp. from six sites around Navassa. Group size indicates the mean number of snails per colony. Source: Williams and Miller, 2003.

	SITE	TOTAL # HOST COLONIES (A)	TOTAL # INFESTED COLONIES (B)	OVERALL INFESTATION (=B/A)	AVERAGE GROUP SIZE
Agaricia spp.	North Shelf	98	4	4%	1.3
	NW Pt.	89	0	0%	–
	East Side	27	2	7%	5.7
	SE Pt.	78	5	6%	1.8
	W. Pinnacles	90	5	6%	1.8
	Lulu Bay	65	2	3%	1
	All Sites	**447**	**18**	**4%**	**2.2**
Montastraea annularis	North Shelf	5	1	20%	7
	NW Pt.	4	1	25%	4
	East Side	1	0	0%	–
	SE Pt.	13	0	0%	–
	W. Pinnacles	4	1	25%	5
	Lulu Bay	9	3	33%	2.3
	All Sites	**36**	**6**	**17%**	**3.8**
Diploria spp.	North Shelf	8	0	0%	–
	NW Pt.	3	0	0%	–
	East Side	1	1	100%	1
	SE Pt.	2	0	0%	–
	W. Pinnacles	0	0	0%	–
	Lulu Bay	27	5	19%	2
	All Sites	**41**	**6**	**15%**	**2**

Corallivorous snails, *Coralliophila abbreviata*, were found on *Agaricia* spp., *Montastraea* spp., and *Diploria* spp. to different degrees (Table 6.3) along transects in the shallower sites (<20 m). Relatively high infestation of the rarer host taxa (i.e., *Diploria* spp. and *Montastraea* spp.) compared to lower infestation of the numerically dominant *Agaricia* spp. (Table 6.3) suggests that some level of host preference is being expressed by these predators. Snails haphazardly collected from a range of host taxa showed substantial variation in mean size (Figure 6.13) and sex ratio consistent with reports from other areas of the Caribbean (Baums et al., 2003; Bruckner et al.,1997).

Although no quantitative data on queen conch, *Strombus gigas*, have been collected, intense harvest of mature conch populations was observed (Miller et al., 2003). Conch population structure should be a high priority for future data collection.

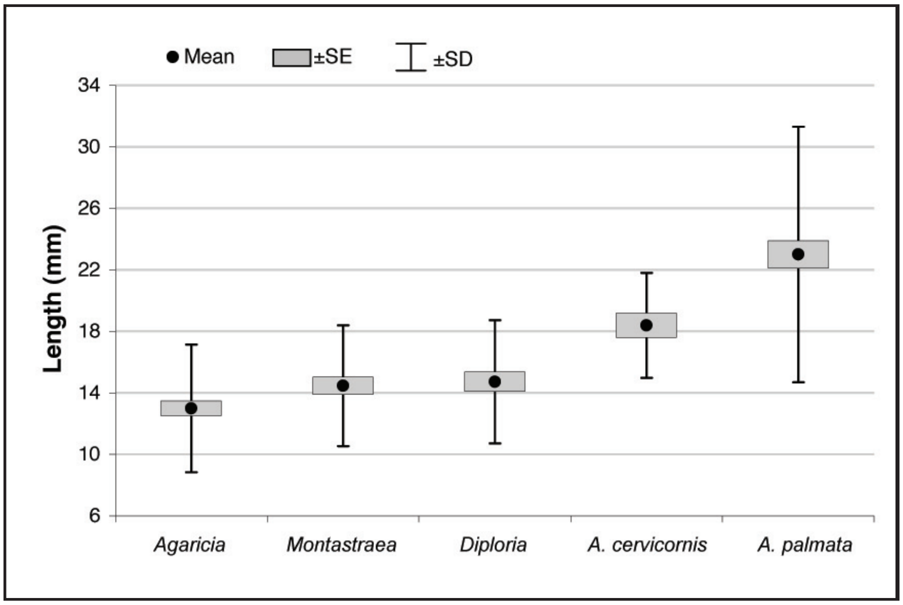

Figure 6.13. Box-whisker plot showing the mean, SE, and SD for snails collected from various coral hosts. Source: Williams and Miller, 2003.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Navassa Island and a 12-mile radius of marine habitat became the 517th NWR on April 22, 1999. Navassa is one of nine NWRs administered by the USFWS as part of the Caribbean Islands NWR complex and the only refuge encompassing marine habitat. The Refuge complex will begin comprehensive conservation planning in 2004 to produce a 15-year management plan for each refuge including Navassa. The planning process will be open to public participation and comment. Thus, while Navassa does not yet have an official management plan, annual expeditions to the Refuge have produced a substantial amount of biological information which will serve as the framework for the management plan.

Six expeditions have been made to the Island to date including two land-based trips. These trips concentrated on inventory and documentation of the flora and fauna of the Island and the establishment of vegetation monitoring plots. Hunting and camping on the Island by transient Haitian fishermen have led to frequent wildfires which have been detrimental to the maintenance of forest habitat necessary for migratory songbirds and nesting seabirds.

The four marine expeditions to date have involved partners including NOAA Fisheries, U.S. Geological Survey, Ocean Conservancy, Shedd Aquarium, American Museum of Natural History, Smithsonian Institution's National Museum of Natural History, and various universities. Permanent transects have now been established around the Island to monitor changes in invertebrate and coral abundance and diversity.

Fishing pressure involving hand lines and traps by transient Haitians has been a concern since 1998. General observations have led to additional questions and further assessment and quantification is needed. The logistical difficulties involved in visiting the Island, language barriers, and international politics are all management handicaps. The USFWS has been fortunate to have so many dedicated partners who have facilitated trips to the Refuge and have contributed much of the research effort. It is hoped that annual expeditions to the Refuge will continue and that additional partners, including Haitian nationals, will be recruited.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

Navassa Island NWR encompasses approximately 290,000 acres of marine habitat in the heart of the Caribbean. Declining coral reef habitat conditions throughout the Caribbean underscores the conservation importance of this Refuge's marine ecosystem. Multinational fishing pressure within this largely marine refuge remains unquantified, but certain. Continuous heavy fishing pressure in the immediate vicinity of the Island appears to be having deleterious effects on coral reef ecosystems. Immediate implementation of systematic monitoring is needed to document ongoing changes. Of particular importance is the collection of quantitative fishery data including catch and effort information. This effort needs to include catch of the critically endangered Hawksbill sea turtles. Regular funding for the Navassa Island NWR is necessary for the accomplishment of this critical conservation effort.

While fishing is clearing having a strong impact on Navassa reef ecosystems, Navassa's small size and high physical disturbance regime imply that its communities will show strong temporal variation. The interpretation of "snapshot" surveys of reef condition is problematic and therefore subsequent periodic surveys must be undertaken at Navassa in order to draw meaningful conclusions regarding possible trends in reef condition.

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The State of Coral Reef Ecosystems of Florida

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INTRODUCTION AND SETTING

Florida is located at the convergence of the subtropical and temperate climate zones (Chen and Gerber, 1990). The Gulfstream (a warm-water boundary current) has a major influence on water temperature and the transport of flora and fauna to the region (Jaap and Hallock, 1990). The Gulfstream intrudes into the Gulf of Mexico as the Loop Current and reverses flow to return to the Straits of Florida, joining the main body of the Florida Current before flowing in a northeasterly direction towards Europe. The influence of the Gulfstream together with the presence of a broad-shallow continental shelf around Florida and the absence of any major rivers have provided conditions for the development of extensive coral reefs (Figure 7.1). Most coral reefs are found in water less than 18 m deep. Rohmann et al. (in press) have estimated that 30,801 km^2 of shallow-water inshore areas around Florida could potentially support coral reef ecosystems. In comparison, the area estimated was 16.4 km^2 in Guam, 1,231.4 km^2 in the Main Hawaiian Islands and 2,207.6 km^2 in Puerto Rico.

Florida Reef Tract

The Florida Reef Tract, which extends from Soldier Key to Tortugas Banks, has coral reef characteristics similar to many areas in the Bahamas and Caribbean Basin (Vaughan, 1914). The undeveloped coastal fringe includes extensive mangrove forests and a mosaic of exposed rock and sediments. Elevated rock formations support coral reef development and the sediments support the most extensive seagrass beds in the world (Fourqurean et al., 2002).

Three types of coral reef habitats found in the Florida Keys are hardbottom, patch reefs, and bank reefs (Table 7.1). Hardbottom or live bottom habitat is the most extensive habitat type, found at a wide range of water depths and characterized by rock colonized with calcifying algae (e.g., *Halimeda* spp.), sponges, octocorals, and several species of stony coral. Local environmental conditions determine the composition of the communities that colonize the rock. Patch reefs typically consist of massive stony corals, with the boulder star coral (*Montastraea annularis*) being most dominant. Other common foundation-building species include *Colpophyllia natans* and *Siderastrea siderea*. Patch reefs are concentrated in north Key Largo, Hawk Channel between Marathon Key and Key West, and the area off Elliott Key. Species diversity and richness of stony corals are highest in patch reef habitats (Jaap et al., 2003). Bank reefs are the most seaward of coral reef habitats in the Florida Keys coastal ecosystem and are frequently visited by recreational scuba divers and snorkelers. Their principal unique feature is the spur-and-groove system, a series of ridges and channels built primarily by elkhorn coral (*Acropora palmata*) (Shinn, 1963). Spur-and-groove systems occur in depths ranging from a few centimeters to 10 m. In deeper waters, spur-and-groove formations may continue seaward as very low relief structures. Often, this type of habitat is referred to as the forereef and may continue to about 30 m in depth. Seaward, sediments separate the fore-reef from deeper reef formations at a depth of about 40 m.

1 Florida Department of Environmental Protection
2 NOAA, Center for Coastal Monitoring and Assessment, Biogeography Team
3 Broward County Environmental Protection Department
4 Florida Fish and Wildlife Conservation Commission
5 NOAA Fisheries, Southeast Fisheries Science Center
6 Nova Southeastern University Oceanographic Center
7 National Coral Reef Institute
8 Florida Keys National Marine Sanctuary
9 NOAA Ocean Service, Special Projects Office
10 U.S. Environmental Protection Agency, Gulf Ecology Division
11 University of Miami, Rosenstiel School of Marine and Atmospheric Sciences
12 Reef Environmental Education Foundation

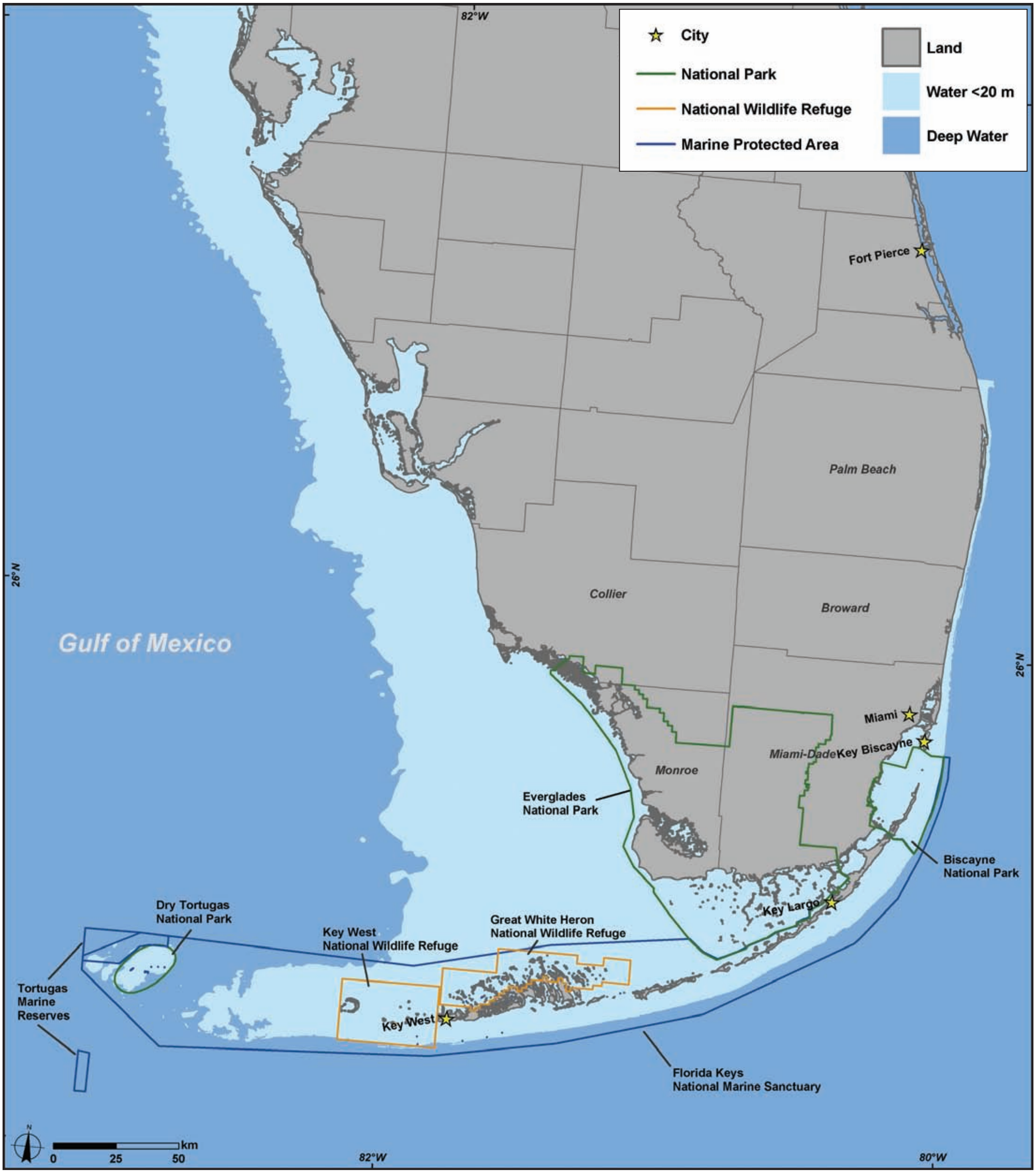

Figure 7.1. Locator map for Florida. Map: A. Shapiro.

Tortugas Banks

The Tortugas Banks are coral reefs that developed on a foundation of Pleistocene karst limestone at depths of 20-40 m. The banks are extensive with low coral diversity, but high coral cover. The most conspicuous coral is *Montastraea cavernosa,* and black coral (Antipatharia) are common on the outer bank edges. The banks are also used by groupers and snappers that support a major fishery.

The Southeastern Coast

This reef system continues the Florida reef tract northwards and runs from northern Monroe County to Martin County in a series of discontinuous reefs paralleling the shore. Duane and Meisberger (1969) and Goldberg (1973) defined the habitat including corals at several locations. Moyer et al. (2003) investigated the ecological and spatial patterns of the benthos on various reefs of Southeast Florida (Broward County; Figure 7.2).

Table 7.1. Habitat area estimates for the Florida Reef Tract. Source: FMRI 1998.

TYPE OF REEF HABITAT	HECTARES	KM^2	ACRES
Hardbottom	82370	824	203540
Patch Reef	3370	34	8330
Bank Reef	29550	295	73010
Total coral reef estimate	115290	1153	284880
Seagrass	292520	2925	722840

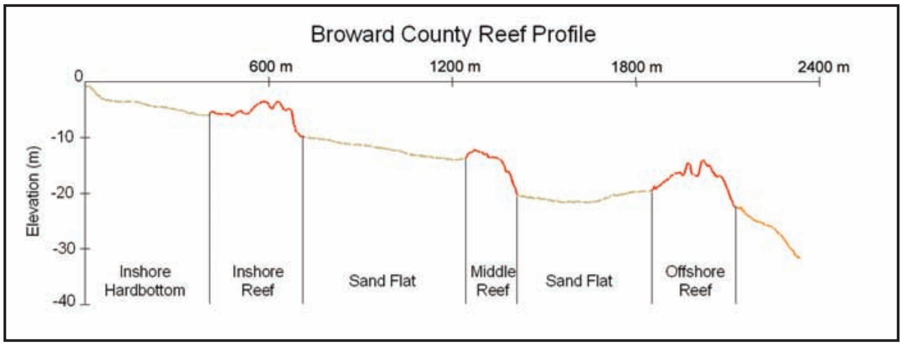

Figure 7.2. A reef profile along a shore-perpendicular transect of high resolution bathymetry data from 0-30m depth off central Broward County. The x-axis represents distance from shore in meters and y-axis represents elevation in meters. The seafloor of the profile is categorized in the sections below the profile line. The red line along the profile represents the three main shore-parallel reef tracts. Source: R. Dodge, National Coral Reef Institute, http://www.nova.edu/ocean/ncri/, Accessed 1/6/2005.

In addition to nearshore hardbottom areas, there are generally three lines of reef – one that nominally crests in 3-4 m of water (inner reef), another in 6-8 m (middle reef), and a third in 15-21 m (outer reef). A series of ridges that are not reefal in origin occur on the shoreward side of inner reef areas (Moyer et al., 2003).

Inner reefs are characterized by macroalgae and numerous small octocorals. The substrate is relict reef of Anastasia Formation limestone and worm reef (*Phragmatopoma* spp.), with breaks and sediment pockets within the reef. Typical sessile organisms are lesser starlet coral (*Siderastrea radians*) and colonial zoanthids (*Palythoa mammilosa* and *P. caribaeorum*). In the past few years, vigorous recruitment of staghorn coral (*Acropora cervicornis*) have occurred, and some extensive aggregations are now present generally inshore of inner reefs in Broward County. Here, monospecific stands of coral form significant habitats (Vargas-Ángel et al., 2003). Spawning activity has been documented in late July to early August (Vargas-Ángel and Thomas, 2002; Vargas-Ángel et al., in prep.).

Middle reefs have more relief and dissecting channels. Octocorals are most conspicuous, with densities of more than 30 per m² in some areas. Abundant stony corals include great star coral (*Montastraea cavernosa*), massive starlet coral (*Siderastrea siderea*), and mustard hill coral (*Porites astreoides)* (Gilliam et al., 2003).

The outer reef system often has stronger vertical relief and exhibits the highest diversity and abundance of sessile reef organisms. Octocorals and large barrel sponges (*Xestospongia muta*) are most conspicuous and visually dominate this reef. Stony corals are somewhat larger than those located on the middle reef. Moderate-sized colonies of star corals are common.

The reef system at St. Lucie Inlet Preserve State Park (27°05´ to 27°09´ N) is the northern limit for subtropical coral reefs on the east coast of Florida. The topography is composed of Anastasia Formation limestone that is covered with reef biota. *Diploria clivosa* forms very large pancake-like colonies and provides the majority of the cover. *Montastraea cavernosa* also attains large sizes. The other species present - *Siderastrea radians, Isophyllia sinuosa, Solenastrea bournoni,* and *Oculina diffusa* - are not large. Stony corals accounted for 3-5% of benthic cover at two 100-m transects (Herren, 2004).

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Coral reefs in Florida face a number of different stressors. These include coral bleaching, diseases, water pollution, physical impacts (such as groundings, dredging activities, and beach renourishment), tropical storms, and winter cold fronts. Other stressors of less concern in Florida include national security activities and trade in coral species.

Climate Change and Coral Bleaching

Coral bleaching due to exceptionally high water temperatures has been reported in Florida since the early 20th century (Vaughan, 1911; Mayer, 1918). Jaap (1979, 1984) also reported coral bleaching events in the Lower Keys following late summer doldrums when water temperatures exceeded 31ºC. Other significant and severe bleaching events on reefs throughout Florida occurred in 1987, 1990, and 1997-98 (Causey, 2001). These bleaching events have caused moderate mortality of the more sensitive stony corals, *Millepora complanata* and *Agaricia agaricites*. Bleaching episodes have become much more severe in space and time in the past few decades.

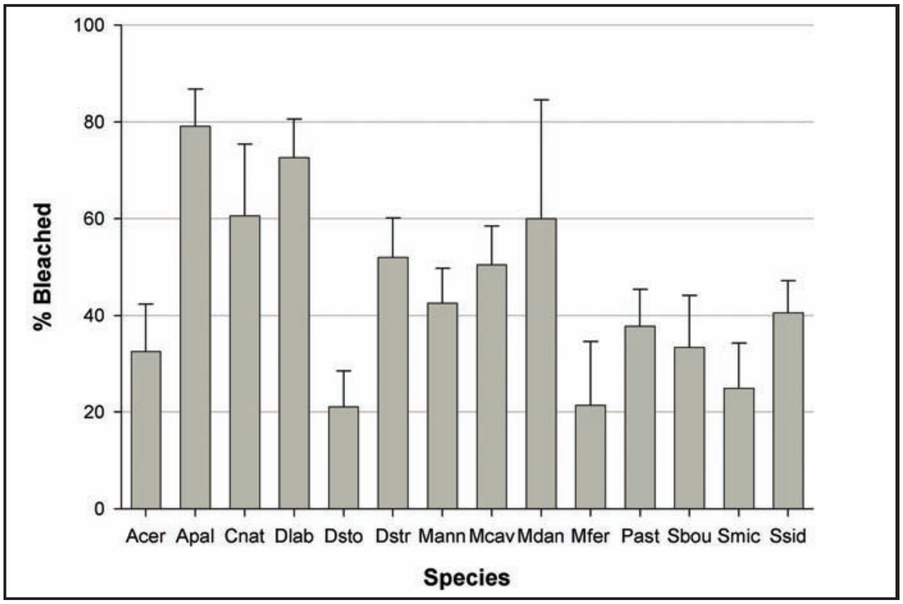

Figure 7.3. Mean percentage of coral colonies that were greater than 50% bleached identified by species assessed in September 1998 in the Lower Keys and the Dry Tortugas sites. Error bars represent 1 SE. X axis legend: Acer: *Acropora cervicornis*; Apal: *A. palmata*; Cnat: *Colpophyllia natans*; Dlab: *Diploria labyrinthiformis*; Dsto: *Dichocoenia stokesii*; Dstr: *Diploria strigosa*; Mann. *Montastraea annularis*; Mcav: *Montastraea cavernosa*; Mdan: *Meandrina danae*; Mfer: *Mycetophyllia ferox*; Past: *Porites astreoides*; Sbou: *Solenastrea bournoni*; Smic: *Stephanocoenia michelinii*; Ssid: *Siderastrea siderea*. Source: Santavy et al., 2001.

Coral bleaching assessments were made during the 1998 global bleaching event by the U.S. Environmental Protection Agency's (EPA) Gulf Ecology Division, in collaboration with the National Oceanic and Atmospheric Administration's (NOAA) Florida Keys National Marine Sanctuary (FKNMS), Mote Marine Laboratory's Center for Tropical Research, and University of Georgia. Surveys were conducted in the Florida Keys, with sites in the Lower Keys, New Grounds, and Dry Tortugas. Details of the sampling design, approach, and methods are described in Santavy et al. (2001). Bleaching was scored if greater than 50% of a coral colony had translucent white tissue present. Every species recorded in this assessment was observed to be bleaching. At least 50% of the colonies of the species *Acropora palmata, Diploria labyrinthiformis, D. strigosa, Colpophyllia natans, Mycetophyllia danaana* and *Montastraea cavernosa* were over 50% bleached (Figure 7.3). Reefs in the Lower Keys exhibited the greatest bleaching (43% ± 5.7 SE) compared to reefs in the Dry Tortugas and New

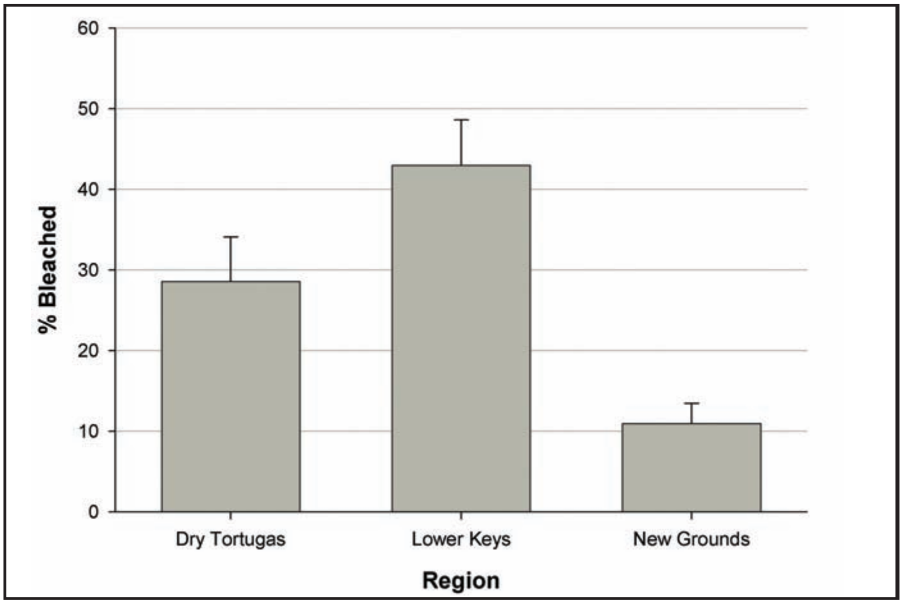

Figure 7.4. Mean percentage of coral colonies that were greater than 50% bleached assessed in September 1998 in the Dry Tortugas, Lower Keys, and New Grounds. Error bars represent 1 SE. Source: Santavy et al., 2001.

Grounds (Figure 7.4). Shortly after the assessments, Hurricane Georges passed over Key West as a Class 3 hurricane which caused substantial physical destruction. The stress from intense bleaching and Hurricane Georges was responsible for significant coral mortality that occurred between surveys in late summer 1998 and late spring 1999. Detailed information concerning bleaching distributions are reported in Santavy et al. (2001).

Disease

Surveys conducted along the Florida Keys Reef Tract during 1998-2002 assessed coral diseases for several applications. The first application was to determine the frequency and distribution of coral condition, using coral disease as the indicator to determine the overall health of corals. This approach was applied during the 2000 survey. The second application was to compare coral diseases between geographical regions in the Dry Tortugas, New Grounds, Key West region, Lower Keys, Middle Keys, and Upper Keys. Coral diseases were assessed by scientists from EPA's Gulf Ecology Division, FKNMS, and Mote Marine Laboratory's Center for Tropical Research. In general, diseases were most abundant in 1998, with observed changes in species composition which suggest that corals are increasingly dying and not recovering. In extreme cases, there has been almost complete deterioration of several keystone species, most notably *Acropora palmata* (Patterson et al., 2002). Although it is clear that new diseases are emerging at an accelerated rate, cause and effect relationships are not well documented. Coral health and diseases have not been critically or thoroughly characterized, and few baseline studies have been conducted in this region. More information about the results of coral disease studies can be found in the 'Benthic Habitats' section.

Tropical Storms

Storms are a normal part of the South Florida ecosystem because of the close proximity of Florida to the Caribbean Basin, where intense hurricanes develop seasonally. Hurricanes that have impacted Florida since 1979 are shown in Figure 7.5. Tropical storms can be a major force structuring coral reef communities through processes such as direct physical impact, increased terrestrial runoff, sedimentation, and pollution. For example, Hurricane Georges (1998) broke and reduced to rubble many large branching elkhorn and staghorn corals which were already weakened by disease (USGS, 1998; AOML, 1999). In 2004, various parts of Florida's coastline were hit by four major hurricanes (Charley, Francis, Ivan, and Jeanne). Hurricane Charley caused moderate damage to coral reefs at Dry Tortugas and off Broward. For instance, at the northeast side of Loggerhead Key, a patch of *Acropora cervicornis* was broken into small pieces and washed inshore; however, a month later surviving fragments appeared healthy. On Bird Key Reef, many large coral formations were dislodged and abundance of benthic algae was drastically reduced on most

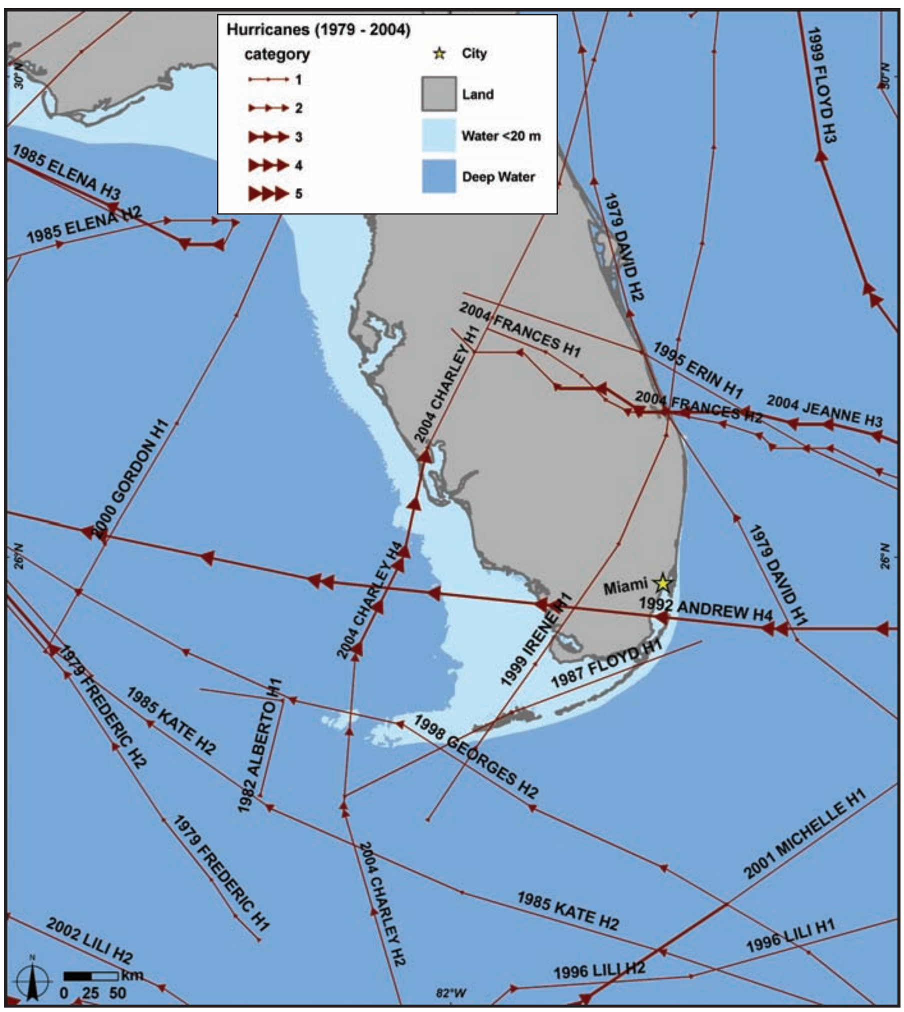

Figure 7.5. The paths and intensities of hurricanes in Florida, 1979-2004. Year of storm, hurricane name and storm strength on the Saffir-Simpson scale (H1-5) are indicated for each. Map: A. Shapiro. Source: NOAA Coastal Services Center.

of the reefs visited after the storm (W.C. Japp, pers. obs.). Hurricanes Francis and Jeanne caused damage to coral reefs off Palm Beach and Martin Counties (W.C. Japp, pers. obs.).

Nevertheless, tropical storms may have beneficial effects on coral reef ecosystems off Florida's southeast coastline. Florida Bay is very shallow (1 m), with a myriad of banks and shoals that quickly dissipate tidal exchanges and prevent regular flushing of the bay. Reduced tidal flushing has contributed to the accumulation of organic matter, sediments, and nutrients which promote phytoplankton blooms that decrease the amount of light available to seagrass beds (AOML, 1999). Increased storm surge and wave action from powerful hurricanes increase tidal flushing, reduce sedimentation and are thought to reduce phytoplankton blooms (AOML, 1999). After Hurricane Georges (1998), however, water quality conditions were not significantly different than before because nutrient-enriched waters remained trapped within Florida Bay by broad, shallow banks in the central and western portions of the bay (AOML, 1999). Additionally, Lirman (2003) found that the abundance of *A. palmata* correlated positively with an increase in storm frequency from one storm every 15 years to one storm every two years, but declined with a further increase in storm frequency. Successful survivorship, reattachment, and growth of coral fragments after storm events may be the only means of propagation for *A. palmata* when sexual recruitment is limited (Lirman, 2003). However, the synergistic effects of multiple stressors (e.g., disease, coastal pollution, and overgrowth by algae) could prevent normal patterns of recovery in corals after storm events (USGS, 1998).

Coastal Development and Runoff

The reefs of mainland Southeast Florida, by virtue of their high latitude and proximity to shore, exist at the environmental extremes for corals. Natural phenomena, such as cold weather fronts; upwelling of cold, nutrient-rich waters; and freshwater runoff from land all contribute to "pushing the environmental limits" for corals and other reef-associated organisms. Anthropogenic activity that leads to a reduction in water quality may result in further physiological stress to corals and adversely impact coral reef ecosystems.

Nonpoint sources of pollution include surface water runoff, storm water discharge, and groundwater seeps. The nonpoint-source pollution may be delivered to the reef directly, as in the case of runoff, through navigational inlets and passes, and through the porous limestone substrate underlying south Florida. Nutrient loading of nitrogen and phosphorus from inland agriculture to the coastal waters offshore of Palm Beach County (mainland Southeast Florida) via surface water discharge are 2,473 and 197 metric tons (mt) per year, respectively, and via submarine groundwater discharge are 5,727 and 414 (mt) per year, respectively (Finkl and Charlier, 2003; Finkl and Krupa, 2003). Studies have estimated that groundwater from the interior parts of South Florida can take five to eight decades to reach the nearshore zone (Finkl and Charlier, 2003). Furthermore, run-off from the Everglades via Florida Bay and the Keys has been found to impact water quality around the Keys (Boyer and Jones, 2002).

Coastal Pollution

The effects of coastal pollution on reef-associated communities are not entirely understood. One obvious impact, however, is an increase in the magnitude and persistence of macroalgal blooms, which have increased worldwide during the past several decades (Morand and Briand, 1996). There is evidence that blooms may be a result of nutrient loading from land-based sources (NRC, 2000). Lapointe (1997) and Lapointe and Barile (2001) linked nitrogen from land-based sewage to macroalgal blooms in Southeast Florida. In Southeast Florida, harmful macroalgal blooms have occurred extensively in the offshore waters of Palm Beach County during the past decade (Lapointe and Barile, 2003), and over the past two years the cyanobacterium (*Lyngbya confervoides*) has covered an extensive area of the middle reef tract offshore Broward County. These blooms have had a significant impact on reef-associated organisms (Lapointe, 1997). The impacts include smothering and resultant mortality, as well as substrates dominated by macroalgae that would naturally be colonized by other organisms, such as corals and sponges. Researchers in Barbados (Tomascik, 1991; Wittenberg and Hunte, 1992) reported decreased coral larval settlement on reefs in nutrient-rich waters. Other impacts of water pollution on reef communities include increased bioerosion rates (reviewed by Risk et al., 2001) and possible links to coral diseases. Patterson et al. (2002) identified the human fecal bacterium (*Serratia marcescens*) as the causal agent of white pox disease in corals in the Florida Keys, and Bruno et al. (2003) reported evidence of nutrient enrichment increasing the severity of disease in sea fans and some coral species.

An extensive water quality monitoring program for the Florida Keys and Florida Bay underway since 1995 (Boyer and Jones, 2003) has reported elevated nitrogen levels in the nearshore areas of the Keys but not in the Tortugas region, suggesting a relationship with land-use patterns. No coastal water quality monitoring is underway for the mainland Southeast Florida region. There is a great need for such a monitoring program, particularly in light of the number of extensive macroalgal blooms that have occurred on mainland reefs in recent years. In addition to monitoring, further research to identify cause-and-effect relationships (i.e., water quality and reef community response) are needed.

The most extensive program underway to reduce water pollution is the National Pollution Discharge Elimination System (NPDES), a Federal program to regulate pollution from point source and stormwater discharges into receiving waters. The NPDES program is mandated in the Federal Clean Water Act (33 U.S.C. § 1251 et seq.) and is administered by the EPA and delegated to states, including Florida. Industrial, municipal, and other facilities must obtain permits if their discharges go directly to surface waters. Facilities discharging stormwater must meet appropriate treatment criteria and may not cause or contribute to a violation of water quality standards. The program has been effective in requiring many private small wastewater treatment plants to eliminate raw sewage discharges. All municipal wastewater treatment plants must attain minimum levels of effluent quality using secondary treatment, including facilities with ocean outfalls. Water quality standards need to be re-evaluated from a perspective that addresses impacts to coral reef systems.

Wastewater in the Florida Keys is handled by approximately 200 treatment plants and numerous private septic tanks. Because of the low land elevation in the Keys, the septic tank drain fields are under tidal influence and nutrient-rich water leaches through the porous limestone into coastal waters. In order to decrease this nutrient loading, Monroe County is undertaking a study of the septic tank problem and consolidation of the wastewater plants into regional facilities.

Tourism and Recreation

Florida's coral reefs are located near the four most densely populated counties of the state (U.S. Census Bureau, 2003). The combined population of these four counties is more than five million, with 2.3 million in Miami-Dade, 80,000 in Monroe, 1.7 million in Broward, and 1.2 million in Palm Beach County (U.S. Census Bureau, 2003). Tourism is Florida's top industry and generates over $50 billion a year for the state's economy. In 2003, Florida hosted over 74 million visitors who participated in reef-based recreation, generating $18 million annually in the Florida Keys (VISIT FLORIDA Year-in-Brief, 2003). Reef tourism is a significant economic asset in Palm Beach, Broward, Miami-Dade, and Monroe Counties, which are all on the list of top ten destination counties for tourists to Florida (Johns et al., 2001; VISIT FLORIDA Year-in-Brief, 2003). The primary tourism activities include snorkeling, scuba diving, fishing, glass bottom boat tours, boat rentals, dive training, and dive shop sales (Table 7.2). By far, the largest economic benefits generated by direct use of the reefs of Southeast Florida are related to recreation and tourist activities. For example, in the June 2000 to May 2001 tourist season, tourism generated over $16 billion in output/sales, including local multiplier impacts. These sales, in turn, generated an estimated $6.2 billion in income, which supported over 251,000 full-time and part-time jobs. In Florida, the Monroe County economy is the most highly dependent on tourism, with 61% of all county employment related to tourist activity.

Johns et al. (2001) estimated direct use of both the artificial and natural reefs and the associated market and non-market economic use values for Southeast Florida. For the four-county area, direct use of natural reefs by both residents and visitors was estimated at 18.4 million person-days of snorkeling, scuba diving, fishing, and viewing coral reefs from glass-bottom boats, which resulted in over $2.7 billion in output/sales (Table 7.2). This activity further generated over $1.2 billion in income that supported over 43,000 full-time and part-time jobs. Annual net direct user value of natural reefs was over $229 million. Residents and visitors to the Florida Keys (Monroe County) spent about 3.9 million person-days of diving, fishing, and viewing coral reefs and $373 million in local sales, which generated about $107 million in income locally that supported over 7,600 jobs. In addition to these economic impacts, users received over $57 million in net annual user value, with an asset value of $1.9 billion.

In Palm Beach County, users spent over 2.8 million person-days on the natural reefs off the coast of the county with economic impacts on the county of $354 million in sales, which generated $141 million in local income and supported 4,500 jobs. Reefs off Palm Beach County had a net annual user value of over $42 million, with an asset value of $1.4 billion. In Broward County, users spent about 5.4 million person-days on the natural reefs, spent $1.1 billion, generated $547 million in local income, and supported about 18,600 jobs (Table 7.2). Reefs off Broward County had a net annual user value of about $83 million and an asset value of $2.8 billion. In Miami-Dade County, users spent over 6.3 million person-days on the natural reefs, generated $878 million in sales and $419 million in income locally, and supported about 12,600 jobs. The reefs of Miami-Dade had a net annual user value of almost $47 million, with an asset value of $1.6 billion (Table 7.2).

Table 7.2. Estimates by county of area and monetary value of recreational and tourism-related activities occurring in coral reef ecosystems of Southeastern Florida, 2000-2001. Source: Johns et al., 2001.

ATTRIBUTE	BROWARD	MIAMI-DADE	MONROE	PALM BEACH
Habitat area (x 1000 hectares)	8.3	7.2	115.3	12.0
Person days of activity (millions of days)	5.4	6.3	3.9	2.8
Sales and Services (millions of $)	1100	878	373	354
Income (millions of $)	547	419	107	141
Number of jobs	18,600	12,600	7,600	4,500
Asset value (millions of $)	2,800	1,600	1,900	1,400
Snorkeling (millions of $)	0.8	1.5	1.5	0.4
Scuba diving (millions of $)	2	0.7	0.5	1.3
Fishing (millions of $)	2.6	4.1	1.8	1.1
Glass-bottom boat rides (millions of $)	0.04	0.01	0.07	0

Fishing

Coral reefs provide the ecological foundation for important fisheries and a tourism-based economy in South Florida that generated an estimated 71,000 jobs and $6 billion of economic activity in 2001 (Johns et al., 2001). Fishing is an important part of this activity and a human stressor on coral reefs.

Florida's reef fisheries are concentrated in South Florida and are complex (Bannerot and Alevizon, 1990; Chiappone and Sluka, 1996). Commercial and sport fisheries target adult reef fishes and spiny lobster for food and sport around bridges and on patch reefs and offshore bank reefs. Fisheries also target live fishes and invertebrates for marine aquaria. Pink shrimp, which are ecologically important as a principal prey item for many reef species, are also economically important and intensively exploited. Adult pink shrimp inhabiting soft and rubble bottoms near coral reefs are targeted by the commercial fishery as a food, and juvenile pink shrimp are targeted as live bait for the recreational fishery in coastal bays and near barrier islands. Finally, pre-spawning subadult pink shrimp are targeted by both food and sport fisheries as they emigrate from coastal bay nursery grounds to offshore spawning grounds.

Total fishing activity reflects Florida's population, which grew tenfold from 1.5 million people in 1930 to 16 million in 2000. In 2000, over five million residents, nearly one-third of Florida's population, lived in the five southern counties adjacent to coral reefs (Palm Beach, Broward, Miami-Dade, Monroe, and Collier Counties). Like residents, recreational fishing (i.e., sport angling and spear fishing) is a popular activity for tourists. Over three million tourists annually visit the Florida Keys alone (Leeworthy and Vanasse, 1999).

Precise data on fishing effort on coral reefs do not exist, but are reflected by statewide fishing statistics. In 2001, for example, an estimated 6.7 million recreational fishers took 28.9 million marine fishing trips in Florida, catching 171.6 million fish, of which 89.5 million (52%) were released or discarded (U.S. DOC, 2003). Although some measures of recreational fishing activity such as the annual number of anglers and fishing trips were unchanged between 1993 and 2002, other measures (e.g., annual totals of fishes caught, released, and landed) may have increased between 1997 and 2002 (Figure 7.6). Additionally, the number of registered recreational boats in five South Florida counties adjacent to coral reefs grew more than 500% between 1964 and 2002, although the number of registered vessels actually used for fishing is unknown (Figure 7.7). In comparison, the number of commercial vessel registrations grew at a much lower rate of about 150% (Figure 7.7). Besides an increased fleet size, average fishing power (the proportion of stock removed per unit of fishing effort) may have quadrupled in recent decades because of technological advances in fishing tackle, hydroacoustics (depth sounders and fish finders), navigation (charts and global positioning systems), communications, and vessel propulsion (Mace, 1997; Bohnsack and Ault, 1996; Ault et al., 1998, in press).

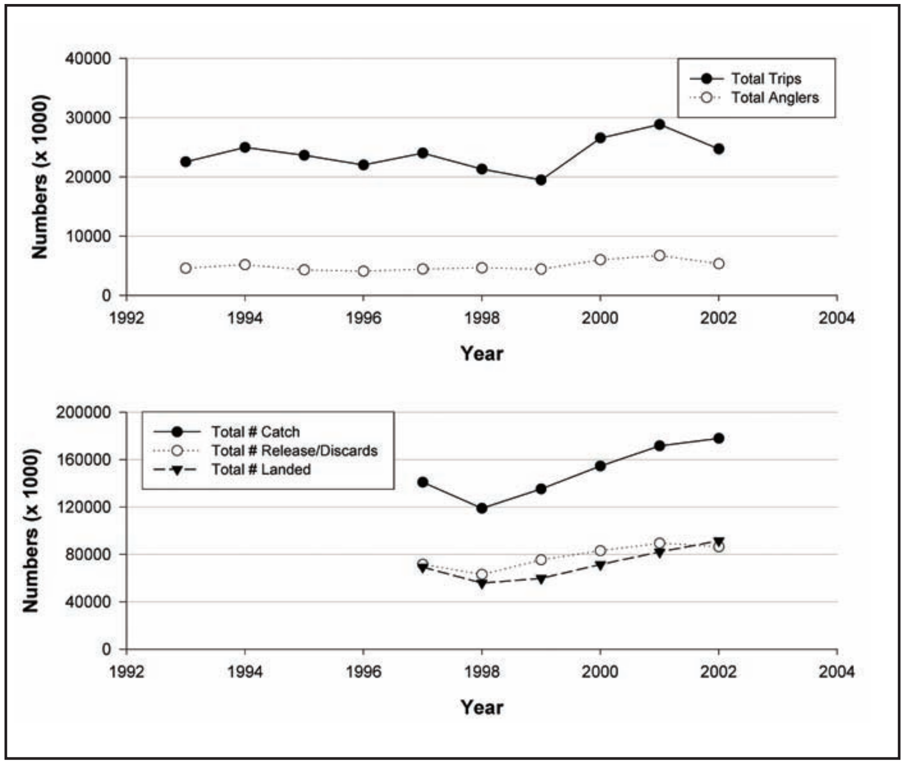

Figure 7.6. Florida total marine recreational fishing trips, angler fishing trips, total catch, and total landings for the period 1993 to 2002 estimated from the MRFSS database. Source: National Marine Fisheries Service SEFSC.

Fishing can stress coral reefs by removing targeted species, killing non-target species as bycatch, and causing habitat damage. Because fishing is size-selective, concerns exist about ecosystem disruption by removal of ecologically important keystone species, top predators (groupers, snappers, sharks, and jacks), and prey (e.g., shrimps and baitfish). Fishing stress is compounded when combined with other stressors such as pollution and habitat damage. From a fishery perspective, whether stocks decline from fishing or detrimental environmental changes, reducing fishing pressure is an appropriate fishery policy choice (Rosenberg, 2003).

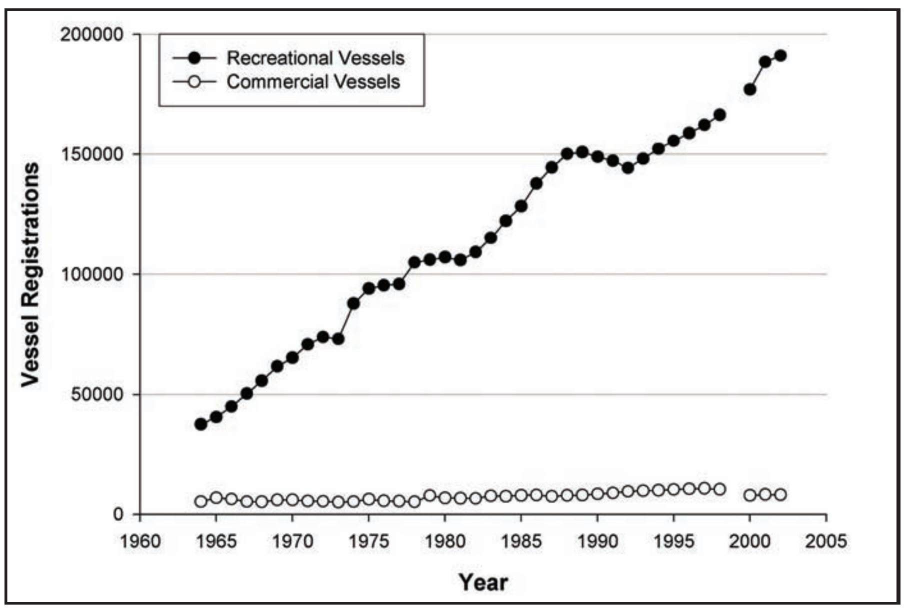

Figure 7.7. Time series of nominal fishing effort for commercial (open circles) and recreational (dark circles) fleets directed at South Florida reef fish from 1964 to 2002. Source: Ault et al. (2001, 2002).

To balance increased fishing pressure, many new fishery regulations have been enacted since the 1980s in Florida state waters by the Florida Fish and Wildlife Conservation Commission (FFWCC; http://www.state.fl.us/gfc/marine) and in Federal waters by the South Atlantic Fishery Management Council (SAFMC, http://www.safmc.net/fishid) and Gulf of Mexico Fishery Management Council (GMFMC, http://www.gulfcouncil.org/about.htm). Their actions include: prohibiting destructive or wasteful fishing gear (e.g., roller trawls, explosives, wire fish traps); requiring reduced bycatch survival (e.g., vessel-holding requirements and limits on number of short lobster used as live bait in lobster traps, escape gaps and release hatches for lobster traps); establishing minimum size and bag limits on a number of reef species landed; establishing seasonal and spatial closures for certain fishing gears (e.g., spears, power heads, lobster diving) and breeding seasons (e.g., for amberjack and black grouper; Bohnsack et al., 1994); limiting or restricting fishing for some species; and limiting entry into certain fisheries. The FKNMS has numerous marine protected areas (MPAs), many of which restrict or eliminate fishing and diving (http://www.fknms. nos.noaa.gov, accessed 2/8/2005). Fisheries for Nassau grouper (*Epinephelus striatus*), goliath grouper (*E. itajara*), queen conch (*Strombus gigas*), and stony corals (Bohnsack et al., 1994) were closed in 1998 and remain closed today.

Trade in Coral and Live Reef Species

The trade in coral and live reef species is not considered a major direct threat to coral reef ecosystems in Florida.

Ships, Boats, and Groundings

Many ship groundings have occurred on Florida's coral reefs (Table 7.3). Federal and state rules and regulations protect the stony coral (Magnuson-Stevens Fishery Conservation and Management Act, FWC Rule 68B-42.009) and there are specific laws and regulations regarding vessel groundings (16 U.S.C. § 1443 and 1437, FS 253.001 and 253.04). Nevertheless, ship groundings and anchors can damage and destroy corals and other biota. According to the FFWCC's law enforcement records, there are between 500 and 600 vessel groundings reported in the FKNMS annually. In addition, there are many unreported groundings that damage resources. FFWCC data indicate that approximately 12-15% (60 to 90) of groundings have involved injuries to coral reef habitat.

Vessel groundings can be arbitrarily classified as small (<10 m length), medium (10 to 30 m), or large (greater than 30 m). Large vessel groundings often result in immediate and long-term damage. Although the vast ma-

Table 7.3. Summary of vessel groundings in Florida. Source: compiled by staff from FFWCC, NSU, FKNMS, unpublished data.

VESSEL NAME	VESSEL SIZE: MEDIUM, LARGE	YEAR OF INCIDENT	LOCATION	INJURED AREA (M^2)
Capt Allen	M	1973	Middle Sambo, FKNMS	Approximately 125
M/V Lola	L	1976	Looe Key, FKNMS	Approximately 200
M/V Wellwood	L	1984	Molasses, FKNMS	1,282
M/V Mini-Laurel	L	1984	FKNMS	270
M/V Alec Owen Maitland	L	1984	FKNMS	661
M/V Mavro Vetranic	L	1989	Pulaski Shoal, Dry Tortugas	15,800
M/V Elpsis	L	1989	Elbow, FKNMS	2,605
USS Memphis	L	1993	Broward County	1,205
M/V Ms Beholdin	L	1993	Western Sambo, FKNMS	????
M/V Firat	L	1994	Broward County, near Port Everglades	1,000
R/V Columbus Iselin	L	1994	Looe Key, FKNMS	345
M/V Sealand Atlantic	L	1994	Port Everlades entrance, Broward County	Approximately 1000
M/V Igloo Moon	L	1996	Biscayne National Park	1,000
M/V Houston	L	1997	Maryland Shoal, FKMMS	7,107
M/V Hind	L	1998	Broward County, near Port Everglades	1000
M/V Pacific Mako	L	1998	Broward County, near Port Everglades	1000
Lagniappe	M	2001	Key West, FKNMS	35
M/V Diego	L	2001	Tortugas Banks	1,886
M/V Alam Senang	L	2003	Broward County, near Port Everglades	216
M/V Puritan	L	2004	Broward County	100 estimated
M/V Eastwind	L	2004	Broward County, near Port Everglades	11,000 preliminary
Terresa Llyn	M	2002	Dry Tortugas	50 estimated
Captain Bozo	M	2002	Dry Tortugas	50 estimated
Blind Faith	M	2002	Dry Tortugas	50 estimated
Adaro	M	2003		
Connected	M		Western Sambo, FKNMS	
Poetic Justice	M			
High Queen and barge	M	2002	St Lucie inlet	?? minimal
Wave Walker	M	2002	The Rocks, FKNMS	
Jacquelyn L	M		Western Sambo, FKNMS	

jority of grounding incidents are caused by small, privately owned vessels often resulting in minimal resource damage to the resources, the cumulative impacts can be detrimental and long-lasting. Several large- and medium-sized vessel grounding incidents have occurred off the east and south coasts of Florida (Table 7.3). Large vessels often create injuries exceeding 1,000 m^2. The majority of vessel groundings in Florida coral reefs are the result of operator error (poor navigating, lack of local knowledge, and inappropriate charts). Several groundings have occurred because of stormy weather or an inappropriate anchorage. Anchors and chains from large ships can also cause substantial damage, as occurred with the ships M/V *Diego* in 2001 and M/V *Puritan* in 2004. Many of the reported incidents included damage from anchor and chain, as well as from the physical impact of the hull. Damage included crushed, broken, and dislodged organisms (e.g., sponges, *Millepora* spp., octocorals, scleractinian corals, zooanthids, anemones, and bryozoans). Large vessels pulverize the limestone reef substrata creating rubble deposits, fractured structure, and in some cases, canyons or trenches. Ships often attempt to free themselves from the reef by engaging the propeller. The propwash from the propeller mobilizes loose material and may create pits, trenches, and piles of sediment and rubble. Damage caused by a propwash can be more severe than the damage caused by hull contact alone. In Broward County, significant damage to coral reefs was caused by the grounding and subsequent propwash of the nuclear submarine USS *Memphis* (Banks et al., 1999).

The type of impact depends upon grounding circumstances such as storm conditions; the ship's cargo, which governs how much the ship draws; and the length of anchor chain or tug boat line used to tow the vessel off the reef. Many large vessel groundings have occurred near Port Everglades, Broward County (Table 7.3), where ships attempting to anchor or at anchor are driven inshore onto the reef by severe weather. In the Florida Keys, large ship groundings have occurred at Pulaski Shoal, Maryland Shoal, Looe Key, and Molasses, Elbow, and Carysfort reefs. Navigational error was the principal cause, although all of the large ships were equipped with advanced navigating technology, such as, global positioning system (GPS) receivers, radar, radio direction finders, and depth recorders. Often, foreign ships do not have local charts; for example, the *Mavro Vetranic* was found trying to navigate from the eastern Gulf of Mexico into the Straits of Florida with a chart that had coverage of the entire Atlantic Ocean at a scale that did not show local aids to navigation (e.g., lighthouses).

Efforts to reduce the effects of vessel groundings have included installing mooring buoys on highly visited reefs in Monroe, Miami-Dade, and Broward Counties. This has reduced chronic effects from small boat anchoring. The State of Florida and FKNMS have published brochures and made information available on the internet to educate users on the risks and best ways to navigate in coral reef areas. The FKNMS has established large vessel avoidance areas and installed Racon beacons on lighthouses between Dry Tortugas and Key Largo. The beacon transmits a unique signal that is received on active radar receivers identifying the reef lighthouse. There is an active effort to find a better anchorage for Port Everglades. Projected future efforts to reduce groundings include extending vessel avoidance zones, prohibiting the use of Port Everglades anchorage when the wind speed exceeds 25 knots, and enhancing management of the Port Everglades anchorage.

Vessels that run aground because of negligent operation are held responsible by natural resource trustees including the State of Florida, NOAA, and National Park Service (NPS). The nominal responsibility of the shipping company-insurance carrier includes assessment, triage, direct restoration, compensatory restoration (and/or punitive actions), and post-restoration monitoring. Small boat owners are also held responsible for their negligent actions. Scaling for compensation and restoration is based on assessing the injury: defining the spatial extent using biological metrics (abundance and cover of coral) and determining the time necessary for recovery to pre-incident status for both the injured area and the compensatory action. The Habitat Equivalency Analysis method is a useful approach in determining compensation restoration (Fonseca et al., 2000; NOAA, 1997, 2000; Milon and Dodge, 2001).

Restoration at grounding sites has taken a variety of forms in order to enhance recovery (Jaap, 2000). While it is impossible to instantly replace an injured coral reef resource, steps can be taken to promote recovery. The typical scenario is to salvage all detached coral and cache them for subsequent reattachment. It is desirable to remove loose injury-generated rubble to expose the reef foundation (limestone rock) and to eliminate a source of material that could be mobilized and create additional injury in future storm events. If the reef framework is fractured to a significant extent, concrete, native limestone boulders and fiberglass rods may be needed and have been used to stabilize the fractured foundation. After the reef has been cleared of rubble and the foundation made stable, corals are reattached based on microhabitat requirements (e.g., orientation to light and waves). In cases where the reef was rendered flat by severe hull injuries, the topographic relief can be enhanced using native limestone, concrete and prefabricated rock structures. These are often secured with concrete and reinforcement rods.

While there are few detailed studies comparing recovery of restored sites with unrestored injury areas, it is clear that there have been some successes. Coral reattachment has been a useful method. A number of monitoring studies off Broward County have demonstrated very high Scleractinian coral reattachment success (80-95%) (Continental Shelf Associates, 2000; Gilliam et al., 2001, 2003; Thornton et al., 2002). After approximately three years, recruitment of coral (octocoral and scleractinian corals) is very common. For example, there are restored areas off Miami-Dade County where measurements of percent cover, density, and diversity of sessile benthic organisms exceed those at a nearby reference site (Miami-Dade County, 2003).

Marine Debris

Lost and discarded lobster, stone crab, and blue crab traps are a common component of marine debris in Florida. Traps and the associated buoys and ropes are commonly lost during both routine fishing operations and when conflicts occur with other fishing gear and boats. Surveys suggest that, of the 500,000 lobster traps currently in the fishery, 20% of them are lost annually. No surveys have been conducted that estimate the number of lost stone crab and blue crap traps, but fishers report that they replace 20% of the 818,000 stone crab traps used annually, and anecdotal reports suggest that during 1998, 30-50% of the 360,000 blue crab traps were lost. Additional trap losses occur during tropical and severe winter storms. During the Ground Hog Day storm in 1998, approximately 80,000 lobster traps and 22,000 stone crab traps were lost in the Florida Keys. The combined effects of Hurricane Georges and Tropical Storm Mitch later that same year destroyed an estimated 111,000 lobster traps and a few thousand stone crab traps.

Trap debris is distributed in coastal environments and underwater. One shoreline debris removal program conducted during 1999 removed 12,700 kg of plastic trap debris and buoys, filling 1,445 50-gallon plastic bags along five miles of shoreline in the Florida Keys (Figure 7.8). An underwater survey conducted in the Florida Keys during 1993 estimated that there were 2.84 lost or discarded traps per ha. Trap debris on shorelines is a significant source of visual pollution, but probably poses little threat to marine life unless the material is reintroduced to the marine environment. However, submerged trap debris is known to cause the loss of vegetation from beneath the traps and may have more severe effects if moved during storms. The impact of trap debris on coral communities is currently being examined.

Figure 7.8. A mountain of debris removed from the Florida Shoreline during 1999. Photo: T. Matthews.

Aquatic Invasive Species

Fish

Within the United States the number of non-native fishes caught in the wild in Florida is second only to the number caught in California. At least 123 non-native fish species have been caught in Florida. Of these, 56 are established in freshwater habitats and at least four are established in estuaries (FMRI, unpublished data;

USGS, 2003). Fifteen species of non-native tropical reef fishes, mainly angelfishes (*Pomacanthus* spp.), surgeonfishes (*Zebrasoma* spp.), and a serranid (*Chromileptes altivelis*), have been observed in southeastern Florida reefs (Semmens et al., 2004; USGS, 2003), but are not known to be established. The ecological impact of non-native species has been discussed by various authors (Taylor et al., 1984; Carlton and Geller, 1993; Simberloff et al., 1997; Carlton, 2001; Kolar and Lodge, 2002).

The red lionfish (*Pterois volitans*) is the only marine species that appears to have become established in Florida (Whitfield et al., 2002; Ruiz-Carus et al., in press). Six lionfish were freed into Biscayne Bay, Dade County on August 24, 1992, when Hurricane Andrew destroyed a large marine aquarium (Courtenay, 1995). Red lionfish were initially sighted on shallow-water reefs off Palm Beach in October 1992 (Courtenay, 1995). Reports of lionfish were sporadic from 1993 to 2001. In 2002, two voucher specimens were captured off St. Augustine and Jacksonville. Sightings were reported in Nassau, Palm Beach, and Miami-Dade Counties. Gonad histology of the voucher female lionfish showed that most likely it spawned in local waters; the male voucher showed a testis in the mid-maturation class (Ruiz-Carus et al., in press). Red lionfish are now found along the seaward edge of reefs and in lagoons, turbid inshore areas, and harbors (Schultz, 1986; Myers, 1991). In the U.S., red lionfish were also observed at artificial reefs and in waters as deep as 79 m off North and South Carolina (Ruiz-Carus et al., in press). Red lionfish are often found during the day under ledges and crevices but may also hunt small fish, shrimps, and crabs in open water at night (Myers, 1991). The paucity of biological data on red lionfish brings new challenges to managers and researchers.

The red lionfish could pose a threat to Florida's fishers, divers, and wildlife inspectors because it is venomous. Furthermore, potential ecological effects include habitat alteration; water quality degradation; and introduction of diseases and parasites, competition, predation, hybridization, and replacement of native species. As introduction of non-native marine fishes is relatively rare, the effects of such introductions are not well documented.

Both the accidental and purposeful introductions of non-native fishes into Florida waters reflect the rise in Florida's consumption and production of tropical ornamental fishes (Ruiz-Carus et al., in press). It is likely that the number of marine species in the market will increase because of improvements in "mini-reef system" aquaria (Larkin and Degner, 2001), and greater access to remote areas where additional non-native species can be obtained (Larkin, 2003).

Coral

Orange cup coral (*Tubastrea coccinea*) is a solitary or cluster of tubes, usually less than 15 cm high and 2 cm in diameter. Larger clusters may include 50 or more bright orange tubes. The tentacles are orange and often extend outward from the top of the tube capturing food.

Tubastrea coccinea is well known in the Pacific Ocean, Red Sea, and Indian Ocean. The species type was found off of Bora Bora by Lesson in 1829. The earliest report of *T. coccinea* in the Caribbean/western Atlantic is in 1943 from Puerto Rico and Curacao and it was subsequently sited throughout the Caribbean Basin (Jamaica-1955, Cuba-1982, Bahamas-1985, western Gulf of Mexico-1999). In Florida, the preferred habitat is on vertical steel structures (sunken ships and engineering platforms). Tubes are usually facing in the direction of the current. A good example is the sunken vessel, U.S. Coast Guard cutter *Duane* off Key Largo, where the southern facing deck structures are veneered with multiple colonies. *T. coccinea* was reported on the *Duane* in 1999 (J. Sprung, pers. comm.) and that it was well established there by March 2002 (W. Jaap, pers. obs.). In the Pacific, *T. coccinea* is often found in caves with swift water movement, usually below 15 m depth.

The appearance of this coral in Florida indicates that some Indo-Pacific reef fauna can reproduce and survive in the western Atlantic. To date, there are no reports of *T. coccinea* replacing native species and it is only known to settle and grow on steel structures. Monitoring is recommended at selected locations to follow the status and trends in abundance and distribution for *T. coccinea*.

Plants

While non-native fishes and corals may threaten Florida's coral reef, non-native plants pose the greatest risks. The world-wide spread of the algae, *Caulerpa taxifolia*, and its effects in the Mediterranean have been well documented (http://www.pbs.org/wgbh/nova/algae/chronology.html). More recently, *Caulerpa brachypus* (Figure 7.9), native to the Pacific region, has been detected in Florida on nearshore reefs and in the Indian River Lagoon. The species was probably released from saltwater aquaria or from ships' ballast water. In the absence of predators it grows unchecked and can smother corals and seagrass beds rapidly if sufficient nutrients are available (http://www.dep.state.fl.us/southeast/hottopics/caulerpa/cbrachypusalertbulletin.pdf). Recent reports from divers and fishers indicate that the algae has now become so thick on reefs in Palm Beach County, that it is forcing lobsters and fish away. The species has also now been observed 100 km north at Fort Pierce, Florida, and Lapointe and Barile (2003) believe the rapid spread is enhanced by anthropogenic enrichment.

Figure 7.9. The 'green menace', *Caulerpa brachypus*, was introduced to Florida from the Pacific. Anecdotal reports indicate that it is flourishing in Florida and poses a threat to native reef organisms. Photo: L. Nall.

Security Training Activities
Security training activities are not recognized as a major threat to coral reef ecosystems in Florida.

Offshore Oil and Gas Exploration
There is currently no oil or gas drilling occurring in state waters. Florida law prohibits future leasing or drilling of the seabed within the state's territorial sea for purposes of oil and gas exploration and development. Holders of any offshore drilling leases that were granted by the state prior to the enactment of the current law must obtain permits under state environmental laws and regulations prior to conducting any drilling activities. No leases exist in Florida areas where coral reef tracts are located.

Other
Subsea Engineering Projects: Fiber Optic Cables and Gas Pipelines
In the past decade, multiple fiber optic cables have been installed off Miami-Dade, Broward, and Palm Beach Counties. The nominal construction included horizontal directional drilling from the coast to beyond the first reef terrace. After exiting from the bore hole, the cable was deployed eastward on the surface of the seafloor. During some cable installations, there were "frac-outs" (i.e., when drilling mud escapes from the bore hole through a crack or void in the rock). These incidents were not serious in terms of mortality or morbidity of marine fauna.

In 1999, AT&T Corporation installed four cables off Hollywood Beach in Broward County. Two of the cable deployments resulted in injuries to numerous coral colonies (Table 7.4), and several large barrel sponges (*Xestospongia muta*) were amputated at their bases. The contracting firm paid for direct and compensatory restoration, which included installing mitigation modules (limestone boulders imbedded in a concrete base).

In April 2001, a second cable injury occurred at the ARCOS-I cable deployment in Sunny Isles, Miami-Dade County. Injuries to corals are provided in Table 7.5. The injuries were repaired and compensatory mitigation included installing a boulder field

Table 7.4. Impacts to coral from AT&T incident. Source: PBS&J, 2000.

IMPACT CATEGORY	AMERICAS II CABLE	COLUMBUS III CABLE
Cable overhanging coral	78	56
Cable lying on top of coral	45	63
Cable abrasion injury	12	29
Totals	**135**	**148**

near the cables. Subsequent to the cable installations in 1999-2001, the State of Florida directed cable companies to install all future cables in areas where there are gaps in the reefs to reduce resource injury risks.

Table 7.5. Impacts to coral from ARCOS incident. Source: PBS&J, 2003.

IMPACT CATEGORY	ARCOS NORTH CABLE	ACROS SOUTH CABLE
Cable overhanging coral	67	75
Cable lying on top of coral	34	23
Cable abrasion injury	8	16
Totals	**109**	**114**

A 36-inch diameter gas pipeline (Gulfstream Gas Natural Gas System) was installed from Mobile Bay, Alabama to Port Manatee, Tampa Bay and began operating in May 2002. The pipeline was required to be buried three feet under the seafloor to a water depth of 200 ft; beyond 200 ft, the pipe was positioned on the seafloor. A trench was created with a submarine plow and the pipe was laid in the trench. In multiple areas in and offshore Tampa Bay, the trenching was impeded by dense-hard rock. In cases of partial pipe burial, the contractor used boulders to cover the pipe; in cases where the plow did not penetrate the rock, the contractor fastened the pipe to the rock with metal hardware. Trenching resulted in injuries to coral and other hardbottom resources within Tampa Bay and the Gulf of Mexico. Injuries also occurred from vessel and barge mooring anchors and cables. Injuries within Tampa Bay were compensated by mitigation projects. Two-hundred sponges and octocorals were moved from hardbottom areas in the pipeline corridor to mitigation structures and eight acres of habitat structures (at six mitigation sites) were installed. Each mitigation site provides 1.3-1.4 acres of limestone boulder-pyramids; each site includes 16 to 17 pyramids which are composed of 20 ft long by 24 ft wide, by 3-4 ft high boulders (ENSR International, 2002). Inspections reveal colonization of these structures by algae, sponges, octocorals, blue crabs, stone crabs, and schools of anchovies and spadefish. In the eastern Gulf of Mexico, the pipeline installation disturbed 27 acres of hardbottom, including sponges, octocorals, and stony coral communities. Installation of nine boulder fields and three pre-fabricated module sites mitigated the injuries. Approximately 49 acres of mitigation was provided at the 12 locations seaward of Egmont Key, in depths ranging from 52 to 120 ft (Continental Shelf Associates, 2001; Sea Byte, 2001). Over 400,000 tons of boulders were deployed in discrete fields. The boulders (at least 3 ft in dimension) were deployed in multiple layers to provide refuge. Inspections of boulders and modules revealed colonization by algae, sponges, hydroids, snapper, schools of anchovies, nurse sharks, and goliath grouper.

Additional gas pipeline projects on the east coast of Florida are currently being reviewed for permits. Two proposals from the Calypso-Tractebel and AES Ocean Express have advanced to the point that permitting may occur in 2005. Another pipeline proposed by El Paso is not as far along in the permitting process. These projects propose to install 24-inch diameter pipelines that would originate in the Bahamas, cross the Straits of Florida, and terminate near Port Everglades (Jupiter for El Paso). The draft environmental impact statements for the first two projects proposed the removal of rubber tires deployed in the 1960s as artificial reefs for mitigation of their impacts. These tires have become unbundled, have moved, and are injuring reef resources. Larger corals in known areas of impact will be relocated to non-impacted sites. The pipeline companies propose to avoid injuring reef habitat by drilling under the reefs and connecting the sections of pipe in non-reef areas. There are concerns regarding deployment of construction equipment, “frac-outs” from drilling, possible of a major storm events during drilling, and deployment of pipes in a major boundary current (Gulfstream or Florida Current) in extremely deep water.

Construction of the pipeline projects will involve direct impacts to coral reef habitat from horizontal directional drilling and associated sump berms, trenching in areas where the pipeline will transit from horizontal directional drilling holes, sedimentation and turbidity associated with drilling and trenching, and possible “frac-outs” during drilling. In addition, some pipeline strings have to be laid out and pulled into horizontal directional drilling holes. Some pulling will occur over coral reef habitat, thereby causing injury from the dragging.

CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

The FKNMS enabling legislation requires a comprehensive water quality status and trends monitoring program with three major components: water chemistry, seagrass, and coral reefs (U.S. DOC, 1996). The protocols and sampling strategies were developed in collaboration with EPA in 1994-95. Water chemistry and seagrass monitoring are conducted by Florida International University; coral reef monitoring is conducted by the FFWCC's Fish and Wildlife Research Institute. The two institutions began collecting data in 1995-96.

The waters of the FKNMS are characterized by complex water circulation patterns, with much of the spatial and temporal variability due to seasonal influences on regional circulation regimes. The Sanctuary is directly influenced by the Florida Current, Gulf of Mexico Loop Current, inshore currents of the southwestern Florida Continental Shelf (Shelf), discharge from the Everglades through the Shark River Slough, and tidal exchange with both Florida Bay and Biscayne Bay (Lee et al., 1994, 2002). Advection from these external sources has significant effects on the physical, chemical, and biological composition of waters within the Sanctuary, as may internal nutrient loading and freshwater runoff from the Keys themselves and episodic upwelling (Leichter et al., 2003).

A spatial framework for water quality management was proposed on the basis of geographical variation of regional circulation patterns (Klein and Orlando, 1994). Quarterly sampling of more than 200 stations in the Sanctuary and on the Shelf, as well as and monthly sampling of 100 stations in Florida Bay, Biscayne Bay, and the mangrove estuaries of the southwestern Florida coast, provide a unique opportunity to explore the spatial variability in water quality measures in South Florida's coastal waters (Figure 7.10). Details on water chemistry sampling strategy, field sampling methods, laboratory analyses, and data processing are available on-line at http://sefrc.fiu.edu/wqmnetwork/ (accessed 1/31/05).

WATER QUALITY

Methods

Several variables were measured *in situ* and from grab samples at 54 fixed stations within the Sanctuary boundary beginning in March 1995 (Figure 7.10). Depth profiles of temperature, salinity, dissolved oxygen (DO), photosynthetically active radiation (PAR), *in situ* chlorophyll *a* (CHL*a*) specific fluorescence, optical backscatterance turbidity, depth, and density were measured by conductivity-temperature-depth (CTD) casts using a Seabird SBE 19 instrument (Table 7.6). Vertical light attenuation (k_d, per meter) was calculated at 0.5 m intervals from PAR and depth (Kirk, 1994) and averaged over the depth of each station. Where it was too shallow to use a CTD, surface salinity and temperature were measured using a combined salinity-conductivity-temperature probe. DO was measured with an oxygen electrode corrected for salinity and temperature. PAR was measured with a Li-Cor irradiance meter. The extent of water stratification was calculated as the difference between surface and bottom density ($\Delta\delta_t$), such that positive values denoted greater densities

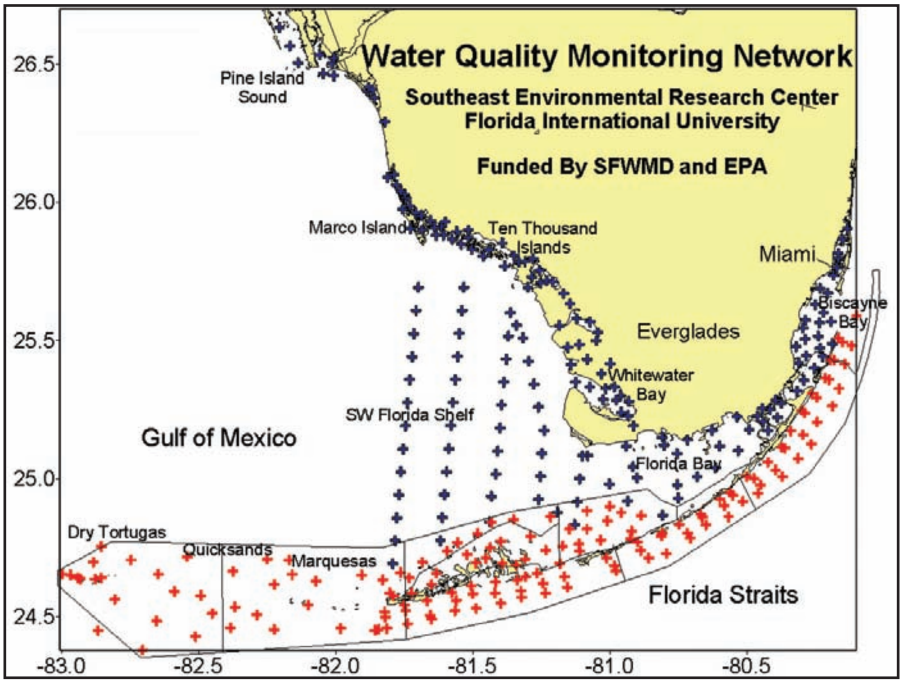

Figure 7.10. The Southeast Environmental Research Center (SERC) Water Quality Monitoring Network showing the distribution of fixed sampling stations (+) within the Florida Keys National Marine Sanctuary (red stations) and Florida Bay, Biscayne Bay, Whitewater Bay, Ten Thousand Islands, and Southwest Florida Shelf (blue stations). Source: Boyer and Jones, 2003.

of bottom water relative to the surface and negative values indicated the opposite. A value of $\Delta\delta_t$ >1 indicated weak stratification, whereas $\Delta\delta_t$ >2 meant strong water stratification.

Water samples were collected from approximately 0.25 m below the surface and at approximately 1 m from the bottom. Unfiltered water samples were analyzed for total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), silicate ($Si(OH)_4$), alkaline phosphatase activity (APA), and turbidity. Fluorescences at initial and after two-hour incubation were measured using a spectrofluorometer (Jones, 1996). Filtrates were analyzed for nitrate+nitrite (NO_x^-), nitrite (NO_2^-), ammonium (NH_4^+), and soluble reactive phosphorus (SRP).

Several parameters were not measured directly. Nitrate (NO_3^-) was calculated as NO_x^- - NO_2^-, dissolved inorganic nitrogen (DIN) was determined as NO_x^- + NH_4^+, and total organic nitrogen (TON) was defined as TN - DIN. DO saturation in the water column (DO_{sat}) was calculated using the equations of Garcia and Gordon (1992). Stations were stratified according to water quality characteristics (i.e., physical, chemical, and biological variables) using multivariate statistical techniques, an approach that has been very useful in understanding the factors influencing nutrient biogeochemistry in Florida Bay, Biscayne Bay, and the Ten Thousand Islands (Boyer and Jones, 2003). Data from individual sites for the complete period of record were plotted as time series graphs to illustrate any temporal trends that might have occurred. Temporal trends were quantified by simple regression with significance set at P <0.05.

Summary statistics for all water quality variables from all 29 sampling events through September 2002 are shown as median, minimum, maximum, and number of sample stations (Table 7.6). Overall, the region was warm and euhaline with a median temperature of 27.1°C and salinity of 36.2 parts per thousand (ppt); DO_{sat} was relatively high at 90.1%. On this coarse scale, the Sanctuary exhibited very good water quality with median NO_3^-, NH_4^+, and TP concentrations of 0.09, 0.30, and 0.20 µM, respectively. NH_4^+ was the dominant DIN species in almost all of the samples (~70%). However, DIN comprised a small fraction (4%) of the TN pool with TON

Table 7.6. Median, minimum (Min.), and maximum (Max.) values and the number of sample stations (n) for water quality variables measured in the Florida Keys National Marine Sanctuary between March 1995 and September 2002. Source: Boyer and Jones, 2003.

VARIABLE	DEPTH	MEDIAN	MIN.	MAX.	n
Nitrate (µM)	Surface	0.087	0	5.902	4386
	Bottom	0.08	0	5.01	2675
Nitrite (µM)	Surface	0.043	0	0.71	4396
	Bottom	0.038	0	1.732	2682
Ammonium (µM)	Surface	0.299	0	10.32	4395
	Bottom	0.268	0	3.876	2680
Total Nitrogen (µM)	Surface	10.83	1.707	211.1	4391
	Bottom	9.036	1.482	152.23	2661
Total Organic Nitrogen (µM)	Surface	10.261	0.389	210.78	4372
	Bottom	8.445	0	151.91	2641
Total Phosphorus (µM)	Surface	0.198	0	1.777	4394
	Bottom	0.185	0	1.497	2663
Soluble Reactive Phosphorus (µM)	Surface	0.013	0	0.297	4383
	Bottom	0.013	0	0.39	2674
Alkaline Phosphatase Activity (µM h^{-1})	Surface	0.06	0	5.616	4232
	Bottom	0.048	0	0.491	2520
Chlorophyll *a* (µg l^{-1})	Surface	0.261	0.01	15.239	4394
Total Organic Carbon (µM)	Surface	199.69	83.77	1653.5	4393
	Bottom	171.6	89.38	883.1	2669
Silicate (µM)	Surface	0.701	0	127.11	4090
	Bottom	0.455	0	30.195	2491
Turbidity (NTU)	Surface	0.62	0	37	4349
	Bottom	0.52	0	16.9	2700
Salinity	Surface	36.2	26.7	40.9	4315
	Bottom	36.2	27.7	40.9	4287
Temperature (ºC)	Surface	27.1	15.1	39.6	4322
	Bottom	26.6	15.1	36.8	4294
Vertical Light Attenuation Coefficient k_d (m^{-1})		0.23	0.003	3.41	3050
Dissolved Oxygen saturation (%)	Surface	90.1	31.2	191.6	4286
	Bottom	89.9	19.3	207	4240
Water Stratification (surface density - bottom density, $\Delta\delta_t$)		0.007	-4.42	6.64	4269

making up the bulk (median 10.3 µM). SRP concentrations were very low (median 0.013 µM) and comprised only 6% of the TP pool. CHL*a* concentrations were also very low overall (0.26 µg/L), but ranged from 0.01 to 15.2 µg/L. TOC was 199.7, a value higher than open-ocean levels but consistent with coastal areas. Median turbidity was low (0.6 nephelometric turbidity units, or NTUs) as reflected in a low k_d (0.23/m). This resulted in a median photic depth of approximately 22 m, which was within 1% of incident PAR. Molar ratios of nitrogen (N) to phosphorous (P) suggested that was P was limited in the water column (median TN:TP = 57), but observed ratios of N to P could have resulted because TN may not be biologically available.

Principal component analysis identified five composite variables (hereafter refered to PC1, PC2, etc.) that accounted for 63.2% of the total variance. PC1 had high factor loadings for NO_3^-, NO_2^-, NH_4^+, and SRP and was named the inorganic nutrient component. PC2 included TP, APA, CHL*a*, and turbidity and was designated as the phytoplankton component. The covariance of TP with CHL*a* implies that, in many areas, phytoplankton biomass may be limited by phosphorus availability. This is contrary to much of the literature on the subject, which usually ascribes nitrogen as the limiting factor for phytoplankton production in coastal oceans. TON and TOC were included in PC3 as the terrestrial organic component. Temperature and DO were inversely related in PC4. Finally, PC5 included salinity and TP, implying a source of TP from marine waters.

Spatial distributions of the mean factor score for each station indicated that water quality varied over the study area (Figure 7.11). The inorganic nutrient component had two peaks in the Backcountry, and along the northern side (bayside) of the Middle Keys (Figure 7.11). The phytoplankton component described a north to south gradient in the Backcountry and Sluiceway that extended west across the northern Marquesas. The terrestrial organic component was highest in eastern Sluiceway extending into the Backcountry and was also distributed as a gradient away from land on the Atlantic side (oceanside) of the Keys. Temperature and DO showed a distribution heavily loaded in the oceanside. Finally, the salinity/TP component showed lower loadings in the nearshore Upper Keys and bayside Sluiceway extending through most Atlantic sites of the Middle and Lower Keys.

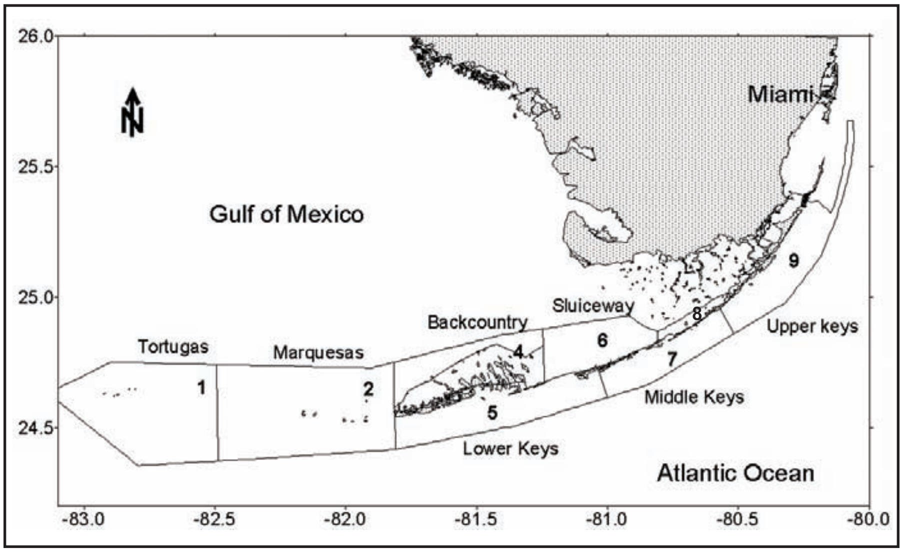

Figure 7.11. Map of South Florida showing the boundary of the Florida Keys National Marine Sanctuary and geographic segments (names and numbers) used for site selection during routine water quality sampling for the period 1995 to 2003. Source: Boyer and Jones, 2003.

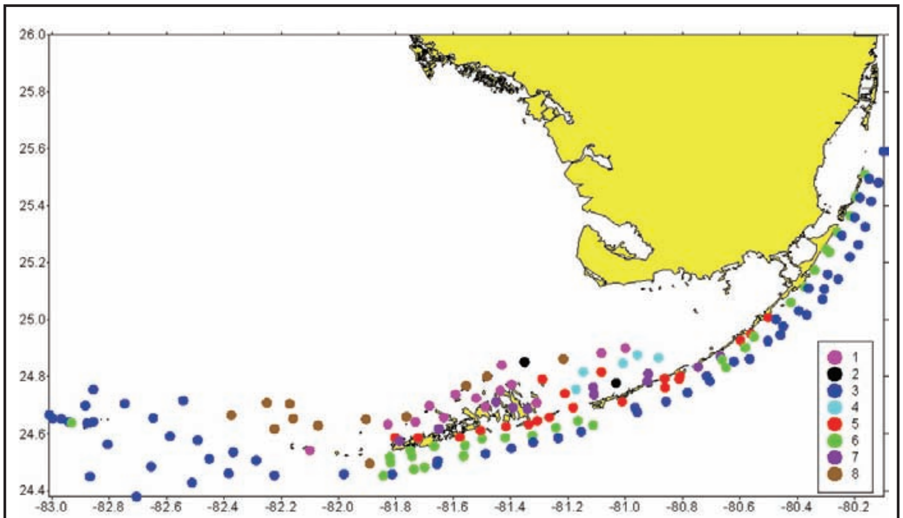

Figure 7.12. Map of sample stations forming distinct water quality groups represented by colored dots. Station groups were identified through objective classification analysis. Source: Boyer and Jones, 2003.

Cluster analysis separated sampling sites (n=150) into eight clusters, with most stations grouped within clusters 1, 3, 5, 6, 7, and 8 (Figure 7.12). Statistically significant differences between clusters indicated a nutrient gradient throughout the Sanctuary (highest to lowest concentrations: clusters 7 & 8 > 1 > 5 > 6 > 3). Cluster 7 was composed primarily of stations located inside the Backcountry, bayside Middle Keys, and inshore sites off Lower Matecumbe Key. This group was highest in inorganic nutrients, especially NO_3^-, TOC, and TON. In the shallow Backcountry sites benthic flux of nutrients might be very important, whereas elevated DIN at inshore Lower Matecumbe sites may be the result of anthropogenic loading. Cluster 8 included the northernmost sites in the Sluiceway, Backcountry, and Marquesas, which had the highest TP, CHL*a*, and turbidity, but was low in inorganic nutrients, DON, and DOC. Water quality in this cluster probably was driven primarily by Shelf circulation patterns.

Cluster 1 was composed of two sites in the northern Sluiceway and 12 sites in the northern Backcountry extending out to the Marquesas (Figure 7.12). This group was high in TP, CHL*a*, and turbidity. The main distinction between Clusters 1 and 8 was that Cluster 8 was higher in CHL*a* and lower in TOC. These clusters may be viewed as a gradient of high-TP Shelf water being attenuated by uptake of nutrients within the Backcountry and/or mixing with Atlantic Ocean waters.

Clusters 5, 6, and 3 may be interpreted as representing an onshore-offshore nutrient gradient (Figure 7.12). Cluster 5 included most of the inshore sites of the Keys, excluding the northernmost and southernmost ones. They were elevated in DIN relative to Hawk Channel and reef tract sites. Cluster 6 was made up of sites in Hawk Channel of the Lower Keys and alongshore sites in the Upper Keys. This group was slightly lower in nutrients than Cluster 5. Cluster 3 was made up of outer reef tract and Tortugas stations. These sites had the lowest nutrients, CHL*a*, turbidity, and TOC in the Sanctuary. A clear gradient of elevated DIN, TP, TOC, and turbidity from alongshore to offshore was observed in the Keys, with the Upper Keys being lower than the Middle and Lower Keys. The elevated DIN in the nearshore zone of the Keys was not observed in the nearly uninhabited Tortugas, indicating an anthropogenic source. No significant onshore-offshore gradient was observed for CHL*a*.

The highest concentrations of CHL*a* were observed on the southwestern Shelf (Figure 7.13), with a strong decreasing gradient toward the Marquesas and Tortugas. This pattern was likely caused by higher TP concentrations on the Shelf because of southward advection of water along the mainland coast. Most parameters were relatively consistent from year to year, with some seasonal excursions. The exceptions were statistically significant increases in TP and decreases in DO and TOC throughout the region (Figure 7.14).

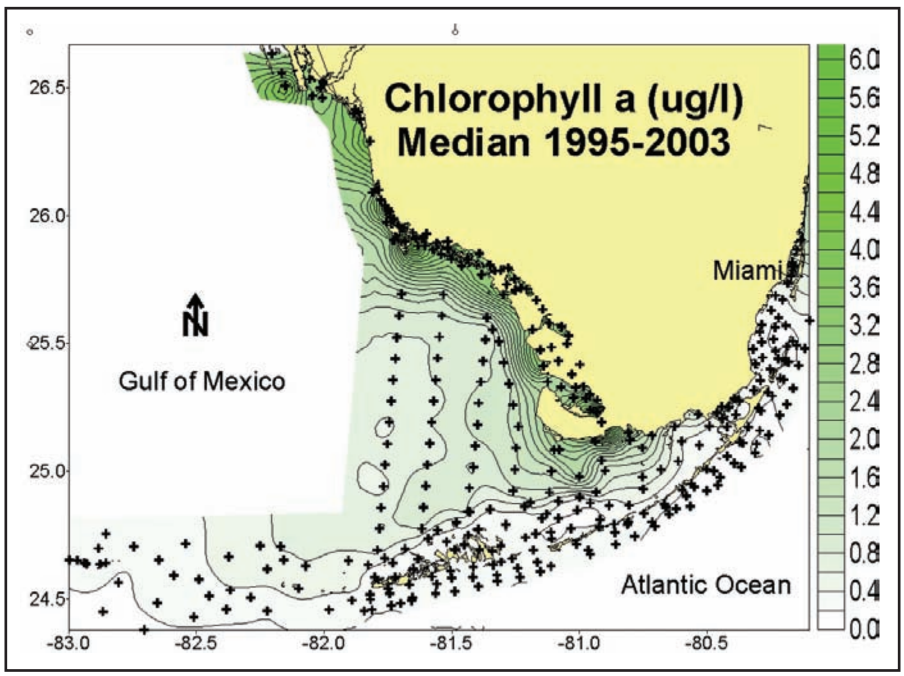

Figure 7.13. Distribution of median concentrations of Chlorophyll *a* in Florida's coastal waters for the period 1995 to 2003. Sampling stations are indicated with a + symbol. Source: Boyer and Jones, 2003.

The local trends described in this study may occur across the whole region, although less pronounced. This spatial autocorrelation in water quality is an inherent property of highly interconnected systems such as coastal and estuarine ecosystems driven by similar hydrological and climatological forcings. Large changes have occurred in Sanctuary water quality over time, and some sustained monotonic trends have been observed (Figure 7.14). However, trend analysis is limited to the window of observation; trends may change, or even reverse, with additional data collection.

The large scale of this monitoring program has allowed a holistic view of broad physical/chemical/biological interactions occurring over the South Florida region. Much information has been gained by inference from this type of data collection program; major nutrient sources have be confirmed, relative differences in geographical determinants of water quality have been demonstrated, and large-scale transport via circulation pathways has been elucidated. In addition, this program demonstrates the importance of looking "outside the box" for questions asked within. Rather than thinking of water quality monitoring as a static, non-scientific pursuit, it should be viewed as a tool for answering management questions and developing new scientific hypotheses.

Downloadable contour maps, time-series graphs, and interpretive reports from the Southeast Environmental Research Center's water quality network (which includes Florida Bay, Whitewater Bay, Biscayne Bay, Ten Thousand Islands, and Southwest Florida Shelf) are available at http://serc.fiu.edu/wqmnetwork (Accessed, 1/31/2005).

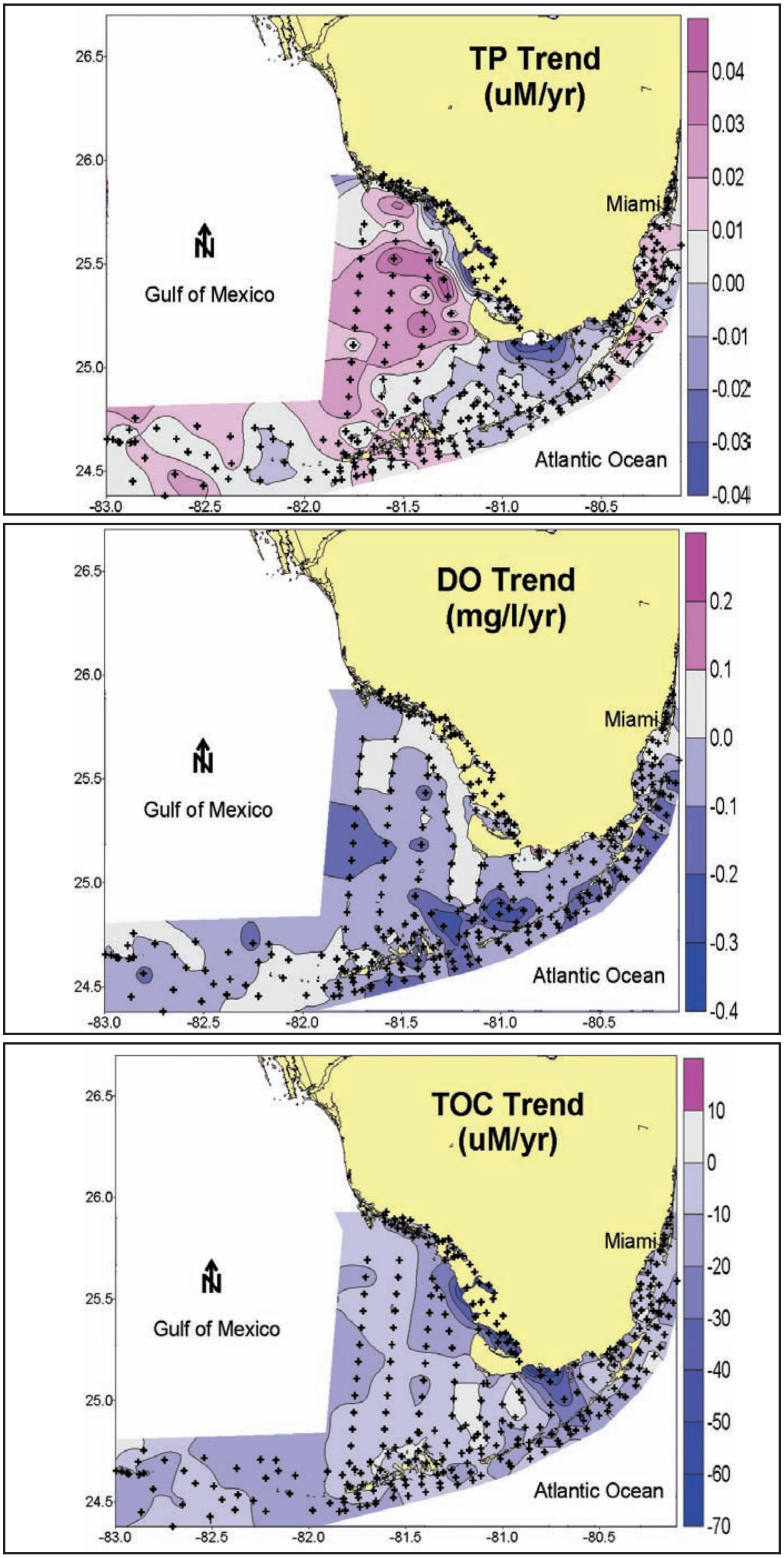

Figure 7.14. Distribution of significant increases in total phosphorus concentrations (top panel) and decreases in dissolved oxygen (middle panel) and total organic carbon (bottom panel). Sampling stations are indicated with a + symbol. Source: Boyer and Jones, 2003

BENTHIC HABITATS

The Coral Reef Evaluation and Monitoring Project

Methods

The FFWCC's Coral Reef Evaluation and Monitoring Project (CREMP) tracks the status and trends of stony corals and selected benthic biota at 53 stations across the Florida Reef Tract from Palm Beach through the Dry Tortugas. The project annually samples at 43 permanent sites in the Florida Keys and Dry Tortugas and 10 sites off the Southeast Florida coast in Palm Beach, Broward, and Miami-Dade Counties. Habitat types include hardbottom, patch reef, shallow offshore, and deep offshore communities. Within stations, sampling consists of a station species inventory (SSI), video transects, and a bioeroding sponge survey. Diseased coral surveys, stony coral abundance surveys, and temperature surveys are also conducted at selected sites. Details on sampling strategy, field methods, and data processing and analyses may be accessed at http://www.floridamarine.org/corals (Accessed 2/8/05).

Results and Discussion

The inventory of coral species richness within FKNMS from 1996 through 2003 exhibited a trend of general decline in stony coral species richness in all reef types and geographic areas (Upper, Middle, and Lower Keys). The number of species observed declined at 74 stations (70%), increased at 21 stations (20%), and remained stable at 10 stations (10%). More coral species were seen at deep reef and patch reef stations than in shallow reef and hardbottom stations (Table 7.7).

Table 7.7. Change in coral species richness among benthic habitats and regions of the Florida Keys and Dry Tortugas between 1996 and 2003. Source: Jaap et al., 2003.

CATEGORY	LOST TAXA		GAINED TAXA		UNCHANGED	
	#	%	#	%	#	%
All stations	74	70	21	20	10	10
Hard bottom	6	55	3	27	2	18
Patch Reef	29	72	3	11	5	14
Shallow offshore	28	72	10	26	1	3
Deep offshore	26	73	5	15	2	6
Upper Keys	23	77	2	7	5	17
Middle Keys	20	69	7	24	2	7
Lower Keys	31	67	12	26	3	7
Dry Tortugas*	9	75	3	25	0	0

*Database for Tortugas is 1999 – 2002. (gains + unchanged)

The number of stations where *Acropora cervicornis* and *Scolymia lacera* were present decreased significantly (P <0.05) while *Copolphyllia natans, Madracis mirabilis, Porites porites, Siderastrea radians, Mycetophyllia ferox,* and *M. lamarkiana* showed decreases (P <0.1). Only *Siderastrea siderea* was observed at a significantly greater number of stations in 2001-2002 than in previous years.

There were trends showing increases in the number of stations where coral disease occurred, number of different types of disease, and number of coral species infected with disease. In 1996, diseased corals were seen at 20 stations, compared with 95 stations in 2003. Black band disease (BBD; Rützler and Santavy, 1983) was least common of the conditions monitored; the incidence of BBD was slightly higher in 1998 and has wavered at low levels in subsequent years. *Colpophyllia natans, Montastraea annularis, Montastraea cavernosa* and *Siderastrea siderea* were the species most infected by BBD. In 1996, white band disease (WBD) was recorded at five stations; in 2002 it was present at 90 stations. WBD in *Agaricia agaricites* was not seen at any stations in 1996, but was seen at 33 stations in 2002. *Montastraea annularis* complex followed a similar pattern with no reports in 1996, but corals at 32 stations showed infection in 2002. Purple spot on *Siderastrea siderea* was also reported. Fourteen species exhibited an increase in diseases: *Agaricia agaricites, Colpophyllia natans, Dichocoenia stokesii, Eusmila fastigiata, Favia fragum, Meandrina meandrites, Millepora alcicornis, Millepora complanata, Montastraea cavernosa, Montastraea annularis* complex*, Porites astreoides, P. porites, S. siderea,* and *Stephanocenia michelinii*.

Coral cover exhibited a significant decline for the period 1996-1999; there was no significant change from 1999- 2003 (Figure 7.15). These changes were most likely related to bleaching episodes in 1997 and 1998 and hurricanes in 1998 and 1999. The areas most influenced by these disturbances were shallow offshore sites. During bleaching events, temperatures were high enough to cause expulsion of zooxanthellae, thereby discoloring many of the zooanthids, fire coral, stony corals, and some octocorals such as *Biareum* spp. The organisms that exhibited the most bleaching were *M. complanata* and *Palythoa mammillosa*. These are sentinel species; they bleach at a slightly lower threshold than many of the other corals. *M. complanata* cover decline was greatest from 1998 to 1999 and has not recovered since then (Table 7.8). The percent cover and frequency of occurrence of corals improved slightly after 2001. The bleaching event in 1997 may have stressed *M. complanata*, and a second exposure to hypothermia in 1998 may have been sufficient to reduce the population drastically.

The golden sea mat (*Palythoa mammillosa*) is conspicuous in shallow reefs. The CREMP analysis pooled all zooanthids (*Zoanthus* spp., *Palythoa* spp., *Ricordia* spp.) into a single category. Virtually all zoanthids observed in the images were *P. mammillosa*. Unlike the fire coral, (*M. complanata*), *P. mammillosa* showed little change in cover after the bleaching disturbance (Table 7.9). A slight reduction in the mean percent cover of *P. mammillosa* occurred between 1997 and 1998, although population levels equaled or exceeded the pre-bleaching period in 2000 and subsequent years.

Hurricane Georges crossed the Straits of Florida near Key West on September 25, 1998. Sombrero Key C-MAN buoy recorded a maximum sustained wind of 82 knots with a peak gust to 92 knots at 1500 Universal Time on September 25 (Table 7.10). Hurricane Georges' greatest influence on coral reef communities was between Sombrero Key and Dry Tortugas. The hurricane's impact was evidenced by the change in *Acropora palmata* cover, which decreased in range, mean, and frequency of occurrence after Hurricane Georges (Table 7.11). Sampling occurred before the hurricane struck in 1998, thus the major decline is most noticeable in 1999 and subsequent years. *A. palmata* exhibited the highest pre-hurricane cover at Western Sambo station two: 15.28% in 1996 and 16.34% in 1997 (Table 7.11). Figure 7.16 provides evidence of the coral cover loss attributed to Hurricane Georges.

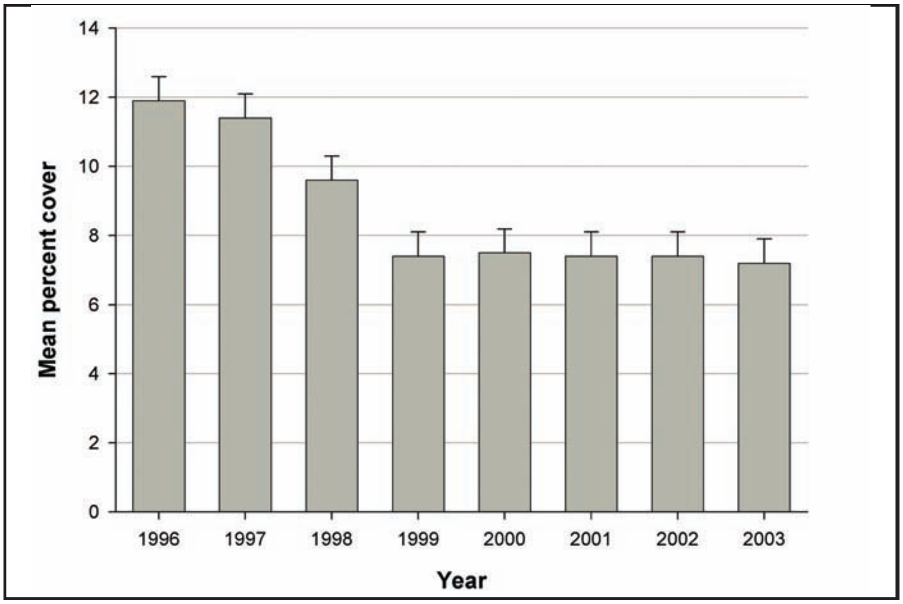

Figure 7.15. Mean percent live coral cover in the Florida Keys National Marine Sanctuary between 1996 and 2003. Source: Jaap et al., 2003.

Table 7.8. Descriptive statistics for annual percent cover of *Millepora complanata* in the Florida Keys National Marine Sanctuary between 1996 and 2002. Source: Jaap et al., 2003.

YEAR	1996	1997	1998	1999	2000	2001	2002
Range	0-15.71	0-17.33	0-16.44	0-1.88	0-1.19	0-0.85	0-0.49
Mean	2.55	2.23	1.56	0.19	0.13	0.09	0.11
Std.dev.	4.54	4.05	3.25	0.37	0.28	0.18	0.17
Freq.	0.85	0.85	0.72	0.48	0.33	0.41	0.46

Table 7.9. Descriptive statistics for annual percent cover of *Palythoa mammillosa* in the Florida Keys National Marine Sanctuary between 1996 and 2002. Source: Jaap et al., 2003.

YEAR	1996	1997	1998	1999	2000	2001	2002
Range	0-25.54	0-24.69	0-20.01	0-22.48	0-24.45	0-21.54	0-25.39
Mean	4.36	4.97	4.4	4.25	4.61	4.48	5.3
Std.dev.	5.4	5.74	4.95	5.11	5.67	5.6	6.32
Freq.	0.92	0.97	0.92	0.94	0.92	0.92	0.89

Table 7.10. Data on conditions during Hurricane Georges at C-MAN Stations in the Florida Keys, October, 1999. Source: NOAA National Hurricane Center, http://www.nhc.noaa.gov/abouttafb.shtml, Accessed: 2/14/2004.

LOCATION	PRESS. (mb)	DATE/TIME (UTC)	SUSTAINED WIND (kts)	PEAK GUST (kts)	DATE/ TIME (UTC)
Lake Worth, FL	1010.0	25/1100	30	35	25/1400
Fowey Rocks, FL	1006.3	25/1000	45	52	25/1000
Molasses Reef, FL	1003.1	25/0800	46	53	25/1400
Long Key, FL	1000.0	25/1000	47	58	25/1400
Sombrero Key, FL	994.5	25/1300	81	92	25/1500
Sand Key, FL	990.5	25/1300	56	71	25/1400
Dry Tortugas, FL	976.3	25/2000	59	68	26/0000

The National Hurricane Center reported that Tropical Storm Irene reached hurricane status over the Florida Straits on October 14, 1999. The center moved over Key West on October 15 (Table 7.12). Most of the hurricane force winds were confined to the east of Irene's center over the lower to middle Florida Keys. Irene made its fourth landfall near Cape Sable, Florida and then moved across southeast Florida before crossing the Keys, into the Everglades. Its sustained and peak wind gusts were less than those of Hurricane Georges (Table 7.10). The second hurricane in 13 months disturbed offshore shallow reefs, but since Hurricane Georges had already reduced populations of *A. palmata* and other organisms, Hurricane Irene's influence was somewhat muted.

Table 7.11. Descriptive statistics for annual percent cover of *Acropora palmata* in the Florida Keys National Marine Sanctuary between 1996 and 2002. Source: Jaap et al., 2003.

YEAR	1996	1997	1998	1999	2000	2001	2002
Range	0-15.28	0-16.34	0-9.96	0-3.40	0-2.72	0-2.44	0-4.88
Mean	2.97	2.91	1.79	0.4	0.33	0.27	0.4
Std.dev.	4.6	4.55	3.2	0.9	0.73	0.58	0.98
Freq.	0.44	0.44	0.38	0.28	0.3	0.28	0.28

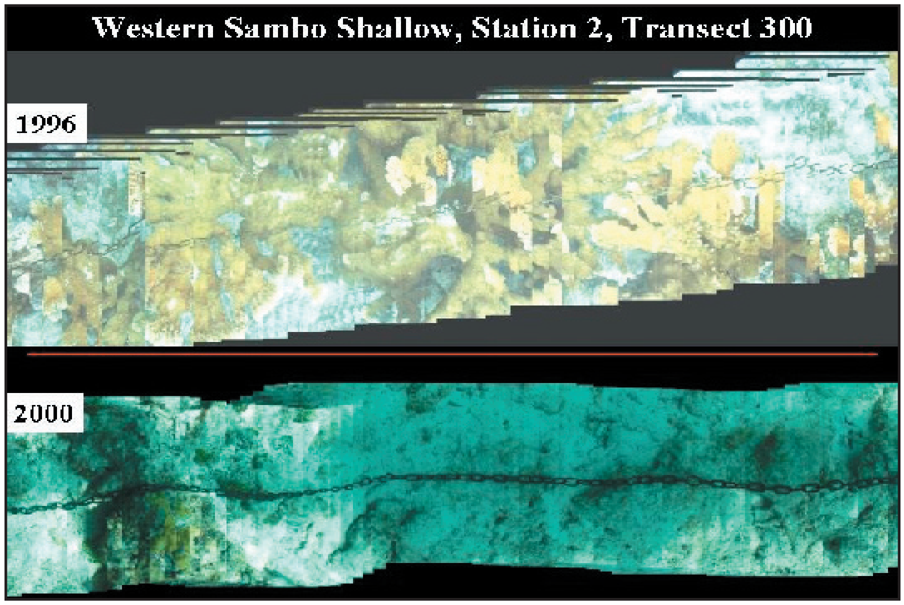

Figure 7.16. Loss of *Acropora palmata* along a video transect at Western Sambo, Florida Keys between 1996 and 2000. Source: Jaap et al., 2003.

Table 7.12. Data on conditions during Hurricane Irene at C-MAN Stations in the Florida Keys, October, 1999. Source: NOAA National Hurricane Center, http://www.nhc.noaa.gov/abouttafb.shtml, Accessed: 2/14/2004.

LOCATION	PRESS. (mb)	DATE/ TIME (UTC)	SUSTAINED WIND (kts)	PEAK GUST (kts)	DATE/ TIME (UTC)
Sombrero Key C-MAN	990.5	15/1700	57	69	15/1530
Molasses Reef C-MAN	991.5	15/2100	53	64	15/2020
Long Key C-MAN	988.7	15/2000	50	61	15/2000
Sand Key C-MAN	987.0	15/1200	43	57	15/0610
Dry Tortugas C-MAN			41	51	15/0850
Key West Intl. Airport	987.6	15/1010	38	47	15/0518

Frequency and Distribution of Coral Diseases

Methods

A broad-scale survey to determine the frequency and distribution of coral disease in the Florida Keys was conducted in August 2000 and incorporated 30 sites from Key Biscayne to the Dry Tortugas. Sites were located in Biscayne National Park, FKNMS, New Grounds, and the Dry Tortugas National Park. A sampling protocol similiar to those used in EPA's Environmental Monitoring and Assessment Program was used to select site locations (Summers et al., 1995; Santavy et al., 2001). The probabilistic sampling design was generated and implemented to estimate the baseline condition of reef corals to compare with future assessments. The survey will be repeated in August 2005.

The study produced unbiased estimates of coral condition with a quantifiable level of uncertainty for the distribution and frequency of coral diseases in the Florida Keys. The distribution of coral disease was assessed as present or absent for each site. The frequency of coral disease was the percentage of diseased coral from each site. The area represented by the study was 41 km^2 of the South Florida Keys Tract. The reef areas of the Florida Keys (Upper, Middle, and Lower Keys; New Grounds; and Dry Tortugas) that contained hard coral bottom were demarcated based on benthic habitat maps of the Florida Keys (FMRI, 1998). Habitat boundaries were redefined by experts to include areas known to have living corals and to eliminate areas that contained only dead or geological reef structure. The design was developed in three steps: (1) regional stratification, (2) overlay of a hexagonal grid on the sample frame, and (3) random selection of multiple sites within grid cells (Summers et al., 1995; Santavy et al., 2005).

Results and Discussion

The areal estimates of coral disease generated by the 2000 survey indicated that at least one coral colony affected by active disease was observed in 85% ± 9 (95% confidence intervals) of the area sampled. Coral disease was widely dispersed throughout the Florida Keys Reef Tract and did not seem to be confined to a particular region. While the presence or distribution of disease was widespread, the proportion of colonies affected by disease or disease prevalence at any particular location was significantly less. The maximum percent of coral colonies affected with disease or maximum prevalence of coral disease in South Florida at any one site during August 2000 was 13%, with 2.2% ± 4 (97 ha) of the sampling area containing this maximum level of coral disease (Figure 7.17). Approximately 15% ± 9 (662 ha) of the area sampled contained no coral disease, whereas 31% ± 14 (1,369 ha) of the area had between 0.4%- 2.2% of the colonies affected by coral disease. Approximately 28% ± 15 (1,236 ha) of the area had greater than 2% and no more than 4% of colonies affected by disease. Finally, 24% ± 4 (1,060 ha) of the sampled area had between 4% and 9% frequency of coral disease. By establishing this baseline, future surveys can examine changes and trends in the spatial and temporal distribution and frequency of coral disease in South Florida (Santavy et al., 2005). This approach will allow the condition of reefs to be classified generally from excellent to degraded, to better communicate their status to the public and policy makers.

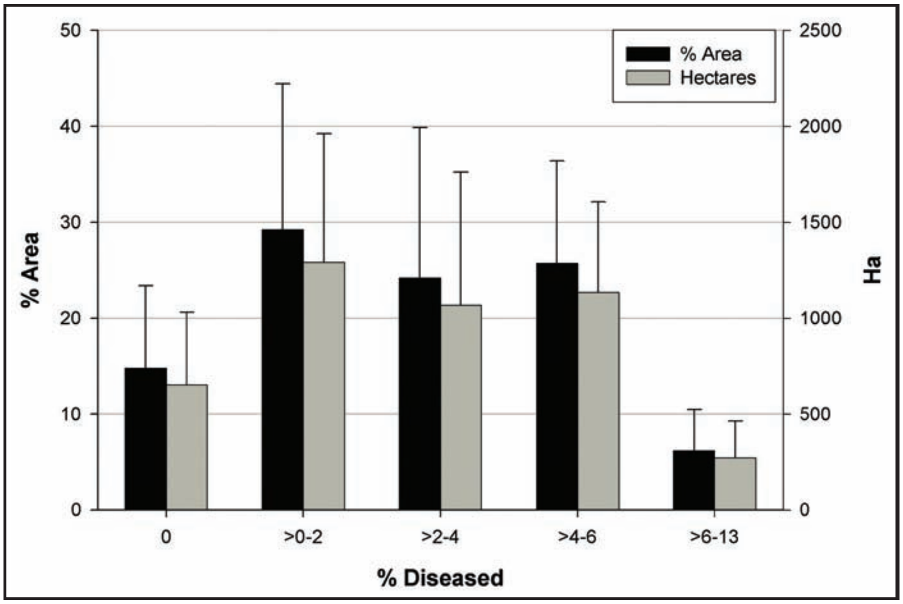

Figure 7.17. Frequency of coral disease or percent area having 0-13% of colonies affected by coral diseases in South Florida Keys Tract. Error bars represent 95% confidence levels. Source: Santavy et al., 2005.

Regional Coral Disease Assessments

Methods

Coral disease prevalence was compared between different geographical regions in the Dry Tortugas, New Grounds, Key West region, Lower Keys, Middle Keys, and Upper Keys from 1998 to 2002 (Figure 7.18). All surveys were conducted using a radial arc transect method developed for the coral disease surveys (Santavy et al., 2001). If the location had sufficient coral coverage (>5%), a permanent installation was made and the site was surveyed. Only the 8-10 m segment of the radial arc transect (113 m^2) was necessary to estimate coral disease (Mueller et al., 1998; Santavy et al., 1999a, 2001). Twenty-two species of scleractinian corals and gorgonian sea fans were surveyed and only colonies greater than 10 cm were counted. *M. annularis, M. faveolata,* and *M. franksii*, the three species of coral contained within the Montastraea annularis complex (Weil and Knowlton, 1994) were combined as a single taxon, *M. annularis*, for data analysis. Two gorgonian sea fan species were combined as *Gorgonia* spp.

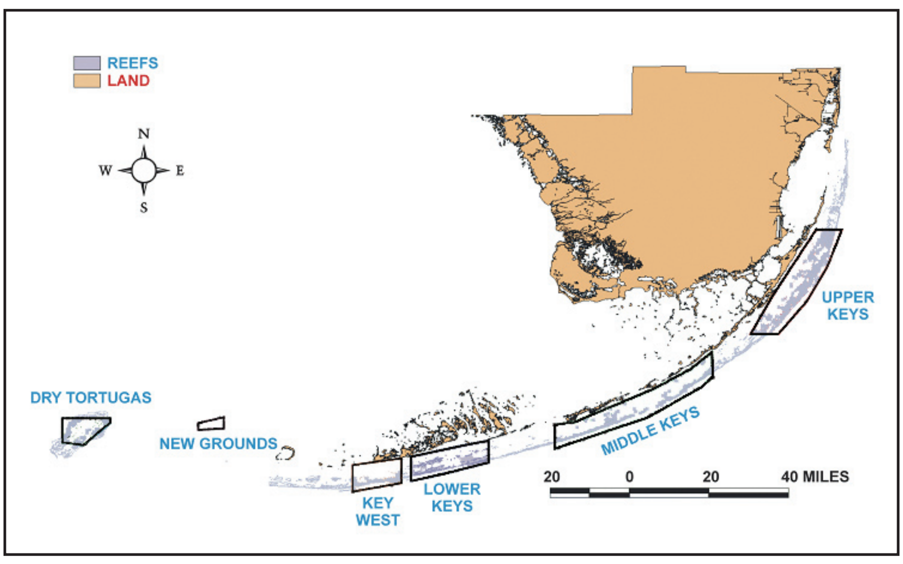

Figure 7.18. Map of the coral disease assessment regions, in which all the sites were contained in this study, including areas in Dry Tortugas National Park, New Grounds, Key West, Lower Keys, Middle Keys, Upper Keys and Biscayne National Park. Source: Santavy et al., 2005.

Only coral colonies containing active disease lesions were enumerated.

The diseases consistently assessed are listed in Table 7.13. Signs used to distinguish coral diseases were obtained from published literature (McCarty and Peters, 1998; Patterson et al., 2002; Santavy and Peters, 1997; Santavy et al., 1999a,b, 2001). No distinction was made between white plague type 1 and 2 (Dustan,1977; Richardson et al.,1998a,b). Additionally, a combination of 13 disease conditions obtained from published literature was used to identify seafan disease (Smith et al., 1996; Nagelkerken et al., 1997a, b; Santavy et al., 2001; Kim and Harvell, 2002).

Table 7.13. Diseases assessed in surveys with corresponding abbreviations and references detailing the signs used in assessing condition. Source: Santavy et al., 2005.

DISEASE NAME	DISEASE ABBREVIATION	SPECIES AFFECTED IN TROPICAL WESTERN ATLANTIC	REFERENCES
Sea Fan Disease	SD	*Gorgonia* spp.	Nagelkerken et al., 1997a, b; Smith et al., 1996.
Black Band Disease	BB	*Diploria strigosa, D. labyrinthiformis, Colpophyllia natans, Montastraea cavernosa, M. annularis, M. frankii, M. faveolata, Siderastrea siderea, Gorgonia* spp.	Antonius,1981; Rützler et al.,1983; Rützler & Santavy, 1983.
Dark Spot Disease	DS	*C. natans, M. annularis* (species complex), *S. siderea, Stephanocoenia intersepta*	Garzón-Ferreira and Gil, 1998.
Hyperplasia	HP	*D. strigosa, Dichocoenia stokesii*	Peters et al., 1986.
Patchy Necrosis/ White Pox	PX	*Acropora palmata*	Bruckner and Bruckner, 1997; Patterson et al., 2002.
Red Band Disease	RB	*Gorgonia* spp., *C. natans*	Rützler and Santavy, 1983; Richardson, 1993.
White Plague	WP	*D. stokesii, Agaricia agaricites, A. lamarchi, C. natans, Dendrogyra cylindrus, D. labyrinthiformis, D. strigosa, Eusmilia fastigiata, Madracis decactis, M. mirabilis, Manicina areolata, Meandrina meandrites, M. annularis* (species complex), *M. cavernosa, S. siderea, Solenastrea bournoni, Stephanocoenia michilinii,* and *hydrocoral Millepora alcycornis.*	Richardson et al.,1998a, b.
White Band Disease 1	WB1	*A. cervicornis, A. palmata, A. prolifera*	Gladfelter, 1982; Peters, 1993.
White Band Disease 2	WB2	*A. cervicornis*	Ritchie and Smith, 1998.
Yellow Blotch Disease	YB	*M. faveolata, M. annularis*	Santavy et al.,1999b.

Results and Discussion

The percentage of diseased coral colonies ranged from 0-43% among all the sites surveyed during the four sampling periods. No geographic location was consistently identified as a 'hotspot' where a high level of disease was sustained at the same site for multiple survey periods. The greatest percentage of diseased colonies occurred at Looe Key back reef site during summer 1998; 42.9% of all the colonies were diseased, with white pox affecting 41.4% of them. Twelve sites had over 20% of the colonies diseased at a single sampling period, and six occurred during the summer 1998 sampling period (Table 7.14). Five of these six sites occurred in the Key West and Lower Keys regions, with white pox affecting the majority of these colonies. The other site was WH01 in the Dry Tortugas. These disease events co-occurred with the single most severe and massive bleaching event recorded in modern history. Table 7.15 shows the percentage of diseased corals encountered in each region. Each region was not assessed during each survey due to limitations based on level of support available. The 2001 survey was incomplete due to the termination of cruises after the events of September 11, 2001.

Table 7.14. Sites with at least 20% disease prevalence in a survey. Abbreviation for diseases: DS=Dark Spots Disease; PX=White Pox Disease; PX_WB=White Pox Disease and White Band Disease on same colony; SD=Seafan Disease; and WB=White Band Disease. Source: Santavy et al., 2005.

REGION	SITE	YEAR	PERIOD	% DISEASED*	PRIMARY DISEASE	% PRIMARY DISEASE	OTHER IMP. DISEASES
Dry Tortugas	White Shoals 2	1998	Summer	22.86 [9]	SD	17.14	DS, WB
Dry Tortugas	Bird Key 4	1999	Spring	28.33 [6]	PX	27.50	WB
Dry Tortugas	Bird Key 5	1999	Spring	27.37 [8]	PX	27.37	
Key West	Rock Key 3	1998	Summer	27.27 [8]	PX	18.80	WB
Key West	Sand Key 2	1998	Summer	36.61 [3]	PX	16.94	WB, PX_WB
Key West	Sand Key 5	1998	Summer	27.78 [7]	PX	22.22	WB
Lower Keys	E. Sambo 3	1998	Summer	31.91 [5]	PX	31.91	
Lower Keys	Looe Key 3	1998	Summer	42.86 [1]	PX	41.43	WB
Middle Keys	Alligator Reef 2	1998	Spring	22.22 [10]	SD	22.22	
Upper Keys	Carysfort Reef 2	1998	Spring	20.00 [11]	SD	20.00	
Upper Keys	Carysfort Reef 3	1998	Spring	32.29 [4]	SD	23.53	PX
Upper Keys	Carysfort Reef 3	1999	Spring	40.00 [2]	PX	25.00	WB, DS

Table 7.15. Percent diseased colonies for each geographic region sampled from 1998 to 2002. Source: Santavy et al., 2005.

REGION	YEAR	PERIOD	% DISEASED
Dry Tortugas	1998	Spring	4.49
	1998	Summer	4.93
	1999	Spring	4.51
	2000	Summer	4.61
	2002	Summer	3.64
New Grounds	1998	Spring	0.98
	1998	Summer	1.13
	2000	Summer	0.46
Key West	1998	Spring	5.91
	1998	Summer	12.8
	1999	Spring	6.84
	2000	Summer	5.34
	2002	Summer	4.55
Lower Keys	1998	Spring	6.81
	1998	Summer	21.19
	1999	Spring	6.41
	2002	Summer	4.55
Middle Keys	1998	Spring	3.36
	1998	Summer	1.84
	1999	Spring	2.46
	2002	Summer	2.38
Upper Keys	1998	Spring	14.17
	1998	Summer	9.8
	1999	Spring	4.23
	2002	Summer	3.22
Biscayne National Park	1998	Spring	8.77
	1998	Summer	3.91
	1999	Summer	0.6

Acroporid Species in the Upper Keys

Methods

The surviving *Acropora* spp. populations in the Upper Florida Keys are scarce and highly patchy in distribution, requiring a focal monitoring approach. In 1998, annual monitoring of *Acropora palmata* populations and their snail predators (*Coralliophila abbreviata*) was initiated at four sites in the FKNMS. Annual surveys record data on size structure and condition of *A. palmata* colonies at each site as well as snail infestation, damselfish territories, and disease prevalence (see Miller et al., 2002 for complete methods). Since 2002, individual colonies of *Acropora palmata* and *A. cervicornis* have been monitored at four sites in the FKNMS and four sites in Biscayne National Park (BNP). Approximately 20 colonies at each site were chosen to reflect the range of conditions present at that site (e.g., health, disease, predation). Colonies were tagged, mapped, extensively photographed, measured (length, width, and height), assessed for condition, and re-surveyed at 4-5 month intervals.

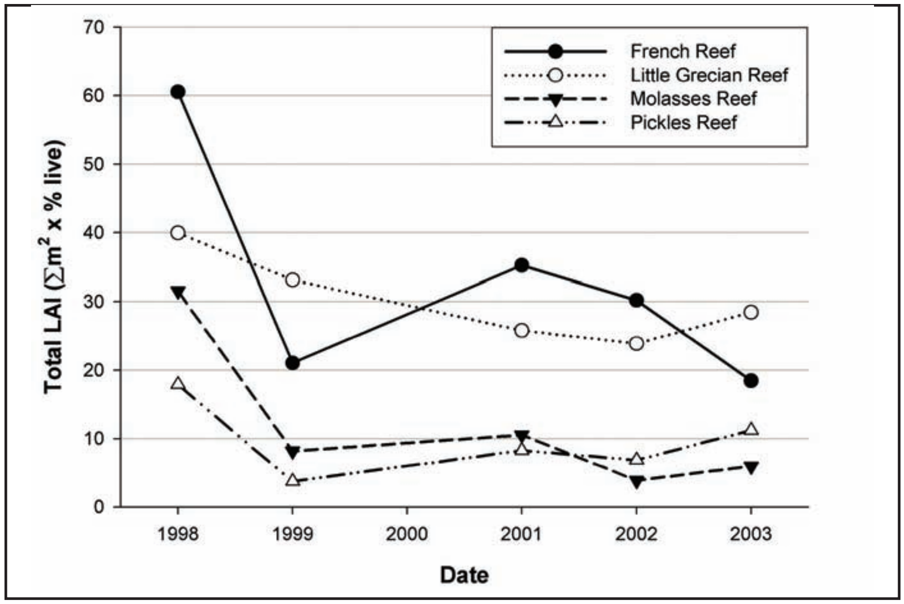

Figure 7.19. Total live area (sum of length x width x % live cover) of *Acropora palmata* at fully censused sites off Key Largo, FL from 1998 to 2003. Source: Miller et al., 2002.

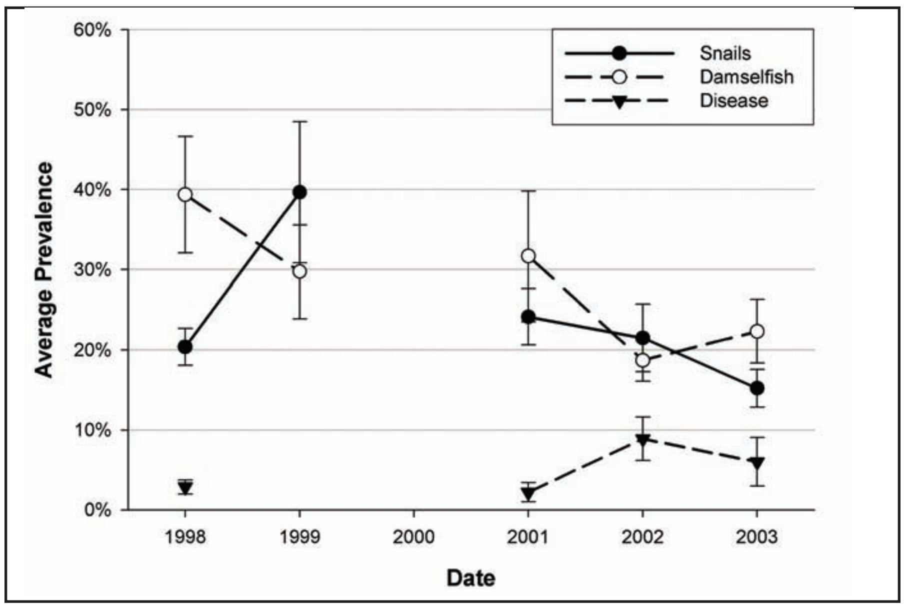

Figure 7.20. Average prevalence of *Acropora palmata* surveyed from reefs (n = 6) in the Upper Florida Keys that were infested with snails (*Coralliophila abbreviata*) inhabited by three-spot damselfish (*Stegastes planifrons*) or displayed active signs of disease (including White Band Disease and White Pox/Patchy Necrosis). Surveys were conducted at 6 reefs including South Carysfort, Horse Shoe, Little Grecian, French, Pickles, and Molasses reefs. Source: Miller et al., 2002.

Results and Discussion

The annual survey of *A. palmata* patches shows that a substantial decline occurred between 1998 and 1999. This interval included two major disturbances: Hurricane Georges and a major bleaching event. Since then, abundance of live coral at these four sites has remained fairly stable but has not shown any recovery (Figure 7.19). The proportion of colonies infested by snail predators increased in 1999 following this decline in coral abundance, but has rebounded back to its previous (1998) level of about 15-20% (Figure 7.20). A similar proportion of colonies are affected by three-spot damselfish biting, but a much smaller percentage of *A. palmata* colonies display signs of active disease (Figure 7.20).

Over most of the study period, predation by snails appeared to be the condition posing greatest impact to recruits of both species in terms of both live tissue loss and decreased growth of individuals. Snail predation is also the most prevalent threat at the population level. However, in April 2003, this individual-based monitoring of *Acropora* spp. colonies led to the discovery of a coral disease outbreak at White Bank Dry Rocks (Figure 7.21). In the observed outbreak, approximately 65% of the *A. cervicornis* colonies had significant or total tissue loss. The tagged population (n=19 colonies) showed a loss of mean colony live tissue coverage from 95% prior to the outbreak to less than 15% in a follow-up survey in February 2004. This event emphasizes the vulnerability of *Acropora* spp. recovery to stochastic events which are difficult, if not impossible to manage or mitigate.

Figure 7.21. An *Acropora cervicornis* colony displays rapid tissue loss at White Bank Dry Rocks, Florida Keys. During this outbreak in spring 2003, many colonies exhibited this condition at several other reef sites in the Florida Keys. Source: Miller et al., 2002.

ASSOCIATED BIOLOGICAL COMMUNITIES

FISH

Fishery-Dependent Monitoring

Various programs that collect data directly from Florida fisheries are summarized in Table 7.16.

Table 7.16. Florida fishery-dependent data collection programs. Source: J. Bohnsack, NOAA Fisheries, SEFSC.

PROGRAM	TARGET	AGENCY	DATE STARTED
Marine Recreational Fishing Statistical Survey (MRFSS)	Recreational fishing from shore, bridge, private, rental and charter boats	NOAA Fisheries	1979
NMFS Headboat Survey	Recreational headboat landings and biostatistical sampling	NOAA Fisheries	1978
Recreational world record gamefish	Largest fish landed by recreational angling by line class and rod type by men and women	International Gamefish Association (IGFA)	1939
Recreational fishing licenses	Recreational marine angling, spiny lobster diving	Florida Fish & Wildlife Conservation Commission	1990
Florida Trip Ticket System	Commercial food fish and invertebrate landings	Florida Fish & Wildlife Conservation Commission	1986
Florida Trip Ticket System	Commercial marine life fisheries	Florida Fish & Wildlife Conservation Commission	1990
General Canvass Landings Statistics (GCLS)	Commercial landings	NOAA Fisheries	1967
Trip Interview Program (TIP)	Commercial biostatistical data	NOAA Fisheries	1985
Commercial Logbook Program	Commercial fishing by fish traps, longlines	NOAA Fisheries	1993
Commercial vessel registrations	Number of commercial vessels	NOAA Fisheries	1985
Biscayne National Park (BNP) Creel Census	Recreational fishing within and adjacent to BNP	Biscayne National Park	1976
Everglades National Park (ENP) Creel Census	Recreational fishing within and adjacent to ENP	Everglades National Park	1972

Florida Fish and Wildlife Conservation Commission

The FFWCC has collected commercial food fish landings since 1986 and commercial marine life fishery statistics since 1990. NOAA Fisheries (U.S. DOC, 2003) collects landings data for commercial and recreational food fisheries, and for recreational charter boats, headboats, private boats and shore fishing. Commercial and recreational spiny lobster fishing effort is reflected by the number of licenses issued (Figures 7.22 and 7.23).

Results and Discussion

Native Americans fished for reef fishes on Florida reefs long before the arrival of European settlers (Oppel and Meisel, 1871). Reef fishing accelerated in the 1920s. Following growing public conflicts and sharp declines in catches, monitoring programs at the species level began in the early 1980s (Bohnsack et al., 1994; Bohnsack and Ault, 1996; Harper et al., 2000).

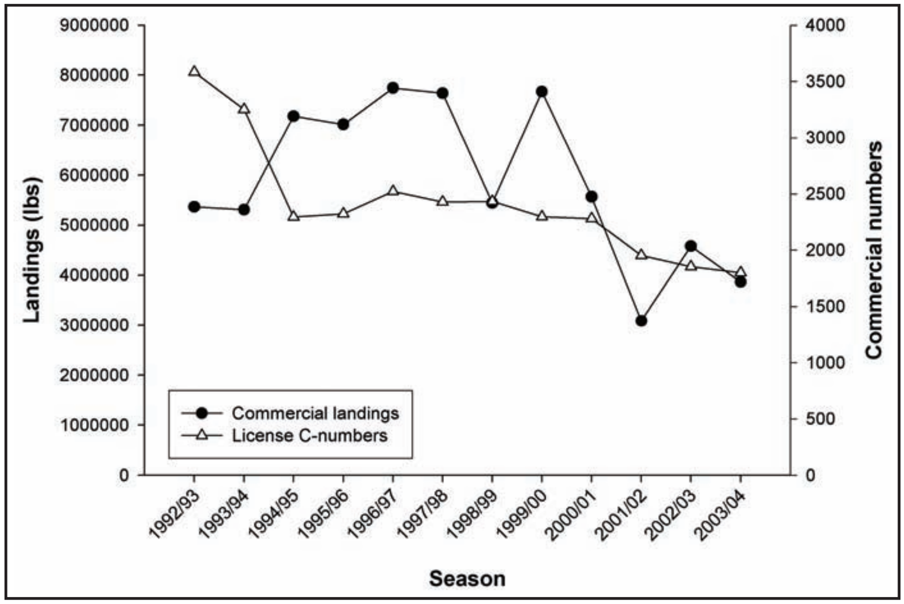

Figure 7.22. Commercial landings and license C-numbers for the spiny lobster fishery in Florida. Commercial landings include catch from traps and from diving. License numbers overestimate the number of vessels since some vessels may have more than one set of C-numbers. Landings for 2003-4 are preliminary. Source: Florida Fish and Wildlife Conservation Commission, unpublished data.

Fishery-dependent reef fish landings trends were reported for the Florida Keys (Bohnsack et al., 1994). Reef fishes accounted for 58% of fish landings. From 1981-1992, mean total annual landings from recreational reef fisheries in the Florida Keys (Monroe County) were 0.107 x 106 kg for headboats in the Tortugas 0.201 x 106 kg for the rest of the Keys, and 1.79 x 106 kg for other recreational fisheries. In comparison, total commercial reef fishery landings were 2.12 x 106 kg for spiny lobster, 1.25 x 106 kg for pink shrimp, 0.17 x 106 kg for grouper, and 1.00 x 106 kg (using 1992 as a benchmark). In the 1980s, pink shrimp landings declined to approximately 40% of previous levels while total grouper declined to less than half of previous levels. Increases in landings were reported for yellowtail snapper, amberjack, and various jacks.

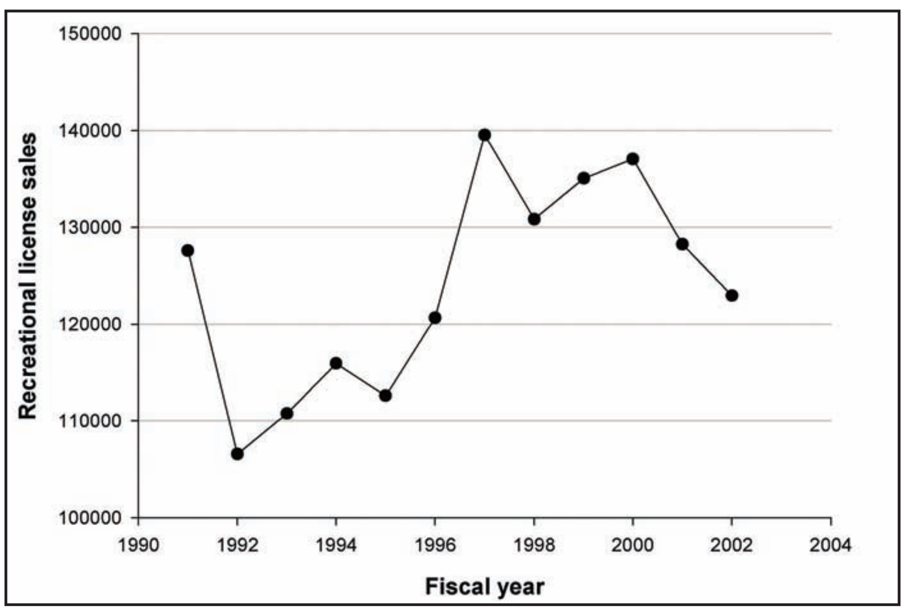

Figure 7.23. Numbers of recreational licenses for the spiny lobster fishery in Florida (1991-2002). Source: Florida Fish and Wildlife Conservation Commission.

Harper et al. (2000) described trends in the recreational hook-and-line and diving fishery in the BNP from 1976-1991 in which more than 170 taxa were recorded. Mean annual landings were 4.77 fish/angler/trip (ranging from 3.80 in 1991 to 5.83 in 1981) and dropped significantly in years following Florida's adoption of new minimum size restrictions in 1985 and 1990. Spiny lobster landings averaged 8.02 per trip and releases averaged 5.73 per trip. Spearfishing accounted for 12% of trips and 10.3% of fish landed by numbers.

In a report to the U.S. Congress (U.S. DOC, 2003) the SAFMC listed six Florida reef fishes (speckled hind, warsaw grouper, black grouper, red porgy, goliath grouper, and Nassau grouper) as either overfished (i.e., depleted below minimum standards) or undergoing overfishing (i.e., being fished at a rate that would lead to overfishing), four species were not overfished and 46 species were in unknown condition. The GMFMC listed two species, goliath and Nassau grouper, as either overfished or undergoing overfishing, while 26 were in unknown condition. More recently hogfish (*Lachnoliamus maximus*) stocks were shown to be overfished and undergoing overfishing in the Florida Keys (Ault et al., 2003) although fishing mortality trends showed a gradual decrease following a fish trap prohibition in 1990 and establishment of minimum size regulations in 1993 (Figure 7.24).

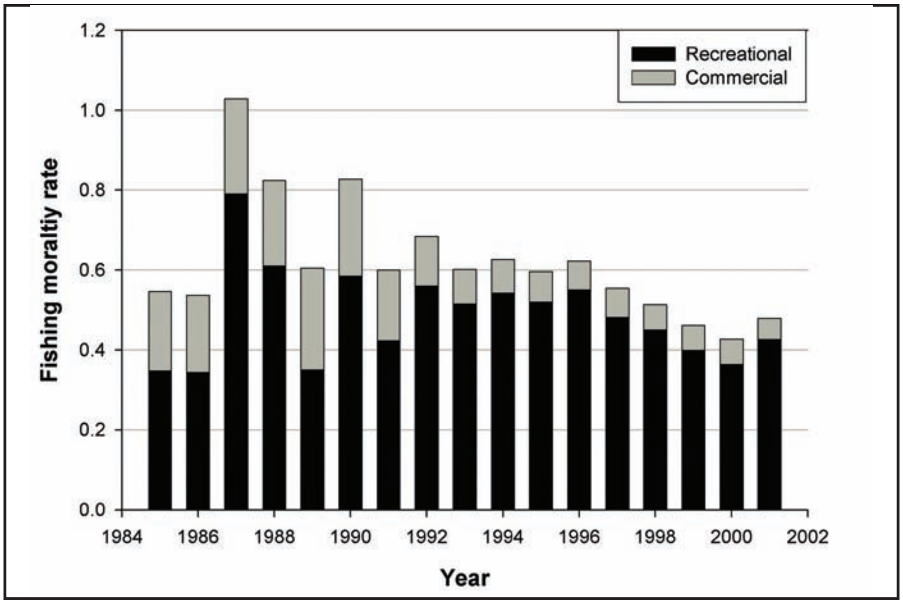

Figure 7.24. Estimated total annual fishing mortality rates (1985-2000) for Florida hogfish showing commercial (light) and recreational (dark) contributions. Source: Ault et al., 2003.

A yellowtail snapper (*Ocyurus chrysurus*) stock assessment (Muller et al., 2003) showed landing trends increased from 1000 mt in 1981 to 1643 mt in 1993, and then declined to 802 mt in 2001. Effort followed a similar trend as landings, increasing to a peak and then declining. Compliance with the 30.5 cm minimum size limit was high. Noncompliance, depending on the region, was 2% for commercial, 4-5% for recreational, and 2-3% for headboat fisheries. Only 0.2% of anglers in the Atlantic region and 1.3% in the Keys exceed the 10 fish per trip limit. The assessment concluded that the stock was neither undergoing overfishing or overfished (http://www.sefsc.noaa.gov/SEDAR2/yellowtailFinal.pdf, Accessed 02/09/05).

Goliath grouper (*Epinephelus itajara*) fishing was closed in Florida and Atlantic waters in 1990 and in the Gulf of Mexico in 1992. In 2003, evidence indicated that the stock was rebuilding and had a 50% chance of being rebuilt by 2006 in its historical core habitat range in southern Florida (Porch et al., 2003).

Fishery-Independent Monitoring

Several monitoring programs collect resource data independent of Florida fisheries.

NOAA Reef fish visual census

Methods

The NOAA Southeast Fisheries Science Center's reef fish visual census (RVC) method has used non-destructive visual survey methods to assess reef fish communities and habitat associations in the Florida Keys since 1979. The goals of the method are to monitor trends and habitat associations of the entire reef fish fauna, and to monitor changes in various MPAs and specifically in FKNMS marine reserves following their establishment in 1997 and 2001. A stationary, centrally located diver in a random 7.5 m-radius plot assesses reef fish composition, abundance (density), and size structure. All species observed for five minutes are listed, counted, and their sizes estimated. Habitat features and depth are also recorded. Details on reef fish monitoring field methods and data processing and analyses are published in Bohnsack and Bannerot (1986) and Bohnsack et al. (1999).

Results and Discussion

The RVC database was used to assess condition and retrospective changes in reef fish stocks in the Florida Keys. Ault et al. (1998) showed that a total of 13 of 16 groupers, seven of 13 snappers, and two of five grunts were found to be below the 30% spawning potential ratio the Federal definition of overfishing at that time. Some stocks appeared to have been chronically overfished since the late 1970s. Thus, 65% of the 35 assessed exploited reef fish stocks were below the then-existing Federal standards for sustainability.

Monitoring of Sanctuary Preservation Areas

Methods

In 1997, the FKNMS established multiple no-take marine reserves, or "sanctuary preservation areas." Annual underwater visual surveys have been conducted to assess changes in reef fish populations in areas open and closed to fishing compared to baselines established between 1994 and 1997.

Results and Discussion

A gradient of fishing impacts in the Florida Keys was found - from a high near human population centers near Miami in the BNP (Ault et al., 2001; Harper et al., 2000) and decreasing to a low southwest to the Dry Tortugas (Ault et al., 2002). In the BNP, the average size fish within the exploited phase for 35 important fishery species has remained relatively constant for the last 25 years and is very close to minimum size of capture and not to the historically unfished population size (Ault et al., 2001). The average size of adult black grouper, for example, was estimated to be 40% of what it was in 1940, fishing mortality was several times the level needed to achieve optimum yield (Figure 7.25), and the spawning stock is now less than 5% of its historical unfished maximum (Figure 7.25).

Overall, 77% of the 35 stocks that could be analyzed were overfished by federal standards, including 13 of 16 grouper species, 11 of 13 snapper, barracuda, and two of five grunt. In addition, stock biomass was below standards for most of the key targeted species within the reef fish fishery (Figure 7.26).

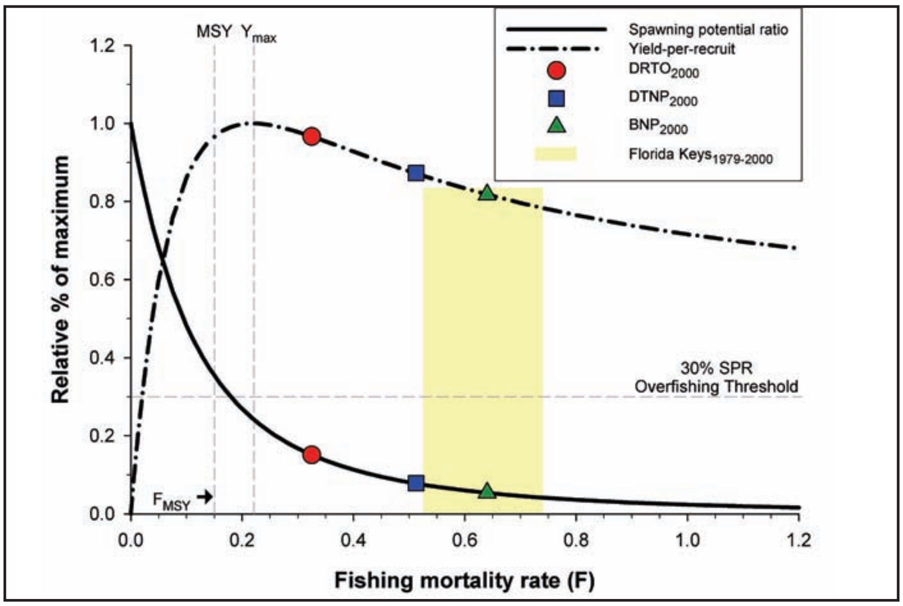

Figure 7.25. Fishery assessment for black grouper, *Mycteroperca bonaci*, in Biscayne National Park and the Florida Keys. Source: Ault et al., 2001.

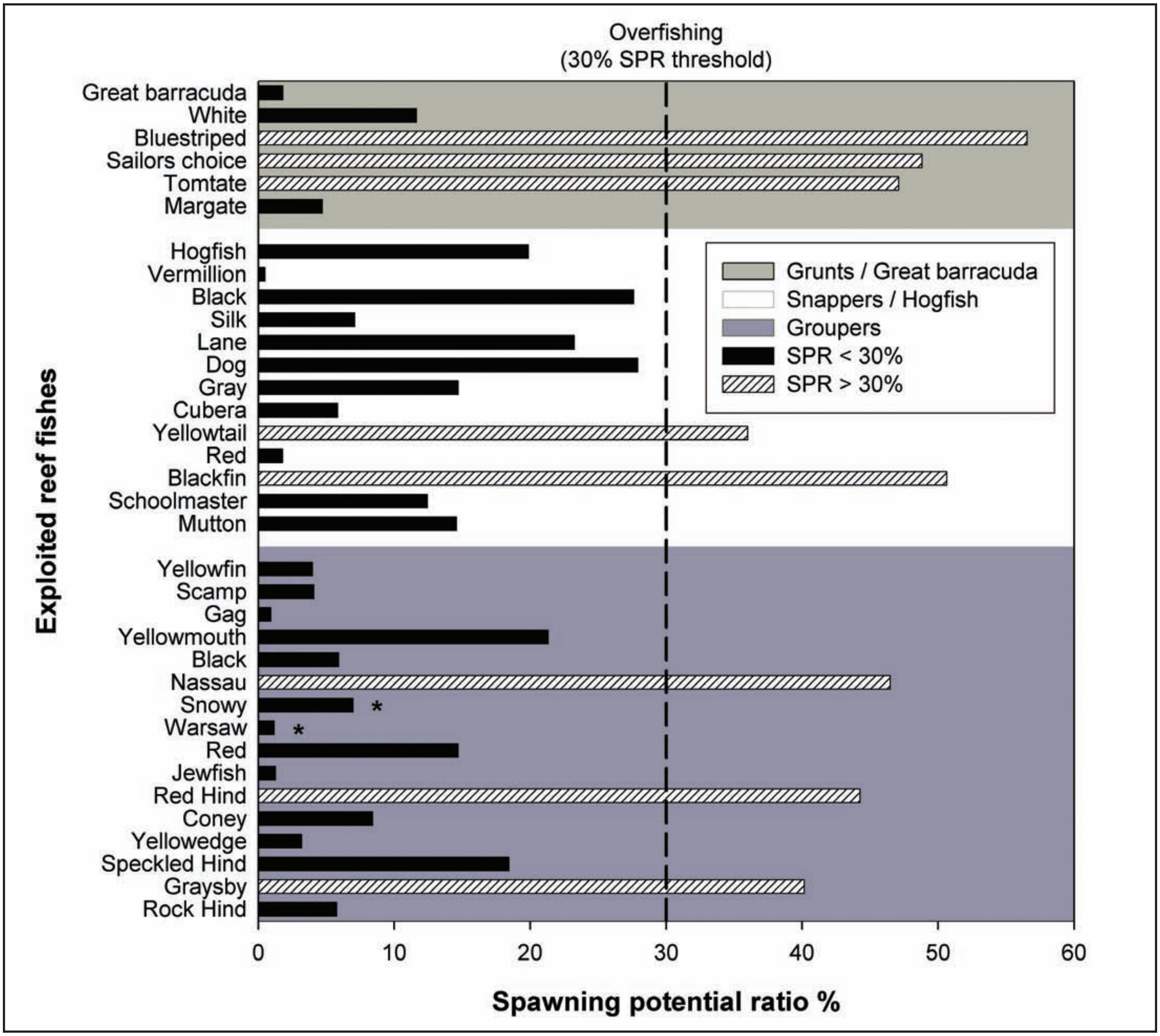

Figure 7.26. Fishery management benchmark spawning potential ratio (SPR) analyses for 35 exploited species of Biscayne National Park-Florida Keys reef fish, comprising groupers, snappers and hogfish, grunts and great barracuda. Filled bars indicate stock 'over-fishing' and hatched bars indicate the stock is above the 30% SPR (U.S. Federal standard). Asterisk indicates estimate from headboat data outside BNP. The high SPR estimate for Nassau grouper is dubious. Source: Ault et al., 2001.

Changes in no-take and fished zones were assessed and compared to a four-year baseline (1994-1997) established before new zone regulations were implemented in 1997. Although no-take zones established in 1997 comprised only 0.5% of the FKNMS, they included about 5.5% of the reef habitat because no-take zones were preferentially selected to include reefs. Preliminary results showed a significant and dramatic increase in mean density of exploitable-sized individuals, but no significant changes for two species not targeted by fishing. In no-take zones within the first three years (1998-2000), densities of economically important exploitable phase yellowtail snapper (*Ocyurus chrysurus*) (Figure 7.27) and combined grouper (Serranidae) increased significantly compared to baseline levels. In the fourth year, gray snapper (*Lutjanus griseus*) had also increased significantly. In comparison, average densities of two non-exploited species, striped parrotfish (*Scarus croicensis*) and stoplight parrotfish (*Sparisoma viride*), were essentially unchanged compared to baseline performance ranges.

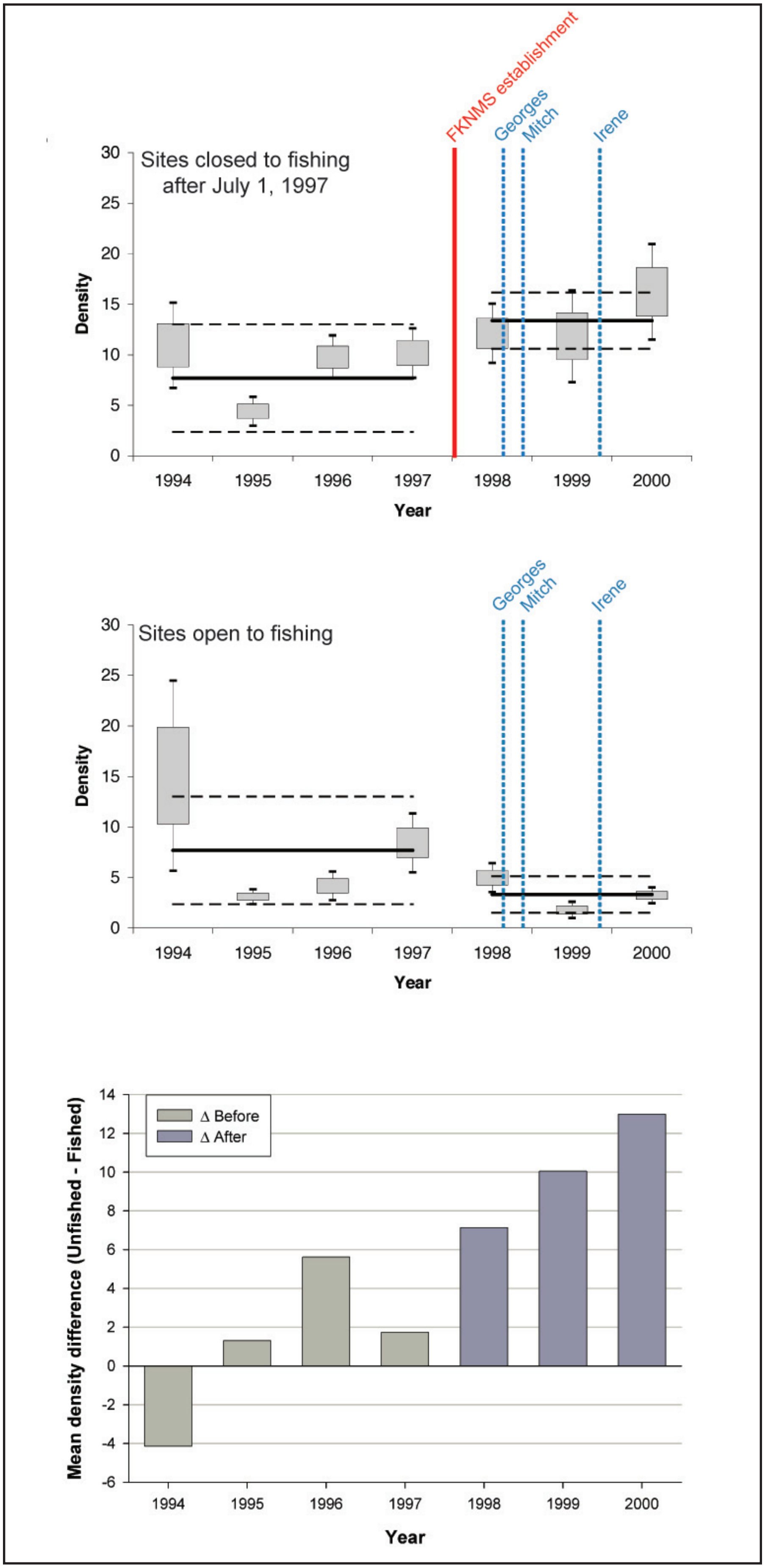

Figure 7.27. Changes in density for yellowtail snapper (*Ocyurus chrysurus*) inside and outside marine reserves in the FKNMS. Source: Ault et al., 2001.

Ferro et al. (2003) used the RVC method to monitor reef fish trends and describe reef composition of the three reef tracts off Broward County, Florida from 1998-2002 (Figure 7.2). They collected 667 samples comprising 86,463 individuals of 208 species from 52 families and showed that reef fish abundance, total biomass and species richness increased from inshore to offshore reefs.

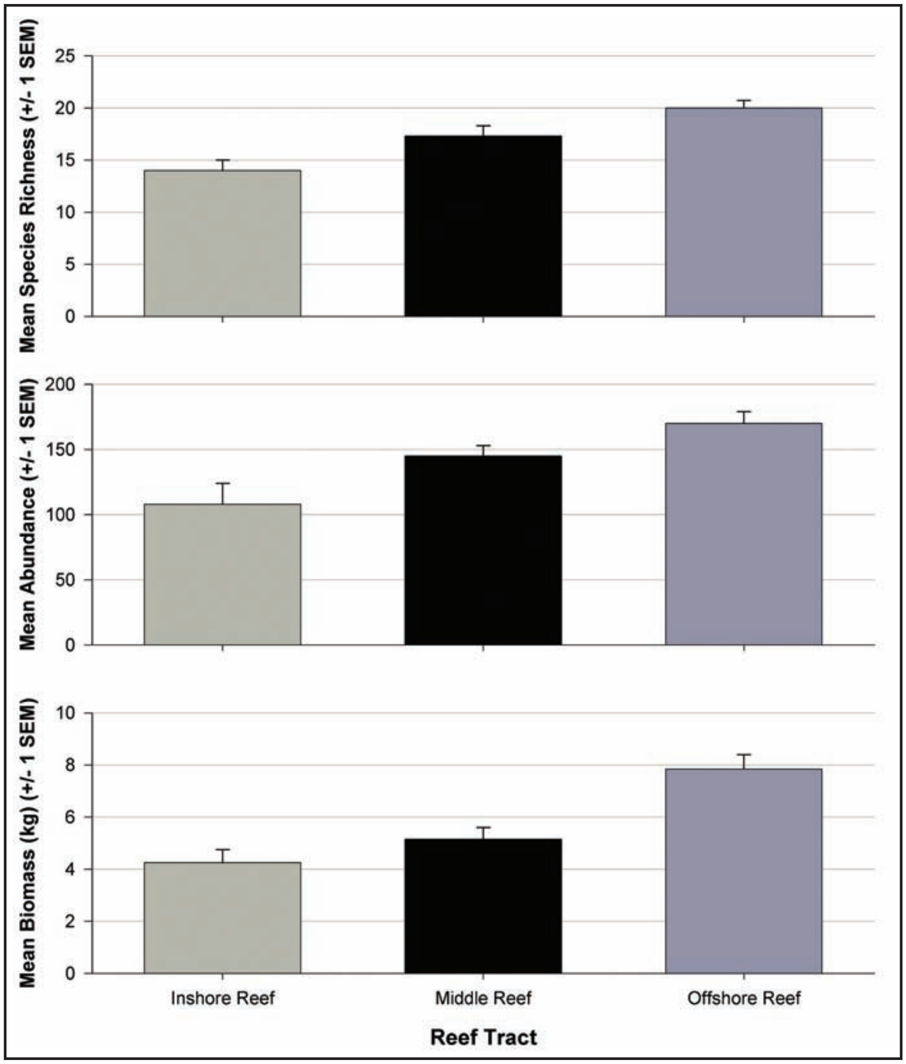

Figure 7.28. Mean fish species richness, abundance, and biomass (n = 667) on the three reef tracts off Broward County, Florida from 1998 to 2002. Source: Ferro et al. 2003.

Reef Environmental Education Foundation Reef Fish Monitoring
The Reef Environmental Education Foundation (REEF) is a nonprofit organization that trains amateur divers to conduct standardized volunteer surveys of reef fishes in an effort to monitor species distributions and changes in reef fish occurrence.

Methods
Volunteers used a roving diver technique (Schmitt and Sullivan, 1996) to develop a comprehensive species list from a dive site and multiple surveys to calculate percent frequency-of-occurrence from a dive site. For each dive, observed species are scored in abundance categories based on what a diver observed. Between 1994 and 2004, over 55,595 individual surveys have been conducted in the Tropical Western Atlantic Ocean. A total of 11,105 surveys were collected in the Florida Keys through 2002. Details of methods are available at http://www.reef.org/ (Accessed 01/23/05).

REEF fish monitoring involves expert REEF divers (members of the Advanced Assessment Team) that visit certain sites to do repeated fish surveys. Figure 7.29 shows trends in sighting frequency for Nassau grouper at no-take reserves and comparable fished sites in the FKNMS. Figure 7.30 shows trends for four angelfish species.

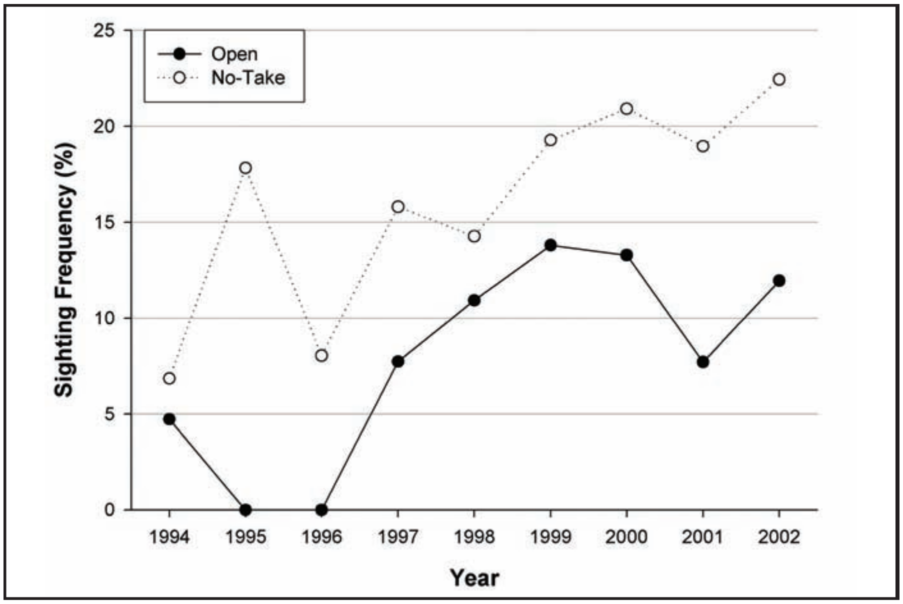

Figure 7.29. Changes in mean sighting frequency for Nassau grouper at 16 reefs in no-take marine reserves and 11 fished reference reefs in the Florida Keys National Marine Sanctuary. Source: Reef Environmental Education Foundation, http://www.reef.org/data/fknms_02.pdf, Accessed 5/3/05.

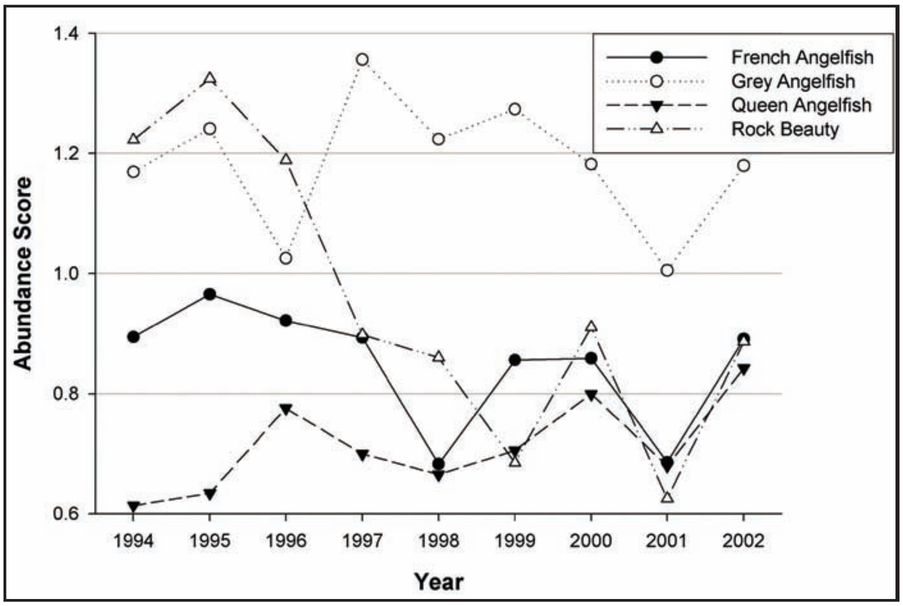

Figure 7.30. Changes in mean abundance scores for four species of angelfish (Pomacanthidae) at 27 sites in the Florida Keys National Marine Sanctuary. Source: Reef Environmental Education Foundation, http://www.reef.org/data/fknms_02.pdf, Accessed 5/3/05.

MACROINVERTEBRATES

FFWCC Spiny Lobster Monitoring
To test the hypothesis that no-take zones would sufficiently protect spiny lobster and that their average abundance and size would increase in protected zones compared to similar fished areas, the FFWCC undertook a lobster monitoring program. Methods included documenting the abundance and size of spiny lobster in 15 no-take and fished reference areas in the FKNMS during the closed and open lobster fishing seasons starting in 1977.

FFWCC Queen Conch Monitoring in the Florida Keys

Methods

The FFWCC initiated a project to monitor the recovery of queen conch (*Strombas gigas*) in the Florida Keys and within no-take marine reserves. Divers conduct belt-transects in locations with conch aggregations, including marine reserves and adjacent reference areas. All conch within 1 m along each belt-transect (laid out across an aggregation) were counted and mapped. Density and area estimates were used to determine population abundance. More information on data collection methods can be found in Glazer and Delgado (2003).

Results and Discussion

Since Florida's queen conch fishery was closed in 1986, there have been signs that adult queen conch have begun to recover (Glazer and Delgado, 2003; Figure 7.31). Within aggregations, overall conch density has increased to approximately 700 conch per ha and the area encompassed by the aggregations is approximately 49.5 ha. Approximately 37,000 adult queen conch were observed within breeding aggregations in 2003. Whereas the recovery of conch stock is occurring fairly rapidly in back reef areas, the lack of spawning and poor recovery of conch aggregations in areas immediately adjacent to the islands remain concerns. The FFWCC, University of Florida, and NOAA have started a joint project to examine the effects of xenobiotics on the reproductive development and output of conch from those aggregations.

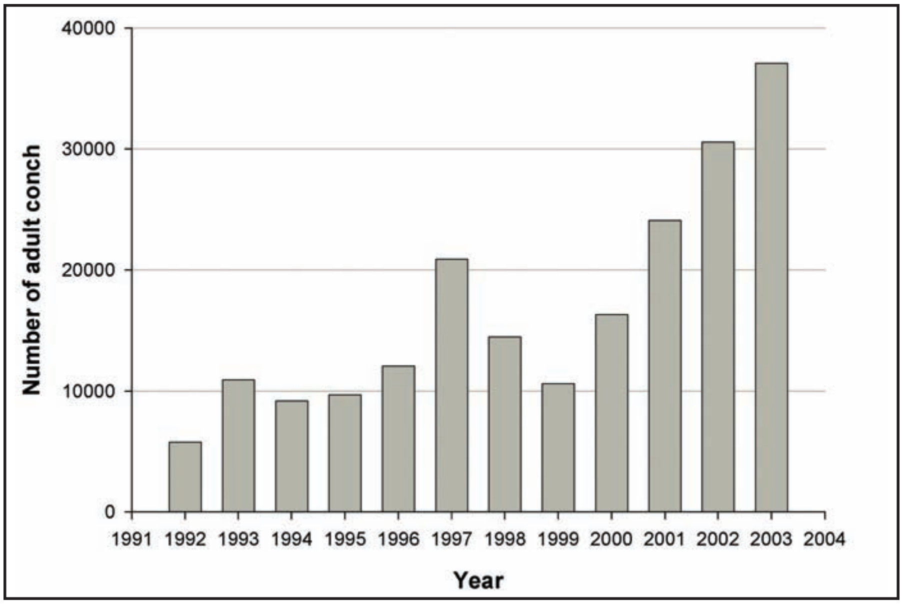

Figure 7.31. Trends in the abundance of adult queen conch, *Strombus gigas*, in the Florida Keys, estimated from yearly monitoring of the breeding aggregations on the backreef. Source: Glazer and Delgado, 2003.

Overall Conclusions and Summary of Analytical Results

Inventories of coral richness show a general decline in stony coral species richness in all reef types and geographic areas. Diseased coral colonies were widely found, although no consistent geographic 'hotspot' was identified. *Acropora* spp. in the Upper Keys declined substantially during 1998-99 due to hurricanes and bleaching; they remain scarce and have exhibited no comeback. Non-native corals and fish have been detected; *Caulerpa brachypus* – a macrophytic algae – is becoming widespread and is of considerable concern.

Effects of coastal pollution on reef communities are not well understood. Elevated nitrogen levels have been detected in nearshore waters, may relate to land use patterns, and have resulted in macroalgal blooms including non-native algal species.

Trends in fisheries effort show a continual increase in the number of recreational anglers in South Florida. A number of key species have exhibited signs of fishing stress. Stocks of the goliath grouper, however, appear to be recovering after a decade of fishery closure.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Mapping

Only about 50% of Florida's coral reef and associated benthic habitats have been mapped. As a result, reliable estimates of the percentage of coral reef and related habitats, as well as the area protected by no-take provisions, cannot be accurately computed statewide.

Mapping efforts were undertaken in the FKNMS in the 1990s. NOAA and FFWCC's Florida Marine Research Institute (FMRI) published digital benthic habitat maps for the Florida Keys in 1998 (FMRI, 1998; Figure 7.32). Recently, the Dry Tortugas region was characterized (Schmidt et al., 1999). Also, Agassiz (1882) produced a remarkable baseline map of Dry Tortugas benthic habitats, which suggests a 0.4 km^2 loss of elkhorn coral in a 100-year period (Davis, 1982). Mapping gaps exist for deeper regions of the Tortugas. The reefs along the Southeastern Florida coast are less well studied. In 1999, Nova Southeastern University's National Coral Reef Institute (NCRI) and the Broward County Department of Planning and Environmental Protection (DPEP) initiated mapping of Broward County reefs. Together with the FMRI, NCRI is presently mapping the reefs of southern Palm Beach and northern Miami-Dade Counties. Maps still need to be completed for the remainder of Miami-Dade and Palm Beach Counties. Reef habitat mapping efforts are underway by the State of Florida and NCRI along the Southeast Florida coast using a variety of techniques including satellite remote sensing, laser-based bathymetry, acoustic bottom classification, and *in situ* diver assessment (Moyer et al., 2003).

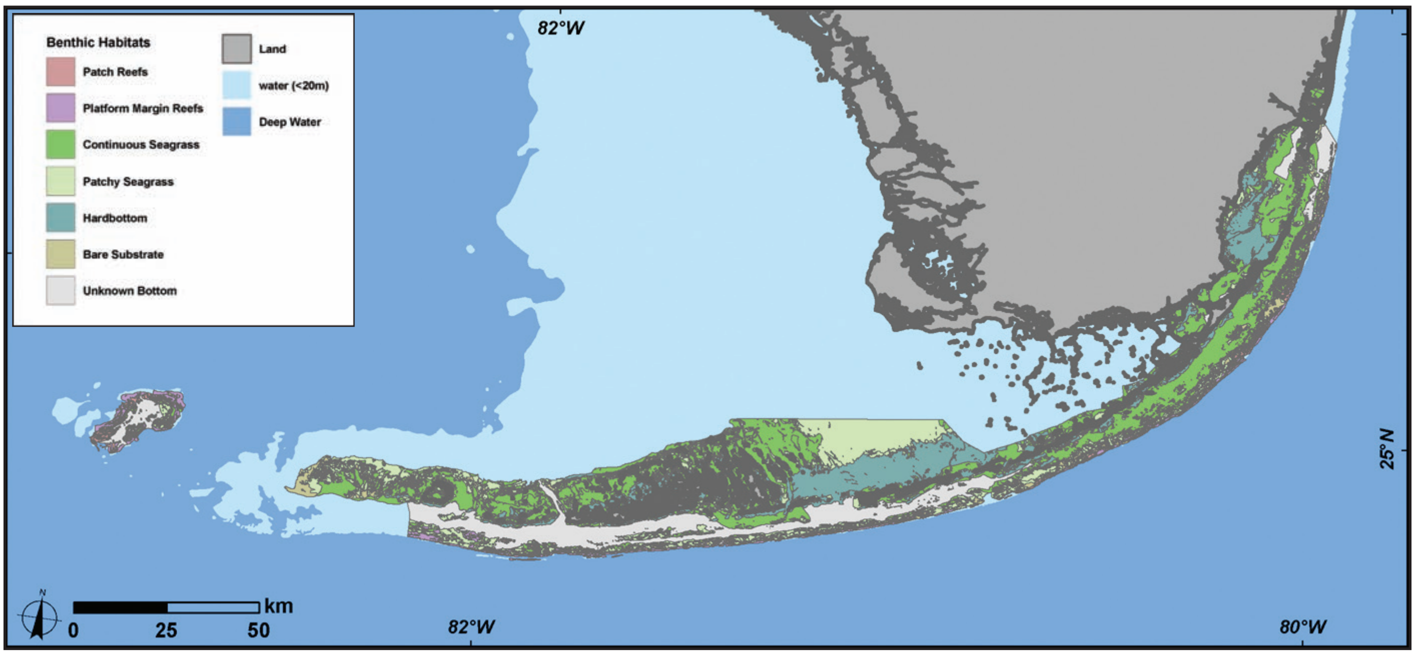

Figure 7.32. Benthic habitat map for the Florida Keys. Map: A. Shapiro. Source: CCMA-BT, http://sposerver.nos.noaa.gov/projects/benthic_habitats/, Accessed 02/14/05.

Improved mapping for specific projects has resulted from aerial photos of nearshore areas and laser-based bathymetry of the three reef tracts off Southeastern Florida. For example, detailed laser depth sounding bathymetry is complete for all of Broward County, offshore to 36 m. A smaller amount of the area is also mapped with multibeam bathymetry and side-scan sonar. Using acoustic seafloor discrimination, NCRI is mapping the distribution of benthic fauna over the reef tracts of Broward County, southern Palm Beach County, and northern Miami-Dade County. The goal is to provide maps that allow quantification of patterns, and thus information on underlying ecological processes. The work proceeds in collaboration with the Broward County DPEP and FMRI.

Estimates of benthic cover are available from some monitoring programs. There is a coral reef distribution map in Jaap and Hallock (1990). No mapping of the Florida Middle Grounds has been conducted to date.

Monitoring, Assessments, and Research

In the FKNMS, a comprehensive research and monitoring program has been implemented to establish baseline information on the various components of the ecosystem and help ascertain possible causes and effects of changes. This way, research and monitoring can ensure the effective implementation of management strategies using the best available scientific information.

Research and monitoring are conducted by many groups, including local, state, and federal agencies, public and private universities, private research foundations, environmental organizations, and independent researchers. Sanctuary staff facilitate and coordinate research by registering researchers through a permitting system, recruiting institutions for priority research activities, overseeing data management, and disseminating findings to the scientific community and the public.

The Water Quality Protection Program (WQPP), which began in 1994 and is funded by the EPA and NOAA, is the most comprehensive, long-term monitoring program in the Florida Keys. The program includes monitoring of three components: water quality, seagrasses, and coral/hardbottom communities. Reef fishes, spiny lobster, queen conch, and benthic cover are also monitored throughout the Sanctuary. Water quality has been monitored at 154 fixed stations since 1995. Water samples are collected to measure salinity, temperature, DO, turbidity, relative fluorescence, and light attenuation. The water chemistry study focuses on detecting NO_3^-, NO_2^-, NH_4^+, DIN, and SRP. Concentrations of TON, TOC, TP, and silicate are also measured, along with CHLA and APA (Jones and Boyer, 2001).

Seagrass monitoring through the WQPP allows for the identification of seagrass the distribution and abundance within the Sanctuary and the tracking of changes over time. Quarterly monitoring is conducted at 30 fixed stations and annual monitoring occurs at 206-336 randomly selected sites (Fourqurean et al., 2002). Permanent stations are co-located at 30 of the water quality monitoring sites to help discern relationships between seagrass health and water quality. This long-term monitoring is also invaluable for determining human impacts on the Sanctuary's seagrass communities.

The CREMP tracks the status and trends of coral and hardbottom communities throughout the Sanctuary (Jaap et al., 2001). The project's 43 permanent sites include hardbottom, patch reef, shallow offshore reef, and deep offshore reef communities. Biodiversity, coral condition, and coral cover are recorded annually at four stations within each site, for a total of 172 stations. This project has recently been extended to reefs of Southeast Florida, adding 10 sites throughout Miami-Dade, Broward, and Palm Beach Counties (Gilliam et al., 2004b).

Broward County's Marine Biological Monitoring Program tracks the status and trends of coral and hardbottom communities in the county (Gilliam et al. 2004a). The program's 25 permanent sites located on the nearshore and offshore reef terraces have been monitored yearly since 1997 by the Broward County DPEP and NCRI. Each site consists of one 30-m belt phototransect, two 30-m fish transects, one stationary fish point count, and a sediment trap. Along each belt phototransect, 40 0.75-m^2 quadrat (framer) images are taken; stony coral species (Millepora and Scleractinia) presence, colony size, and condition (diseased or bleached) are recorded; and sponge and octocoral densities are recorded. Fish species abundance and size classes are also recorded along transects and during point counts. Sedimentation rate and grain size analysis is determined bimonthly.

In addition to the WQPP, the FKNMS Zone Monitoring Program monitors the 24 discrete marine reserves located within the Sanctuary. Implemented in 1997, the goal of the program is to determine whether these fully protected zones effectively protect marine biodiversity and enhance human uses related to the Sanctuary. Parameters measured include the abundance and size of fish, invertebrates, and algae, as well as economic and aesthetic values of the Sanctuary and compliance with regulations. This program monitors changes in ecosystem structure (size and number of invertebrates, fish, corals, and other organisms) and function (coral recruitment, herbivory, predation). Human uses of zoned areas are also tracked. Lastly, continuous monitoring of certain physical parameters of seawater and ocean conditions are recorded by instruments (C-MAN stations) installed along the Florida Reef Tract as part of the Florida Keys Seascape program (SEAKEYS, 2002). There are six C-MAN stations from Fowey Rocks to the Dry Tortugas and one in Florida Bay. These stations gather data and periodically transmit to satellites, to provide near real-time reports available on the Internet. For the past 10 years, the Sanctuary has maintained a network of 27 thermographs located both inshore and offshore throughout the Keys that record water temperature every two hours.

As baselines are being documented, FKNMS managers are developing a comprehensive science plan outlining specific management objectives and their associated monitoring and research needs. This is an evolving, adaptive management approach to help ensure management decisions are supported by the best available science. The science plan will identify high-priority research and monitoring projects to help fill gaps in understanding the ecosystem and its responses to management actions. Recognizing the importance of an ecosystem approach to management, the Sanctuary engages agencies working on the Comprehensive Everglades Restoration Plan to achieve appropriate restoration goals for the entire ecosystem, including coral reefs and seagrasses. Active monitoring of natural resources is a Sanctuary priority in order to detect changes occurring as a result of water management regimes and restoration.

Along Florida's southeastern coast, much of the present monitoring originated as impact and mitigation studies for activities that had adverse impacts to specific sites (e.g., dredging, ship groundings, pipeline and cable deployments, and beach renourishment). In the past, such studies have been of limited duration (e.g., one to three years) and the focus has been largely on beach renourishment, restoration for grounding impacts, and some baseline data collection from reference areas. Monitoring has begun in Broward County at 25 fixed 30-m^2 sites for environmental conditions (sedimentation quantities and rates, water quality, and temperature), and coral, sponge, and fish abundance and/or cover (Figure 7.33). Assessment studies by NCRI scientists also identify the distribution, abundance, and disease condition of staghorn corals in Broward County. Research on the reproductive status and potential of *Acropora cervicornis* is also being conducted. There have been a number of discrete fish surveys on the reefs of Miami-Dade and Palm Beach Counties, most of which have been associated with beach renourishment projects or artificial reef management (Lindeman and Snyder, 1999; P. Light, pers. comm.; Avila, 2005). However, there is currently a concerted effort underway by NCRI scientists to complete a baseline survey of reef fishes off Broward County (Ettinger et al., 2001; Harttung et al., 2001; Ferro et al., 2003). Initiated in 1998, this NOAA-funded survey is recording fishes on the edges and crests of the three major reef lines.

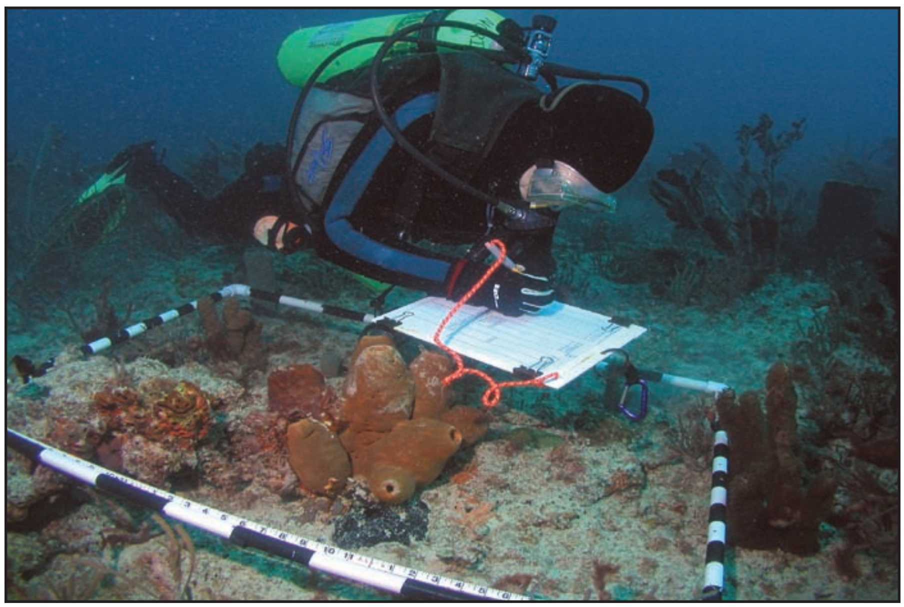

Figure 7.33. Researcher conducting reef monitoring offshore of Broward County, Florida. Photo: D. Gilliam.

The initial survey was completed in 2003 and consists of more than 650 point-counts. In addition, during summer 2001, NCRI scientists inventoried fish on the first 30 m of the inshore reef at 158 m intervals for 25 km of shoreline using multiple visual techniques (point-count, 30 m transects, and 20 minute random swims) (Baron et al., 2001). Broward County now has a database comprised of more than 1,000 visual censuses from the shore to 30 m for reef fish. The NCRI inventory of reefs off Broward County is continuing with a NOAA-funded survey of the fishes in 30-150 m depths using a remotely operated vehicle.

Researchers at NCRI are also currently involved in a multivariate, hypothesis-driven study of the interaction of fish, transplanted corals, coral recruits, and potential coral attractants or optimal substrates (Figure 7.34). Research variables include four potentially different fish assemblages (determined by reef complexity) and biofilm and coral recruitment on settlement plates made of concrete, concrete and iron, concrete and quarry rock, or concrete and coral transplants. Results of this three-year study should yield information critical to reef restoration.

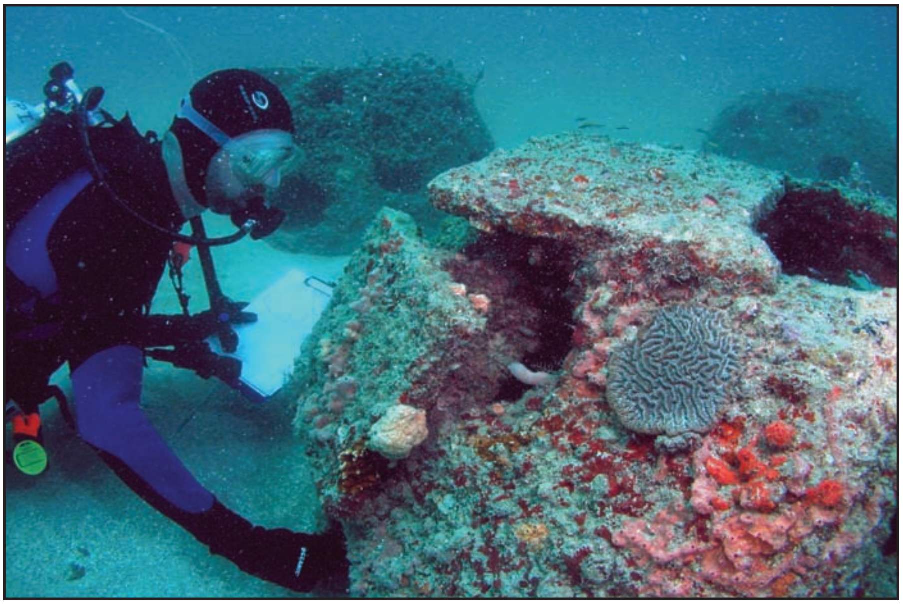

Figure 7.34. Researcher assessing coral recruitment on experimental artificial reef modules offshore of Broward County, Florida. Photo: D. Gilliam.

MPAs and Fully Protected Reserves

As with monitoring, assessment, and research programs, coral reef conservation and management through the designation and implementation of MPAs varies widely. The largest and best-known MPA in Florida, the FKNMS, was designated in 1990, thereby placing 9,850 km^2 of coastal waters and 1,381 km^2 of coral reef area under NOAA and State of Florida management. Immediate protective measures were instituted as a result of Sanctuary designation, including prohibitions on oil and hydrocarbon exploration, mining, and other activities altering the seabed, as well as restrictions on large ship traffic. Coral reefs were protected by prohibiting anchoring on coral, touching coral, and harvesting or collecting coral and 'live rock.' To address water quality concerns, discharges from within the Sanctuary and areas outside the Sanctuary that could potentially enter and affect local resources were also restricted.

In addition, a network of marine zones was instituted in 1997 in the Sanctuary to address a variety of management objectives. Five types of zones were designed and implemented to achieve biodiversity conservation, wildlife protection, and the separation of incompatible uses, among other goals. Three of the zone types (sanctuary preservation areas, ecological reserves, and special use/research-only areas) are fully protected areas, or marine reserves, where lobstering, fishing, spearfishing, shell collecting, and all other consumptive activities are prohibited.

The 1997 zoning plan established 23 discrete fully protected zones that encompass 65% of the Sanctuary's shallow coral reef habitats. The largest zone at that time, the 30.8 km^2 Western Sambo Ecological Reserve, protects offshore reefs as well as other critical habitats, including mangrove fringe, seagrasses, productive hardbottom communities, and patch reefs. In July 2001, the 517.9 km^2 Tortugas Ecological Reserve was implemented (see Figure 7.1). It is now the largest of the Sanctuary's fully protected zones. Located in the westernmost portion of the Florida Reef Tract, the Reserve conserves important deep-water reef resources and fish communities unique to this region of the Florida Keys. Together with the other fully protected zones, the Tortugas Ecological Reserve increased the total protected area of coral reefs within the Sanctuary to 10%.

The Tortugas Ecological Reserve is also significant because it adjoins a 157.8 km^2 research natural area in the Dry Tortugas National Park, a zone where shallow seagrass, coral, sand, and mangrove communities are now conserved. Anchoring is prohibited in the research natural area, and scientific research and educational activities consistent with management of this zone require advance permits from the NPS. To protect important fish nursery and spawning sites, no fishing is allowed in the research natural area. Wildlife viewing, snorkeling, diving, boating and sightseeing are managed in this zone primarily through commercial tour guides. Together, the Sanctuary's Tortugas Ecological Reserve and the Dry Tortugas National Park's research natural area fully protect nearshore to deep reef habitats of the Tortugas region and form the largest, permanent marine reserve in the U.S.

Overall, the Sanctuary management regime uses an ecosystem-wide approach to comprehensively address the variety of impacts, pressures, and threats to Florida Keys marine ecosystems. It is only through this inclusive approach that the complex problems facing coral reefs can be adequately addressed.

The BNP encompasses 683 km^2 of waters just south of Miami, including the majority of Biscayne Bay and a substantial portion of the northern reef tract with 291 km^2 of coral reefs. The Park is renowned for its productive coastal bay, nearshore, and offshore habitats, including islands, mangrove shorelines, seagrass beds, hardbottom communities, and coral reefs, which provide important recreational opportunities and spectacular scenic areas. The NPS is concerned about degradation of BNP resources in the face of coastal development, increases in the number of recreational boats visiting the Park, and fishing pressure. The Park is revising its general management plan to allow for management zones that would give greater protection to Park resources, including natural resources reserve areas where fish nurseries and spawning habitats would be protected from fishing and other disturbances. In addition, the BNP is developing a cooperative plan with the State of Florida to adopt a coordinated and seamless approach to protecting and restoring fishery resources both within and outside Park boundaries.

The Key West National Wildlife Refuge and Great White Heron National Wildlife Refuge overlap with portions of the FKNMS in the backcountry of the lower Keys and an extensive area around the Marquesas Islands between Key West and the Dry Tortugas. The Refuges, established in 1908 and 1938, respectively, contain over 1,619 km^2 of lush seagrass beds, reef tract, patch reefs, hardbottom communities, and pristine mangrove islets. A cooperative agreement between the U.S. Fish and Wildlife Service (USFWS) and State of Florida on the management of these submerged lands created a number of wildlife management zones in the refuges. These zones direct human activities away from sensitive wildlife and habitats, and help ensure their continued conservation. The USFWS, as administrator of the National Wildlife Refuge System, works cooperatively with the State and the FKNMS to protect these sites.

Of the state parks in Southeast Florida, two are considered marine. One of the oldest marine parks in the world (acquisition began in 1959), the John Pennekamp Coral Reef State Park is located in Monroe County on Key Largo. It covers 249 km^2 and has 461 km^2 of coral reefs, seagrass beds, and mangrove swamps. The Lignum Vitae Key Botanical State Park, which includes Shell Key, is located in Monroe County, west of Islamorada. The Park's submerged habitats are located in Florida Bay and the Atlantic Ocean, and include fringing mangrove forest, extensive seagrass beds, patch reef, and sand flats.

Gaps in Monitoring and Conservation Capacity

Current monitoring in the FKNMS has largely focused on detecting changes within the fully protected zones and determining Sanctuary-wide status and trends of water quality, seagrasses, and corals. While some trends are beginning to show and provide a source of hypotheses to be tested continued monitoring is critical. These data will facilitate the detection of long-term changes in communities locally and ecosystem-wide.

Reef monitoring programs in southeastern Florida are limited by a lack of comprehensive inventories of the non-coral components of the marine communities. Baseline assessments of additional sites are needed. Furthermore, new monitoring programs should be developed at sites within counties in the region. The first step should be to develop a functional classification of the reef habitats. For effective selection of monitoring sites, this classification should incorporate criteria to ensure that both representative habitats and unique sites receive attention.

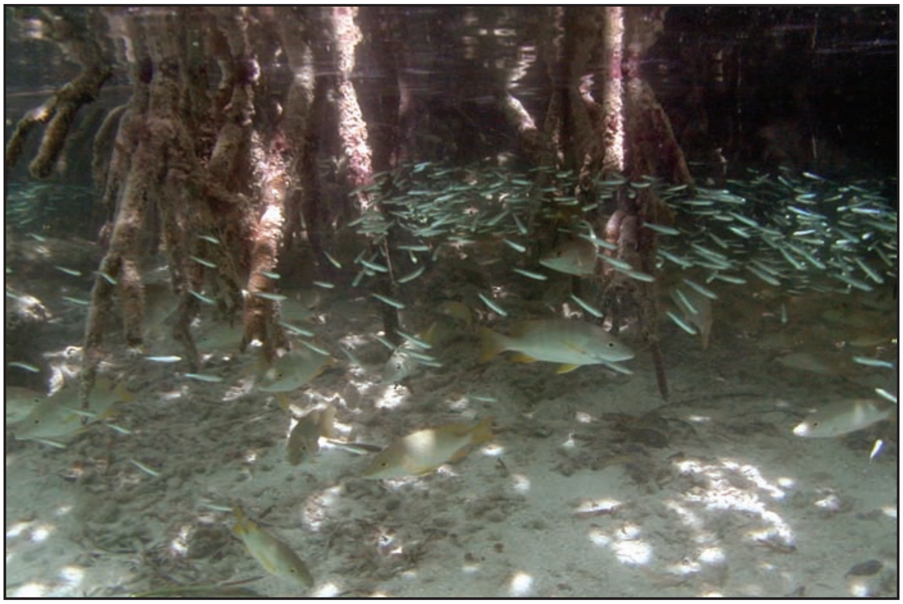

Figure 7.35. Mangrove prop roots serve as an important nursery area for some reef fish species. Photo: M. Kendall.

The databases of reef fish in Broward, Miami-Dade, and Palm Beach Counties are based on visual survey techniques that can overlook a substantial number of cryptic species (as many as 37% in a recent Caribbean survey; Collette et al., 2001). Thus, intensive and broad-scale monitoring is necessary to obtain a complete record of resident ichthyofauna. In addition, fish assemblages below a depth of 30 m are poorly characterized, yet they are exploited by recreational fishers. Likewise, the structure and composition of reef fish communities in seagrass and mangrove habitats of Port Everglades and the Intracoastal Waterway remain a mystery to researchers. Such habitats can be important nursery sites for several reef associated fishes (Figure 7.35; Leis, 1991). Given the high level of human activity in these areas, monitoring of reef fish communities is necessary.

In May 2002, Coleman and Jaap (W. Jaap, pers. obs.) mounted an expedition to the Florida Middle Grounds to sample sites surveyed by Hopkins in 1975. Data collected at most of the sample stations indicated that the sessile benthic community remained very similar to the status described by Hopkins et al. (1977). However, grouper and snapper populations were extremely depleted. Reefs along the southeast coast and the Middle Grounds banks should be fully mapped to develop map products including a reef atlas similar to that recently published for reef areas off Brazil. The Brazilian reef atlas includes high quality maps, aerial and satellite photographs, underwater habitat photos, and short descriptions of the reefs and resources.

Government Policies, Laws, and Legislation

When President George H. W. Bush signed the Florida Keys National Marine Sanctuary and Protection Act into law in 1990, the FKNMS became the first national marine sanctuary designated by Congress. Authority for the Sanctuary, along with the 12 other national marine sanctuaries, is established under the National Marine Sanctuaries Act of 1972 (16 U.S.C. 1431 et seq., as amended). The FKNMS is administered by NOAA under the U.S. Department of Commerce, and is managed jointly with the State of Florida under a co-trustee agreement because over half of the Sanctuary waters are state territorial waters. The co-trustees agreement commits the Sanctuary to periodically review the Sanctuary's management plan.

In 1997, a comprehensive management plan for the Sanctuary was implemented. It contains 10 action plans and associated strategies for conserving, protecting, and managing the significant natural and cultural resources of the Florida Keys marine environment. Largely non-regulatory, the plan's strategies are to educate citizens and visitors, use volunteers to build stewardship for local marine resources, appropriately mark channels and waterways, install and maintain mooring buoys for vessel use, survey submerged cultural resources, and protect water quality. As previously described the Sanctuary management plan also designated five types of marine zones to reduce pressures in heavily used areas, protect critical habitats and species, and reduce use conflicts. A total of 24 fully protected zones were implemented in 1997 and 2001, covering approximately 6% of the Sanctuary and protecting 65% of shallow bank reef habitats and about 10% of coral reefs.

Most of the smaller zones (sanctuary preservation areas) are located along the offshore reef tracts and encompass the most heavily used spur-and-groove coral formations. In these areas, all consumptive activities are prohibited. The effectiveness of these zones and other biological and chemical parameters are monitored under the FKNMS Research and Monitoring Action Plan.

With guidance from the U.S. Coral Reef Task Force, the Florida Department of Environmental Protection and the FFWCC have coordinated formation of an interagency Southeast Florida Action Strategy Team (SEFAST) for coral reef conservation and management. This team is developing a local action strategy (LAS) to improve coordination of technical and financial support for the conservation and management of coral reefs from the southern Miami-Dade County line to Hobe Sound (Martin County). The Southeast Florida Coral Reef Initiative is targeting this region because the coral habitats are close to shore and co-exist with intensely urbanized areas that lack a coordinated management plan.

SEFAST is made up of four workgroups: Awareness and Appreciation; Fishing, Diving and Other Uses; Land-Based Sources of Pollution and Water Quality; and Maritime Industry and Coastal Construction Impacts. The workgroups are tasked with 1) outlining and presenting issues and threats at stakeholder workshops, 2) combining information from public input and technical advisory committees, 3) further defining threats to coral habitats, and 4) proposing projects to minimize harmful effects. The outcome will be a coordinated plan to address causes of coral degradation and provide a roadmap for successful management.

Commercial fishing remains one of the largest industries in the Florida Keys, but it is regulated heavily by State and Federal fishery management councils. Regulations for most commercial invertebrates and finfish include annual catch quotas, closed seasons, and gear catch size restrictions. The State of Florida also collects landing information on approximately 400 kinds of fish, invertebrates, and plants to track species trends and evaluate regulations. The reefs of southeastern Florida are in state territorial waters and protected from some impacts by state laws and regulations. These include fishing regulations, dredging permits, and a law protecting corals from harvest, sale, or destruction. Broward County has a small boat mooring program intended to reduce anchoring impacts on reefs.

OVERALL STATE CONCLUSIONS AND RECOMMENDATIONS

Due to its high latitude and proximity to the continental U.S., reefs in Florida exist at the environmental extremes for coral. Natural phenomena such as cold fronts and freshwater run-off, as well as heavy use, introduction of non-native species, offshore and coastal construction activities, and water quality degradation are all stressors to Florida's reefs. These factors provide challenges to Florida's coral reef managers and emphasize the need for careful conservation of the resource. Overall, immediate action is needed to curtail alarming declines in coral reef condition throughout Florida.

Habitat maps have been prepared for the Florida Keys and the Tortugas, but only about half of Florida's coral reef and benthic resources have been mapped. Reefs on the southeastern Florida coast are not as well studied as those of the Keys. Broward County has begun a mapping program. NCRI has begun mapping programs in Broward, Palm Beach and Miami-Dade Counties. Mapping has been improved through the use of laser-based bathymetry. Detailed mapping of all benthic resources is essential. The distribution of non-native species - especially *Caulerpa brachypus* - should also be determined, and methods to restrict its spread must be examined.

There are a considerable number of minor and major ship groundings on Florida's reefs resulting in part from increased recreational and commercial boating activity. Groundings result in significant injury to coral, seagrass, and hardbottom resources. The majority of groundings is due to small vessels causing minor damage individually, but considerable cumulative effects. Installation of mooring buoys has reduced the chronic impacts of small boat anchoring. These efforts need to be expanded, especially for large vessels near ports. The State of Florida and the FKNMS have been educating boaters to limit risks and improve navigation in coral reef areas, and these efforts should be expanded.

Large vessel avoidance and Racon beacons in lighthouses have resulted in declines in large vessel groundings. State and FKNMS officials have improved their response to grounding events and improved their restoration methods of damaged sites, thereby reducing the extent of damage. Reef restoration is a fertile field of study necessary to determine effective and efficient ways to restore degraded coral reef ecosystems.

Effects of coastal pollution on reef communities are not well understood, however, there is evidence that it has resulted in macroalgal blooms including non-native species. A comprehensive water quality monitoring program for Southeast Florida does not exist, but is necessary to establish a relationship between water quality and reef community response in the area. Permitting programs have been effective in reducing raw sewage discharges. Monroe County is undertaking a study of the septic tank problem and possible consolidation into regional facilities. Continued monitoring is critical to establish a relationship between coastal activities and coral resource conditions.

Coral reefs provide the ecological foundation for a multibillion dollar fisheries and tourism-based economy in South Florida. Thus reducing fishing pressure is an appropriate goal. The regional fisheries councils and State of Florida have prohibited destructive or wasteful fishing gear, established minimum size and bag limits, as well as seasonal closures, and restricted the taking of some species. Numerous MPAs have been established to restrict fishing. Exploitable species have shown significant increases in these areas. Monitoring and appropriate regulation must be maintained to prevent overfishing.

Management programs in southeastern Florida are limited by a lack of comprehensive inventories. The State of Florida has formed the SEFAST to develop a LAS for coral reef conservation and management in the area. Such a plan is essential if these resources are to co-exist with the intensely urbanized area.

Local communities that are culturally and economically supported by coral reefs are working to employ management strategies and to focus on alleviating controllable human impacts. For example, in southeastern Florida, the environmental impacts of fisheries, dredging, vessel anchorages, vessel groundings, freshwater management, and nutrient inputs should receive attention to maximize reef protection in this area. In the Florida Keys, the community is continuing to pursue solutions that address wastewater and stormwater problems, habitat degradation, and overfishing.

Citizens, stakeholders, elected officials, and resource managers must work together to improve water quality, minimize physical impacts to corals and seagrasses, reduce nonpoint pollution, and increase education to instill a stronger sense of stewardship in Floridians for their coral reefs.

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The State of Coral Reef Ecosystems of the Flower Garden Banks, Stetson Bank, and Other Banks in the Northwestern Gulf of Mexico

Emma L. Hickerson[1], G.P. Schmahl[1]

INTRODUCTION AND SETTING

The East and West Flower Garden Banks (EFGB and WFGB) were designated as the Flower Garden Banks National Marine Sanctuary (FGBNMS) through the National Oceanic and Atmospheric Administration (NOAA) in January 1992. The two banks are prominent geological features located near the outer edge of the continental shelf in the northwestern Gulf of Mexico, approximately 192 km southeast of Galveston, Texas (Figure 8.1). These features, created by the uplift of underlying salt domes of Jurassic origin, rise from surrounding water depths of over 100 m to within 17 m of the surface. The northernmost thriving coral reef communities in North America cap the shallow portions of the EFGB and WFGB. They are relatively isolated from other coral reefs of the Caribbean and Gulf of Mexico, located over 690 km from the nearest reefs of the Campeche Bank off Mexico's Yucatan Peninsula, and over 1,200 km from the coral reefs of the Florida Keys. The area of the EFGB (27 54.5' N, 93 36.0' W) comprises about 65.8 km^2 of which about 1.02 km^2 is coral reef. Located 19.3 km to the west, the WFGB (27 52.5' N, 93 49.0' W) comprises about 77.2 km^2 of which about 0.4 km^2 is coral reef (Gardner et al., 1998).

Structurally, the coral reefs of the Flower Garden Banks are comprised of aggregations of large, closely spaced boulder and brain coral heads that grow to up to 3 m or more in diameter and height (Figure 8.2). Reef topography is relatively rough, with many vertical and inclined surfaces. Between groups of coral heads, there are numerous sand patches and channels. Coral growth is relatively uniform over the entire top of both banks, occupying the bank crests down to about 50 m. As the reef slopes on the flanks of the coral caps, the corals grow flatter and individual heads can cover large areas. Despite the low species numbers on the reef crest, the reefs exhibit extremely high coral cover, ranging on average between 45-52% down to 30 m depth, and 70% in areas down to at least 43 m depth.

Probably due to its geographic isolation, water temperature, and other factors, there is a relatively low diversity (only about 21 species) of reef-building corals on the Flower Garden Banks. Interestingly, the coral reefs of the Flower Garden Banks contain no elkhorn or staghorn corals, and no shallow-water sea whips or sea fans (gorgonians) that are common elsewhere in the Caribbean. Deepwater surveys below 43 m, however, reveal a rich diversity of gorgonians and antipatharian corals.

Stetson Bank was added to the FGBNMS in 1996. It is located 48 km to the northwest of the WFGB and is also associated with an underlying salt dome. Stetson Bank is classified as a mid-shelf bank (Rezak et al., 1985), and is comprised of claystone/siltstone outcrops forming distinct pinnacles near its northern edge. Stetson Bank is not a true coral reef, but it does contain a low diversity coral community in addition to a prominent sponge fauna. Stetson Bank is dominated by fire coral (*Millepora alcicornis*) and in certain areas, ten-ray star coral (*Madracis decactis*). These two species comprise about 32% coral cover in the pinnacle region. Stetson Bank is composed of claystone outcroppings that have been pushed up to within 17 m of the sea surface. Including the two dominant species, about 10 species of coral have been documented. The pinnacle region is the most conspicuous feature of the bank, which stretches along the northwest face of Stetson Bank for approximately 500 m. With the addition of Stetson Bank, the FGBNMS encompasses 145.8 km^2 and includes the entire bank areas of each of the three features, including the shallow coral reef areas.

The user groups of the FGBNMS are recreational SCUBA divers and recreational and commercial fishers. Three dive charter vessels routinely visit the Sanctuary. Limited data are available to sufficiently quantify the numbers of private vessels and fishing vessels visiting the FGBNMS.

In addition to the coral reefs within the FGBNMS, there are a number of other reefs and banks in the northwestern Gulf of Mexico that contain corals or coral communities. The Flower Garden Banks and Stetson Bank are but

1 Flower Garden Banks National Marine Sanctuary

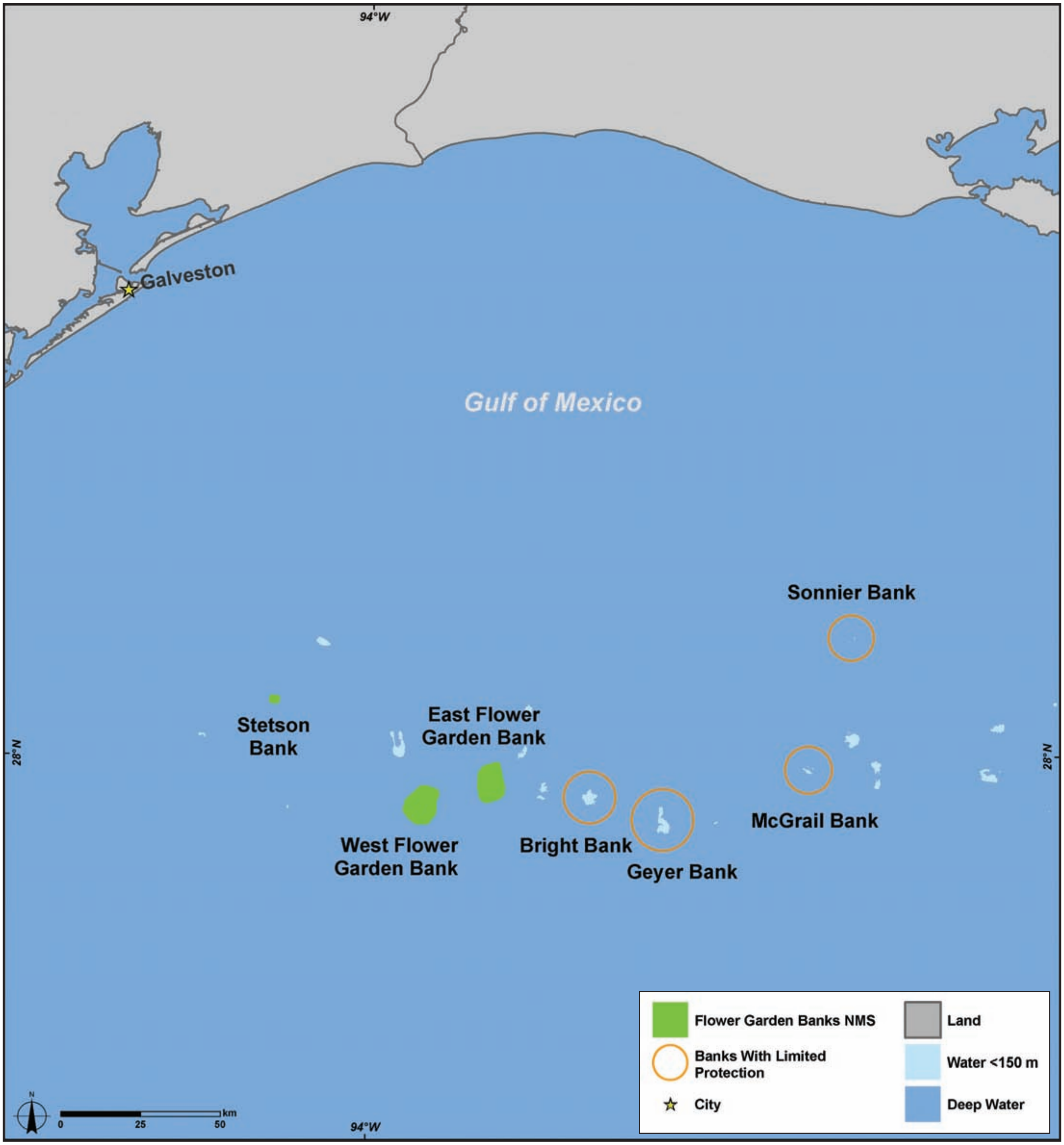


Figure 8.1. Map showing the locations of the coral banks of the Gulf of Mexico. While some of the banks are protected by the provisions of the FGBNMS, unprotected coral communities are present at Bright, Sonnier, Geyer, and McGrail Banks. These banks are part of the network of reefs and banks which are biologically and ecologically associated with the ecosystems of the FGBNMS. Map: A. Shapiro. Source: D. Weaver.

three of a network of over one hundred continental shelf-edge features off the coasts of Texas and Louisiana. Many of these topographic features were the subjects of baseline scientific investigations in the late 1970s and early 1980s (Rezak et al., 1985). These studies first documented that a number of the banks contained coral reef resources. Recent surveys by FGBNMS staff and collaborators have further characterized several of these features. At least four of these reefs and banks harbor important populations of scleractinian coral: Bright Bank (11 species; Rezak et al., 1985; FGBNMS observations), Sonnier Bank (nine species; Rezak et al., 1985; Weaver et al., in press), Geyer Bank (four species; Rezak et al., 1985, FGBNMS observations), and McGrail Bank (nine species; Rezak et al., 1985; Weaver et al., in press; FGBNMS observations). The coral communities at McGrail Bank are especially significant. Recent surveys have revealed a community dominated by the blushing star coral (*Stephanocoenia intersepta*) which covers up to 30% (Schmahl and Hickerson, in press) of the seafloor in some areas at depths between 45 m and 60 m (Figure 8.3).

Figure 8.2. Large boulder corals are a striking feature of the FGBNMS landscape. The coral caps of the FGBNMS boast over 50% coral cover. Photo: Joyce and Frank Burek.

In addition, many of the other banks in the northwestern Gulf of Mexico contain significant communities of a variety of deeper water coral assemblages, characterized by antipatharians, gorgonians, solitary corals, and species of branching corals such as *Oculina* spp. and *Madrepora* spp. These types of communities are typically observed in depths from 60 m to 150 m. All of the reefs and banks in this vicinity provide hard bottom substrate that has been colonized by a high diversity of benthic invertebrates, and provide important habitat to a wide range of reef fish species (Dennis and Bright, 1988). These banks are currently unprotected, with the exception of regulation of direct impacts from oil and gas development. Further investigations are warranted to fully determine the extent of these coral resources.

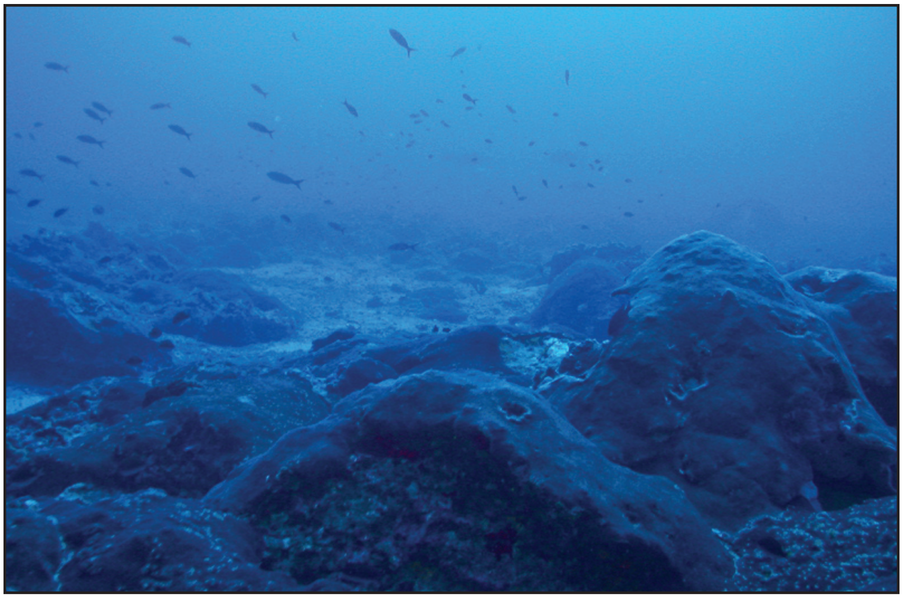


Figure 8.3. McGrail Bank *Stephanocoenia* community at approximately 42 m depth. Estimates of percent coral cover reach upwards of 30%. Photo: FGBNMS and National Undersea Research Center-University of North Carolina, Wilmington.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

The location and depth of these coral reefs buffer them somewhat from the short-term effects of global warming and climate change. However, even though the effects of coral bleaching are relatively low to date (less than 4% annually; Hagman and Gittings, 1992; Gittings et al., 1993; US DOI-MMS, 1996; Dokken et al., 1999, 2003; Precht et al., in press), some bleaching is routinely observed, mostly when the water temperature approaches 30°C. Data on bleaching incidence from 1989-2003 is given in Figure 8.4. Overall, bleaching has resulted in negligible mortality (Hagman and Gittings, 1992). However, bleaching events and their severity are predicted to increase as global ocean temperatures increase.

Diseases

The incidence of disease is very low at the EFGB and WFGB of the FGBNMS. Observations of white plague type II were noted in *Montastraea annularis, M. cavernosa, Colpophylia natans,* and *Diploria strigosa* during the 2002-2003 monitoring effort (Precht et al., in press) outside the random transect surveys. No white band disease is present.

Considering the magnitude of the threat from coral diseases, we feel it is important to increase awareness among scuba divers to thoroughly wash scuba equipment, particularly wetsuits, before traveling to a new diving destination. There is no indication that disease can be transmitted through unclean gear, but proactive behavior may lessen the risk of disease transmission.

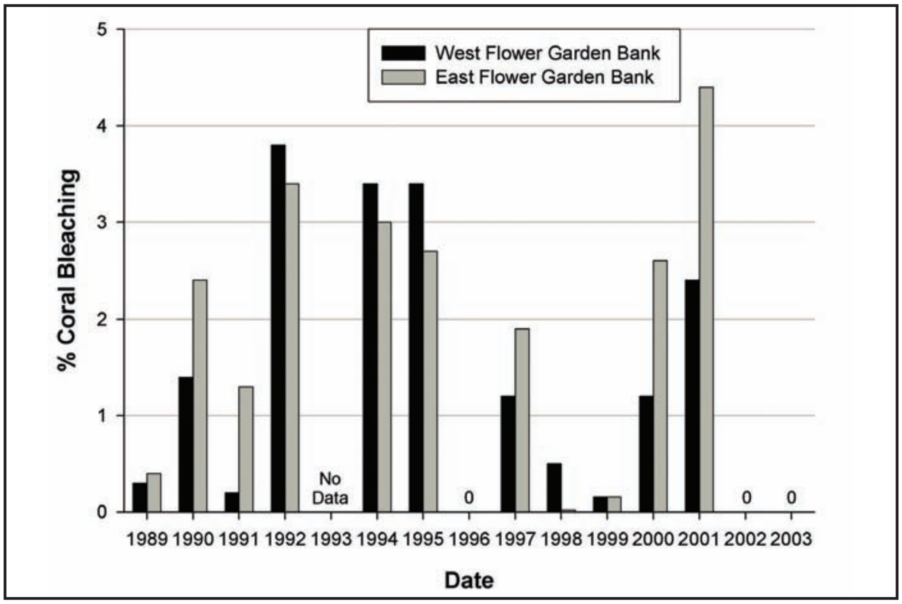


Figure 8.4. Incidence of bleaching at the East and West Banks of the FGBNMS from 1989-2003. Source: USDOI-MMS, 1996; Dokken et al., 1999, 2003; Precht et al., in press.

Tropical Storms

Since 1979, three hurricanes have passed near the Flower Garden Banks (Figure 8.5). At the EFGB and WFGB, it is suspected that coral boulders would be susceptible to toppling, particularly *Diploria strigosa* heads that are subjected to bioerosion, a process that produces mushroom-shaped colonies - large heads of coral on spindly coral stalks (Figure 8.6)

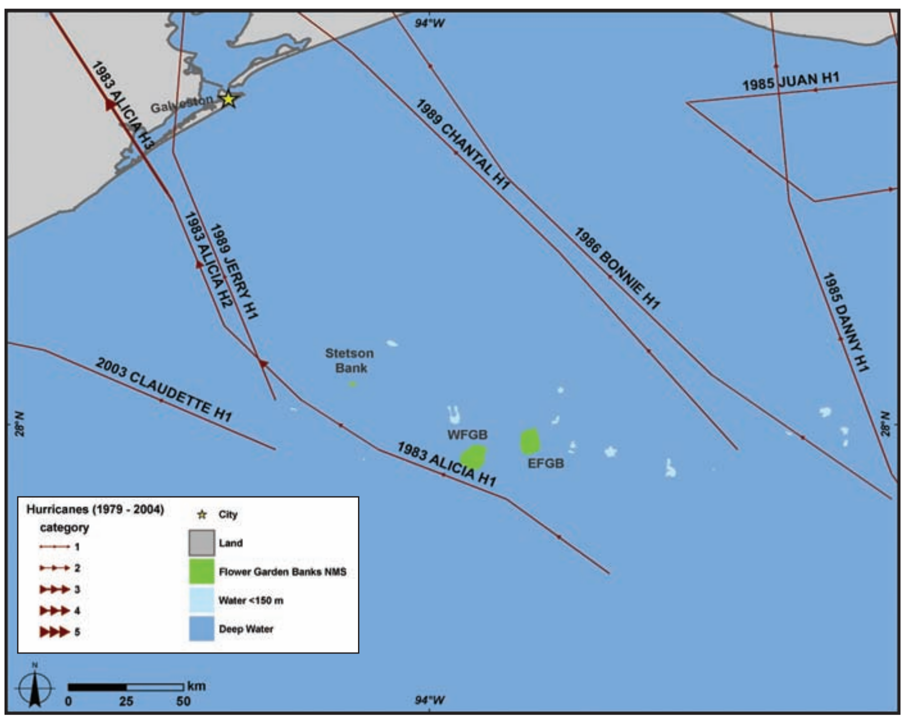


Figure 8.5. A map showing the paths and intensities of tropical storms passing near the FGBNMS and nearby banks, 1979-2004. Year of storm, storm name and storm strength on the Saffir-Simpson scale (H1-5) are indicated for each. Map: A. Shapiro. Source: NOAA Coastal Services Center.

Anecdotal reports from scuba divers noted up to 1.5 m sand waves in the sand flats of the Banks after tropical storms. At Stetson Bank, scouring of the claystone/siltstone valleys occurs, as well as toppling of the claystone pinnacles.

Figure 8.6. These colonies of *Diploria strigosa*, mushroom-shaped due to bioerosion at their base, may be more susceptible to toppling during storms. Photo: Joyce and Frank Burek.

Coastal Development and Runoff

Primary sources of potential degradation of water quality include coastal runoff, river discharges, and effluent discharges from offshore activities such as oil and gas development and marine transportation (Deslarzes, 1998). Oxygen-depleted (hypoxic) near-bottom waters have been found in a large area of the northern Gulf. Although relatively far from the Flower Garden Banks, there is concern that this area could grow and impact the outer continental shelf. Often called the 'dead zone' this area has included up to 16,500 km^2 on the continental shelf from the Mississippi delta to the Texas coast.

General coastal runoff and degraded nearshore water quality can potentially impact the banks through cross-shelf transport processes which bring turbid, nutrient-rich water offshore. Deslarzes (in press) postulates the fluorescent bands observed in the carbonate skeletons of some corals come from the seasonal transport of nearshore water onto the FGBNMS, which may be tainted by urban, agricultural, and biological contaminants.

Research using nitrogen isotopes suggests a pathway for direct primary nitrogen input from coastal river sources from a considerable distance. While nitrogen isotopes from the Flower Garden Banks have signatures of ocean origin (K. Dunton, pers. comm.), benthic algae from Stetson Bank have a distinct nitrogen isotope signature similar to plants found in coastal estuarine systems. These findings suggest that coastal influences are reaching only as far as Stetson Bank.

Coastal Pollution

Coastal pollution is not a major concern at this offshore location.

Figure 8.7. Recreational dive charter vessel on mooring at FGBNMS. Photo: Russ Wilkins.

Tourism and Recreation

Recreational scuba diving is popular and the demand appears to be increasing. There are currently three live-aboard charter dive vessels that regularly visit the banks (Figure 8.7). Each of these vessels can carry up to 35 divers. In 1997, a survey of charter dive operations revealed that an estimated 2,350 divers visited the Flower Garden Banks. These divers spent $870,000 in Texas, of which approximately $636,000 was spent in the local economy of Freeport, where it generated $1.1 million in sales/output, $477,000 in income, and 24 full-time and part-time jobs. An additional $234,000 was spent in other areas of Texas, with $559,000 in sales/output, $228,000 in income, and 11 jobs (Ditton and Thailing, 2001). While scuba diving has helped these economie, resource managers suspect that recreational dive vessels often discharge inadequately treated sewage effluent into Sanctuary waters.

Fishing

The impacts of fishing and associated fishing activities are not well known. At this time, only traditional hook and line fishing is allowed in the Sanctuary. However, illegal fishing by both commercial long-liners and recreational spearfishers has been reported. Targeted fishing efforts, which are allowed under current regulations, could have a significant detrimental impact on snapper and grouper populations.

Lost and discarded fishing gear has been observed in the FGBNMS. Such objects can cause localized physical injury to coral reefs and have been known to entangle and injure loggerhead sea turtles and other organisms. Fishing bycatch has occasionally been reported by scuba divers, and shrimping bycatch is illegally discarded on Stetson Bank. Stetson Bank is closer to shore, and is often targeted by recreational fishers (Figure 8.8). It is suspected that Stetson Bank is more prone to mechanical injury by fishing due to the relatively soft nature of the claystone/siltstone substrate. Continuous weakening of the substrate by fishing gear could possibly render it more susceptible to tropical storm and hurricane events.

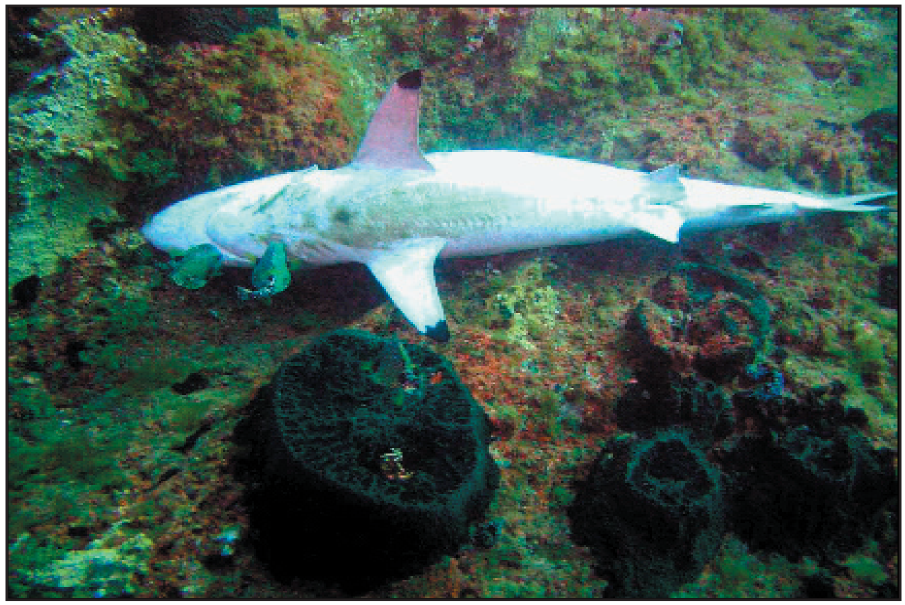


Figure 8.8. Dead spinner shark (*Carcharhinus brevipinna*) on Stetson Bank in April 2004. While it is not known what caused the death of this animal, it is suspected that the death resulted from fishing activity. Photo: C. Loustalot.

Trade in Coral and Live Reef Species

This activity is prohibited by Sanctuary regulations.

Ships, Boats, and Groundings

Groundings do not occur at the FGBNMS due to the depth of the coral caps. However, anchors from large ships can have devastating local impacts to the living coral reef. Over the last 20 years there have been a number of incidences of significant impacts caused by the anchoring of large industry vessels, freighters, and fishing vessels (Gittings et al., 1992). Foreign-flagged cargo vessels have occasionally anchored at the Flower Garden Banks without knowing of the anchoring restrictions. There have been at least three large vessel anchoring incidents since 1994. In 2002, the FGBNMS became the first international 'no-anchor zone' through the development of new language integrated by the International Maritime Organization.

Marine Debris

Lost and discarded fishing gear, including long-lines, floats, and nets have been observed at the Flower Garden Banks and Stetson Bank (Figure 8.9). Such incidents cause localized physical injury to coral reef resources, and have been known to entangle and injure resident and transient sea turtles and other organisms. Debris originating from historic activities, including seismic cables from acoustic surveying efforts, remain embedded in the coral reef around the flanks of the EFGB and WFGB. Remnants of anchors and old engine blocks are scattered throughout the three sites.

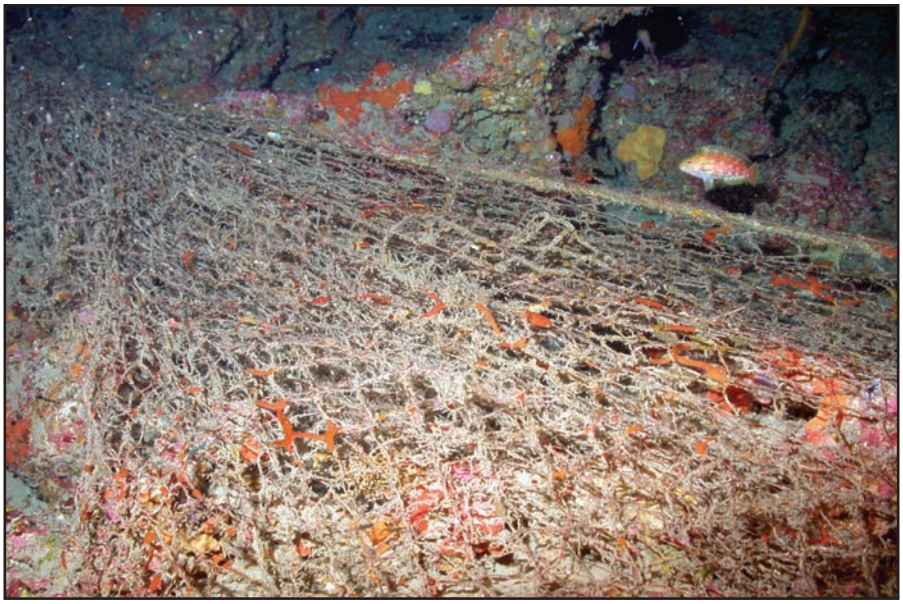


Figure 8.9. A discarded net on WFGB. Photo: FGBNMS and National Undersea Research Center-University of North Carolina, Wilmington.

Aquatic Invasive Species

In August 2002, an invasive coral species, *Tubastraea coccinea*, was photographed at the EFGB on reef substrate at around 24 m depth (Figure 8.10). Prior to this report, no evidence of the coral had been reported on natural reef substrate in the Gulf of Mexico. However, it was known to inhabit the underwater structures of seven oil and gas platforms off the Texas coast. The first known sighting of *T. coccinea* on platforms in the Gulf occurred in 1991, and it was later documented on several other platforms in the Gulf of Mexico (Fenner, 2001; Fenner and Banks, 2004). This coral species currently thrives on High Island A389A (HIA389A), a gas platform located within the EFGB boundaries. In September 2004, several dozen colonies of *T. coccinea* were also documented by the FGBNMS research team at Geyer Bank, located 52 km east-southeast of the EFGB. This is further evidence of the threat to natural reef ecosystems by this invasive species.

Figure 8.10. *Tubastraea coccinea*, an invasive coral species, was found on the underwater structure of gas platform HIA389A, which is located within the boundaries of the FGBNMS. This species threatens natural reef habitats both within and outside Sanctuary boundaries. Photo: Joyce and Frank Burek.

Security Training Activities

No security training activities occur in the FGBNMS.

Offshore Oil and Gas Exploration

The northern Gulf of Mexico is one of the most active areas for oil and gas exploration and development in the world. By the end of 2003, approximately 6,500 production platforms had been installed (of which approximately 2,400 were removed), about 43,300 wells had been drilled, and 168,474 km of pipeline installed (Figure 8.11).

The Gulf of Mexico accounts for more than 91% of the oil and 97% of the natural gas produced in offshore U.S. waters (J. Sinclair, pers. comm.).

Within the four-mile zone of both the EFGB and WFGB regulated by the U.S. Department of the Interior-Minerals Management Service (MMS), there are currently 14 production platforms (six at the West Bank and eight at the East Bank, including one subsea station) and approximately 178.24 km of pipeline, half of which are dedicated oil pipelines (Deslarzes, 1998). Over the past two years, three platforms and approximately 134 km of pipeline have been added within the MMS four-mile regulatory zones of the East and West Banks. One platform and approximately 17.44 km of pipeline is located within 6.5 km of Stetson Bank. There is one gas production platform (HIA389A) located within the EFGB boundary, less than 2 km from the coral cap (Figure 8.12). Recent exploration activities have been conducted by this platform. A pipeline has been constructed through the Sanctuary to tie in HIA389A to a subsea station outside of the Sanctuary boundaries. This pipeline will be used to bring in product from the subsea station to HIA389A for processing and shipment to shore.

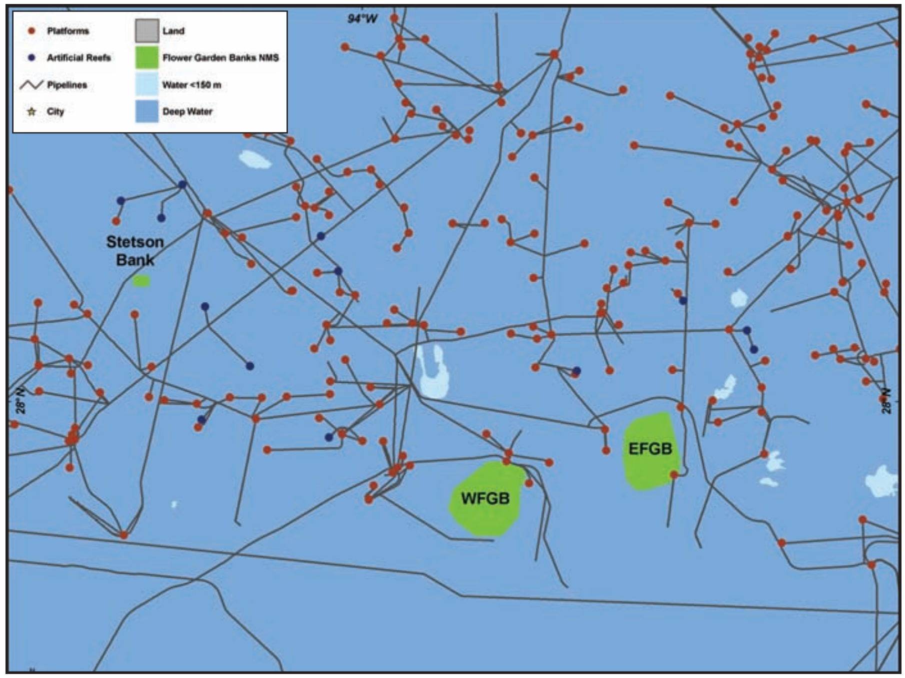


Figure 8.11. Oil and gas infrastructure in the vicinity of the FGBNMS. Blue circles indicate inactive platforms that have been cut off at depth and converted to artificial reefs. Map: A. Shapiro. Sources: D. Weaver; U.S. DOI-Minerals Management Service.

Potential impacts from offshore oil and gas exploration and development include accidental spills, contamination by drilling, related effluents and discharge, anchoring of vessels involved in placing pipelines, drilling rigs and production platforms, seismic exploration, use of dispersants in oil spill mitigation, and platform removal. In spite of the intense industrial activity, long-term monitoring studies indicate no significant detrimental impact to the coral reefs of the FGBNMS from nearby oil and gas development (Gittings, 1998). Fortunately, there have been no major oil spills or impacts from these activities.

While the structures of the platform appear to provide artificial substrate for both motile and sessile marine populations, there is growing concern that the oil and gas structures may act as vectors for the spread of invasive and exotic species. An example is the introduction and establishment of sergeant majors (*Abudefduf saxatilis*) at the FGBNMS and recent (1997) appearance of yellowtail snapper (*Ocyurus chrysurus*). Pattengill (1998) suggests that these resulted from "hopping" along the platforms in the eastern side of the Gulf, where they have been reported by recreational fishers. We suspect that this is the vector used by the orange cup coral, *T. coccinea,* to reach the EFGB.

Figure 8.12. Gas platform HIA389A (W&T Offshore) is located within Sanctuary boundaries, within 1 mile of the coral cap. Photo: FGBNMS.

CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

East and West Flower Garden Banks, Long-Term Monitoring Project

Since 1989, the coral caps of the East and West Banks of the FGBNMS have been monitored annually through a contract funded cooperatively by the FGBNMS and MMS. Since 2002, the contract has been held by a group led by PBS&J, GeoMarine, Inc., and Dauphin Island Sea Lab. Monitoring of Stetson Bank is not included in the contract. The data presented below are from the long-term monitoring report through 2001. The most recent investigations (2002-2003) are currently in press and will be included in future reporting efforts.

The FGBNMS Long-Term Monitoring (LTM) Project is conducted within a 100 m^2 area on the reef cap, and evaluates water quality (temperature, salinity, light attenuation, pH, turbidity, DO_2), reef diversity, growth rates, long-term changes in individual coral colonies, accretionary growth, general coral reef community health, fish, lobster, and *Diadema* surveys (Figure 8.13). Water samples are analyzed for nitrogen, nitrate, nitrite, dissolved ammonia, soluble reactive phosphorus and total phosphorus, and chlorophyll A. It is realized that the 100 m^2 study site does not incorporate discreet zones found elsewhere in the coral reef area (e.g., *Madracis mirabilis* fields).

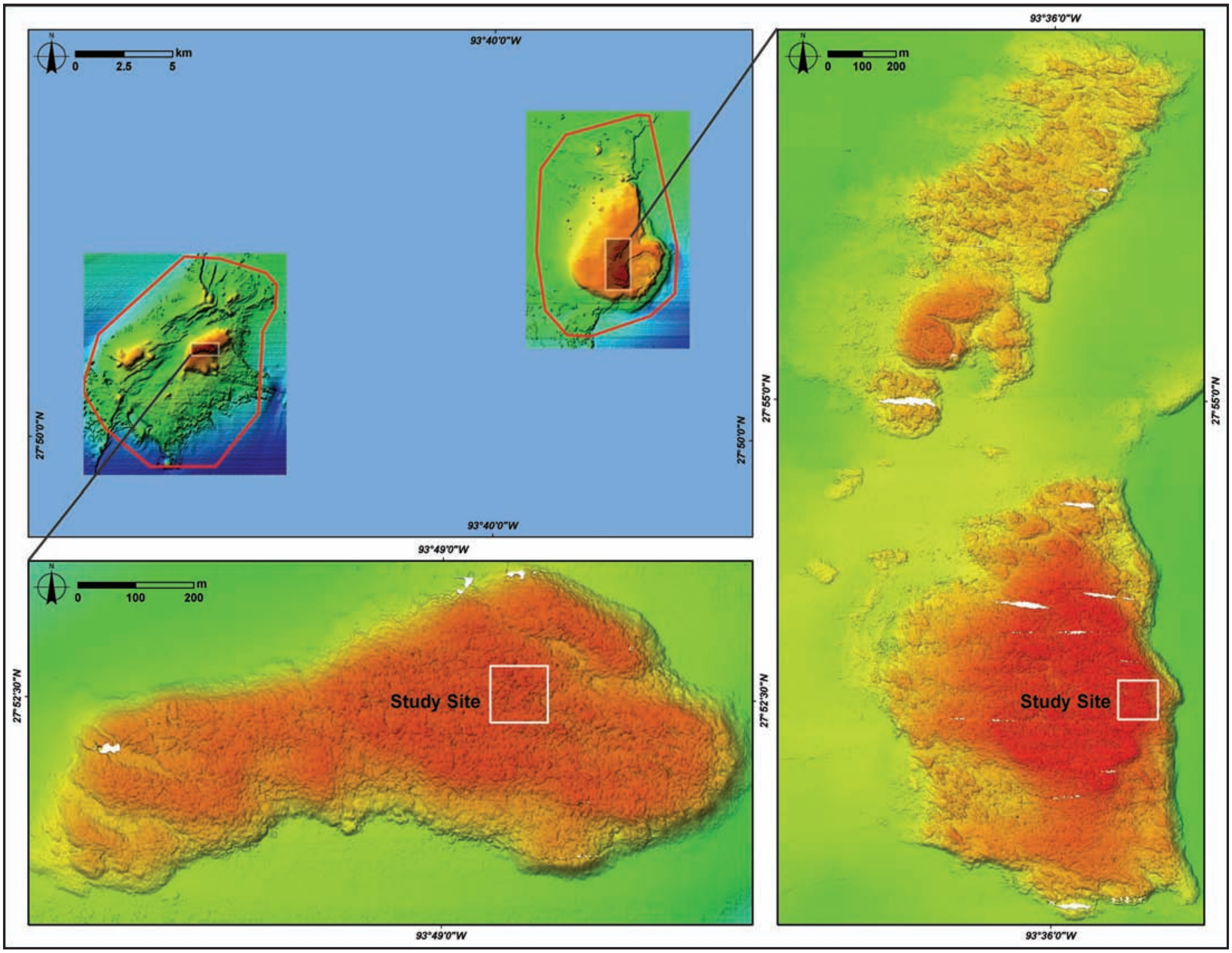


Figure 8.13. West and East FGB 100 m^2 study sites located on the coral caps (indicated in red). The coral caps represent less than 2% of the area within the Sanctuary boundaries. Map: A. Shapiro. Source: Gardner et al., 1998; D. Weaver.

Atlantic and Gulf Rapid Reef Assessment Surveys
Benthic and fish communities at one site on each of the East and West Banks were assessed using the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol in August 1999.

Reef Environmental Education Foundation Fish Surveys
The Reef Environmental Education Foundation (REEF) conducts fish surveys annually at the FGBNMS using roving diver surveys. The surveys do not quantify the abundance or biomass of the fish community, but all observations are entered into the REEF database. Methods and data are available at http://www.reef.org.

Other Sanctuary Activities
In addition to the AGRRA and REEF programs which are summarized in Table 8.1, the FGBNMS supports (by providing shiptime on chartered or Sanctuary vessels) several researchers investigating a wide array of topics. In addition, the Sanctuary research team conducts an annual data collection cruise, but funding limitations have precluded data analysis to date. Sanctuary staff encourage recreational divers to submit observations of charismatic megafauna, such as sharks, rays, and sea turtles, as the observations are maintained in the Sanctuary's database.

The most recent available data from the FGBNMS LTM Project and AGRRA surveys are presented below to characterize the status of reef ecosystems at the FGBNMS. The combination of these results best describes the status of the resources, with limitations as noted below.

Table 8.1. Coral reef ecosystem monitoring activities that occur at the FGBNMS.

ECOSYSTEM COMPONENT	PROGRAM	SOURCE
Water Quality	FGBNMS LTM	Most recent report: Dokken et al., 2003. Current contractor: PBS&J 2002-2003 report: Precht et al., in press
Benthic Habitats	FGBNMS LTM	Most recent report: Dokken et al., 2003. Current contractor: PBS&J 2002-2003 report: Precht et al., in press
	AGRRA	AGRRA Program: Pattengill-Semmens and Gittings, 2003.
Reef Fish	FGBNMS LTM	Most recent report: Dokken et al., 2003. Current contractor: PBS&J 2002-2003 report: Precht et al., in press
	REEF	REEF database (www.reef.org)
	AGRRA	AGRRA Program: Pattengill-Semmens and Gittings, 2003.

WATER QUALITY

East and West Flower Garden Banks, Long-Term Monitoring Project

Methods

YSI 6600 Datasondes are deployed at the reef crests of all three banks of the FGBNMS. Sensors log the following measurements at 30 minute intervals: temperature, salinity, photosynthetically active radiation (PAR) irradiance, pH, turbidity, and DO_2. Quarterly servicing is maintained (Figure 8.14), although more regular servicing is recommended. Servicing is inhibited by weather conditions and access to the site. Quarterly water sampling is conducted at the surface, midwater, and near bottom. A reference PAR irradiance sensor has historically been maintained on the gas platform HIA389A located within 2 km of the coral cap at the EFGB, although it is not presently collecting data.

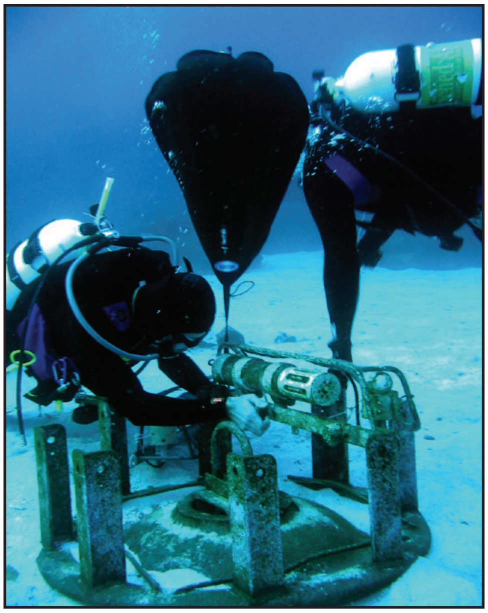
Results and Discussion

Only the EFGB and WFGB are discussed here; Stetson Bank data has been collected, but not yet analyzed.

The mean PAR irradiance and corresponding values for -k were lower at the WFGB than at the EFGB during 1997-1999; however, it does not appear that these differences were statistically significant. Seasonal variation in light levels was clearly evident in the plot of PAR values recorded at the HIA389A Platform. Seasonal variation in PAR was present, but less coherent for values recorded by the instruments at the EFGB and WFGB. Data gaps are frequent due to equipment failure.

Between September 23, 2001 and November 2003, salinity, turbidity, dissolved oxygen, and pH, in addition to temperature and PAR, were continuously measured at 30 minute intervals. During this period, salinity at EFGB ranged from about 32-38 ppt; salinity at WFGB ranged from about 33-37 ppt. Sensor integrity is questionable for other parameters.

Seawater temperatures were obtained from the Hobo-Temp recording thermographs (Onset Instruments, Pocasset, Massachusetts) deployed on the reef crest of EFGB and WFGB. 2002-2003 data show minimum temperatures at the EFGB and WFGB as 19.06°C and 18.99°C, respectively. Maximum temperatures were 20.24 °C and 30.22 °C, respectively (Figure 8.14). Due to equipment failure of the sensor at the EFGB, no data was recorded from April to November 2000, or from May 15 to August 26, 2003 at that site.



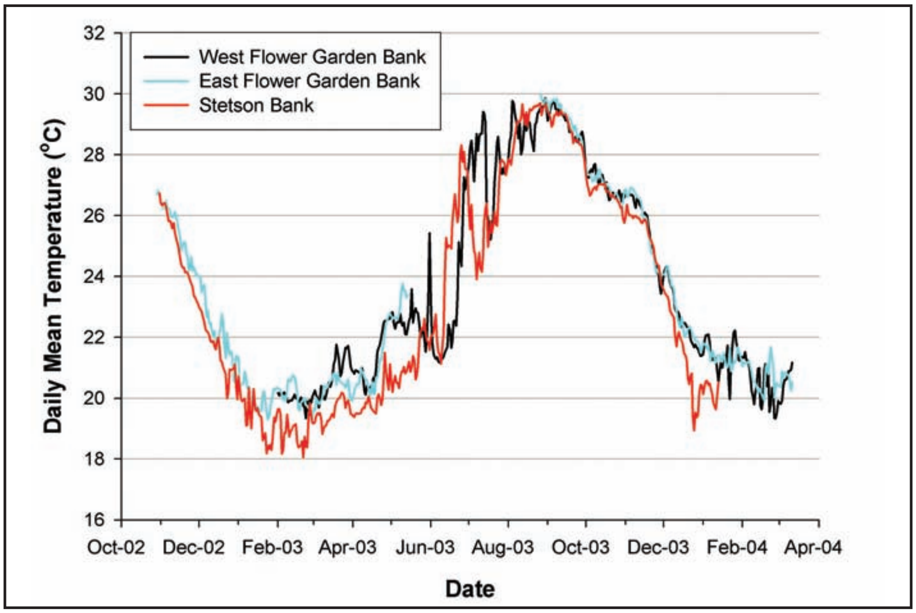


Figure 8.14. Left: YSI 6600 Datasonde quarterly servicing at the FGBNMS. Photo: PBS&J. Right: daily mean temperatures collected from October 2002 to April 2004. Source: Precht et al., in press.

BENTHIC HABITATS

East and West Flower Garden Banks, Long-Term Monitoring Project

Methods

A 100 m^2 study site has been established at both the EFGB and WFGB, and virtually all formal monitoring occurs within these areas. The following is a description of the methods outlined in the Statement of Work for the contracted monitoring effort co-funded by FGBNMS and MMS (MMS Document: NSL-GM-04-06; GOM-C4100, Section C). The monitoring includes several elements:

- Random Photographic Transects: 14 random photographic and/or digital video transects that are 10 m in length. Mean percent cover and standard deviation for each year and bank are calculated for coral species and other cover categories;

- Permanent Growth Stations: photographs of 60 permanent stations for monitoring growth of the scleractinian coral *Diploria strigosa*;

- Repetitive Quadrat Stations: 40 repetitive quadrat stations to detect and evaluate long-term changes in individual coral colonies. In addition to the initial 40 stations, nine repetitive quadrat stations have been established at the EFGB in coral reef habitat at deeper depths (30-40 m); and

- Sclerochronology: Cores of *Montastraea faveolata* coral colonies are taken biannually on each bank in odd numbered years to determine annual growth.

Results and Discussion

The results presented below are from the FGBNMS long-term monitoring report covering the years 1996-2001 (Dokken et al., 2003). A subsample of results from the 2002-2003 field season are also included where available (Precht et al., in press).

Random Photographic Transects—East Bank Community Composition and Structure (1996-2001)

From 1996 to 2001, mean percent cover of the *Montastraea annularis* complex increased, then increased again in 2003 on the WFGB, and decreased in 2002-2003 on the EFGB (Table 8.2). During the 2000-2001 and 2003 sampling years, coral cover ranged from 51.6-57.1% on the WFGB and 53.2-61.8% on the EFGB (Figure 8.15). The 2003 data reflect an overall reduction of coverage by the *Montastraea annularis* complex of at least 10%. Both *Porites astreoides* and *Millepora* spp. reflect higher percent coverages in 2003.

Total algal cover was greatest in 1999, then fell in both 2000 and 2001, and in the case of the WFGB, decreased by a factor of a third in 2003. *Diploria strigosa* was also highest during 1999 and likewise declined in both 2000 and 2001. Although a minor component, cover of *Siderastrea* sp. was highest (1.8%) in 1996 and fell to less than 1% in successive years. Cover of the remaining coral species as well as sponges remained relatively stable throughout the monitoring period of 1996 to 2001, but increased in coverage at both banks in 2003. Cover of reef rock was highest in 1998, the year before algal cover peaked, then declined. An additional parameter, calcareous bare turf was measured in the 2002-2003 data. This includes calcareous encrusting algae, including reds that may not be decipherable from bare space, and short turf algae <3 mm in size. This comprises a large component (at least 28% for both banks) in the 2003 data (Figure 8.15).

Table 8.2. Percent cover in 2000, 2001, and 2003 for random transects in the WFGB and EFGB. Standard deviations are in parentheses. Source: Dokken et al., 2003; Precht et al., in press.

	WFGB			EFGB		
SPECIES	**2000**	**2001**	**2003**	**2000**	**2001**	**2003**
Agaricia agaricites	0.3 (0.2)	0.3 (0.2)	0.24 (0.08)	0.2 (0.2)	0.4 (0.4)	0.33 (0.11)
Agaricia fragilis	0.007 (0.03)	0.003 (0.01)	0	0	0.1 (0.6)	0.01 (0.01)
Colpophyllia natans	3.6 (4.3)	2.8 (2.7)	2.17 (0.84)	2.6 (3.3)	2.6 (3.0)	3.29 (1.4)
Diploria strigosa	8.1 (6.7	9.5 (5.8)	9.04 (2.68)	6.2 (2.8)	3.9 (4.1)	6.19 (1.55)
Montastraea annularis complex*	30.9 (11.6)	35.1 (12.0)	33.8 (4.31)	39.5 (9.6)	44.8 (12.9)	28.47 (2.98)
Montastraea cavernosa	5.8 (11.7)	2.1 (3.7)	2.67 (1.10)	4.8 (5.7)	3.6 (5.0)	4.24 (1.41)
Scolymia sp.	0.01 (0.02)	0.003 (0.009)	0.04 (0.03)	0.01 (0.02)	0.002 (0.009)	0.01 (0.01)
Stephanocoenia mechelinii	0.9 (0.9)	0.3 (0.6)	0.96 (0.45)	0.1 (0.2)	0.2 (0.5)	0.76 (0.32)
Mussa angulosa	0.3 (0.6)	0.07 (0.2)	0.07 (0.04)	0.2 (0.4)	0.06 (0.3)	0
Madracis sp.	0.2 (0.4)	0.06 (0.1)	0.37 (0.29)	0.8 (2.3)	0.2 (0.3)	0.83 (0.34)
Porites astreoides	2.5 (1.6)	2.0 (0.9)	3.77 (0.46)	2.6 (1.7)	4.6 (2.7)	5.69 (0.98)
Porites porites	0.1 (0.6)	0.003 (0.01)		0.04 (0.08)	0.03 (0.1)	
Siderastrea sp.	2.0 (4.0)	0.002 (0.009)	2.04 (1.1)	0.03 (0.1)	0.2 (0.5)	0
Millepora sp.	0.7 (0.8)	0.7 (0.9)	1.94 (0.54)	1.3 (1.5)	0.9 (1.2)	2.23 (0.43)
Total Coral	**51.6 (13.7)**	**53.1 (11.4)**	**57.13 (3.81)**	**58.3 (6.7)**	**61.8 (10.0)**	**53.2 (3.01)**

Montastraea annularis complex is comprised of *M. annularis*, *faveolata*, and *franksi*

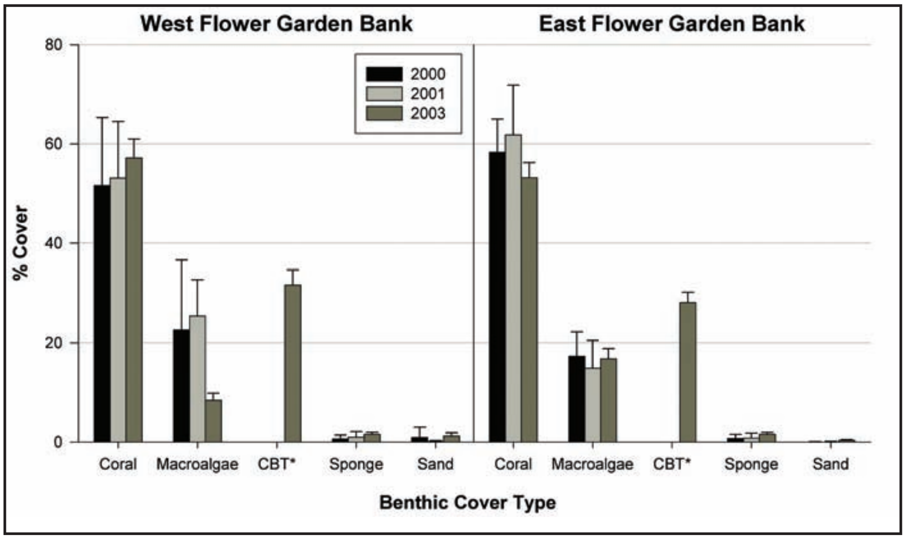


Figure 8.15. Benthic cover composition at the EFGB and WFGB from 2000-2003. Source: Dokken et al., 2003; Precht et al., in press.

Random Photographic Transects—East Bank, Comparisons Among Years (1996-2001)

ANOVA indicated that there were significant differences among years for five of the 13 coral species as well as total coral, total algae, and reef rock. Three overlapping, homogenous subsets of years were delineated for the *M. annularis* complex. The greatest difference was between the two years with highest cover, 2000 and 2001 and the two years with lowest cover, 1996 and 1997. Total coral, with four overlapping subsets, exhibited a similar pattern due to the dominance of the *M. annularis* complex in the community. Cover of other coral species tended to overlap greatly with primary differences between the years of highest and lowest cover. Algal cover in 1999 was significantly higher than all other years and cover in 2000-2001 was significantly greater than 1996-1998. Reef rock was significantly higher than other years in both 1998 and 1999.

Random Photographic Transects—West Bank Community Composition and Structure (1996-2001)

Cover of the *M. annularis* complex and total coral increased slightly between 1996 and 2001. Total algal cover increased dramatically between 1997 and 2001. Although a minor component, cover of *Millepora* sp. was highest in 1997 and fell to less than 1% in each successive year. Also a minor component, *Siderastrea* sp. cover generally increased from 1996 to 2000, then dropped in 2001 to the lowest value recorded. Cover of the remaining coral species as well as sponges remained relatively stable throughout the monitoring period of 1996-2001. Cover of reef rock was highest in 1998 and 1999, declining by about 50% in each subsequent year.

Diversity was relatively stable between 1996 and 1999, increasing slightly in 2000, but then decreasing to a low in 2001. Evenness and dominance were fairly stable throughout the study period. Overall community similarity was 85%.

Random Photographic Transects—West Bank, Comparisons Among Years (1996-2001)
Only one coral, *Madracis* sp., a minor component of the coral community, exhibited significant differences among years. In 1999, *Madracis* spp. cover was significantly higher than all other years except 2000. There were also significant differences among years in algae cover and reef rock, with the delineated homogenous subsets representing the years of highest and lowest cover.

There were significant positive correlations between total coral cover and cover of the *M. annularis* complex, *D. strigosa*, and *M. cavernosa*. Cover of reef rock was significantly negatively correlated with algal cover. Runs tests indicated no significant trends only random variation in deviations above or below median for any species or reef component.

Permanent Growth Stations (2001-2002)
A total of 22 analyses were completed for the EFGB, with 15 advances and three retreats recorded. The remaining four cases could not be evaluated. A total of 13 analyses were completed for the WFGB, with eight advances, three retreats, and two cases that could not be evaluated. Assuming a null hypothesis of equal probabilities of advances and retreats, the two-tailed, cumulative binomial probability of 15 or more advances out of 18 at EFGB is $p=0.008$, which is significant at $\alpha=0.05$. The two-tailed, cumulative probability of eight or more advances out of 11 at WFGB is not significant at $p=0.227$. Combining the data from the two banks yields 23 advances, six retreats, and six cases that could not be evaluated. The two-tailed, cumulative binomial probability of 23 or more advances out of 29 is $p=0.002$, which is significant.

Permanent Growth Stations (2002-2003)
A total of seven analyses were completed for EFGB, with four advances and three retreats. A total of five analyses were completed for WFGB, with one advance, three retreats, and one case that could not be evaluated. The sample sizes were too small to perform the binomial test on the banks separately. Combining the data from the two banks yields five advances and six retreats, and the two-tailed, cumulative binomial probability of six or more retreats out of 11 is $p=1.000$, which is not significant.

There were significantly more advances than retreats at EFGB from 2001 to 2002, and this drove the overall significant result for 2001-2002. When considering both banks over both years of analysis, however, the results did not depart from the null expectation of equal numbers of advances and retreats. Although the samples for 2002-2003 were limited (a problem that the rehabilitation of stations has corrected for future years), we can conclude that the *Diploria* colonies may not have been growing, but they did not appear to be retreating either.

Repetitive Quadrat Stations
In general, the species composition and percent cover of the coral community in the 8 m^2 repetitive quadrats is similar to that found in the analysis of the random inside transects at EFGB. Overall, mean coral cover was about 7% lower than the inside random transects in 2000 and 10% in 2001; mean cover of the *M. annularis* complex was also 2-7% lower. *D. strigosa* mean cover was higher than the inside transects in both years. The mean cover of the remaining species was somewhat lower than that found in the inside transects, and four uncommon species, *Agaricia agaricites, A. fragilis, Scolymia* sp., and *Siderastrea* sp., were not found in the analysis of the 8 m^2 repetitive quadrats.

Sclerochronology
Four cores were taken from separate *Montastraea faveolata* colonies at the East Bank in August 2003. Estimated growth ranged from 0.77-1.07 cm from 1997-2003, with an overall mean of 0.92 cm ± 0.11 (Precht et al., in press). The highest mean growth rate occurred in 1999-2000 and the lowest occurred in 2002-2003 (Figure 8.16). One core showed a partial mortality line in 1999; however, subsequent growth was established by surrounding polyps.

Four cores were taken from *M. faveolata* heads at WFGB in August 2003. Estimated growth ranged from 0.63-0.85 cm ±0.07, with an overall mean rate of 0.76 cm ± 0.07 (Precht et al., in press). The highest mean growth rate occurred in 1999 and the lowest in 2002. Like the East Bank, one core showed partial mortality in 1999, but subsequent recovery was seen by surrounding polyps.

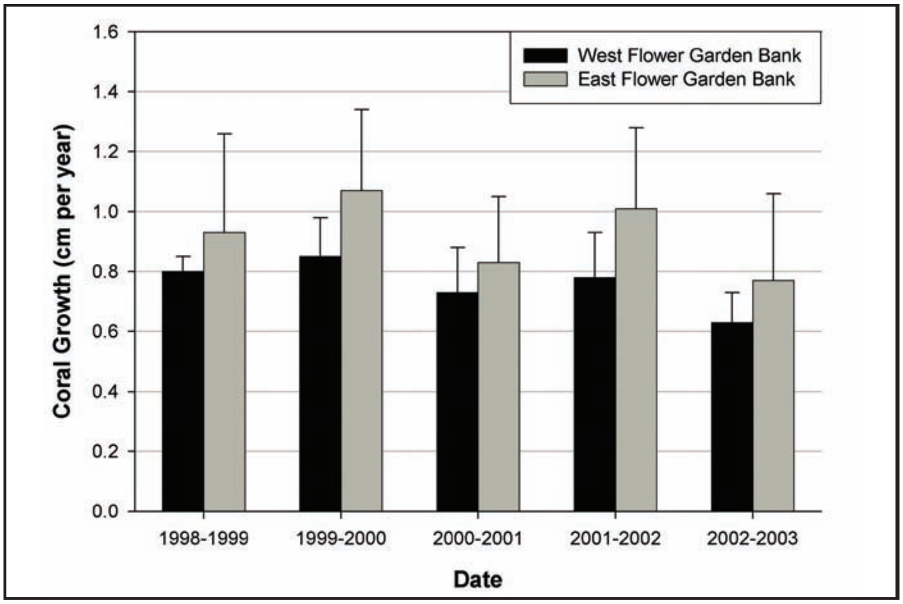


Figure 8.16. Mean annual coral growth (cm) with standard errors for 1998-2003 from *Montastraea faveolata* cores (n=4) collected at EFGB and WFGB in August 2003. Source: Dokken et al., 2003; Precht et al., in press.

Atlantic and Gulf Rapid Reef Assessment

Methods

A team of seven scientists and three REEF experts conducted the AGRRA surveys (Pattengill et al., 2000) on EFGB and WFGB from August 15-20, 1999, at depths between 18-25 m. At the EFGB, 160 coral colonies were surveyed, 67 algae quadrats examined, 15 roving diver fish surveys conducted, and 12 fish belt-transects conducted. At the WFGB 135 coral colonies and 55 algae quadrats were examined, 11 roving diver fish surveys conducted, and 12 fish belt-transects performed.

Results and Discussion

The AGRRA surveys revealed very healthy reefs with high coral cover, dominated by impressive, healthy, and large corals, little macroalgae, and abundant fish populations. At the EFGB and WFGB, the average coral cover was 53.9% and 48.8%, respectively. The reefs were dominated by relatively large mounding corals primarily in the genera *Montastraea, Diploria,* and *Colpophyllia*. This was reflected in the average coral diameters from EFGB and WFGB, 81 and 93 cm, respectively. The percent of recent coral mortality was very low (<2.5%) at both sites. Macroalgal cover was very low at both sites, however at EFGB, a cyanobacterial mat was observed among the algae. Minimal bleaching was observed. The widespread 1998 bleaching event did not occur at the Flower Garden Banks. Few incidences of disease were recorded in the transects but parrotfish bites on coral were common at both sites. Overall, these reefs, which exist at the northern limits of reef development, appear to be very healthy with stable populations of coral, little macroalgae, and robust fish populations.

Benthic Habitat Mapping

In addition to the activities listed above, attempts are currently underway to further characterize the benthos in the FGBNMS through bathymetric and benthic habitat mapping activities. High resolution bathymetric maps have been developed for approximately 3,932 km^2 of the northwestern Gulf of Mexico reefs and banks to date, including 1 m resolution bathymetric maps of the coral caps at EFGB and WFGB. In addition, georeferenced remotely operated vehicles (ROV) surveys completed in the past several years are providing valuable input for the creation of coarse benthic habitat maps for the entire Sanctuary, which will provide managers with essential information about the marine community. Sanctuary staff are working with other scientists from NOAA, particularly NOAA's Center for Coastal Monitoring and Assessment-Biogeography Team, to integrate FGBNMS map products with those developed for the Florida Keys and the U.S. Caribbean. Draft maps are scheduled for completion in fall 2005.

ASSOCIATED BIOLOGICAL COMMUNITIES

East and West Flower Garden Banks, Long-Term Monitoring Project

FISH

Methods

Fish counts were performed at both banks using stationary visual techniques for quantitatively assessing community structure of coral reef fishes (Bohnsack and Bannerot, 1986). A minimum of 24 surveys were performed at each bank to provide a statistically sound assessment of reef fish abundance and diversity. Survey sites were selected randomly from within the study location.

Results and Discussion

A mean of 51 fish species (SD=3.5) per year were observed at the EFGB and WFGB in 2002 and 2003. Fish abundances showed no significant differences between banks and years. The mean species richness per diver survey was shown to have a significant difference (p=0.0243) between the EFGB (16.72 species per diver survey) and the WFGB (18.55 species per diver survey). Only surveys at the WFGB proved to be significantly different (p=0.026) between years with 19.71 species per diver survey in 2003 and 15.72 species per diver survey in 2002. The observed species richness in 2002 at the EFGB and WFGB was 54 and 53 respectively, and 46 and 52, respectively in 2003.

The Shannon-Wiener index of diversity (H') is a common ecological measure of community structure that integrates the number and variety of species found in a given area or region. The diversity value (H') consists of both a richness measure (no. of species) and an evenness measure (how individuals are distributed among species).

Shannon-Wiener diversity indices are very similar at both banks in 2002 and 2003 (Table 8.3). The highest value was for WFGB in 2003 (1.19) and lowest for EFGB in 2003 (0.90). Diversity indices for 2002 are 1.14 and 1.16 for WFGB and EFGB, respectively. Index values for evenness (J') were calculated for the fish communities at both banks in 2002 and 2003 as well. As mean richness values were statistically lower on the EFGB than the WFGB, and evenness values (J') were generally lower at EFGB than at WFGB, it follows that the overall diversity (H') would exhibit a similar pattern.

Table 8.3. Shannon-Weiner diversity index (H') and Evenness values (J') for fish populations at EFGB and WFGB in 2002-2003. Source: Precht et al., in press.

INDEX	2002		2003	
	EFGB	WFGB	EFGB	WFGB
Diversity (H')	1.16	1.14	0.90	1.19
Evenness (J')	0.67	0.66	0.54	0.69

Expressed as density values (no. of fish/area), overall fish abundance for the EFGB and WFGB in 2002 was 82.78 and 73.29 per 100 m^2 respectively, and in 2003 was 157.53 and 84.62, respectively. The increase in density at the EFGB in 2003 was primarily attributed to the increased abundance of two species: *Clepticus parrae* and *Chromis multilineata*. Divers recorded 63.66 *C. parrae* per 100 m^2 at EFGB in 2003, which represents a large increase in density from 2002, when the observed density of *C. parrae* was 14.59 per 100 m^2. The observed density of C. *multilineata* also increased at EFGB from a value of 5.50 per 100 m^2 to 32.94 per 100 m^2. *Thalassoma bifasciatum*, *C. parrae*, and *Paranthias furcifer* were consistently among the top five most abundant fishes. *C. cyanea, C. multilineata, Stegastes planifrons,* and *S. partitus* were also among the most abundant fishes regularly encountered in diver surveys.

A mean of 21 families (SD=0.82) were recorded. Labridae, Pomacentridae, and Serranidae were consistently the three most abundant fish families observed at the Flower Garden Banks with densities ranging from 6.92 Serranids per 100 m^2 at the EFGB in 2002 to 70.74 Labrids per 100 m^2 at the EFGB in 2003. Pomacentrids, Serranids, and Labrids are also the three best represented families with 12, 10, and 6 species having been recorded for each, respectively.

SEA URCHIN AND LOBSTER SURVEYS

Methods
Long spined urchin (*Diadema antillarum*) surveys were conducted to establish current population levels as a basis for comparison with future observations (Table 8.4). Surveys were conducted approximately 1.5 hours after sunset using site boundaries as transect lines. Two transects, each 100 m long and 2 m wide were surveyed using the same site boundary transect lines as those used for the video transects at each study site. Spiny lobster (*Panulirus argus*) and spotted lobster (*P. guttatus*) surveys were conducted in a similar manner.

Results and Discussion
For urchin and lobster counts, only descriptive data exist due to the low numbers observed. The *D. antillarum* populations continue to be depressed. No lobster data were presented by Dokken et al. (2003), and no lobster were reported during the surveys in 2002-2003 along the prescribed survey lines (Precht et al., in press).

Table 8.4. Average number of *Diadema antillarium* per m^2 on the EFGB and WFGB from 1996-2001. Source: Dokken et al., 2003.

YEAR	EFGB	WFGB
1996	No counts made due to sea conditions	0.0033 m^2
1997	No counts made due to sea conditions	0.0038 m^2
1998	0.023 m^2	No counts made due to sea conditions
1999	No counts made due to sea conditions	No counts made due to sea conditions
2000	0.018 m^2	0.030 m^2
2001	0.005 m^2	0.050 m^2

Atlantic and Gulf Rapid Reef Assessment (AGRRA)

Methods
A team of seven scientists and three REEF experts conducted the AGRRA surveys on EFGB and WFGB from August 15-20, 1999. Details of the methods used are contained in Pattengill et al. (2000). The reef surveys were conducted at depths between 18-25 m. At the EFGB, 160 coral colonies were surveyed, 67 algae quadrats examined, 15 roving diver fish surveys conducted, and 12 fish belt-transects conducted. At the WFGB, 135 coral colonies and 55 algae quadrats were examined, 11 roving diver fish surveys conducted, and 12 fish belt-transects performed.

Results and Discussion
A total of 126 fish species were seen at EFGB and WFGB. One new record for the banks was recorded: sharptail eel (*Myrichthys breviceps*). The eel was seen at the WFGB, and had also been recorded on video earlier in the summer of 1999. Preliminary analyses of fish transect data showed high similarity between the EFGB and WFGB locations. Differences were seen in the butterflyfish and seabasses. The density of the reef butterflyfish (*Chaetodon sedentarius*) was two and a half times greater at the WFGB. Similarly, the density of graysby (*Epinephelus cruentatus*) at the WFGB was approximately twice that found at EFGB. Grunts were absent at both banks, a distinguishing characteristic of the Flower Garden Bank's fish assemblages. Average size of parrotfish and seabass was relatively high, reflecting the low fishing pressure.

Overall Condition and Summary of Analytical Results
The overall health of the reefs of the EFGB and WFGB continues to be described as stable, supporting approximately 50% coral cover comprised of primarily robust and massive species. Initial estimates of coral cover at the deep stations of the EFGB indicate upwards of 69% coral cover (W. Precht, pers. comm.). *Montastraea* spp. dominates the community, with *D. strigosa* also providing substantial cover. The stability of the system is evidenced by the continued high coral cover. Very little coral disease has been documented at the site. The FGBNMS appears to be insulated from mortality resulting from bleaching events. Bleaching

occurs, but minimally, and usually is followed by 100% recovery. Algae appear to play a balanced role in the reef habitat, and do not appear threatening to the coral component. Water conditions continue to be consistently good.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Regulations governing the FGBNMS are authorized under the National Marine Sanctuaries Act, as amended, 16 U.S.C. 1431, and are contained within the Code of Federal Regulations 15 C.F.R. 922, Subparts A, E, and L, available on the Internet at http://www.sanctuaries.nos.noaa.gov/oms/omsflower/omsflowerpubdoc.html. They are designed to protect the sensitive coral reef features of the Sanctuary. They prohibit anchoring of any vessel within the Sanctuary; mooring of any vessel greater than 100 feet on a Sanctuary mooring buoy; oil and gas exploration and development within a designated no activity zone (almost the entire Sanctuary); injuring or taking coral and other marine organisms; using fishing gear other than traditional hook and line; discharging or depositing any substances or materials; altering the seabed; building or abandoning any structures; and using explosives or electrical charges.

In 2001, the International Maritime Organization designated the FGBNMS as the world's first international no-anchor zone. This designation enhances the protection and awareness of the site by providing guidance and regulations at an international level.

Over the past five years, the Sanctuary research team has conducted dedicated ROV cruises exploring the portions of the Sanctuary below the depths of the coral reef cap. Over 35 species of antipatharians and gorgonians, as well as several species of azooxanthelate corals have been found in deeper waters. There is some indication that the coral reef areas and deepwater habitat may be important spawning areas for several species of grouper.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

The coral reef ecosystem at the Flower Garden Banks is thriving, despite its location in the middle of one of the largest oil and gas fields in the world. Each year, Sanctuary staff review dozens of new requests for pipeline or platform installation within the MMS four-mile regulatory zone. One unresolved concern associated with oil and gas activities is the large quantities of contaminated water, or 'produced water,' that is generated during offshore oil platform operations. The effects of produced water on coral reef ecosystems are unknown and represent a significant knowledge gap that needs to be addressed in response to the expansion of oil and gas activities in the region.

Other substantial knowledge gaps exist, in part due to the difficulty of accessing this relatively remote location. While distance from shore may lessen some of the impacts attributed to recreational use, it also hampers monitoring of human activities, research with respect to recreational use of the area by divers and fishers, and enforcement of Sanctuary regulations. While some data on visitor use can be attained by a variety of remote methods such as overflights, satellite imagery, and remote radar systems, the Sanctuary needs to increase on-site observation, management, and enforcement.

The location of the Flower Garden Banks also makes the logistics involved in monitoring activities difficult and expensive, which limits the frequency of sampling and the total area able to be surveyed during data collection. Under the current methods, sampling points are limited to a 100 m^2 area in the shallowest part of the coral caps, which represents a fraction of the total area of the banks. Limitations in sampling frequency and spatial distribution of survey sites restrict scientists' analytical power to measure change with a sufficient level of confidence, especially when trying to account for adjacent reefs or banks. Addition of monitoring data from banks and reef areas in other parts of the Gulf of Mexico would help scientists understand the role of these banks in relation to coral reef ecosystems in the wider Gulf region.

Despite these limitations, the LTM Project results indicate that the EFGB and WFGB reefs are relatively pristine as compared to other Caribbean reef systems. Budget constraints have precluded the analysis of Stetson Bank monitoring data to date, but analysis of existing data is a priority for increasing management capability. Anecdotal and photographic observations made at Stetson Bank are noted (e.g., a recent algal bloom), but cannot be acted upon without quantitative evidence.

The observations indicating that FGBNMS is an important spawning area for several species of grouper warrants further investigation, and highlights the importance of considering a no-take marine reserve to protect the biodiversity of this region. While it is clear that the reefs of the FGBNMS are biologically and ecologically connected with the numerous reefs and banks found in the northwestern Gulf of Mexico, a newly described endemic wrasse (Weaver and Hickerson, in press) documented at all three banks of the FGBNMS illustrates the uniqueness on a local scale.

The FGBNMS harbors a close to pristine coral reef ecosystem. It is crucial that the status of this resource be maintained in its current condition. In a world of declining coral reef health, this site can be used as a standard for comparison to all other Caribbean coral reef systems, and may function as a source of recruits for neighboring regions.

It should be recognized that several reefs and banks that exist in the vicinity of the FGBNMS also harbor deep coral reef communities. These banks include Bright, Geyer, Sonnier, and McGrail Banks. No regulations currently protect these resources other than from the direct impacts from oil and gas activities.

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The State of Coral Reef Ecosystems of the Main Hawaiian Islands

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INTRODUCTION AND SETTING

Hawaii is one of the most isolated archipelagos in the world and as a result, possesses some of the highest marine endemism recorded anywhere on earth. Because they are located in the middle of the Pacific Ocean, Hawaii's coral reefs are exposed to large open ocean swells and strong tradewinds that have a major impact on the structure of these coral reef communities. The archipelago consists of two regions: the Main Hawaiian Islands (MHI) which consists of populated, high volcanic islands with non-structural reef communities and fringing reefs abutting the shore (Figure 9.1), and the Northwestern Hawaiian Islands (NWHI) consisting of mostly uninhabited atolls and banks which are the subject of a separate chapter. This island chain stretches for over 2,500 km from the island of Hawaii in the southeast to Kure Atoll (the world's highest atoll latitudinally) in the northwest.

Coral reefs were important to the ancient Hawaiians for subsistence, culture, and survival. According to the Hawaiian Creation Chant, the kumulipo, the coral polyp was the first creature to emerge from the sea during creation. The early Hawaiians recognized that coral reefs were a building block of the islands and used coral in religious ceremonies to honor and care for ocean resources. Today, Hawaii's coral reef communities provide protection from storm waves, create the large surf that makes Hawaii world famous, provide food for sustenance, and are critically important to the State's approximately $800 million per year marine tourism industry.

Over 70% of the state's 1.2 million people live on Oahu, and are mostly concentrated in the Honolulu metropolitan area. In addition to the resident population, nearly seven million tourists visit Hawaii each year. This concentrated number of people has put pressure on Hawaii's coral reefs through various direct and indirect means. In general, Hawaii's coral reefs are in better condition than many other reefs around the world, although urban areas and embayments have suffered from land-based sources of pollution, overfishing, recreational overuse, and alien and invasive species.

1 NOAA/ NOS/ NCCOS/ Center for Coastal Monitoring and Assessment, Biogeography Program.
2 Oceanic Institute
3 Hawaii Department of Land and Natural Resources, Division of Aquatic Resources
4 National Park Service
5 Bishop Museum
6 University of Hawaii
7 Hawaii Coral Reef Initiative
8 Environmental Protection Agency
9 NOAA/NOS/ Hawaiian Islands Humpback Whale National Marine Sanctuary
10 Hawaii Sea Grant Program
11 U.S. Geological Survey
12 Washington State University

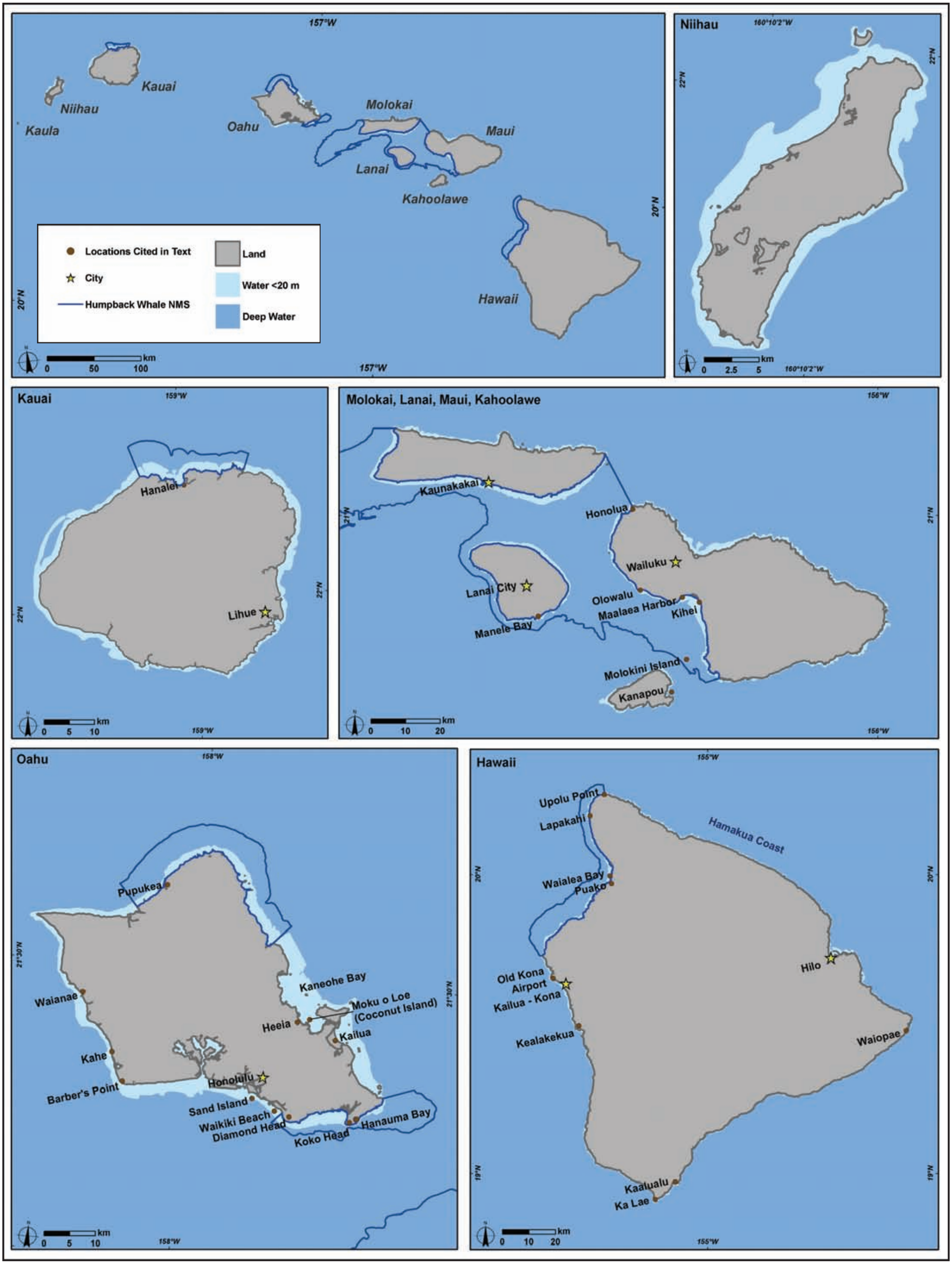

Figure 9.1. Maps of the MHI showing locations mentioned in this chapter. Map: A. Shapiro.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

Hawaiian waters show a trend of increasing temperature over the past several decades (Figure 9.2) that is consistent with observations in other coral reef areas of the world (Coles and Brown, 2003). The first documented multi-locational coral bleaching occurred in Hawaii in late summer of 1996, with a second event in 2002 (Jokiel and Brown, 2004). Although bleaching events may have occurred prior to 1996, there is no quantitative or qualitative record of previous episodes. These documented bleaching events in Hawaii were triggered by a prolonged regional positive oceanic sea surface temperature anomaly greater than 1°C that developed offshore during the time of the annual summer temperature maximum. High solar energy input and low winds further elevated inshore water temperatures by 1-2°C in reef areas with restricted water circulation (e.g., Kaneohe Bay, Oahu) and in areas where mesoscale eddies retain water masses close to shore for prolonged periods of time (Figure 9.3).

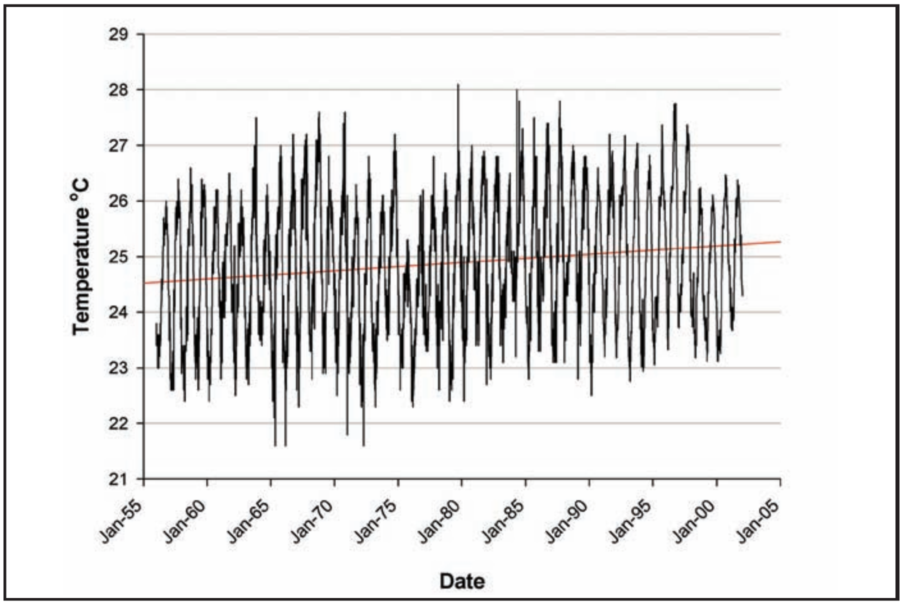

Figure 9.2. Weekly averaged points for NOAA Fisheries temperature series taken at Koko Head, Oahu (21°17'N, 157°41'W) and weekly IGOSS-NMC data series that overlapped temporarily. Data sets were merged. Source: Jokiel and Brown, 2004.

Bleaching was recorded throughout the State of Hawaii in 1996, with the most severe impact observed on Oahu and lesser bleaching reported on Maui and Hawaii. On Maui, weekly temperatures on reefs at eight locations on the southwest coastline showed a range of 28.0-28.5°C in late August and early September, with peak temperatures approaching 29°C. Corals began to bleach at Olowalu, Maui in late August, but the extent and severity of bleaching was minor, with less than 10% of the corals being affected. Recovery occurred after several months.

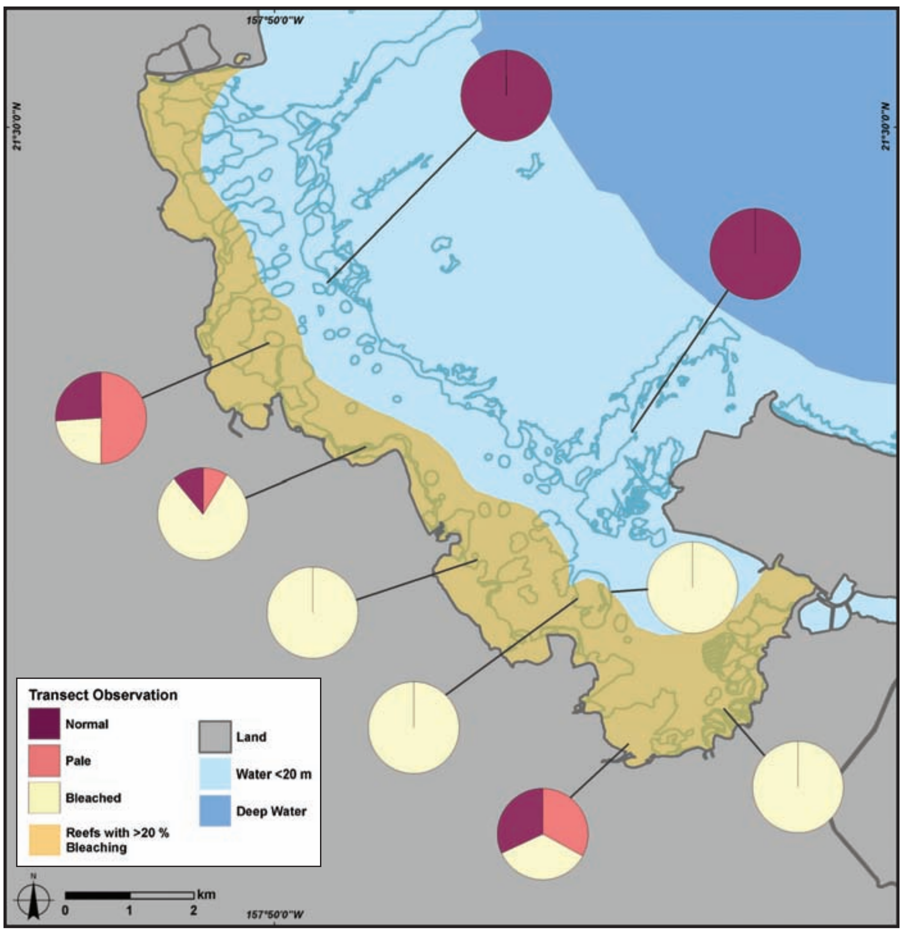

Figure 9.3. Map of Kaneohe Bay, Oahu. Shaded area shows reef areas with a high proportion of bleached corals (>20%) on 31 August 1996. Pie charts show relative portions of bleached, pale and normal coral coverage on transects located throughout Kaneohe Bay at that time. Source: Jokiel and Brown, 2004.

The second major bleaching event in the NWHI transpired during the summer of 2002 (Aeby et al., 2003). A detailed description of this event is provided in the chapter on the NWHI's coral reef ecosystems.

Diseases

Coral populations in the Hawaiian Archipelago continue to be spared from epidemic disease outbreaks unlike many other corals reefs around the world. Baseline surveys for coral disease were recently conducted at 18 sites around Oahu. The average prevalence of disease (no. diseased colonies/total no. colonies) was estimated at 0.95% (range 0-4.4%). Differences in disease prevalence were found among coral genera, with *Porites* having the highest prevalence of disease. The most common condition found on *Porites* was growth anomalies or 'tumors' (Figure 9.4). Prior studies found growth anomalies on *Porites* from both Oahu and Hawaii Island (Hunter, 1999; Work and Rameyer, 2001). Similar growth anomalies have not yet been documented on *Porites* in the NWHI despite intensive coral disease surveys (Aeby, unpublished data). The cause of *Porites* tumors has not yet been elucidated, but the occurrence of tumors on *Porites lobata* is positively correlated with colony size (a broadly generalized proxy for colony age; Hunter, 1999).

Another common disease found in both the MHI and NWHI is *Porites* trematodiasis caused by the larval stage of the digenetic trematode, *Podocotyloides stenometra* (Aeby, 1998; Figure 9.4). The greatest abundance of infected coral has been found on the reefs in Kaneohe Bay on the windward side of Oahu (Aeby, 2003). In Kaneohe Bay, infected corals have been found in all reef zones from the reef flat to the bottom of the reef slope and have persisted on the reefs since the 1970s (Cheng and Wong, 1974; Aeby, 2003). Trematode infection can cause reductions in coral growth of up to 50% (Aeby, 1992).

General coral necroses also commonly occur on Hawaiian reefs. Hunter (1999) found that necrotic patches followed one of three outcomes: 1) complete recovery, 2) successional change from turf to crustose coralline algae on which new coral recruits become established, or 3) persistence of the turf community with a net loss of coral cover.

No major die-off of corals has ever been documented due to disease in Hawaii. However, increasing human usage and the impacts of global climate change are causing concern about the health of Hawaiian reefs. Plans are currently underway to extend baseline disease surveys out to the MHI. The Hawaii Department of Land and Natural Resources - Division of Aquatic Resources (DAR) will also be integrating coral disease assessment into its monitoring program.

The endangered Hawaiian green sea turtle is affected by fibropapillomatosis (FP), a disease that causes external and internal tumors in turtles. Turtles with FP also have significant additional complications including inflammation with vascular flukes, bacterial infections, poor body condition, and necrosis of salt gland (Work et al., in press). Recent evidence suggests the herpes virus as a probable cause or co-factor of FP (Herbst, 1995). In Hawaii, FP has been found in 40-60% of observed turtles, with juvenile turtles constituting most of the cases (Balazs and Pooley, 1991). A recent study found that the majority of stranded turtles were juvenile turtles affected by FP and suggested that FP may detrimentally affect survival in juveniles (Work et al., in press).

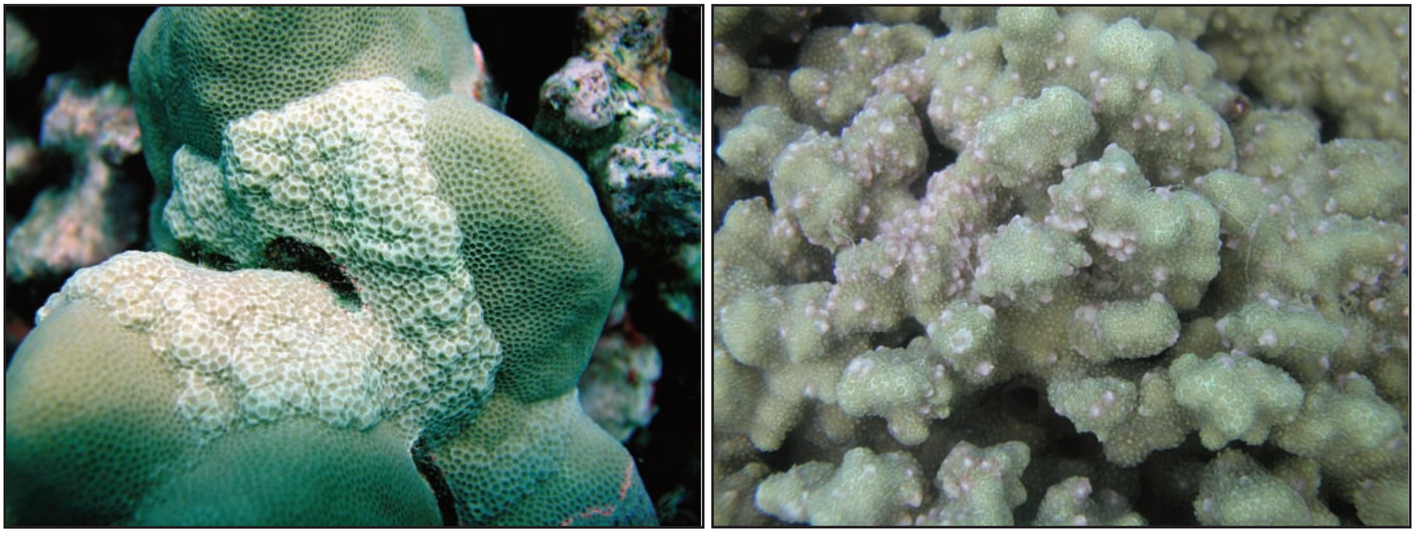

Figure 9.4. Left panel shows *Porites lobata* with tumor. Right panel shows *Porites compressa* with Trematodiasis. Swollen, pink nodules on the coral colony indicate polyps infected with the trematode. Photos: G. Aeby.

As such, FP may pose a significant threat to the long-term survival of the species (Quackenbush et al., 2001).

Figure 9.5. Large winter swells, such as this in Peahi, Maui, impact the structure of coral reef communities in Hawaii. Photo: E. Brown.

Tropical Storms

By virtue of its isolation, the structure of Hawaiian reefs is molded by a unique set of biogeographical factors and physiological tolerances which limit community assemblages to a relatively few hearty species. Another unique aspect of the geographical location of Hawaii is direct exposure to long-period swells emanating from winter storms in both the northern and southern hemispheres (Figure 9.5). Breaking waves from surf generated by Pacific storms is the single most important factor in determining the community structure and composition of exposed reef communities throughout the MHI (Dollar, 1982; Dollar and Tribble, 1993; Dollar and Grigg, 2004; Jokiel et al., 2004). The exception to this general rule is sheltered embayments that make up less than 5% of the coastal areas of the MHI.

Hawaiian coral community structure has been shown to respond to storm wave stresses of varying frequency and intensity as described by the 'intermediate disturbance hypothesis' (Grigg, 1983). Moderate cover and peak diversity is attained as the result of a continual cycle of intermediate intensity disturbances. High coral cover with low species diversity is found in sheltered embayments and areas protected from direct swells (e.g. south Molokai).

Based on the structure of coral communities on dated lava flows on the island of Hawaii, it has been projected that it takes about 50 years for Hawaiian reefs to regain peak diversity following a catastrophic event (Grigg and Maragos, 1974). A 30-year study documenting the impacts of storm waves of varying intensity on the west coast of the island of Hawaii has shown that shallow zones, populated primarily by a pioneering species of cauliflower coral, recovered completely within 20 years to pre-storm conditions, while deep reef slope zones showed only the initial stages of recovery during the same period. In addition, the study showed that recovery might not always result in immediate replacement of the same dominant species in a particular zone (Dollar, 1982; Dollar and Tribble, 1993; Dollar, 2004).

The cycle of repetitive impact and recovery is also a major factor in the present-day lack of reef accretion in exposed areas throughout the Hawaiian Islands. Extensive pre-Holocene (last major glacial epoch, approximately 11,000 years ago) reefs have been noted throughout the Hawaiian chain. This may be due to greater storm wave intensity now relative to earlier periods (Rooney et al., 2004), or an increased resistance of pre-Holocene Hawaiian coral communities to such storms, possibly through species components more adapted to rapid recovery (Dollar and Tribble, 1993). As a result, the only reef accretion that is presently taking place in Hawaii occurs in sheltered embayments or inside barrier reefs that are protected from storm wave impact. A good understanding of the response of reef systems to natural stresses is an important aspect in evaluating the effects of human activities because responses of reef ecosystems to human-induced stress are superimposed on natural cycles of impact and recovery.

The few studies in Hawaii to date that examined the effects of storms on fishes show that surf height and degree of wave exposure have negative relationships with various measures of fish assemblage organization (Friedlander and Parrish, 1998a; Friedlander et al., 2003). This relationship suggests that habitats protected from the highest wave energies maintain larger fish populations with greater richness and diversity of species. Walsh (1983) found that the impacts on the fish assemblage following a large "kona" storm were ameliorated by the presence of deeper water refuges.

Large storms and typhoons can also affect local fisheries by damaging essential fish habitat (Figure 9.6). In recent decades, two major hurricanes (Hurricane Iwa, 1982; Hurricane Iniki, 1992) struck the islands and caused considerable coral and habitat damage on Oahu and Kauai (W. Aila, pers. comm.). Hurricane Iwa damaged extensive inshore reef areas, especially the prime aquarium fishing grounds along Oahu's western and southern coast (DLNR-DAR, undated; Pfeffer and Tribble, 1985). Hurrincane Iniki also impacted coral reef communities on Oahu (Brock, 1996; Coles and Brown, in prep.), but limited evidence suggests the effects may have been less than with Iwa (Miyasaka, 1994a, b).

Fish catch and value declined around Oahu after the hurricanes but rebounded somewhat in the following years (Walsh et al., 2004; Figure 9.7). With the loss of collecting habitat, collectors concentrated their efforts on those sites still relatively intact and economically viable. The net result of storm effects, when combined with overfishing, was a drastic long-term decline in the abundance of key targeted species such as yellow tangs (*Zebrasoma flavescens*) around Oahu (Figure 9.7).

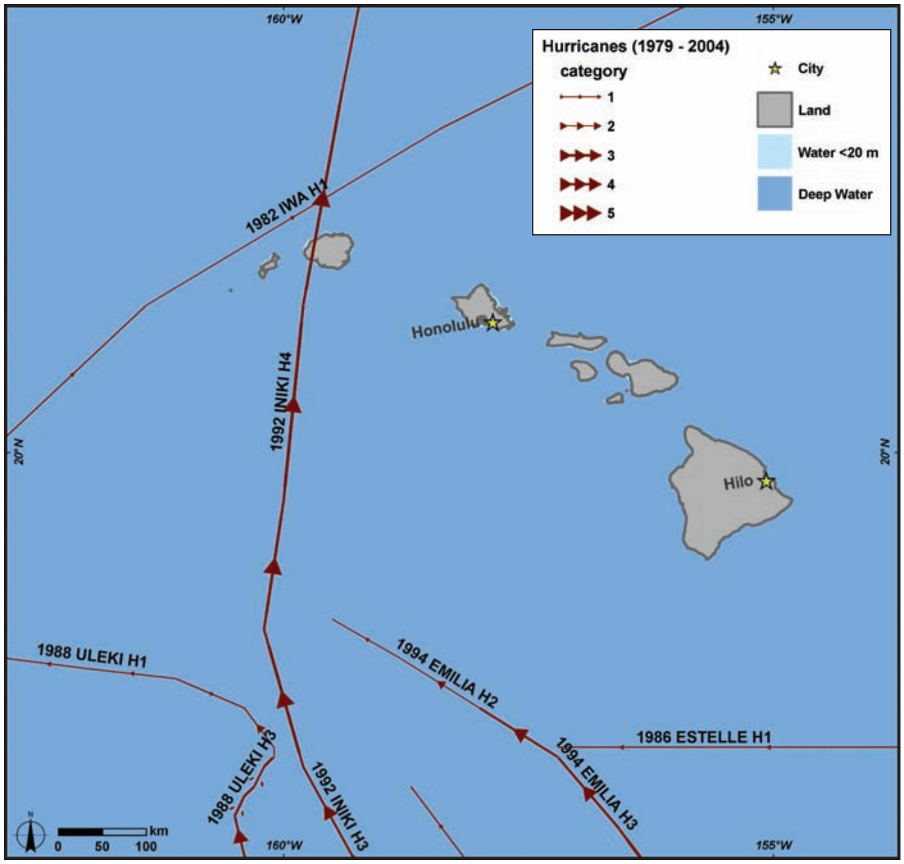

Figure 9.6. A map showing the paths and intensities of tropical storms passing near the MHI from 1979-2004. Year of storm, storm name and storm strength on the Saffir-Simpson scale (H1-5) are indicated for each. Map: A. Shapiro. Source: NOAA Coastal Services Center.

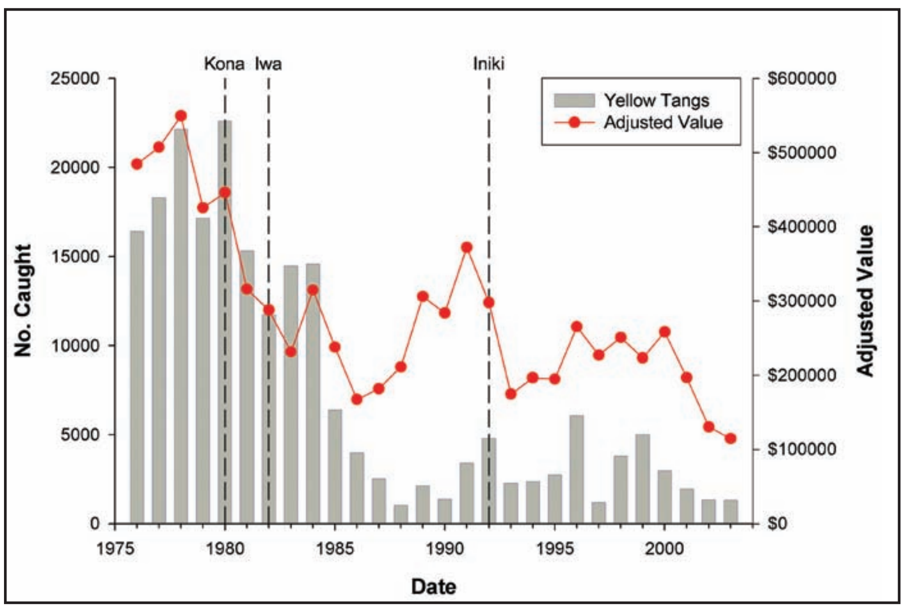

Figure 9.7. Value (adjusted for inflation) of all aquarium fish caught on Oahu and number of yellow tangs caught in primary collecting areas of south and west Oahu. Dashed lines indicate year of major storms. Source: Walsh et al., 2004.

Coastal Development and Runoff

Coastlines of Hawaii continue to be developed for a variety of land uses. On all of the islands, agricultural lands (primarily for sugarcane and pineapple) are changing to residential and resort uses. Coastal development can bring a suite of social and environmental consequences including conflicts over shoreline access and viewplanes, the need for flood water storage and protection, infrastructure demands, and degradation of coastal waters from cumulative increases in runoff and groundwater contamination. Changes in land use from large-scale agriculture, which periodically exposes land to erosion, may result in an overall decrease in sediment delivery to the ocean.

Figure 9.8. This steep roadcut at a construction site on Kauai is vulnerable to erosion and movement of sediments to the beach and nearby coral reef ecosystems. Practices to stabilize the slope include terracing, erosion control matting, hydromulch, and wattles. Photo: W. Wiltse.

Many of Hawaii's low-lying coastal areas were once wetlands and flood plains before being altered for agriculture and development. These areas served as excellent filters, removing sediments and nutrients from streams before the water entered the ocean. Development inevitably increases the amount of impervious surface and runoff. Runoff is generally diverted to storm drain systems that, like underground rivers, transport trash, soil, pathogens, and chemical pollutants to Hawaii's streams and coastal waters (Figure 9.8). As coastal areas are developed, floodplains filled, storm drains constructed, and streams channelized, more sediment is delivered to nearshore waters. For example, Kulanihakoi Stream (Kihei, Maui) was recently channelized near the shoreline as part of a condominium development, removing a coastal wetland that flooded regularly. The new stream channel solved the flooding problem but increased turbidity in coastal waters has resulted.

Harbor facilities on all the MHI are being improved to accommodate new large cruise ships, an inter-island car/cargo ferry, and large container ships. Harbor improvements involve dredging to deepen and widen entrance channels and turning basins, as well as construction of new piers, waterfront work areas, jetties, and breakwalls. The harbor improvements have the potential to impact coral reefs and areas used for recreation, such as surfing and canoeing. Proposed expansions can affect longshore transport and water quality as well. In Kahalui Harbor on Maui, the proposed development and expansion of pier space to accommodate cruise ships may result in displacement of several canoe teams from the harbor, due in part to the added security zones that would also be designated with the expansion and the resulting lack of protected water area for paddling. At Maalaea Harbor on Maui, a $10 million expansion of berthing facilities and reconfiguration of the entrance channel has been planned for 40 years. The preferred design is controversial because it will eliminate 4 acres of coral reef and impact a surf site, while providing over 100 new berths for recreational and commercial boats. No new construction or approval of permits has been considered to date with this proposed project due to the fact that the impacts to the coral reefs and offshore surf site have yet to be adequately addressed.

Coastal Pollution

Point Sources:

In areas near offshore sewage outfalls, long-term studies show little or no effect of water chemistry on coral communities. This was not the case in the period from approximately the 1950s to 1970s when discharge of poorly treated sewage on shallow offshore areas of Sand Island (Dollar, 1979) and in Kaneohe Bay resulted in significant damage to coral reef communities (Smith et al., 1981). In the 1980s, Hawaii took significant action to improve coastal water quality by removing most wastewater outfalls from bays and shallow waters. Moving sewage outfalls to deep offshore waters (~40-75 m) has allowed significant recovery to the previously stressed areas (Dollar and Grigg, 2003). Another reversal of impacts from point source discharges has occurred on the Hamakua Coast of the island of Hawaii, where reef communities that were severely damaged by point source discharges of sugarcane processing waste have recovered following the closure of sugar plantations (S. Dollar, pers. obs.).

Seven major wastewater treatment plants discharge to the coastal ocean in Hawaii (Table 9.1). All but three of these discharge through deepwater outfalls (>40 m). Under terms of a consent decree filed in November 1991 with the Federal district court for violations of the Federal Clean Water Act, the City and County of Honolulu agreed to provide $8 million for a comprehensive water quality study in Mamala Bay, the bight extending from Diamond Head to Barber's Point along the southern coast of Oahu. Several studies were undertaken to determine the impact, if any, of the outfalls on the health of aquatic animals and plants. The conclusion of one study was that "there is no quantitative evidence supporting the view that the discharge of sewage is impacting the shallow reef resources shoreward of the two sewage outfalls" (E.A. Kay, J.H. Bailey-Brock, and R.E. Brock, all of the University of Hawaii). In fact, the authors found that the armor rock placed over the outfall pipe provided excellent habitat for fish and coral communities.

Table 9.1. Wastewater treatment plants that discharge to Hawaii's coastal waters. Source: U.S. EPA.

	LEVEL OF TREATMENT
Deepwater Discharges (>40 m)	
Sand Island, Oahu	Advanced primary
Honouliuli, Oahu	Advanced primary
Waianae, Oahu	Secondary
Kailua, Oahu	Secondary
Hilo, Hawaii	Secondary
Shallow Water Discharges (<40 m)	
East Honolulu, Oahu	Secondary
Ft. Kamehameha, Oahu	Secondary

Other discharges permitted through the National Pollutant Discharge Elimination System (NPDES), such as those from aquaculture facilities, shipyards, and power plants, release waste and cooling water through outfalls into estuaries or coastal waters. Hawaii state law precludes NPDES-permitted facilities from discharging wastes to inland waters such as streams.

A relatively new form of potential point source discharge of nutrients is from open ocean cage aquaculture. The first such venture in Hawaiian waters is located approximately 3 km offshore of Ewa on the southern shoreline of Oahu, and presently consists of three cages in which Pacific threadfin (*Polydactylus sexfilis*) are grown out from fingerlings to a commercially viable size. Continued monitoring of the water column in the vicinity of the cages, which is required for NPDES compliance, has revealed that suspended nutrient subsidies are relatively small and diluted within tens of meters of the cages. Water quality constituents at the boundaries of the elliptical zone of mixing (1,800 m x 1,200 m) centered at the cages have been shown to not differ from control stations (Bailey-Brock, 2004). Monitoring of benthic community structure under the cages has revealed a localized region of markedly different infauna, presumably as a result of particulate delivery to the sediment surface from the cages. The region of altered sediment community composition encompasses an elliptical area extending 400 m alongshore and 100 m in the inshore direction at a water depth of about 40 m (Bailey-Brock, 2004). The Mamala Bay study has documented that the predominant currents in the area during all seasons are easterly-westerly, which carries material offshore. There is not a strong likelihood that particulate material from the aquaculture cages will result in negative effects to inshore coral communities. However, active monitoring of the environmental effects of the aquaculture cages is continuing.

Nonpoint Sources:

Sediment discharge is probably the leading cause of alteration of reef community structure in the MHI. Several major sources of erosion have ceased or are reversing, which will likely lower the potential for negative effects in the future. Examples include the closure of large agricultural plantations, cessation of live fire training on the island of Kahoolawe, and culling programs of feral ungulates on the islands of Lanai and Molokai. Dollar and Grigg (2004) have documented a decrease in coral cover of about 30% in a sheltered embayment on Maui (Honolua Bay), which they attributed to burial by sediment emanating from storm runoff from pineapple fields (Figure 9.9). Planned conversion of these pineapple fields to other land uses (residential, resort, and mixed agriculture) will provide a "natural experiment" to evaluate the relative influence of different land uses on coral reefs in embayments in Hawaii.

In many areas of the Hawaiian Islands, nearshore water chemistry is a mixture of oceanic water and freshwater emanating from both submarine groundwater discharge at or near the shoreline and surface water runoff. Except for the island of Kauai, both groundwater and surface water discharge are equivalent to about 20% of rainfall (Yuen and Associates, 1992). Kauai has a higher percentage owing to greater overall rainfall. Groundwater in Hawaii typically contains two to three orders of magnitude higher concentrations of dissolved nitrogen and phosphorus than seawater. Thus, groundwater nutrients are an important natural factor of nearshore marine water chemistry. The groundwater nitrogen load reflects natural background and anthropogenic sources from wastewater and fertilizers. Calculations using values from U.S. Geological Survey (USGS) groundwater models show that pristine groundwater contributes about 1,800 tons of nitrogen annually to the nearshore ocean along the west coast of the island of Hawaii.

Figure 9.9. Maui shoreline showing nearshore sediment plumes resulting from runoff from pineapple fields after a Kona rainstorm. Photo: USGS.

Monitoring programs seldom demonstrate a conclusive impact to Hawaiian reef communities from nonpoint source inputs. Runoff and groundwater have lower salinity than ocean water and in the absence of turbulent mixing, form a low-density surface layer. As a result, the elevated pollutant concentrations are not in contact with the bottom, hence there is little opportunity for exposure to reef communities.

On neighbor islands, most of the sewage treatment plants discharge secondary treated wastewater into the ground through 15-60 m deep injection wells. In some cases, a portion of the effluent is reused for irrigation, providing additional opportunity for nutrient and particulate removal. Plumes from these injection wells have not been identified and traced. However, models predict that the wastewater plumes mix with groundwater and discharge to the ocean fairly close to the shoreline in water less than 30 m deep.

Cesspools are a potentially harmful source of untreated wastewater, containing nutrients and pathogens that seep into the ocean along the shoreline. Hawaii has an estimated 100,000 cesspools, more than any other state (EPA, unpublished data).

While there is no statewide nutrient budget to assess the total magnitude of anthropogenic nutrient subsidies to groundwater, Soicher and Peterson (1997) developed such a comparison for the relatively small region of West Maui (Figure 9.10). In this region, 91.3% of the nitrogen delivery to the ocean is from factors associated with anthropogenic activities. It is of interest to note that since this estimate was compiled, sugarcane farming has ceased, and the last crops of pineapple are currently being harvested. While there have been no

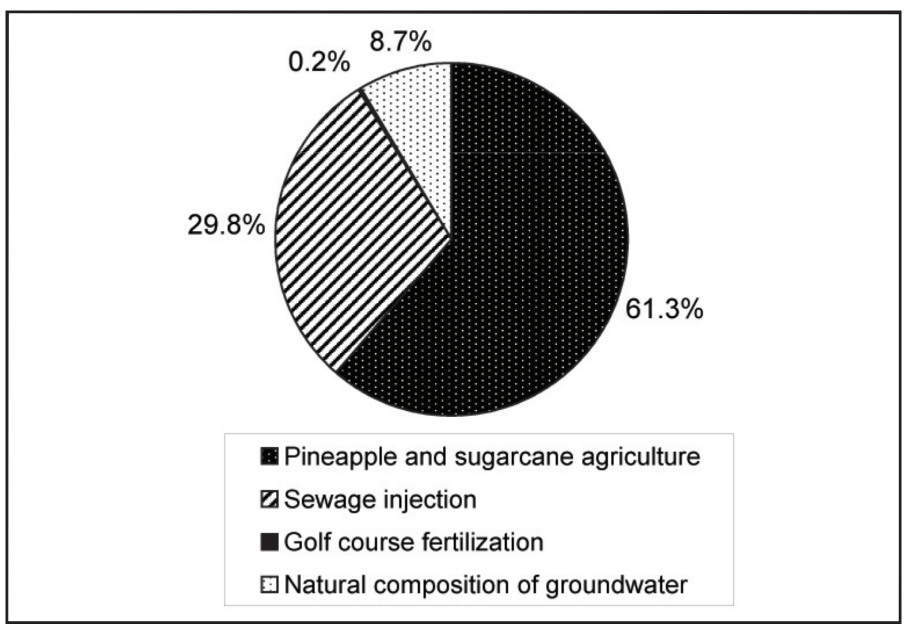

Figure 9.10. Total nitrogen delivery to the ocean from groundwater discharge in 1995 off of west Maui. Source: Soicher and Peterson, 1997.

documented impacts to the reefs in West Maui as a result of the additional nutrients, this coastline is known to have nuisance algal blooms.

Toxic pollutants are seldom measured in Hawaii's marine waters. In southern Kaneohe Bay, Hunter et al. (1995) reported elevated concentrations of lead, copper, chromium, and zinc in oyster tissues near stream mouths. High levels of dieldrin and chlordane were also found in oyster tissues at some sites. In the Hanalei River and Estuary, the USGS (Orazio et al., 2003) reported quite low concentrations of semi-volatile aliphatic hydrocarbons, polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), organochlorine pesticides, certain hydrophobic organics, and metals. Most organic contaminants were below, or slightly above, limits of detection.

The USGS recently completed an assessment of water quality of streams and groundwater on the island of Oahu during 1999-2001 (Anthony et al., 2004). Anthony et al. (2004) found toxic contaminants in streams that drain urban and agricultural lands, and in groundwater supplies (although few chemicals exceeded the drinking water standards in groundwater). In Oahu's urban streams, some of the highest levels of termite-treatment chemicals in the U.S. were reported. The USGS conducted no analyses in the marine environment where ocean mixing and dilution must be considered. Based on the USGS findings, screening of estuaries and coastal waters for toxic contaminants such as chlordane, dieldrin, and diazinon is warranted. Sediment particles containing toxic contaminants are easily transported to the ocean with storm flows and may be deposited at stream mouths and on reef flats.

Kaneohe Bay remains a site of innovative work to establish the links between water quality and effects to reef communities. At present, an instrument array called the Coral Reef Instrumented Monitoring Platform (CRIMP) provides near real-time data at five to 10 minute intervals in order to characterize the biogeochemical and physical conditions of the water column of the coral reef environment of Southern Kaneohe Bay. CRIMP has been able to characterize changes from high intensity, short duration storms that previously were either "averaged" or undetected by manual sampling at longer time intervals (E. DeCarlo, pers. comm.). Results to date show that there are significant spikes in water chemistry constituents following storm events, but the elevated concentrations rapidly return to background levels following the storm. The model will be used to examine the timing and magnitude of fluxes of terrestrial materials to reef biota.

Tourism and Recreation

Tourism is Hawaii's primary industry with state projections estimating about 6.7 million visitors arriving in 2004 and spending more than $11.4 billion. An increase in tourism since 2003 is partially the result of the return of Asian travelers and the launching of a new Hawaii-based inter-island cruise ship with a passenger capacity of over 2,000 per trip. Between 1982 and 2002, there was a 66% increase in tourism representing a growth of over 2 million visitors (Hawaii DBEDT, 2003).

There are over 1,000 ocean tourism companies, generating an estimated $700 million in gross revenues annually (Clark and Gulko, 1999). Over 80% of Hawaii's tourists participate in some form of ocean recreation, from sunbathing and swimming, to snorkeling and surfing, to jet skiing and parasailing (Hawaii DBEDT, 2002). Most, if not all, of this activity occurs around Hawaii's coral reefs that generate almost $364 million each year in added value (Cesar and van Beukering, 2004).

Hawaii also consistently ranks as one of the top dive destinations in diver surveys conducted annually by Rodale's Scuba Diving magazine. Nearly 52% of all visitors participate in diving or snorkeling activities during their stay in Hawaii (Hawaii DBEDT, 2002). Other than beach going, snorkeling and scuba diving activities outrank all other forms of recreational activities participated in by both U.S and Japanese visitors to Hawaii (Hawaii DBEDT, 2002).

Hawaii's marine life conservation districts (MLCDs) and other calm water locations are highly sought after locations in which to dive and snorkel and are marketed by the visitor industry as "must see destinations" (Clark and Gulko, 1999; Figure 9.11). Popular sites have high visitation and high economic value (Table 9.2). Hanauma Bay, a 41 ha marine protected area (MPA), and the surrounding City Nature Preserve generates over $31 million each year in added value (van Beukering and Cesar, 2004). Over the next 50 years, this translates to nearly $2 billion in total benefits from this one site alone.

Often the most popular sites are lacking in or have minimal shore side facilities, which increase the potential for impacts affecting the nearshore resources. As popularity increases, management agencies are faced with continuous and growing challenges to define the appropriate levels of use and how to gauge and monitor impacts.

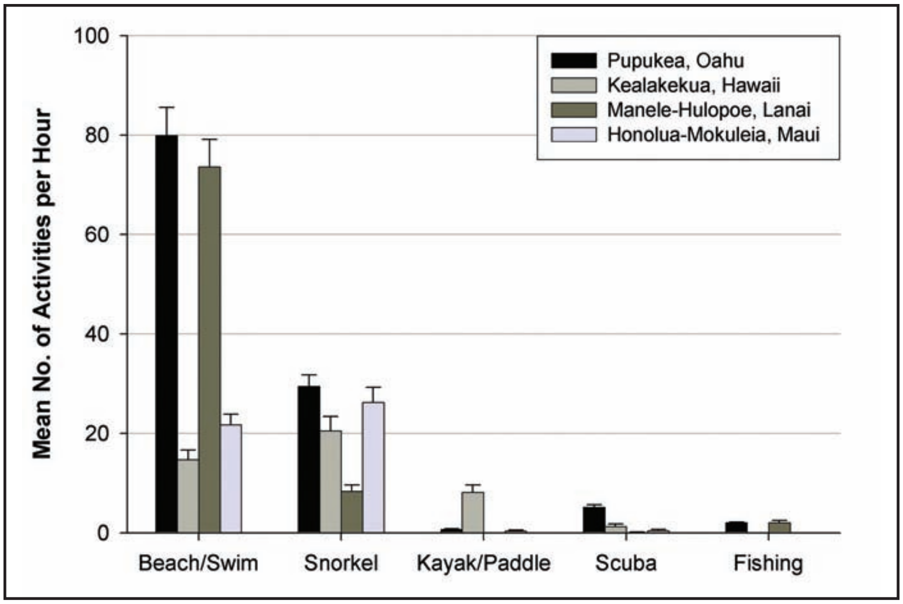

Figure 9.11. Patterns and types of use at four MPAs in Hawaii. Fishing is prohibited or restricted in all of these areas. Source: Holland and Meyer, 2003.

Table 9.2. Summaries of annual human use at various locations in Hawaii. All locations except Waikiki Beach are MLCDs.

LOCATION	NO. OF VISITORS
Waikiki Beach, Oahu	8,355,448[1]
Hanauma Bay, Oahu	1,751,318[1]
Pupukea, Oahu	177,600[2, 3]
Manele/Hulapoe Bays, Lanai	277,400[2]
Molokini Shoal, Maui	400,000[4]
Honolua/Mokuleia Bays, Maui	160,000[2]
Kealakekua Bay, Hawaii	189,800[2]

[1] DBEDT State Data Book, 2002.
[2] Adapted from Holland and Meyer, 2003 (based on mean hourly usage).
[3] Reflects only summer use for five months, as there is minimal use in the winter.
[4] Estimation by S. Hau, pers. comm.
* MLCDs are marine protected areas established to conserve and protect marine resources.

Recent studies have shown that extensive damage to corals can occur in shallow, calm water sites with high levels of human use (Rodgers and Cox, 2003). Trampling can occur in shallow nearshore reef flats which often possess fragile and delicate coral species. The greatest concentrations of human-substrate contacts occurred at shoreline access points where people stood or waded as they enter and exit the water (Holland and Meyers, 2003).

In both the trampling study (Rodgers and Cox, 2003) and the human use impacts study (Holland and Meyer, 2003), results indicated that patrons who were provided a brief orientation and given flotation devices for snorkeling were less likely to impact the reef than those visitors with no interpretive information or training. Mandatory education efforts at Hanauma Bay each year help conserve reefs statewide since visitors generally go to two or three additional sites during their stay and residents snorkel or dive at 10 sites per year. The cumulative effect of educating visitors and residents has resulted in improved behavior at sites across the state (Davidson et al., 2003).

In a recent assessment of the economic benefits and costs of marine managed areas in Hawaii, a total of 1,380 divers, snorkelers, and beachgoers at six sites where surveyed regarding their willingness to pay a coral reef conservation fee for more active management. More than 75% indicated that they would be willing to pay for reef conservation and the average payment indicated by respondents was $3.77 per experience. Based on these results, management improvements could be provided for a small fee including basic facilities, enforcement compliance, education/awareness, assessment and monitoring, and infrastructure (e.g., parking, moorings, etc.). These fees would result in significant benefits to the sites and a decrease in visitor impacts. Other mechanisms to define and determine appropriate levels of use are still needed as efforts continue to minimize the impacts from use while maintain the health of the ecosystem.

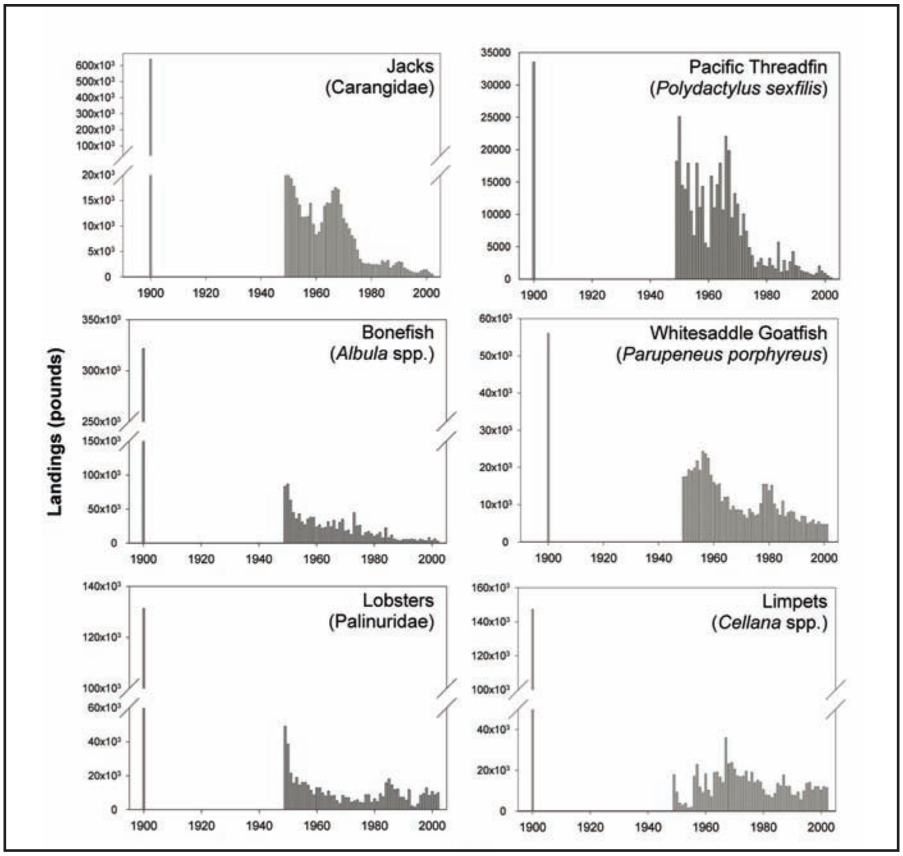

Figure 9.12. Commercial catch data from Hawaii DAR from 1948 to present. 1900 data from statewide market surveys conducted by the United States Fish Commission. Sources: Cobb, 1905; DAR Commercial Landings Database.

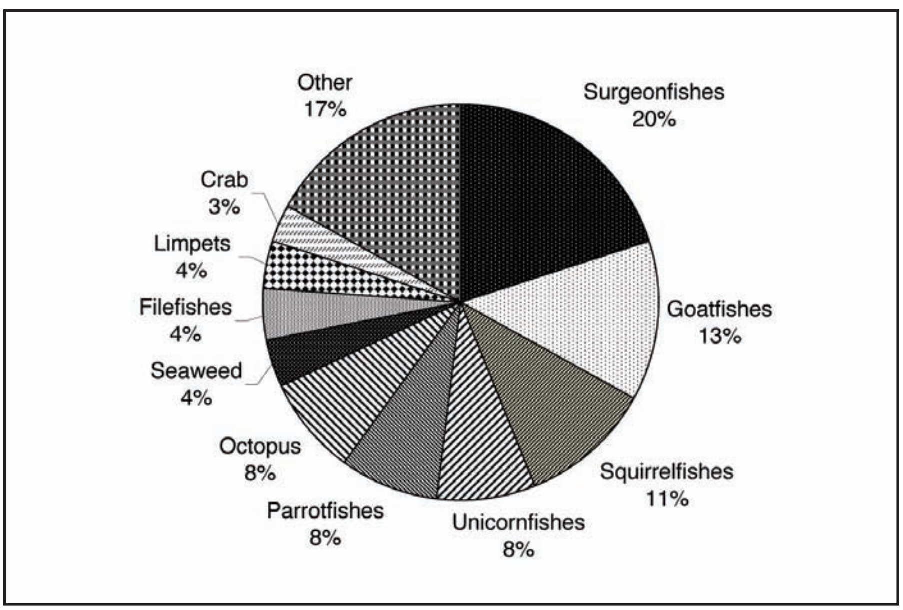

Figure 9.13. Top 10 taxa of commercially harvested coral reef organisms excluding coastal pelagic fish from 2001 commercial catch data. Source: DeMello, 2004.

Fishing

Fishing has been a way of life for Hawaii's people for centuries, with fish and shellfish providing the major protein source for the Hawaiian people (Kamakau, 1839; Titcomb, 1972). The traditional system in Hawaii emphasized social and cultural controls on fishing with a code of conduct that was strictly enforced (Friedlander et al., 2002a; Poepoe et al., in press). After western contact, a breakdown of the traditional kapu system and the demise of the watershed as a management unit led to the virtual elimination of traditional Hawaiian fisheries management practices (Smith and Pai, 1992; Lowe, 2004).

Over the past 100 years, the coastal fisheries in Hawaii have undergone enormous changes (Shomura, 1987; Friedlander, 2004). Overfishing is cited as the primary reason for the declining resources both by general ocean users (DLNR-DAR, 1988) and commercial fishers (Harman and Katekaru, 1988). Factors contributing to the decline of inshore fisheries include a growing human population, destruction or disturbance to habitat, introduction of new fishing techniques (i.e., inexpensive monofilament gill nets, scuba equipment, geographic positioning systems, power boats, sonar fish finders), and loss of traditional conservation practices (Lowe, 1996; Birkeland and Friedlander, 2002).

Commercial landings for a number of important species have shown dramatic declines since the 1900s (Figure 9.12). With the exception of jacks, which have been associated with ciguatera poisoning, consumer demand and wholesale prices to fishers alone do not explain the dramatic decline in landings. The number of commercial fishers participating in the coral reef fishery rose from 282 in 1966 to a peak of 1,178 in 1996, with the current level at 925 commercial fishers (DeMello, 2004). Excluding coastal pelagic fishes, which account for 80% of the nearshore commercial catch, 139.500 kg of coral reef fish were landed in 2001, consisting mainly of surgeonfishes, goatfishes, soldierfishes, unicornfishes, parrotfishes, and octopus (Figure 9.13; DeMello, 2004).

Underreporting by commercial fishers and the existence of a large number of recreational and subsistence fishers without licensing or reporting requirements have resulted in uncertainty in actual fisheries catch statistics for the state (Lowe, 1996). The nearshore recreational and subsistence catch is likely equal to or greater than the nearshore commercial fisheries catch, and recreational and subsistence fishers take more species using a wider range of fishing gear (Friedlander and Parrish, 1997; Everson and Friedlander, 2004).

The proliferation of long and inexpensive gill nets has allowed new fishers to enter the fishery and set nets deeper and in locations not previously harvested (Clark and Gulko, 1999). Intensive fishing pressure on highly prized and vulnerable species has led to substantial declines in catch and size as well as raised concerns about the long-term sustainability of these stocks (Smith, 1993; Friedlander and Parrish, 1997; Friedlander and DeMartini, 2002). Pacific threadfin is considered one of the premier Hawaiian food fishes and was reserved for the ruling chiefs in ancient Hawaii. The mean size of threadfin in all sexual categories has declined significantly since the 1960s, while the proportion of juveniles has increased from 6% to 40% of the catch during this time period (Friedlander and Ziemann, 2003; Figure 9.14).

Fishers frequently cite the lack of adequate enforcement of fishing and marine resource laws as one of their major concerns (Harman and Katekaru, 1988; DLNR-DAR, 1998). The Hawaii Division of Conservation and Resources Enforcement (DOCARE) is the state's primary agency for enforcement of natural resource regulations. Although the number of enforcement officers has increased substantially over the past 50 years, the number of fishing citations for freshwater and saltwater issued per officer has declined over time to 2.3 citations per officer per year (Figure 9.15).

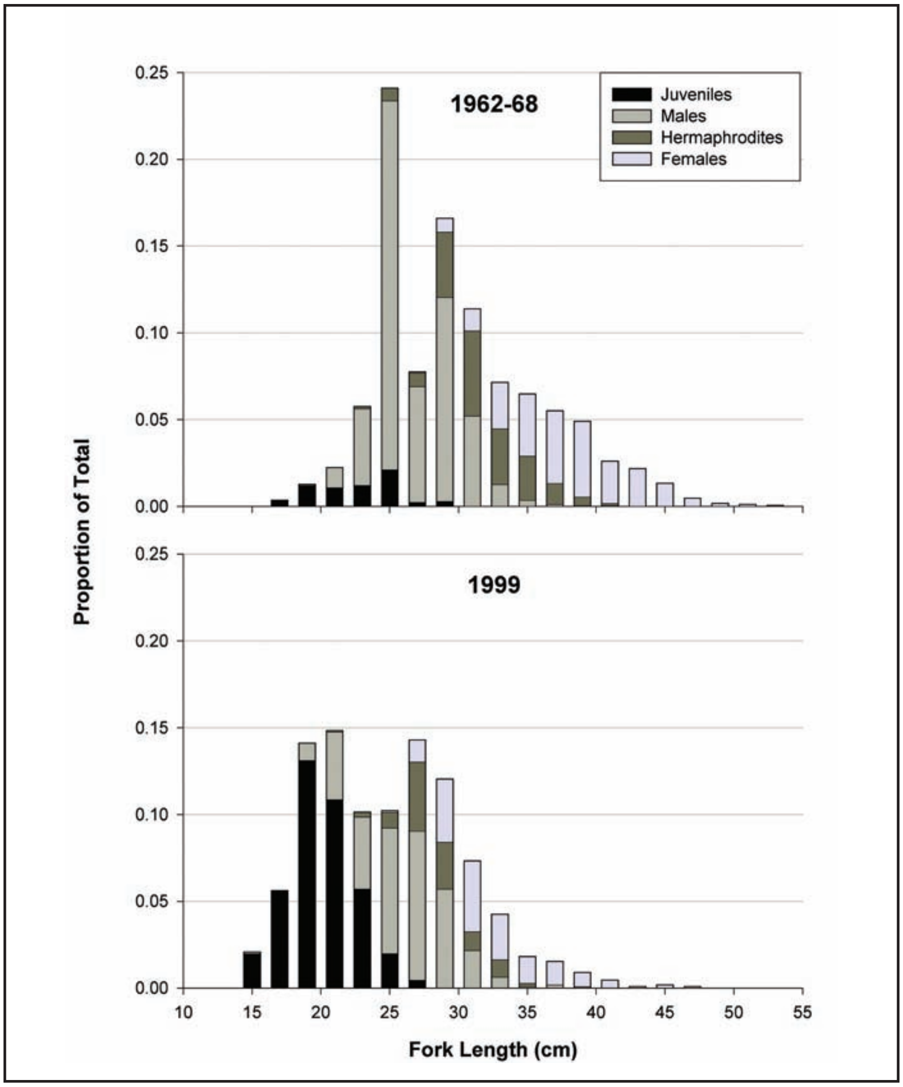

Figure 9.14. Proportion of juveniles, males, hermaphrodites, and females for Pacific threadfin (*Polydactylus sexfilis*) on windward Oahu from 1962 to 1968 (upper panel) and during 1999 (lower panel). Source: Friedlander and Ziemann, 2003.

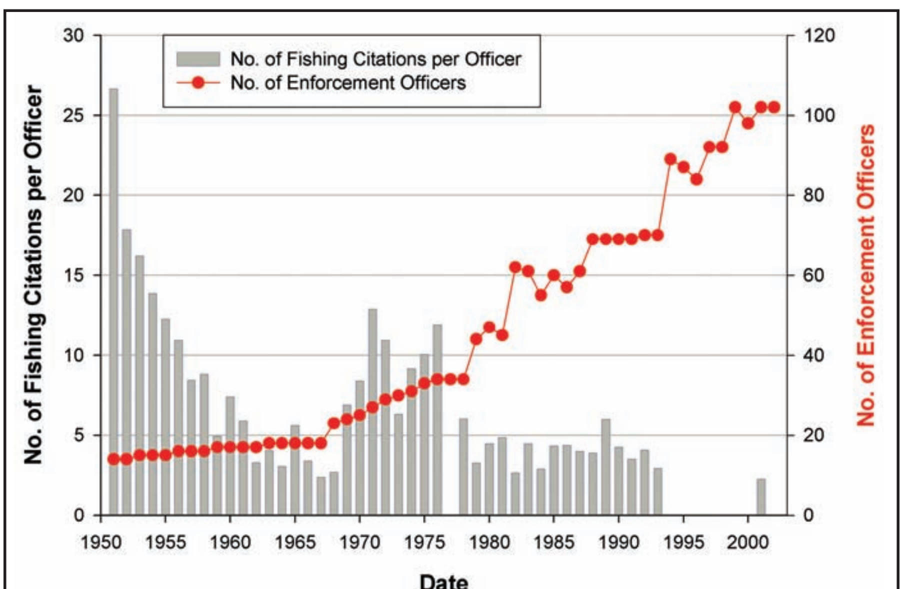

Figure 9.15. Number of fishing citations (including arrests) issued per DOCARE officer, and the number of officers over time. Gap in data due to unavailability of information. Source: DOCARE Database.

In 1981, Hawaii's legislature expanded DOCARE's traditional enforcement duties to include non-natural resource issues. Although legislation stipulated that the primary duty of enforcement officers would be the enforcement of conservation and resource laws, the proportion of citations (including arrests) related to natural resource violations (primarily hunting and fishing) has decreased in recent years and presently constitutes only 33% of total DOCARE citations. However, DOCARE's responsibilities also increased substantially in 1991, when the Division of Boating and Ocean Recreation was created within Hawaii's Department of Land and Natural Resources, and the agency found that it must now also enforce all boating safety, small boat harbor, and ocean recreation regulations. A DOCARE volunteer officer program created in 1973 has similarly declined and the number of volunteer officers in the program is presently only 20% of what it was 20 years ago.

In contrast to some other states, Hawaii DOCARE officers are presently prohibited from inspecting the bags, containers (e.g., coolers), or vehicles of any recreational fisher unless they have probable cause that a violation has taken place (HRS Title 12, subtitle 5). With the increase in responsibilities to enforce both natural resource and other laws, and the limitations on inspections and funding, it is unlikely that enforcement of existing and future rules and regulations will increase substantially.

Trade in Coral and Live Reef Species

It is against Hawaii state law to take or sell stony coral or live rock (i.e., marine substrate where living material is visibly attached). A number of recent enforcement cases have documented trafficking in Hawaiian corals, including one conviction resulting in over $1 million in fines and seven convictions resulting in jail time as long as seven months.

The commercial aquarium fishery in Hawaii has developed over the last 50 years into one of the state's major inshore fisheries, with landings of over 708,000 specimens with a reported value of $1.06 million (Walsh et al., 2004). As the aquarium industry is composed of both independent contractors (collectors) and wholesalers, which may or may not be collectors themselves, the overall economic value of the aquarium fishery is estimated to be substantially higher than the reported value. Cesar et al. (2002) estimated industry gross sales at $3.2 million and industry profits at $1.2 million. A 1993 analysis based on export figures by an aquarium trade group calculated total sales of Hawaiian fish (inclusive of freight and packing) at $4,909,654 (Hawaii Tropical Fish Association, unpublished data). DAR reported the total average fishery value for fiscal year 1993-1994 as only $819,957 (Miyasaka 1994a, b).

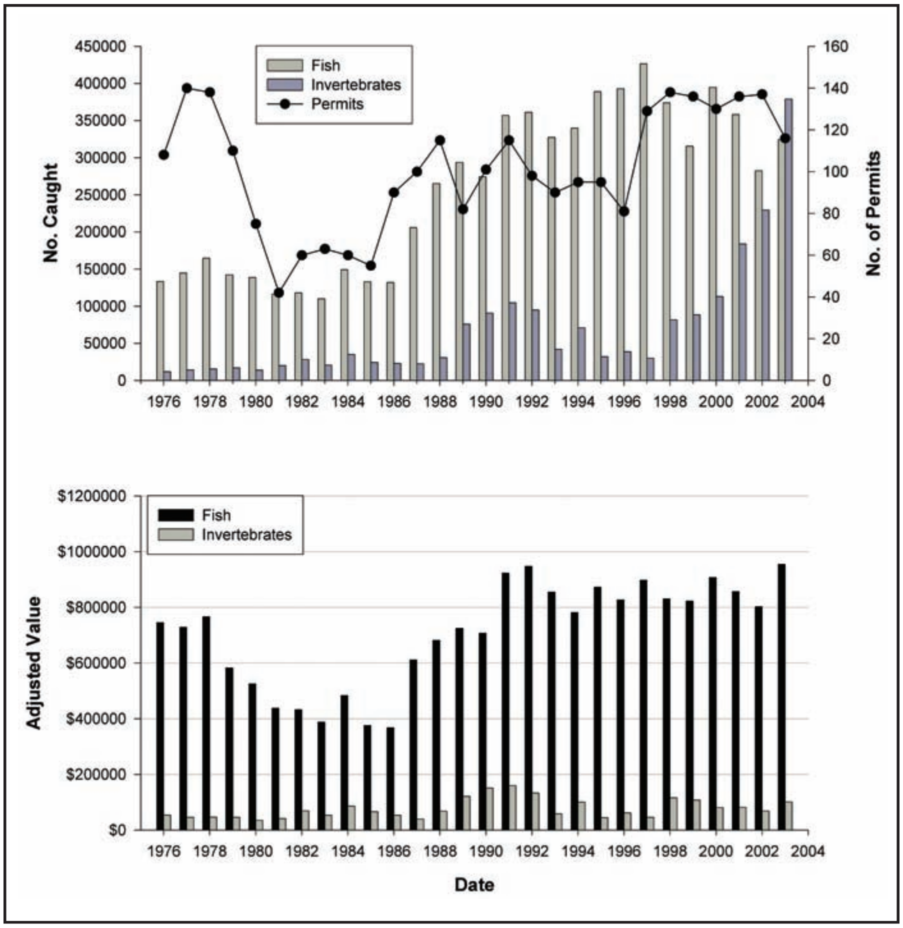

Figure 9.16. Upper panel shows the number of commercial aquarium permits issued statewide and the numbers of fish and invertebrates reported caught. Lower panel shows dollar value of commercially caught fish and invertebrate aquarium specimens. Value is adjusted for inflation by means of Honolulu Consumer Price Index (Hawaii Dept. of Labor and Industrial Relations). Source: Walsh et al., 2004.

While the overall economic value and total catch of the aquarium fishery in the state has been relatively stable over the last decade (Figure 9.16), there have been substantial changes in value on each of the islands (Figure 9.17). The value (adjusted for inflation) of the Oahu aquarium fish catch in fiscal year 2003 has declined by 76% while that of Hawaii Island has increased 282%.

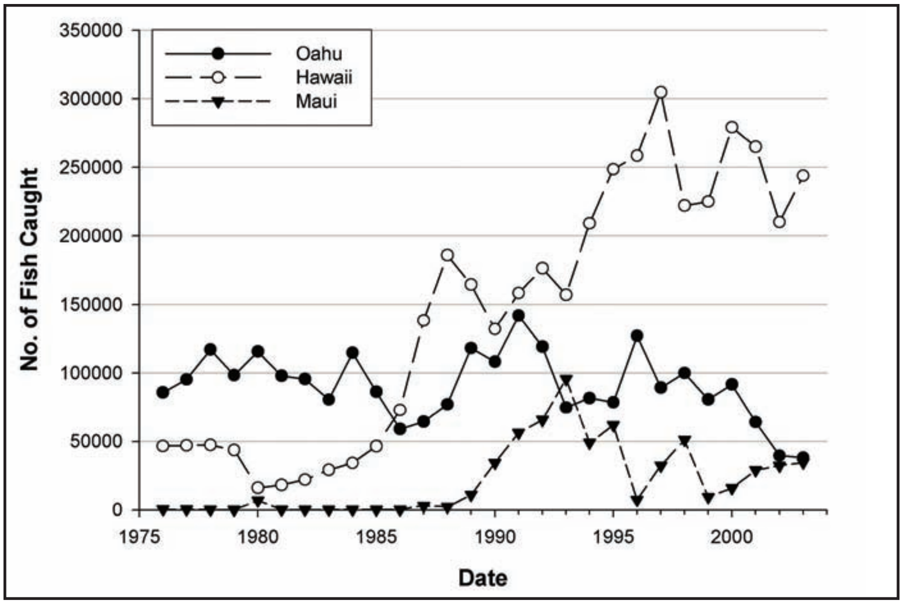

Figure 9.17. Number of aquarium fish caught on each island per fiscal year. Kauai catch omitted due to low numbers. Source: Walsh et al., 2004.

The overall aquarium catch has been diverse, comprising 235 taxa of fish and 37 taxa of invertebrates. A relatively small number of species dominates the catch; the top 10 species constitute 73.3% of the total historical catch (Walsh et al., 2004; Table 9.3). Surgeonfishes, butterflyfishes, and wrasses are the most commonly caught fish species, while feather duster worms, hermit crabs, and shrimp predominate among the invertebrates. The yellow tang (*Zebrasoma flavescens*) accounts for 37% of the total catch.

Table 9.3. Top 10 taxa of collected animals from FY 1976-2003. Source: Walsh et al., 2004.

TAXA	COMMON NAME	TOTAL CAUGHT	% OF TOTAL
Zebrasoma flavescens	Yellow tang	3,386,860	37.2
Sabellastarte sanctijosephi	Feather duster worm	741,949	8.1
Hermit crabs	Hermit crabs	707,654	7.8
Ctenochaetus strigosus	Goldring surgeonfish	346,944	3.8
Acanthurus achilles	Achilles tang	337,781	3.7
Naso lituratus	Orangespine unicornfish	298,884	3.3
Centropyge potteri	Potter's angelfish	287,668	3.2
Forcipiger flavissimus	Forcepsfish	251,523	2.8
Zanclus cornutus	Moorish idol	187,662	2.1
Halichoeres ornatissimus	Ornate wrasse	121,766	1.3

Subsequent to the overall contraction of the aquarium fishery in the late 1970s and early 1980s due to a downturn in the economy (Figure 9.7), there has been an increasing trend in the number of commercial fishery permits on all islands (Figure 9.16). In the early days of the fishery, most collecting activity was centered on the island of Oahu, which accounted for between 64% (1976) and 84% (1981) of the fish catch. This fishery has declined over the years due to hurricane impacts and localized overfishing, with the current catch from Oahu accounting for only 12% of the total catch. Low-value invertebrates are increasingly replacing fishes. In contrast to Oahu, the aquarium fishery on the island of Hawaii has experienced a 645% increase over the last two decades and now accounts for 55% of the catch and 68% of the total state fisheries value. The expansion on Hawaii was due to both an influx of new collectors and the relocation of collectors from Oahu.

Recent research shows that collecting activities in Hawaii can significantly affect targeted species (Tissot and Hallacher, 2003). A network of fish replenishment areas (FRAs) has been established on the island of Hawaii to ensure sustainability of the aquarium fishery and to reduce user conflicts. Four years after implementation of the FRAs in 2000, there were significant increases in the abundance of several targeted species, and the overall value of the fishery is at an all-time high. Catch report compliance is low on the island of Hawaii and likely elsewhere within the state. Actual aquarium catch is thought to be underreported, but specific management actions are increasing reporting compliance by collectors.

Ships, Boats, and Groundings

More than 16,000 recreational and commercial vessels are currently registered in Hawaii. On average, three to five ship groundings are reported each year in the MHI, but these values are likely an underestimate as many recreational vessel groundings go unreported. In most cases, responsible parties have not had to cover the cost for vessel salvage, and restitution for damage is rarely made. Cruise ships currently make over 400 port calls annually in Hawaii, and this figure is expected to triple in the next few years. The limited port facilities have raised concerns about anchoring areas and potential reef damage. In February 2005, a 550-ft bulk carrier freighter ran aground off SW Oahu causing considerable damage to corals to a depth of 70 ft.

Marine Debris

Each year, thousands of kilograms of debris wash onto Hawaii's shorelines. This debris poses entanglement and ingestion threats to endangered Hawaiian monk seals, sea turtles, and sea birds (Henderson, 1984; Balazs, 1985). Fishing gear can snag on a reef, leading to the damage and breakage of coral heads and eventually mortality (Donohue et al., 2001; Yoshikawa and Asoh, 2004).

Several efforts are made each year to clean up marine debris. One such effort is the National Marine Debris Monitoring Program (NMDMP), which is coordinated by the Ocean Conservancy and for which trained NMDMP volunteers monitor selected beaches across the state and conduct monthly beach cleanups. Another effort is the "Get the Drift and Bag It" event, part of the Ocean Conservancy's International Coastal Cleanup, which is coordinated locally by the Hawaii Sea Grant Program. In 2002, nearly 2,000 volunteers across the state collected over 13,000 kg of marine debris along 151 km of shoreline in this one-day event. Over 100 divers removed 590 kg of underwater debris from 38 km of underwater area. The majority (54%) of the collected debris was derived from shoreline and recreational activities, with the remainder comprised of debris from smoking related (37%) and ocean/waterway activities (7%). Of all the debris types noted, cigarettes, plates, utensils, caps, and lids were the most common, accounting for over half of all debris collected (The Ocean Conservancy, 2002). Debris from ocean and waterway activities (i.e., fishing line and nets) are the most common types of entangling debris and many times do not wash ashore.

In 2003, in conjunction with the International Coastal Cleanup, two focused cleanup events were conducted in remote areas that are impacted almost entirely by ocean-borne debris. At Kanapou Beach, Kahoolawe, staff and volunteers cleaned almost 2,700 kg of marine debris (primarily plastics) from this particular area in a one-day effort on a half kilometer strip of beach. At Kaalualu Bay, on the south coast of the island of Hawaii, over 100 volunteers cleaned approximately three km of coastline in two days. Over 36,000 kg of marine debris, mostly ocean-borne plastic and nets, were removed.

While statewide coastal cleanup events have documented that the majority of Hawaii's debris is from land-based sources, there is a substantial amount of marine debris that washes ashore from sources outside Hawaii, particularly at more remote coastlines. Therefore, efforts are needed not only to continue the ongoing, local volunteer activities, but also to address this issue on the high seas and with Pacific Rim communities that share the impacts and responsibility for this marine pollution.

Aquatic Invasive Species

The coral reef communities surrounding the Hawaiian Islands have been inundated with alien species over the last century (Coles and Eldregde, 2002; Coles et al., 1999a; Eldredge and Smith, 2001; Friedlander et al., 2002b). Due to extreme isolation and subsequent high levels of endemism, alien invaders pose a significant threat to the native diversity of these unique marine environments. Perhaps because Hawaii lies in the middle of the Pacific Ocean and is located on shipping routes across the Pacific, the islands have intercepted more nonindigenous marine species (NIMS) than other tropical locations (Carlton, 1987). The estimated number of NIMS in Hawaii includes 287 invertebrates, 20 algae, 20 fish, and 12 flowering plant species (Eldredge and Smith, 2001). While the majority of NIMS in Hawaii are invertebrates, many of these species are cryptic and/or have remained in highly disturbed harbors and other fouling environments. These factors have made it difficult to determine the impacts and interactions that the invaders may be having on native marine flora and fauna. However, the larger and more conspicuous nonindigenous marine algae (NIMA) have become increasingly more common along Hawaiian shores over the last several decades (Smith et al., 2002; Smith et al., 2004; Smith, 2003).

Out of the 20 or more species of NIMA introduced to Hawaii since the mid-1950s, recent surveys indicate that at least five of these have become well established (Smith et al., 2002). Several species of the red algal genera *Kappaphycus* and *Eucheuma* were introduced to open reef cultures in Kaneohe Bay, Oahu in the 1970s for experimental aquaculture for the carrageenen industry. Following experimental manipulations, plants were left on the reef. Some 30 years later, at least two of these species (*Kappaphycus alvarezii* and *Eucheuma denticulatum*) have spread throughout Kaneohe Bay and are beginning to appear on reefs outside of the bay (Woo et al., 1999; Rodgers and Cox, 1999; Smith et al., 2002; Smith, 2003). These species are particularly threatening to the integrity of Hawaiian reefs, as they are able to overgrow, smother, shade, and kill reef-building corals (Figure 9.18; Smith, 2003). These species generally grow in large three-dimensional mats that monopolize the benthos. Not only do these invaders kill coral, but they denude the three-dimensional complexity or rugosity (i.e., roughness) on a reef, thus posing negative cascading effects to the entire reef community.

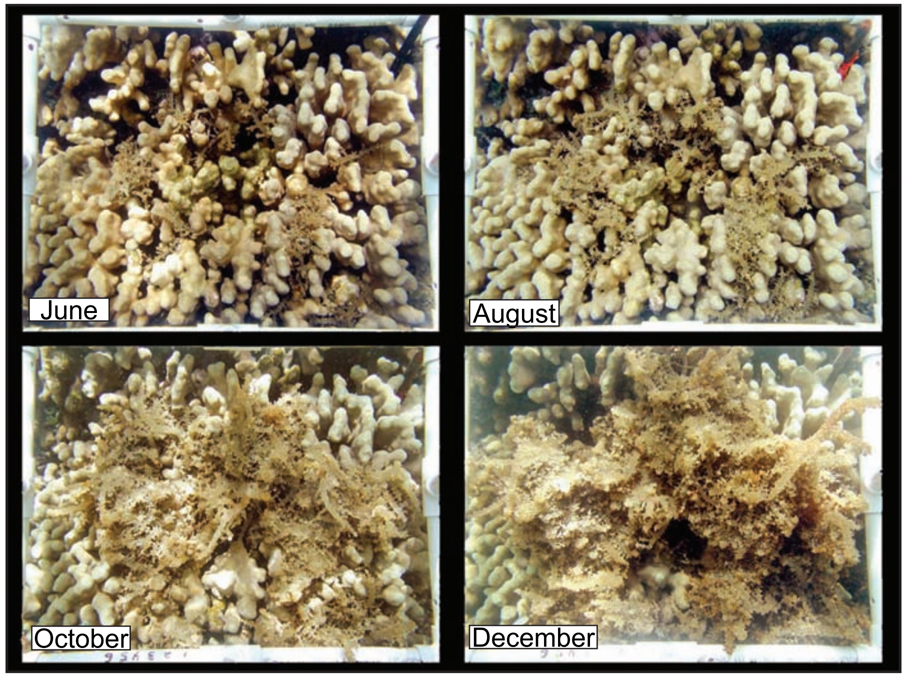

Figure 9.18. Representative photographic sequence showing the invasion of the red alga *Eucheuma denticulatum* into a live *Porites compressa* colony on a patch reef in Kaneohe Bay, Oahu, 2002. Several quadrats were permanently marked on a variety of reefs using steel pins and photographs were taken monthly for one year to monitor algal invasion and coral growth. Source: Smith, 2003.

Hypnea musciformis was introduced from Florida to Kaneohe Bay, Oahu in 1974. This species is now the second most widespread of the NIMA species in Hawaii and is found on all of the MHI except the island of Hawaii. This alga forms massive blooms on the shallow reef flats on the island of Maui (Hodgson, 1994). A recent economic evaluation has estimated that because of these blooms, the State of Hawaii suffers net losses of over $20 million per year due to reduced occupancy rates in hotels and condominiums, reduced property value in the impacted area, and direct costs associated with removing rotting seaweed from beaches (Figure 9.19; van Beukering and Cesar, 2004).

Figure 9.19. The introduced seaweed, *Hypnea musciformis*, forms massive blooms that have negative ecological and economic impacts. Photo: J. Smith.

Gracilaria salicornia was introduced to Waikiki and Kaneohe Bay for experimental aquaculture in 1971 and 1978, respectively. The source population had been known to exist on the island of Hawaii prior to the 1950s.

There is some support for the idea that this population on the island of Hawaii was an early 20th century introduction from ship ballasts originating in the Philippines, where *G. salicornia* is native (I. Abbott, pers. comm.). In 1999, *G. salicornia* still had a distinct and localized distribution (Smith et al., 2002). However, more recent surveys indicate that *G. salicornia* has become increasingly common on the island of Oahu (Smith et al., 2004). It is the most common species in the shallow reef areas off of Waikiki and readily overgrows and kills reef-building coral. Coral cover has declined significantly in Kaneohe Bay and Waikiki as a result of the *G. salicornia* invasion. At the same time, new populations continue to emerge across the state.

Acanthophora spicifera, another red alga, was accidentally introduced to Honolulu Harbor in the 1950s on a heavily fouled barge originating from Guam. This species has now spread throughout the MHI and can be considered naturalized. While it is now a common component of the intertidal community, it generally does not form large monospecific blooms. However, high abundances have been recently documented from the reef slope area at numerous locations on West Maui (J. Smith, unpublished data).

Avrainvillea amadelpha, a green alga, is currently considered to be a cryptogenic (i.e., of uncertain origin) species. It was first documented on Oahu in the 1980s and has since become highly abundant on Oahu's south shore. It is unclear how this species got to Hawaii or even where it originated from specifically, but it is likely to have been a home aquarium introduction through the dumping of live rock. This species appears to be competing with Hawaii's native seagrasses. Very little is known about the impacts and interactions of *A. amadelpha* on Hawaii's reefs, but it is currently the subject of active research (K. Peyton, unpublished data).

Only three invasive or potentially invasive species of invertebrates occur on Hawaiian coral reefs. The Philippine mantis shrimp (*Gonodactylaceus falcatus*) is common in Kaneohe Bay (Coles et al., 2002a), where it has displaced the native shrimp (*Pseudosquilla ciliate*) from coral rubble habitats (Kinzie, 1968), and in Waikiki (Coles et al., 2002b). The snowflake coral (*Carijoa riisei*) can occur in high densities from the intertidal zone (Coles et al., 2002b) to over 100 m deep where optimal growth conditions are provided by reduced light and moderate current. It occurs under ledges and in caves at many reef sites throughout the MHI and overgrows black coral beds off Maui between 75 m and 100 m that may be important source populations for shallow water black coral assemblages (Grigg, 2003). Other observations suggest that *C. riisei*, which was first reported in Hawaii in Pearl Harbor in 1972 (Evans et al., 1974; Devaney and Eldredge, 1977), is highly fecund and has a rapid growth rate (S. Kahng, pers. comm.), resulting in the proliferation of this species.

A third introduced invertebrate recently designated as potentially invasive (Coles et al., 2004) is the orange keyhole sponge (*Mycale armata* Thiele). This sponge was observed at five of 41 rapid assessment sites, but at all sites other than in Kaneohe Bay, it was a minor component of the sessile benthos and appeared neither abundant nor invasive. However, in Kaneohe Bay and especially on reefs on or near Coconut Island, this sponge has become abundant and is growing at a sufficient rate to overgrow the dominant corals *Porites compressa* and *Montipora capitata.* The spatial extent and degree of competition among *M. armata* and other corals has not been established at present.

Previous studies of the presence and impact of nonindigenous (introduced or alien) and cryptogenic marine species, collectively termed NIS, in Oahu's harbors and embayments have indicated that 15-23% of the total biota in these enclosed or semi-enclosed areas is composed of confirmed or putative introductions (Table 9.4). Earlier surveys have not indicated a substantial presence of NIS on surveyed Hawaiian coral reefs except in Kaneohe Bay and at Waikiki where NIS comprised 14.5 and 6.9%, respectively, of total biota identified (Table 9.3). Remote areas such as Kahoolawe, the NWHI and Johnston Atoll showed NIS to be a minor component of the reef total biota, comprising 0.3-1.5% of the total identified biota.

At least 13 species of introduced marine fishes have become established in Hawaii (Eldredge, 1994). The Marquesan sardine (*Sardinella marquesensis*) was intentionally introduced as a tuna baitfish in the 1950s, while the gold spot herring (*Herklotsichthys quadrimaculatus*) was an accidental baitfish introduction that has proliferated at the expense of a local endemic silverside (*Atherinomorus insularum*; DeMartini et al., 1999). A mullet (*Valamugil engeli*) and goatfish (*Upeneus vittatus*) were unintentional introductions that arrived with the Marquesan sardine (Randall, 1987). The mullet is not important in the local fishery, but may be displacing the

Table 9.4. Numbers of marine nonindigenous (N), cryptogenic (C), nonindigenous plus cryptic (NIS), and total species in Hawaii and Johnston Atoll.

LOCATION	(N)	(C)	TOTAL NIS	TOTAL SPECIES	% N + C	SOURCE
Hawaiian Islands						
Oahu, Pearl Harbor	69	26	95	419	23	Coles et al., 1997, 1999a
Oahu, South Shore Commercial Harbors	73	27	100	585	17	Coles et al., 1999b
Kaneohe Bay	82	34	116	617	14.5	Coles et al., 2002a
Waikiki	33	19	52	749	6.9	Coles et al., 2002b
Kahoolawe	3	0	3	298	1	Coles et al., 1998
Midway	4	0	4	444	1.5	DeFelice et al., 1998
French Frigate Shoals	2	0	2	617	0.3	DeFelice et al., 2002
41 additional sites	18	8	26	486	5.3	Coles et al., 2004
Johnston Atoll	5	5	10	668	1.5	Coles et al., 2001

more valuable native mullet (*Mugil cephalus*). Several introduced tilapia species are also thought to reduce the abundance of the valuable native mullets through competition for food and other resources (Randall, 1987; Eldredge, 1994).

Between 1951 and 1961, 11 demersal fish species (six groupers, four snappers, and one emperor) were intentionally introduced into Hawaii (Oda and Parrish, 1981; Randall, 1987). Of these species, the blacktail snapper (*Lutjanus fulvus*), bluestripe snapper (*Lutjanus kasmira*), and peacock grouper (*Cephalopholis argus*) have established viable breeding populations in the state. The latter two species have proven to be particularly controversial because they have adapted well to Hawaiian waters and are often blamed for depletion of desirable species due to competition or predation.

Bluestripe snappers have been by far the most successful fish introduction to the Hawaiian coral reef ecosystem. From some 3,200 individuals introduced on the island of Oahu, the population has expanded its range as far north as Midway in the NWHI (~2,400 km). These records suggest a dispersal rate of about 33-130 km/yr and attest to the interconnectedness of the entire archipelago. Recent research suggests that the purported impact on native species may be substantially less than what fishers commonly believe. A study of the interactions of bluestripe snappers with native deepwater snappers found little habitat or dietary overlap with native deepwater snappers (Parrish et. al., 2000). Preliminary results of feeding interactions between bluestripe snapper and shallow-water reef fishes do not suggest predatory effects on native populations by the introduced snapper, or vice versa (Schmacker and Parrish, 2004). Likewise, state fisheries data do not suggest a strong negative impact of this snapper on landings of deepwater snappers.

Similarly, studies of bluestripe snappers in shallow water environments have not detected direct negative impacts on other fish species. Friedlander et al. (2002b) found that while bluestripe snappers associated with many native species, no clear and consistent relationships were observed that would suggest strong common dependence on an important, limited resource (e.g., space, shelter, food, and foraging grounds). Oda and Parrish (1981) reported that commercially important fish species were not eaten by bluestripe snapper nor did they appear to have diet overlap with food fish such as goatfishes (Mullidae) or soldierfishes (Holocentridae).

Of the six species of groupers introduced to Hawaii, only peacock groupers (*Cephalopholis argus*) have become established. Peacock grouper now occur on all of the MHI and in low numbers on some of the NWHI. Increases in abundance have been noted at several locations since the early 1990s (Figure 9.20). Although this species was introduced to augment declining populations of food and game fishes, it has not been well received by most Hawaii fishers due to concerns about ciguatera poisoning. Peacock grouper have been blamed for a multitude of problems on the reefs, most notably a decline in important aquarium fish such as the yellow tang (*Zebrasoma flavescens*). Ongoing feeding studies have failed to find yellow tangs in the stomachs of peacock grouper (J. Dierking, pers. comm.; Walsh, pers. obs.). Peacock grouper appear to be omnivorous,

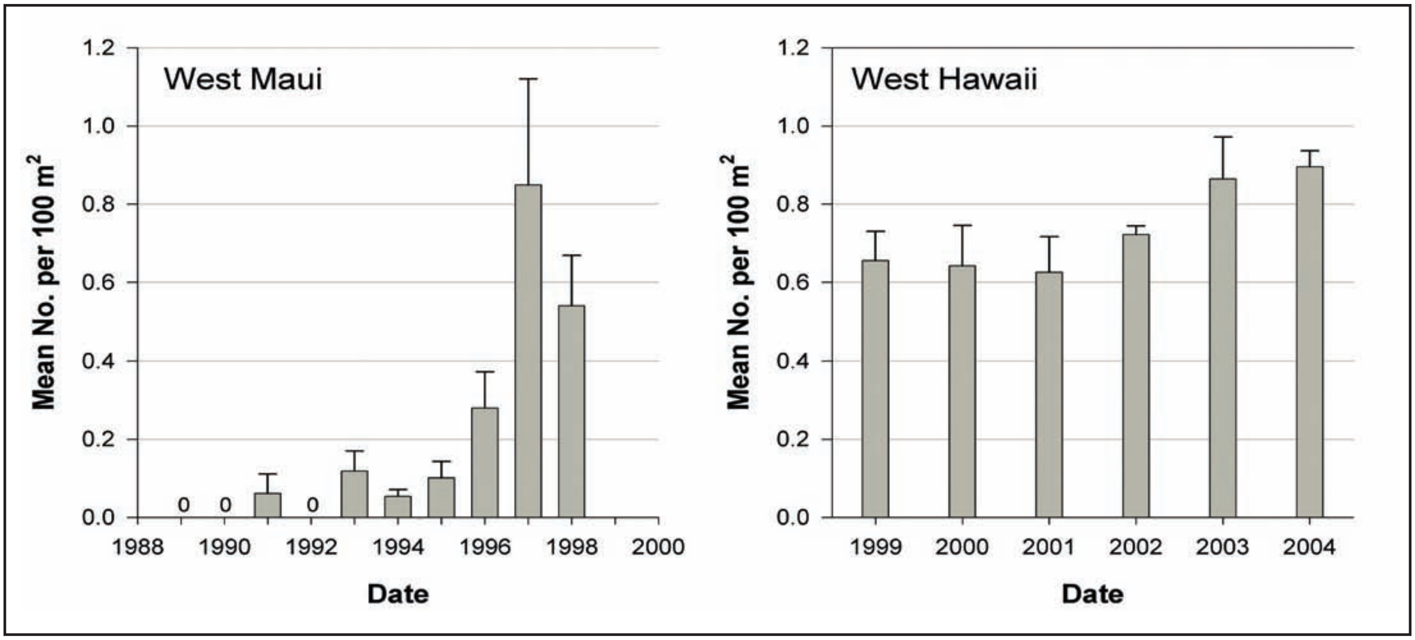

Figure 9.20. Mean abundance of peacock grouper on transects along West Maui (left panel) and West Hawaii (right panel). Source: E. Brown, unpublished data; West Hawaii Aquarium Project, unpublished data.

feeding on both invertebrates and a range of fish types (diurnal/nocturnal), rather than targeting certain types of prey. Studies to date have not found any relationship between peacock grouper densities and species richness (i.e., number of species per transect), number of fishes, or recruitment, suggesting that they may not be having the dramatic impact on reef fish populations that has been attributed to them. In fact, Peacock grouper were found to have a positive relationship with other piscivores, which suggests that they are not outcompeting or otherwise negatively impacting these piscivores.

Security Training Activities

In Hawaii, the extensive presence of U.S. air force, army, coast guard, marine and naval installations makes the military the second largest economic activity in the state. Many of these areas are closed to fishing and this prohibition has resulted in high abundance of some targeted resource species. Large jacks are not frequently encountered around Oahu but large individuals and high numbers of these species have been observed in Pearl Harbor, likely due to restrictions on fishing at the facility (R. Brock, pers. comm.). The island of Kahoolawe was used as a military bombing target until 1990, and fishing restrictions resulted in certain sites having the highest biomass of reef fish and greatest number of predators compared to other sites around the MHI (Friedlander and DeMartini, 2002). Kaula Rock, a live-fire and bombing target 35 km southwest of Niihau, is also closed to harvest and is noted for its abundance of jacks and other large species. Recent surveys around Kaneohe Bay Marine Corp Base, Oahu have noted greater abundance and larger sizes for many reef fishes compared with other areas around Oahu.

Negative impacts on coral reefs resulting from military activities include unexploded ordinance, pollution, and vessel groundings. Unexploded ordnance have been observed at all of the above mentioned locations as well as numerous other areas around the MHI that were previously used as bombing targets and live-fire training areas. The approximately 2,024 hectares of sediments (e.g., mud and sand) comprising the bottom of Pearl Harbor act as a sink or repository for many of the chemicals entering the harbor. Chemical contaminants found in the harbor have led State of Hawaii, U.S. Navy, and other Federal officials to notify the public and issue warnings to alert fishers not to eat any fish caught in the harbor. Amphibious training exercises have resulted in groundings and reef damage on several occasions.

Offshore Oil and Gas Exploration

No offshore oil and gas exploration occurs in Hawaiian waters.

Other

Crown-of-thorns starfish *(Acanthaster planci)*

At present, outbreaks of crown-of-thorns starfish (COTS; Figure 9.21), *Acanthaster planci*, do not appear to be a problem in Hawaii except in isolated incidents. The last reported large-scale occurrence of COTS was in August 1969 when approximately 20,000 COTS were observed off the south shore of Molokai (Branham et al., 1971). There have only been scattered reports of COTS aggregations since this time and all have been of considerably lesser magnitude.

Figure 9.21. A crown-of-thorns starfish, *Acanthaster planci*, consuming its prey. Photo: S. Holst.

CORAL REEF ECOSYSTEMS—DATA GATHERING ACTIVITIES AND RESOURCE CONDITION

Current coral reef monitoring, research, and assessment activities, including those that are represented in this report, are summarized in Table 9.5. Monitoring locations are shown in Figure 9.22.

Table 9.5. Extant monitoring programs investigating coral reef ecosystems in the MHI.

PROGRAM	OBJECTIVES	START DATE	FUNDING	PARTNERS
Hawaii Coral Reef Assessment and Monitoring Program (CRAMP)	Long-term monitoring of benthos and fishes across a statewide network of sites	1997	HCRI, USGS, EPA	UH-Manoa, NOAA, DAR, USGS
West Hawaii Aquariumfish Project (WHAP)	Assess aquarium fish collecting and MPA effectiveness	1998	HCRI, DAR	Washington State Univ., DAR, Oregon State, UH-Hilo
Spread of alien algae in Kaneohe Bay, Oahu	Examine spread of alien algae and assoc. fish assemblages	1999	HCRI	UH-Manoa
Fish Habitat Utilization Program (FHUP)	Examine fish habitat utilization patterns and MPA effectiveness statewide	2002	NOAA	DAR, NOAA, UH-Manoa, UH-Hilo, HIMB, NPS
Physical factors and biological processes affecting nuisance algae in W. Maui	Examine linkages of physical and biological related to nuisance algae	2003	NOAA, HCRI	NOAA, DAR, UH-Manoa, USGS, DOH
DAR statewide marine research and surveys of fish and habitat	Habitat and species status relative to recreationally fished species	1970s	USFWS	DAR
Hanalei Bay Marine Communities Investigation	Long-term trends in benthic and fish	1992	NOAA, DAR, USGS, Hanalei Heritage River	NOAA, DAR, Hanalei Heritage River Hui, HIMB, USGS
Reefcheck	Volunteer, community-based monitoring protocol to measure the health of coral reefs on a global scale.	1996	NOAA, CZM, DAR	Oceanwide Sci. Instit., Waikiki Aquarium, Windward C.C., Hawaii Pacific Univ., Hanauma Bay Edu. Center, MOP
The Reef Environmental Education Foundation (REEF)	Volunteer scuba divers and snorkelers collect information on marine fish populations	2001	CZM, NFWF, PADI – Project Aware, NOAA, NMSP	Maui Community College MOP, Project SEA-Link, Hawaii Coral Reef Network, DAR
Kahe Point Coral monitoring	Long-term trends in coral community	1973	HECO	HECO, AECOS, Sea Engineering
Reef Watchers Program	Volunteers monitor and provide data on near shore and intertidal sites	1999	HCRI, CZM/DBEDT, NFWF, NOAA, Harold Castle Foundation, HCF, TNC, CCN	DAR, TNC, CCN, DOE, UH-Hilo, Washington State University and West Hawaii participating residents
Kapoho Reef Watch	Monitor human use, water quality, and marine biota around Waiopae tide pools	2003	HCF, NFWF, VHCA, Kapoho Kai Water Assoc.	Cape Kumukahi Foundation, UH-Hilo, DAR, DOCARE, NOAA
USGS Study of Coral Reefs in the Pacific Ocean	Mapping, monitoring, remote sensing, sediment transport studies, and collection of tide, wave, and current data from remote stations.	2000	USGS	USGS, UH-Manoa, HIMB, DAR, NPS
DAR Coral Reef Monitoring	Benthic and fish monitoring	2003	NOAA, HCRI	UH-Hilo, UH-Manoa, NPS
Oahu Offshore Islets Surveys	Assessment of resources at offshore islets around Oahu	2004	NOAA	DAR, UH, NOAA, USFWS

AECOS – AECOS Inc. Environmental Consulting Company
CCN – Community Conservation Network
CZM – Hawaii Coastal Zone Management
DAR – Hawaii Department of Land and Natural Resources, Division of Aquatic Resources
DOE – Hawaii Department of Education
DOH – Hawaii Department of Health
EPA – Environmental Protection Agency
HCF – Hawaii Community Foundation
HCRI – Hawaii Coral Reef Initiative Program
HECO – Hawaii Electric Company
HIMB – Hawaii Institute of Marine Biology
MOP – Univ. of Hawaii Marine Options Program
NOAA – National Oceanic and Atmospheric Administration
NFWF - National Fish and Wildlife Foundation
NMSP – National Marine Sanctuary Program
NPS – National Park Service
PADI – Professional Association of Diving Instructors
UH – University of Hawaii
USFWS – U.S. Fish and Wildlife Service
USGS – U.S. Geological Survey
VHCA – Vacationland Hawaii Community Association

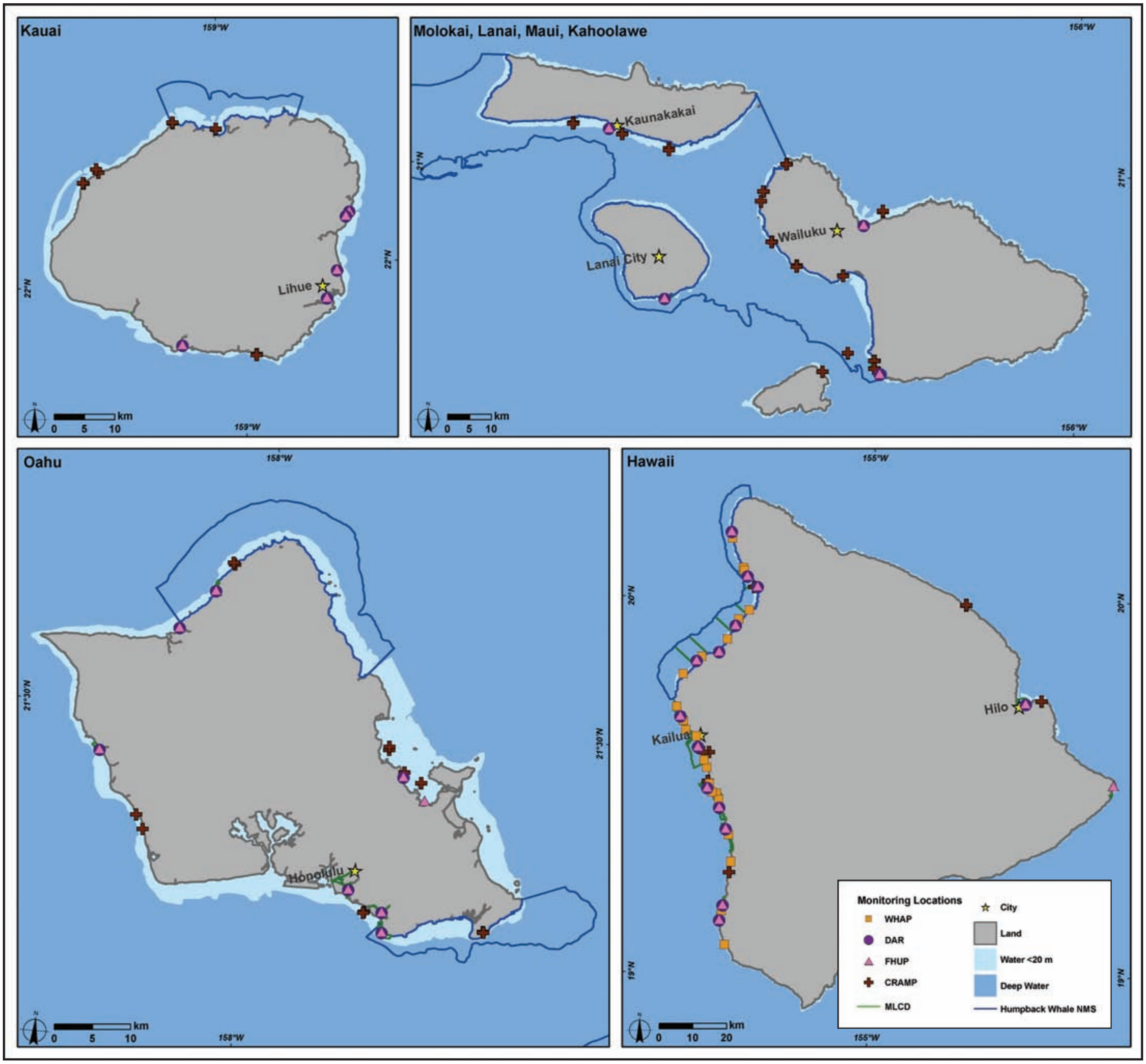

Figure 9.22. Monitoring locations in the MHI. Map: A. Shapiro.

The monitoring programs presented in Figure 9.22 represent the major programs with the greatest spatial and temporal coverage in the MHI. In addition, there have been numerous studies and monitoring programs of short duration or limited spatial scope that extend back nearly 100 years.

The DAR has been collecting data on fish and habitat at all of the state's MLCDs since the 1970s. This is the longest running extant monitoring program in Hawaii and occurs on all major islands. The Hawaii Coral Reef Assessment and Monitoring Program (CRAMP) examines spatial and temporal changes at sites on Oahu, Kauai, Maui, Hawaii, Molokai, and Kahoolawe which encompass broad spectrum of environments and management regimes. Several monitoring sites sampled in the 1970s and 1980s were incorporated into the current CRAMP monitoring program, thus providing a 30-year time span at some locations. The West Hawaii Aquariumfish Project (WHAP) was established to monitor aquariumfish along the west Hawaii coastline. This program covers a broad spatial scale (~150 km) and includes a robust sampling design that evaluates various levels of fisheries management. The National Oceanic and Atmospheric Administration's (NOAA) Center for Coastal Monitoring and Assessment - Biogeography Team (CCMA-BT) has developed digital benthic habitat maps for much of the MHI. Using these maps, CCMA-BT has been conducting an extensive evaluation of Hawaii's MLCDs and adjacent areas in cooperation with DAR and the University of Hawaii.

WATER QUALITY

There are no statewide comprehensive water quality monitoring programs assessing sediment or chemical impacts to coral reef areas in Hawaii. Water quality at beaches is monitored for bacteria that indicate a risk to human health. Pollutant concentrations normally decrease sharply with distance from shore, and offshore water quality in Hawaii is generally good.

Hawaii's Department of Health (DOH) regularly monitors indicator bacteria (*Enterococcus*) at swimming beaches. In recent years, DOH has also collected data on turbidity, nutrients, and chlorophyll a at specified shoreline stations (knee-deep water) and in perennial streams. DOH uses these data, and other available data that meet specific quality criteria, to identify streams and coastal segments that are "water quality impaired" (i.e., where state water quality criteria (Hawaii Administrative Rules, Title 11, Chapter 54; http://www.hawaii.gov/health/about/rules/admrules.html, Accessed 1/19/05) are regularly exceeded. A list of impaired waters is reported to the U.S. Environmental Protection Agency (EPA) every two years, as required by the Federal Clean Water Act (33 USC § 1251 et seq.) Section 303(d). Although the listings are a function of available data rather than the result of a comprehensive statewide sampling design, it is not surprising that the number of listed waters corresponds, roughly, with island population size (Table 9.6).

The impaired coastal waters are primarily harbors, semi-enclosed bays, and protected shorelines, where mixing is reduced and resident time of pollutants is long when compared with exposed coasts. Several bays that have coral reefs, such as Kaneohe Bay and Pearl Harbor (Oahu), Nawiliwili Bay (Kauai), and Hilo Bay (Hawaii), are included on the list. Because offshore water quality is generally good and few data sets are available to characterize water quality around reefs, deeper and offshore waters where coral reefs occur are generally not included on the list. The most widely distributed coastal pollutants are nutrients, sediments, and *Enterococcus* (Table 9.6).

Table 9.6. Number of waterbodies by island where ambient pollutant concentrations regularly exceed State water quality criteria. ND = No Data.

POLLUTANTS	HAWAII	KAUAI	MAUI	MOLOKAI	OAHU
Sediments	14	7	41	2	45
Enterococcus	8	9	3	ND	23
Nutrients	4	5	11	1	54
Chlorophyll a	8	2	22	ND	34
Toxics: Metals, pesticides, PCBs	ND	ND	ND	ND	3
Total Coastal Stations Listed	20	16	41	2	61
Population Size	148,677	876,156	58,463	128,241	7,404

A source of information on offshore water quality is the multitude of ongoing water quality monitoring programs associated with permit requirements for specific activities (Table 9.7). These include the assessment of point source discharges, such as sewage outfalls and cooling water discharges, required for NDPES permits. Results for NPDES permit monitoring are submitted to the DOH. Nonpoint source inputs from land-based sources, such as resorts and golf courses, are monitored through a variety of state and local permit requirements. Data generally include constituents listed in the State of Hawaii Water Quality Standards: dissolved inorganic nutrients (nitrate + nitrite [NO_3^- + NO_2^-]), ammonium [NH_4^+], orthophosphate [PO_4^{3-}], and silica [Si]), chlorophyll a, salinity, turbidity, pH, temperature, and dissolved oxygen. In total, approximately 3,000 ocean water samples are analyzed annually by private entities as required by permit conditions. These permit-related data have not been synthesized by island or region into a comprehensive database or report.

Table 9.7. Long-term water quality monitoring programs in the main Hawaiian Islands.

ISLAND	LOCATION	PROJECT	PERMIT REQUIREMENT	DURATION	FREQUENCY	SAMPLES PER SURVEY
Kauai	Port Allen	Kauai Island Utilities Coop	NPDES	1990-	Quarterly	50
	Kekaha	Agribusiness Devel. Corp.	NPDES	2000-	Bi-Annual	15
	Kekaha	Ceatech USA	NPDES	1998-	Quarterly	27
Oahu	Sandy Beach	East Honolulu WWTP	NPDES	1965-	Semi-Monthly	18
	Ewa	Ocean Pointe	DLNR	1990-	Quarterly	60
	Barbers Point	Chevron USA	NPDES	1985-	Quarterly	20
	Ewa	Cates International	NPDES	2000-	Quarterly	21
Lanai	Hulopoe Bay	Castle & Cooke	Maui Co. LUC	1989-	Quarterly	21
Maui	Honolua	Kapalua Land Co.	None	1990	Annual	32
	Honokohua	Kapalua Land Co.	None	2001	Annual	32
	Napili	Kapalua Land Co.	None	2001	Annual	16
	Kaanapali	North Beach	Maui Co.			
	Makena	Makena Resort	LUC, DOH	1990	Bi-Annual	50
Hawaii	Keahole Point	NELHA	DOH, Hawaii Co.	1987-	Quarterly	72
	Hilo Bay	Hilo WWTP	NPDES	1985-	Monthly	18
	Hamakua	Papaiko WWTP	NPDES	1985	Semi-Annual	6
	Hamakua	Kulaimano	NPDES	1985	Semi-Annual	5
	Hokulia	Oceanside 250	DOH, Hawaii Co.	1989-	Quarterly	47
	Kukio	Kukio Resorts	DOH, Hawaii Co.	1989-	Quarterly	37
	Maniniowali	Kukio Resorts	DOH, Hawaii Co.	2000-	Quarterly	21
	Waikoloa	Waikoloa Land Co.	DOH, Hawaii Co.	1987-	Quarterly	26

NPDES – National Pollutant Discharge Elimination System
DLNR – Department of Land and Natural Resources
LUC – Land Use Commission
DOH – Department of Health

BENTHIC HABITATS

CCMA-BT Benthic Habitat Mapping

The CCMA-BT initiated a nearshore benthic habitat mapping program for the MHI in 2000. A NOAA Citation jet collected aerial photographs and hyperspectral imagery which was used to delineate habitat polygons in a geographic information system (GIS). Habitat polygons were defined and described according to a hierarchical habitat classification system consisting of 27 discreet habitat types. The project, which was completed in 2003, mapped 774 km^2 of nearshore habitat in the islands and produced a series of 87 maps that are currently being distributed via a print atlas, a CD-ROM, and on-line at http://biogeo.nos.noaa.gov/products/hawaii_atlas, Accessed 02/28/05. The benthic habitat maps are depicted in Figure 9.23.

Hawaii Coral Reef Assessment and Monitoring Program

The CRAMP was established in 1998 and produced a comprehensive description of the spatial differences and the temporal changes in coral reef communities in the MHI. Spatial information described the major ecological factors controlling the status of reef coral communities in the MHI. Temporal trends documented patterns of reef decline, recovery, and stability.

Methods

The CRAMP monitoring sites were selected to give a cross-section of locations that differed in perceived environmental degradation, level of management protection, quantity of previous data, and extent of wave exposure. Two reef areas, a shallow (generally 3 m) and a deep (generally 10 m) station, were surveyed at each of the 30 statewide sites at least twice since 1999. Digital video transects, fixed photoquadrats, visual belt fish transects (Brock, 1954), substrate rugosity, sediment samples and additional qualitative data were collected at various times over the study period. Detailed methods and data analysis are described in Brown et al. (2004) and Jokiel et al. (2004). Total mean percent coral cover by station, mean percent coral cover by species within a station, and species richness and diversity (Shannon-Weiner Index) were documented. The monitoring site data were supplemented in the spatial dimension using a rapid assessment technique (RAT). The RAT is an abbreviated version of the CRAMP monitoring protocol, using a single 10 m transect to describe benthic cover, rugosity, and sediments. The RAT, however, is not designed to produce the type of data needed to detect temporal change. Other data sources included U.S. Navy WAM models (for wave direction and height) and the State of Hawaii GIS database (for data on population demographics, watershed characteristics, and precipitation levels).

Results and Discussion

Average coral coverage for all 152 reef stations (CRAMP plus RAT) combined was 20.8% ± 1.7 standard error (SE), with six species accounting for most of the coverage (20.3%). The six dominant species were: *Porites lobata* (6.1%), *Porites compressa* (4.5%), *Montipora capitata* (3.9%), *Montipora patula* (2.7%), *Pocillopora meandrina* (2.4%), and *Montipora flabellata* (0.7%).

Spatial patterns:

The spatial data set (CRAMP plus RAT) revealed that various biological parameters (i.e., coral cover, coral species richness, and coral diversity) showed a significant relationship with physical factors such as the geologic age of the islands, mean wave height, mean wave direction, rugosity, sediment composition, and rainfall. These observations are consistent with and amplify the findings of previous studies:

• Geologic age is a major factor influencing reef coral community structure. The Hawaiian Islands formed over a hot spot located near the southeast end of the archipelago and have gradually moved to the northwest on the Pacific plate over millions of years. The islands are thus moving to higher latitude over time so there is a high correlation (r=0.95) between island age and latitude. Light and temperature conditions favorable to coral growth diminish with increasing latitude and increasing island age. Grigg (1983) previously demonstrated this trend over the range from the island of Hawaii (19˚N) to Kure Atoll (28.5˚N). The present study was conducted over a smaller latitudinal range (19˚N to 22˚N), but with a much more extensive sample size and validated these observations.

• Sites exposed to the larger west and northwest swells on the older islands (e.g., Kauai and Oahu) generally

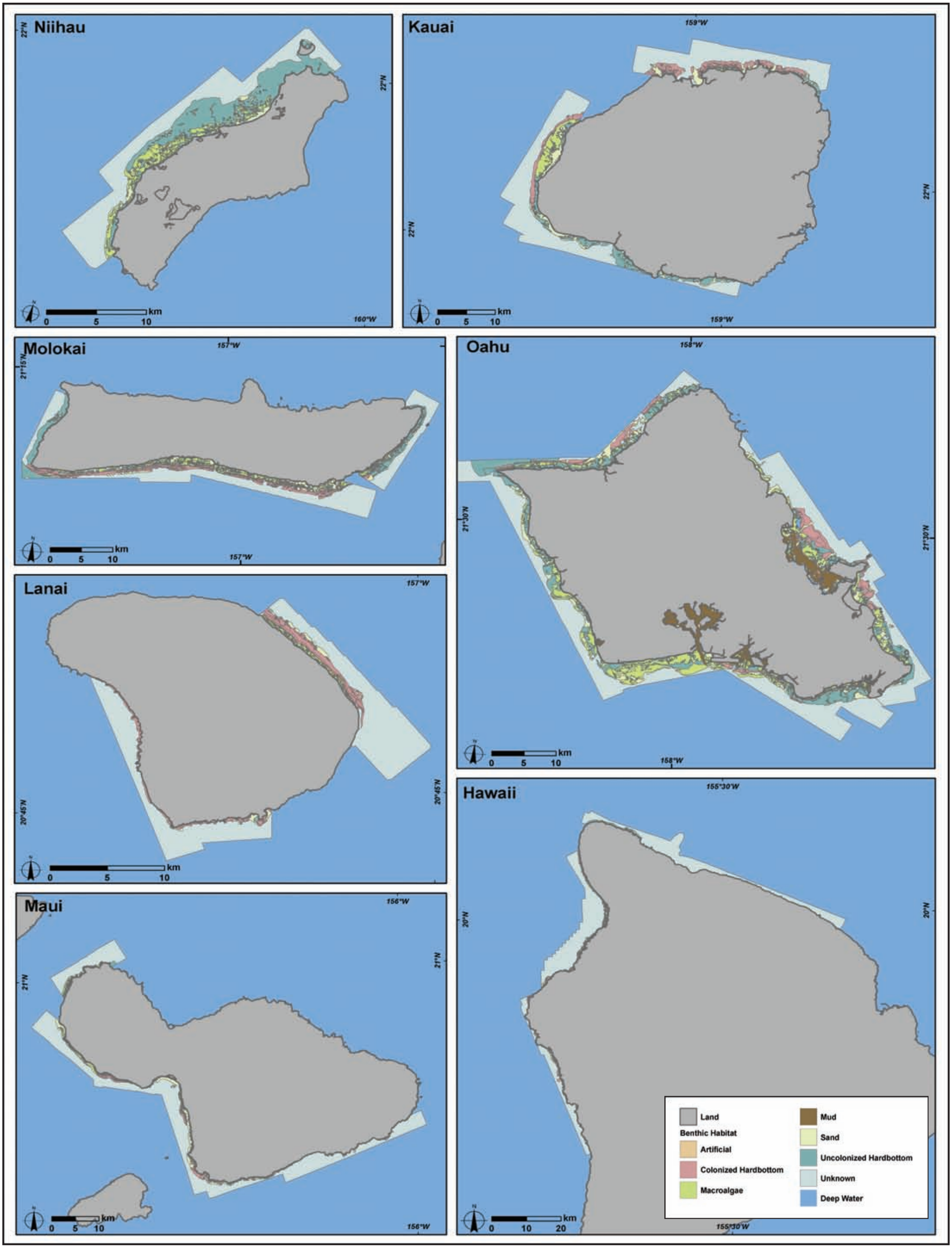

Figure 9.23 Nearshore benthic habitat maps were developed in 2003 by CCMA-BT based on visual interpretation of aerial photography and hyperspectral imagery. For more info, see: http://biogeo.nos.noaa.gov. Map: A. Shapiro.

had lower coral coverage, species richness, and diversity. Mean wave direction (expressed as compass bearing) showed a negative relationship with coral cover, species richness, and diversity. This is because major storm surf in Hawaii arrives along a gradient that roughly diminishes in a counter clockwise direction from the north (Moberly and Chamberlain, 1964). The largest and most frequent storm surf arrives during the winter from the north Pacific swell (bearing 315°) with the less frequent and less damaging storm waves during the summer from the south swell (bearing 190°) and trade wind swell (bearing 45°). Storlazzi et al. (2003) showed that waves in Hawaii can reach destructive levels that will damage corals and restrict species distribution patterns.

• Rugosity measurements showed that areas of antecedent high rugosity allow corals to attach and grow on higher substrata not influenced by sand and sediment movement along the bottom. Rogers et al. (1984) found that coral larvae preferentially recruited to vertical surfaces and suggested that this pattern also applied to areas of higher rugosity. As coral reef communities develop, the structure and continued accretion of the coral skeletons further increase rugosity. Thus both physical and biological components are involved in development of high rugosity environments.

• Sediment components played a role in explaining variation in the coral assemblage characteristics. Percent organics, an indicator of terrigenous input, showed negative relationships with coral species richness and diversity. Higher percent organic content was also important in explaining decline in coral cover over time. Other studies have determined that increased terrigenous input has an adverse impact on reef communities (e.g., Acevedo and Morelock, 1988). Continuing work by the USGS in Hawaii is helping to define the influence of sediment on reef development.

• Higher levels of rainfall in a watershed corresponded to lower levels of coral cover on adjacent reefs. Jokiel et al. (1993) described the negative impacts of low salinity water on coral reef assemblages in Kaneohe Bay, Oahu.

Temporal trends:

• Coral cover at most stations changed less than 10% (absolute) over the three-year period. A total of 29 of 60 stations experienced a statistically significant change in coral cover from the initial baseline survey to the last survey conducted (Figure 9.24). Sixteen stations showed a significant decline in coral cover, with the greatest drop of 19% occurring at the Kamalo 3-m station on Molokai. In contrast, 13 stations increased in coral cover, with the greatest increase of 14% at the Papaula Point 4-m station on Maui. One problematical site (2-m station at Kaalaea, Oahu), showed high fluctuations between samplings. This appeared to be due to several slumping events involving large sections of reef which moved the marking pins and blocks of live coral between the pins.

• Patterns of change in coral cover observed in the CRAMP investigation are consistent with observations of other studies in Hawaii. For example, coral coverage declined at monitoring sites in Kaneohe Bay in the past three years, which continues a trend documented during the previous 20 years (Hunter and Evans, 1995).

• The downward trend on Hawaiian coral reefs as measured in this study appears to be most prevalent in the central portion of the archipelago on the islands of Oahu, Molokai, and Maui (Figure 9.25). Most of the human population of Hawaii resides on Oahu (72%) and Maui (10%). Molokai has a lower human population, but suffers from extreme erosion and sedimentation of reefs along the south shore due to inadequate watershed management (Roberts, 2000). Maui also suffers from impaired watersheds and population centers that are adjacent to major reef areas (West Maui Watershed Management Advisory Committee, 1997). The islands of Kauai and Hawaii have relatively low human population and show an increase in coral reef coverage. At Kahoolawe, a former military target island, the condition of sediment-impacted reefs have held steady following the removal of all grazing animals, cessation of bombing, and a massive program of revegetation.

• Temporal trends should be interpreted with caution over the relatively short time span of the study. This study did identify six reefs (10% of the total) that had major shifts in absolute coral cover (>10%), warranting further experimental investigation and more detailed observations in the future.

Environmental variables that explained changes in coral cover included rugosity, mean wave height, and watershed area (Jokiel et al., 2004).

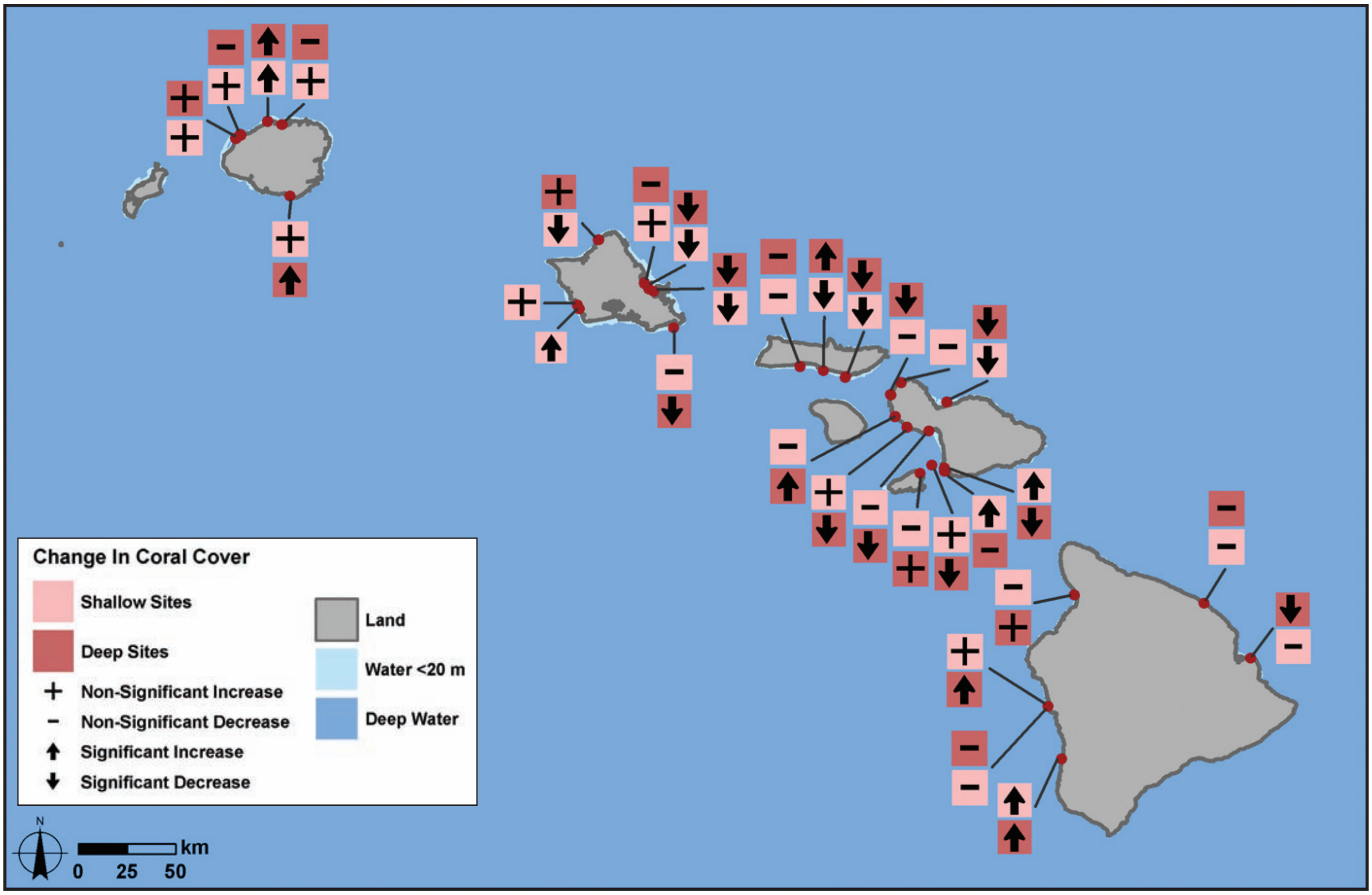

Figure 9.24. Results of CRAMP monitoring efforts since 1999 show trends in coral cover at sites across the state. Shallow sites (3 m) are shown in light pink and deeper sites (8 m) are shown in dark pink. Source: Jokiel et al., 2004.

• Stations with higher rugosity or more topographical complexity experienced greater declines in coral cover.

• In contrast, stations exposed to higher mean wave height or situated adjacent to larger watersheds had significant increases in coral cover.

Turgeon et al. (2002) reported "the consensus of many ecologists is that, with a few exceptions, the health of the near-shore reefs around the MHI remains relatively good." On the other hand, some researchers, local fishers and recreational divers with long-term experience observe that reefs in many areas of Hawaii have declined over past decades. For example, Jokiel and Cox (1996) have noted degradation of Hawaiian reefs due to human population growth, urbanization, and coastal development. Absence of the catastrophic short-term reef declines that have been noted in other geographic areas (e.g., Hughes, 1994) can lead to the impression that Hawaiian reefs are in good condition. Slow rates of decline, however, will eventually result in severely degraded reefs. The spatial patterns and temporal change

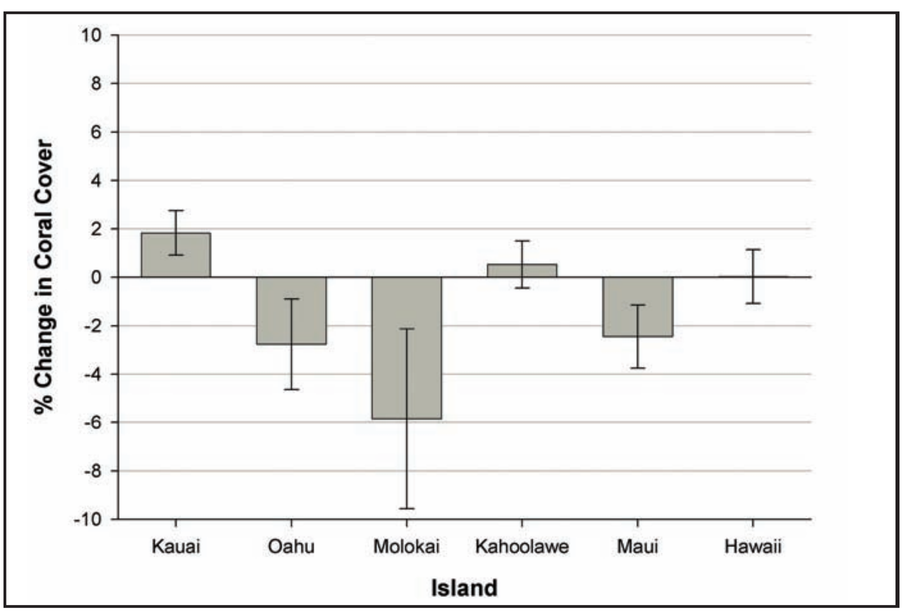

Figure 9.25. Trends in coral cover between 1999-2002 at CRAMP sites show a decline for the islands of Oahu, Molokai, and Maui. Source: Jokiel et al., 2004.

of coral reef community structure in relation to human population that were observed in this study suggest that the rapidly growing human population of Hawaii may be having a negative effect on the reefs. Long-term monitoring will be required to differentiate the observed short-term declines in coral cover from natural oscillations (Done, 1992) in Hawaiian reef community structure (Hughes and Connell, 1999).

Long-Term Monitoring at Selected Sites

Selected sites throughout Hawaii have been monitored over a longer time period (>10 years) and were incorporated into CRAMP to extend the historical perspective including one site on Kauai, five on Oahu, and two on Maui (Table 9.8). Puako, Hawaii, which is not part of CRAMP, is included because it has also been surveyed for over 10 years. Coral cover at several stations within each site has been surveyed sporadically over the years (Table 9.8). Different methods have been used but studies that have compared methods produced similar results (e.g., Brown, 2004). For comparative purposes, only transects or quadrats that sampled the same spatial habitat as CRAMP were utilized.

The selected sites may not be representative of wave exposed reefs around Hawaii because six of the nine sites (12 of 15 stations) are located in protected embayments. Sites such as Hanauma Bay, Honolua Bay, and Olowalu, however, are high human use areas and changes at these reefs have important management implications. In addition, long-term data sets on coral cover are uncommon and provide benchmarks for future comparisons. Temporal results for all of the sites are listed in Table 9.8.

Table 9.8. Average percent coral cover at selected sites that have been surveyed at time periods spanning 10 or more years. Overall percent change (Δ) from the initial survey to the last survey is shown in the last column. Data sources for each station are listed below. * indicates locations within Kaneohe Bay.

ISLAND	SITE	STATION	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	Δ
Kauai	Hanalei Bay	3m[1,2]																								15						16	26		17	17	2
		8m[1,2]																								20						28	30		26	36	16
Oahu	Kahe Point	3m[2,3]												19	19	15	16	16	18	22	20	18	17	12	10	5	5	4	5	9	7	12	13	15	15		-4
	Pili o Kahe	3m[2,3]												19	12	10	10	9	8	10	11	12	18	17	16	14	11	9	8	8	7	9	7	10	11		-8
	Kaalaea*	2m[2,4,5]		92												82							79									62	51	49	67	59	-33
		8m[2,4,5]		7												11							9									3	2	4	3	3	-4
	Heeia*	2m[2,4,5]		33												64							62									36	23	18	24	22	-11
		8m[2,4,5]		1												15							2									8	7	7	5	7	6
	Moku o Loe*	2m[2,4,5]		6												45							21									30	20	16	13	14	9
		9m[2,4,5]		0												4							3									8	7	6	4	9	9
	Hanauma Bay	3m[2,6,7]							28																47	28		28		28	33	24	26		22		-6
		10m[2,6,7]							38																40	36		33		32	25	27	27		22		-15
Maui	Honolua Bay	North 3m [2,7,8,9,10,11]					39					23												51	56		41	35	28	28	24	15	17	15	14		-25
		South 3m [2,7,8,9,10,11]					43					36															42	42	38	33	28	21	27	23	24		-19
	Olowalu	3m[2,10,12]																			31						32	30	23	30	30	23	25	22	23		-8
		8m[2,10,12]																									55	56	47	57	51	55	54	53	51		-4
Hawaii	Puako	3m[7,13]											66											42	42	43		47		58	60						-5
		10m[7,13]											63											46	41	43		44		59	45						-18

DATA SOURCES

1 Friedlander et al., 1997
2 Jokiel et al., 2004
3 Coles, 1998
4 Maragos, 1972
5 Hunter and Evans, 1995
6 Anderson, 1978
7 Hunter, 1999
8 Environmental Consultants, 1974
9 Torricer et al., 1979
10 Brown, 1999
11 Dollar and Grigg, 2004
12 Ambrose et al., 1988
13 Hayes et al., 1982

Statewide Trends

Hanalei Bay, Kauai

Total coral cover at the 3-m station appears to be holding steady while total coral cover at the 8-m station has increased nearly 17% (84% relative increase).

Kahe Point and Pili o Kahe, Oahu

Both stations appear to be undergoing 12-13 year oscillations in total coral cover. The temporal patterns, however, do not coincide. Pili o Kahe reached a low point in coral cover in 1986 (8% ± 1% SE) and 1998 (7% ± 2% SE). In contrast, coral cover at Kahe Point declined in 1983 to 15% ± 2% SE and to 4% ± 1% SE in 1995.

Kaalaea, Kaneohe Bay, Oahu

The Kaalaea 2-m station has experienced a decline in total coral cover of 34% (36% relative decrease). Total coral cover at the 8-m station was higher in 1983 (7%) compared to 1971 (11%-68% relative increase), but then decreased to 3% (72% relative decrease) by 2003. Much of the decrease in coral cover was attributed to slumping of the reef slope (Jokiel et al., 2004).

Heeia, Kaneohe Bay, Oahu

The Heeia 2-m station followed a similar pattern to the Kaalaea 8-m station with higher total coral cover in 1983 (64%) compared to 1971 (33%-93% relative increase). By 2003, coral cover declined to 22% (66% relative decrease). The percent cover at the 8-m station appears to have increased since 1971, but has fluctuated in the interim.

Moku o Loe, Kaneohe Bay, Oahu

At Moku o Loe, coral cover increased in 1983 at the 2-m station by 39% (680% relative increase), but subsequently declined to 14% in 2003 (68% relative decrease). In comparison, coral cover at the 9-m station has slowly increased from 0% to almost 9% since 1971.

Hanauma Bay, Oahu

The Hanauma Bay 3-m station experienced an 18% increase (65% relative increase) in coral cover from 1976 to 1992. Subsequently, coral cover steadily declined to 22% (25% absolute decline, 53% relative) by 2002. The Hanauma Bay 10-m station had similar total coral cover values in 1976 (38%) and 1992 (40%), and then declined to 22% (18% absolute, 45% relative decrease) by 2002.

Honolua Bay, Maui

The 3-m stations on the north and south reefs appeared to be relatively stable from 1974 until 1994. From 1994 to 1998, coral cover declined from 41% to 14% (66% relative decrease) at the north station and from 43% to 24% (44% relative decrease) at the south station. Since 1999, coral cover has stabilized at both stations.

Olowalu, Maui

The Olowalu 3-m station showed a gradual decline in coral cover of 8% (26% relative decrease) since 1998. In contrast, the Olowalu 8-m station has remained relatively stable from 1994 to 2002, with total coral cover between 51-55%.

Puako, Hawaii

Total coral cover appears to be increasing at the Puako 3-m station (18% absolute increase, 43% relative increase) to 1982 levels, after an initial drop of 23% (36% relative decline) from 1982 to 1991. In comparison, total coral cover at the 10-m station was 63% in 1982 and only 46% in 1991. This was a 17% decline (27% relative decline) that increased to 58% (12% absolute increase, 27% relative increase) in 1997 and subsequently decreased to 45% in 1998. The increase in coral cover at the 10-m stations was mirrored at the 3-m station until 1998 when trends diverged at the two stations.

Summary

The long-term trends at the selected sites show that the majority of the stations (13 out of 18) have declined since the first survey. Several of these stations (e.g., Kahe Point 3-m station) have experienced minor decreases in coral cover that can be explained by measurement error and therefore are not ecologically relevant. Explanations for the major declines (>10%) include reef slumping (e.g., Kaalaea; Jokiel et al., 2004) and sedimentation (e.g., Honolua Bay; Dollar and Grigg, 2004). Dollar and Grigg (2004) have suggested that embayments with restricted circulation, such as many of the sites previously listed, are more susceptible to anthropogenic stresses. Intermittent sampling, however, confounds most of the monitoring studies. As shown in the Kahe data, oscillations in coral cover may be occurring that are not detected from the sporadic sampling at the other stations. Therefore, inferring that the selected sites are in fact declining should be interpreted with caution. At present, however, these data sets are the best indicators of long-term trends in Hawaiian coral reefs.

ASSOCIATED BIOLOGICAL COMMUNITIES

West Hawaii Aquariumfish Project

In response to longstanding concern and controversy over marine aquarium collecting in West Hawaii, the nineteenth Hawaiian legislature passed Act 306 in 1998 which established the West Hawaii Regional Fisheries Management Area in the nearshore waters from Upolu Point (North Kohala) to Ka Lae (Kau). One of the primary goals of the legislation was to improve management of fish resources by designating a minimum of 30% of the West Hawaii coastline as FRAs where aquarium fish collecting was prohibited.

Methods

Study sites were established in early 1999 in six existing reference areas, eight open areas adjacent to FRAs, and all nine FRAs. Using stainless-steel bolts cemented into the bottom, four permanent 25-m transects were established in a H-shaped pattern at each of the study sites.

Fish densities were estimated by a pair of divers who conducted visual surveys along each transect. Divers swam side by side and surveyed a column 2 m wide (4 m total width). On the outward-bound leg, larger planktivores and wide-ranging fishes were recorded. On the return leg, fishes closely associated with the bottom, new recruits, and fishes hiding in cracks and crevices were recorded.

Power analysis of preliminary fish transect data indicated that the observational design would detect 10–160% changes in the abundance of the principal targeted aquarium fishes in West Hawaii during the first year using reasonable error rates ($\alpha=\beta=0.10$).

Results and Discussion

Over the course of the four years of the WHAP study, overall aquarium fish abundance (top 10 species) has been increasing (linear regression, $p<0.05$) in FRAs, including control and open sites (Figure 9.26). Notably, FRAs have become quite comparable to pre-existing MPAs that have been in existence for 13 years or more. Although there was a tendency for non-aquarium species to increase during this period, the trend was not significant ($p=0.07$). Three years after closure of the FRAs, there were significant increases in the overall abundance of fishes targeted by collectors. Interestingly, the estimated increase in abundance (26%) is the same amount as the estimated re-

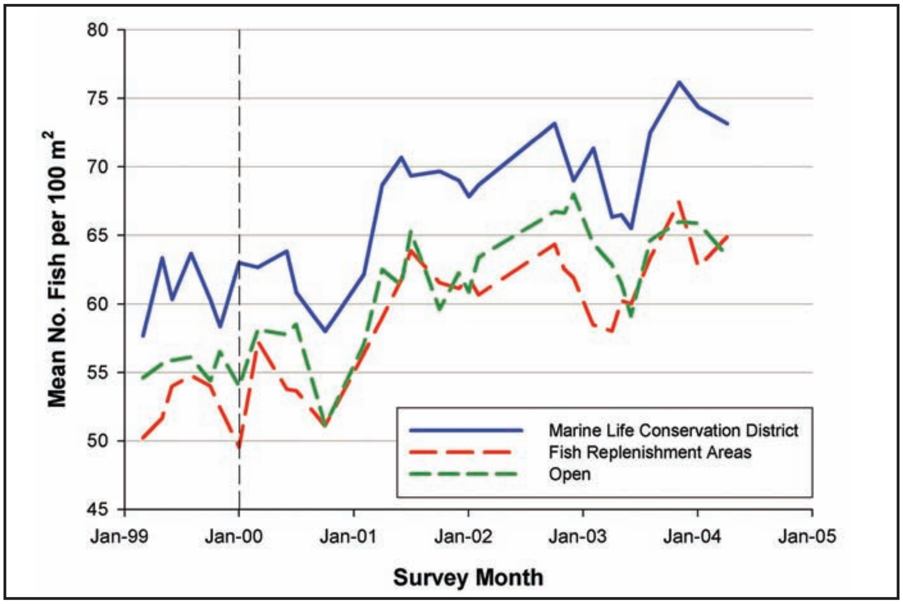

Figure 9.26. Overall abundance through time of top 10 most collected aquarium fishes. Dashed line represents FRA establishment. Source: Tissot et al., 2004; WHAP, unpublished data.

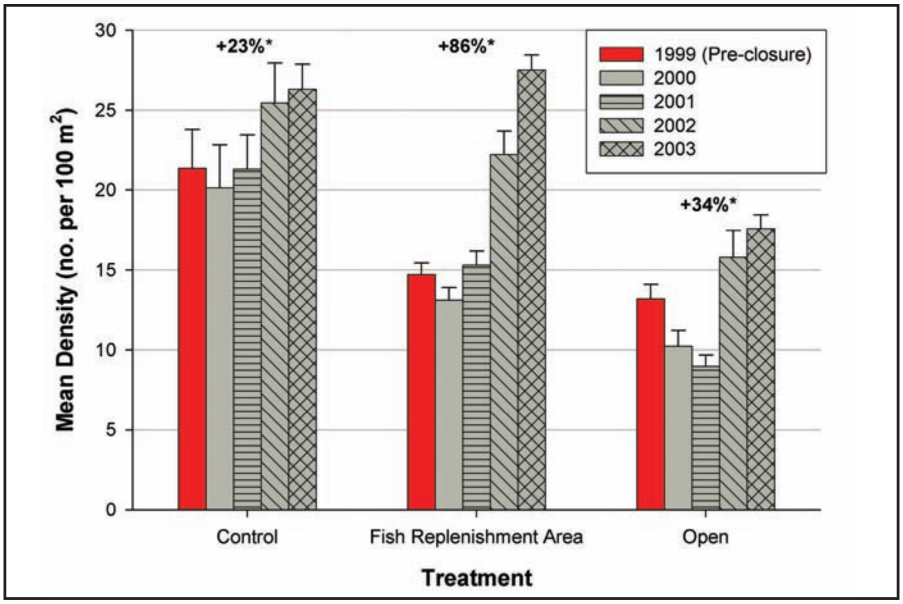

Figure 9.27. Comparison of yellow tang (*Zebrasoma flavescens*) abundance in pre-closure (1999) and post-closure years (2000-2003). Percentages are two sample comparisons between 1999 and 2003 (*values are significant using a two sample t-test at α=0.05). Source: Tissot et al., 2004; WHAP, unpublished data.

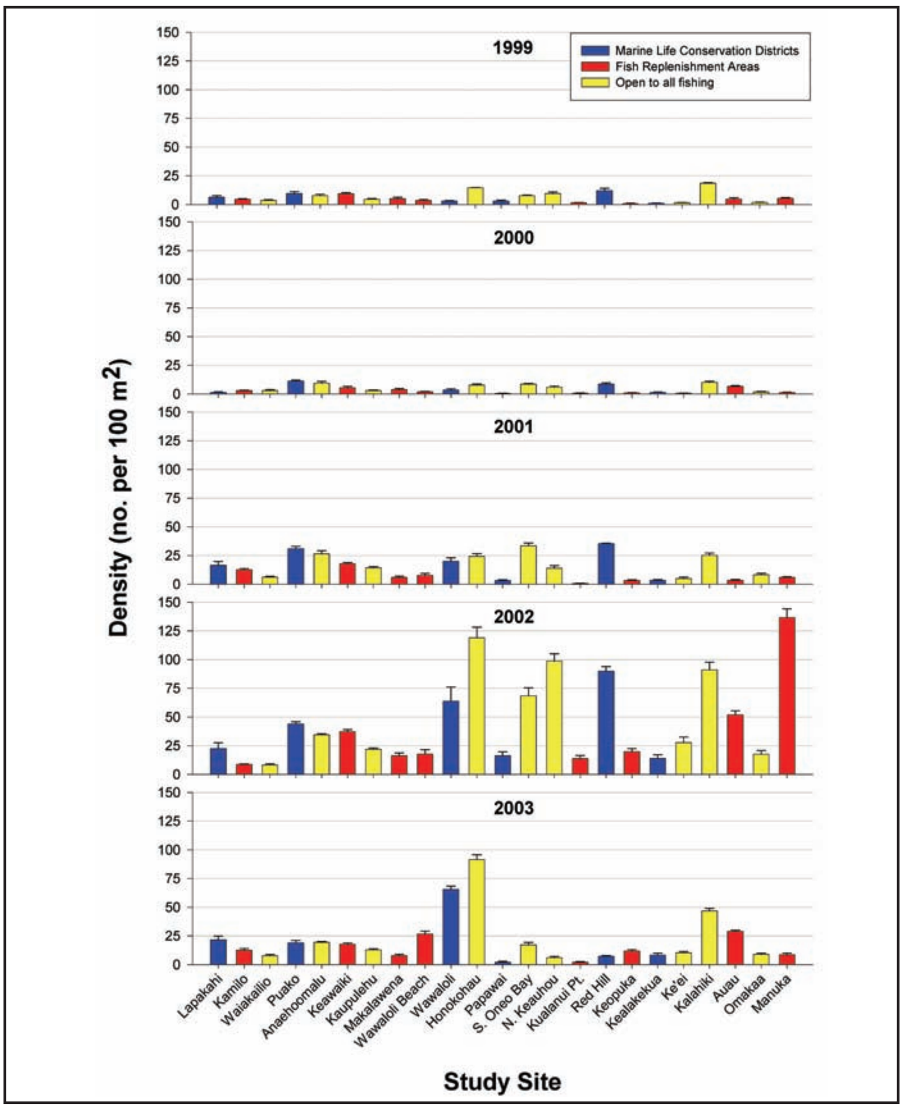

Figure 9.28. Density of *Zebrasoma flavescens* young-of-year at all study sites during 1999-2003. Source: Tissot et al., 2004; WHAP, unpublished data.

duction due to collectors prior to FRA closure, suggesting that as a group, these fishes may have increased to their pre-exploitation levels (Tissot et al., 2004). Yellow tangs (*Zebrasoma flavescens*) increased in density by 86% within FRAs between 1999 and 2003, or about 12.2 fish/100 m^2 (Figure 9.27). The yellow tang is by far the most heavily collected fish in West Hawaii, accounting for 79% of the total catch. The recovery of yellow tang populations was undoubtedly related to the high number of newly recruited fishes observed in 2001-2002 (Figure 9.28). Large recruitment events are uncommon in West Hawaii but are likely to be an important factor determining the effectiveness of MPAs to help replenish depleted fish populations.

There were no significant changes among non-collected species within FRAs or in aquarium and non-aquarium species in areas outside of FRAs. Furthermore, no aquarium fishes declined in abundance in open areas as might be expected if the intensity of harvesting increased outside of the FRAs.

Although specific FRAs varied in their degree of effectiveness, the overall results demonstrate that MPAs can promote recovery of fish stocks depleted by fishing pressures in Hawaii, at least in heavily exploited species, without significant declines outside of MPAs. Overall, FRAs have successfully reduced conflicts between collectors and other resource users, promoted a sustainable fishery, and enhanced aquarium fish populations. The success of the FRAs in West Hawaii is likely to increase as aquarium fishes grow and mature within these MPAs and further replenish near-shore reefs.

Hanalei Bay Marine Communities Investigation

In 1992, the DAR's MHI Marine Resource Investigation Program identified Hanalei Bay, Kauai as one of five key sites upon which to focus extensive field research programs. This Program provides a broad base for understanding the state's living marine systems and is directed towards more effective management (Friedlander and Parrish, 1998a; Friedlander, unpublished data). Hanalei Bay is one of the largest embayments on the island of Kauai and serves as a major recreational area for residents of many north shore communities and neighboring areas. The recent designation of the Hanalei River as an American Heritage River has increased the community's awareness and involvement in protecting its marine environment.

Methods

Abundance of fishes on hard substratum was assessed using standard underwater visual belt transect survey methods. Twenty-two transects (25 m x 5 m) were permanently established in a wide variety of habitats throughout the bay to assess fish and associated benthic communities (Friedlander and Parrish, 1998a, b).

Retrospective analysis of Hanalei data

Monthly visual fish censuses of transects from December 1992 to November 1994 showed that surf height and degree of wave exposure were negatively correlated with several measures of assemblage organization (Friedlander and Parrish, 1998a). Most measures of fish assemblage structure were lower during the winter months when large north Pacific swells and heavy rainfall, coupled with high river discharge, impacted the bay.

Fish censuses were conducted at 20 of the 22 permanent sites in June 1999, September 2003, and June 2004. Species richness, biomass, and diversity have all either increased or were constant during this time period (Figure 9.29).

Three introduced fish species (bluestripe snapper, blacktail snapper, and peacock grouper) have become well established in Hanalei Bay (Friedlander et al., 2002b) and their contribution to total fish biomass has increased from 15% in 1993 to as high as 39% in 1999 (Figure 9.30). The bluestripe snapper is the most important, currently accounting for 23% of total fish biomass in the bay. The blacktail snapper appeared in large numbers in 1999 but was not observed in high abundance in 2003 or 2004. A large rain event just prior to the 1999 sample date may have caused blacktail snappers to move out onto the reef temporally. The pea-

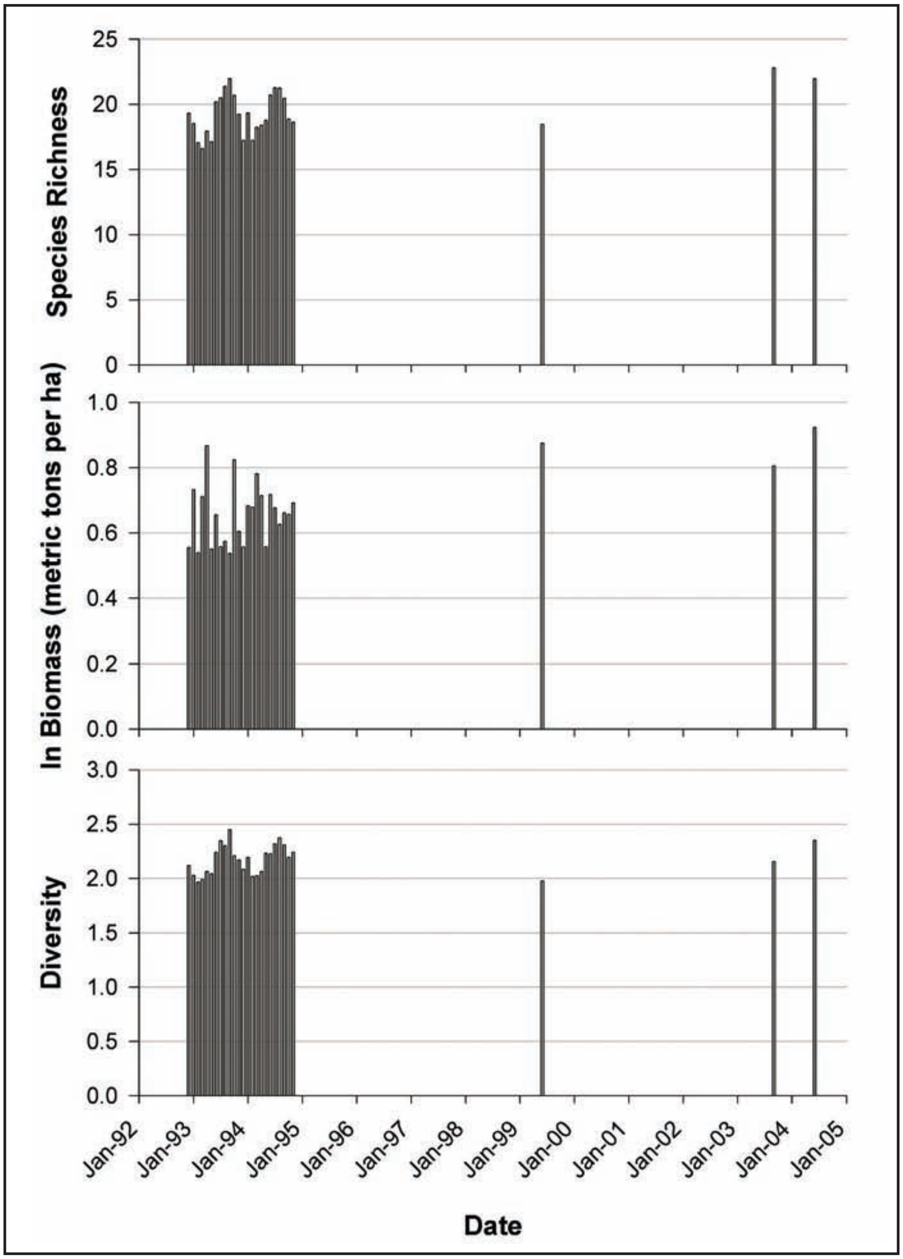

Figure 9.29. Mean fish species richness (upper panel), mean fish biomass (middle panel), and mean fish diversity (lower panel) in Hanalei Bay, Kauai. Note natural log scale for graph of mean fish biomass (middle panel). Source: Friedlander and Parrish, 1998a; Friedlander, unpublished data.

cock grouper has steadily increased in importance from less than 1% of fish biomass in 1993 to nearly 7% in 2004. Increases in total fish biomass since the early 1990s cannot be attributed solely to introduced species, as other elements of the fish assemblage have also increased over this time period. Reduced fishing pressure has been cited as one potential reason for these trends.

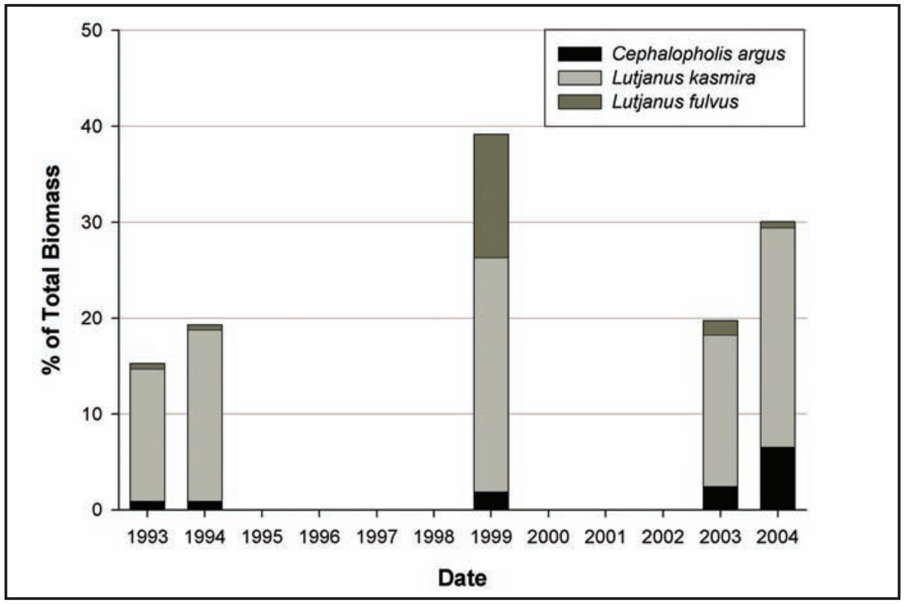

Figure 9.30. Percent contribution of introduced species, peacock grouper (*Cephalopholis argus*), bluestripe snapper (*Lutjanus kasmira*), and blacktail snapper (*L. fulvus*), to total fish biomass in Hanalei Bay, Kauai. Source: Friedlander and Parrish, 1998a; Friedlander, unpublished data.

Waikiki-Diamondhead FMA – Results of a rotational closure

Unique among Hawaiian marine managed areas, a rotational closure strategy has been applied in the Waikiki Diamond Head Fishery Management Area (FMA). Created in 1978, the FMA initially operated on a four-year cycle: two years of closure followed by two years in which fishing was permitted. In 1988, a portion of the FMA was converted to a permanently closed area by becoming the Waikiki MLCD, and the rotational cycle in the remaining area was changed to one year open followed by one year closed.

As part of the DAR's reef monitoring program, fish populations in the FMA, including the 'Kapahulu' portion of the FMA which subsequently became the MLCD, have been monitored since 1978. Overall trends in biomass of fishery-target species in the FMA and MLCD are displayed in Figure 31. Within the FMA, biomass of fishery-target species has tended to increase during periods of closure, but such increases have been insufficient to compensate for declines occurring during open periods. Overall, there has been a striking decline in biomass of fishery-target species in the FMA from 40-50 g per m^2 in the early years after its creation to around 10 g per m^2 in recent years (Figure 31).

Assessment of the effects of fishing and closure on the FMA and the adjacent fully-closed MLCD has been complicated by declines in habitat quality, particularly within the MLCD. Beginning in the early 1990s, habitat quality was degraded by, among other things, the gradual overgrowth of much of the reef by the alien algae, *Gracilaria salicornia*. However, the initial effect of full closure was a dramatic reversal of the previous downward trend in fish biomass (Figure 9.31, B); during the first three years of full closure, biomass of target species averaged nearly 40 g per m^2 more in the MCLD than in the adjacent FMA ($p<0.05$, paired t-test). The impact of habitat decline on fish populations appears to have been much more severe within the MLCD than in the FMA, but even in the post habitat-decline period (Figure 9.31, C), biomass of target species within the MLCD is nearly double that in the FMA (paired t-test $p<0.05$).

Within the FMA, substantial reductions in the size of the largest fishes observed during surveys coincided with the downward trend in biomass. In the early 1980s, 40-50 cm and larger acanthurids and scarids were commonly observed during fish-counts, but in recent years, the maximum size recorded per survey has averaged around 30 cm for acanthurids and less than 20 cm for scarids. Very large scarids, which were regularly encountered between 1979 and 1985 (seen during 115 of 376 surveys), have virtually disappeared from the FMA; individuals of that size have been recorded in only three of 78 surveys conducted since 1990. Less dramatic but still significant declines in maximum size have also occurred in other commonly targeted fish families, such as mullids and carangids. In contrast, there have been no declines or downward trends in the maximum size of any of the previously mentioned families within the Waikiki MLCD.

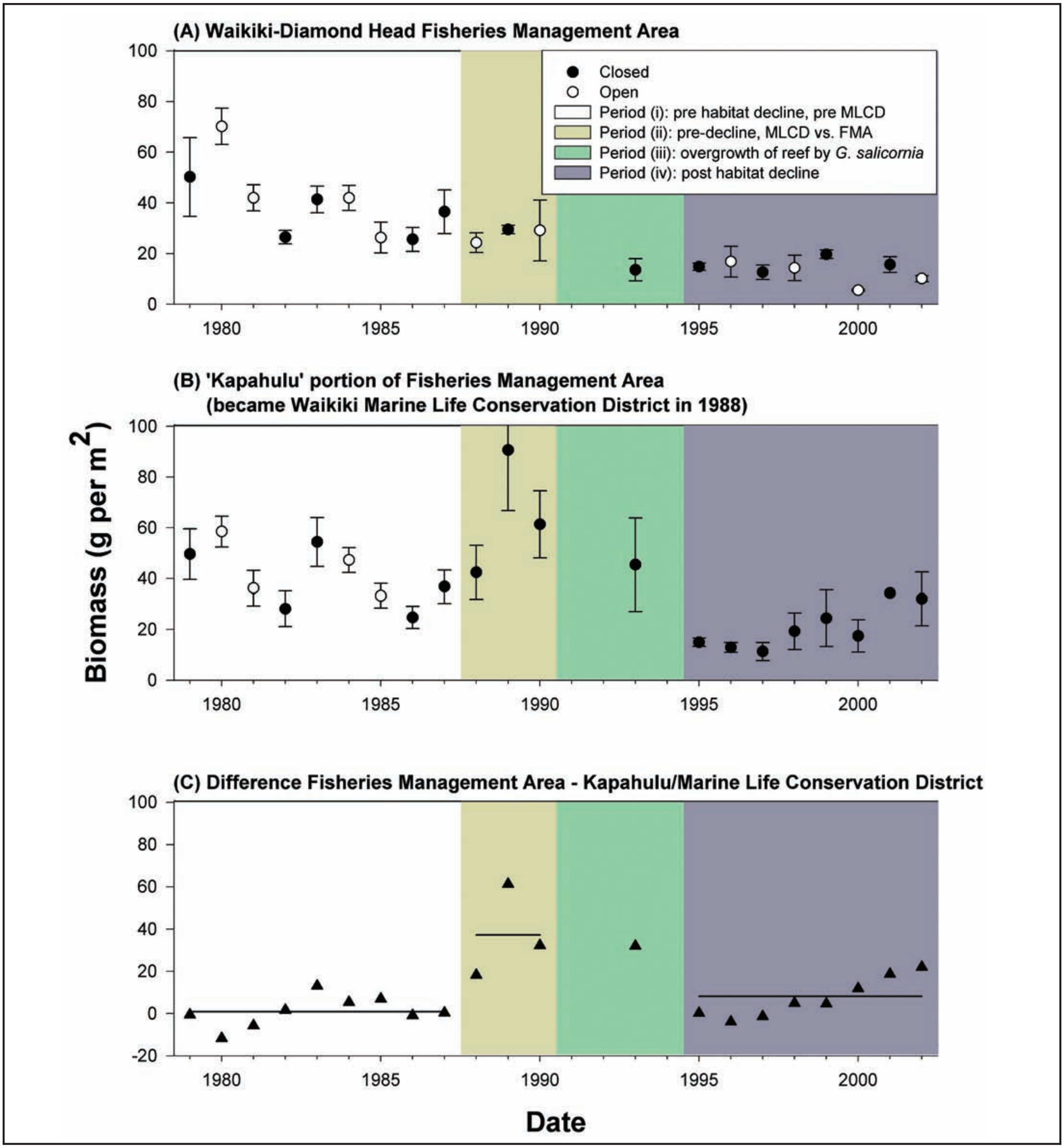

Figure 9.31. Annual mean biomass and SE (g/m^2) of main fishery-target species in Waikiki Diamond Head FMA (upper panel) and Kapahulu/Waikiki MLCD (middle panel). Lower panel indicates mean differences between FMA and Kapahlu/MLCD over four periods: (i) 1978-1987, when both were within original boundaries of the FMA; (ii) 1988-1990, immediately after creation of the MLCD, when (A) was rotationally managed and (B) fully-closed; (iii) 1990-1995, a period of significant algal overgrowth and habitat degradation; and (iv) 1995-2002, post habitat degradation in FMA and MLCD. Closed circles represent years when fishing was prohibited, open circles represent years when fishing was permitted. Source: Williams et al., in review.

Both the FMA and MLCD now largely consist of low quality coral reef habitat, with shallow areas dominated by fleshy algaes and patchy coral cover. In the absence of any long-term habitat data, it is difficult to unequivocally determine the relative impacts of fishing or protection compared to habitat declines, but significant differences between the FMA and immediately adjacent MLCD indicate that rotational closure has been much less effective than permanent closure as a means of conserving fish populations.

CRAMP Management Regime Comparison Study

The CRAMP sampled the fish and benthic communities at 60 locations around the MHI in 2000 (Friedlander et al., 2003). Of these 60 locations surveyed, 18 had some level of protection from fishing associated with them. No-take areas (Hanauma Bay MLCD, Honolua Bay MLCD, Molokini Crater MLCD, and Moku o Loe (Coconut Island-Hawaii Marine Laboratory Refuge)) had the highest values for most fish assemblage characteristics, followed by areas under customary stewardship (Kaho'olawe Island Reserve and Ahihi-Kinau Natural Area Reserve). Locations under community-based management with customary stewardship harbored fish biomass that was equal to or greater than that of no-take MPAs, although light fishing pressure and the remoteness of these locations may also contribute to the high biomass observed (Figure 9.32).

General linear models were used to assess the importance of various environmental parameters and fisheries management regimes on fish assemblage characteristics (Table 9.9). Locations with protected status explained significant portions of variation in species richness (p=0.001), biomass (p=0.01), and diversity (p=0.008). For each of these characteristics, locations protected from fishing (no-take and customary stewardship) had higher numbers of species, greater biomass, and higher diversity.

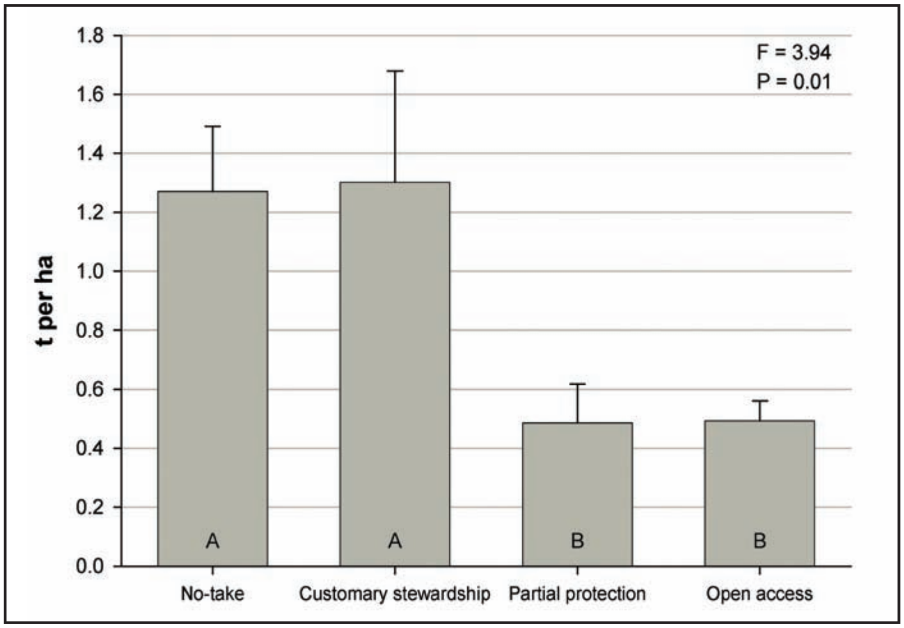

Figure 9.32. Comparisons of fish biomass (t ha-1) under various levels of protection from fishing. Error bars are standard error of the mean. Statistical results of one-way ANOVA are shown. Levels of fishing protection with the same letter designation are not significantly different (Tukey HSD multiple comparisons test, a=0.05). Source: adapted from Friedlander et al., 2003.

The variability in species richness was explained by rugosity, live lobate coral cover, and areas protected from fishing which were all significant parameters ($F_{8,51}$=6.73, p<0.001). The variability in the number of individuals was explained by rugosity, live branching and lobate coral cover which were all significant parameters ($F_{8,51}$=5.57, p<0.001). Rugosity and protected status were significant in explaining the variability in biomass ($F_{8,51}$=4.86, p<0.001). Diversity was explained by rugosity, the degree of wave exposure (exposed, sheltered, and embayments), and protected status ($F_{8,51}$=7.42, p<0.001).

Areas with limited protection from fishing had values for fish assemblage characteristics that were lower

Table 9.9. Influence of various environmental variables and management regimes on fish assemblage characteristics in the MHI base on results of multiple regression models (GLM). Significant statistical results in bold. Source: Friedlander et al., 2003.

PARAMETERS	SPECIES		NUMBER		BIOMASS		DIVERSITY	
	F	p	F	p	F	p	F	p
PHYSICAL								
Depth	0.02	0.893	3.39	0.072	0.63	0.431	1.16	0.287
Rugosity	**7.70**	**0.007**	**4.62**	**0.036**	**4.92**	**0.031**	**4.11**	**0.048**
Wave Exposure	2.8	0.080	0.65	0.526	0.06	0.945	**11.5**	**<0.001**
BIOTIC								
Coral cover (plate)	2.31	0.135	0.71	0.402	1.42	0.239	<0.01	0.955
Coral cover (branching)	2.03	0.161	6.14	0.017	2.71	0.106	1.3	0.260
Coral cover (lobate)	**5.48**	**0.023**	**5.42**	**0.024**	3.09	0.085	1.02	0.319
MANAGEMENT REGIME								
Protected Status	**11.70**	**0.001**	2.40	0.128	**7.02**	**0.011**	**7.58**	**0.008**

than areas where fishing was restricted, and similar to areas completely open to fishing. The Pupukea MLCD is a partially protected area that has recently received additional protection through the expansion of existing boundaries and the restriction of most fishing activities within the reserve. The existing data will help to serve as a baseline in determining whether these new regulations enhance the fish assemblage within the reserve over time. MPAs in the MHI with high habitat complexity, moderate wave disturbance, a high percentage of branching and/or lobate coral, coupled with legal protection from fishing pressure, had higher values for most fish assemblage characteristics.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Addressing Alien Species

The 2003 Hawaii legislature and Hawaii Governor Linda Lingle established the Hawaii Invasive Species Council to address gaps in Hawaii's current invasive species prevention and response measures. Governor Lingle introduced legislation in 2004 requesting $5 million from state general funds for alien species prevention, response, research, and education. Three million dollars was appropriated by the State legislature to begin to address this problem. One of the integrated elements of this larger initiative is the focus on aquatic invasive species (AIS).

In December 2003, with guidance from the Federal Aquatic Nuisance Species Task Force as well as input from representatives of state and Federal agencies, industry, non-governmental organizations, and other stakeholders, the State of Hawaii AIS Management Plan was developed to comprehensively address AIS issues throughout Hawaii. The plan focuses on marine and freshwater alien species of concern and outlines a coordinated approach to minimize the harmful ecological, economic, and human health impacts of AIS. The plan calls for the prevention and management of their introduction, expansion, and dispersal into, within, and from Hawaii. It is the first comprehensive plan for aquatic nuisance species that has been developed for a tropical marine ecosystem.

Water Quality

Bare soils at coastal construction sites are very vulnerable to erosion. Construction projects >1 acre are required by DOH (via NPDES permit authorization) and Hawaiian counties (via grading permits) to use best management practices to control erosion. Nevertheless, heavy rainfall at development sites on Hawaii and Kauai has resulted in significant sediment discharge to the ocean. In both cases, lawsuits and enforcement actions delayed the work and cost the developer millions of dollars in remediation, penalties, and legal fees.

Stormwater runoff in major urban areas of Oahu is regulated by the City and County of Honolulu's (CCH) NPDES permit issued by DOH. The permit requires CCH to monitor stormwater quality and use best management practices (e.g., street cleaning, inlet maintenance) to improve water quality. The other counties are not subject to stormwater permits.

Many communities are organizing integrated watershed management projects to address polluted runoff and other water concerns. These watershed projects have many parallels with traditional Hawaiian watershed management. Hawaii's local action strategy (LAS) for addressing pollution threats to coral reefs is a multi-agency partnership building upon ongoing land management efforts and coral ecosystem monitoring in three watersheds: Hanalei, Kauai; Honolua, Maui; and Kawela to Kamalo, Molokai. Pollution control projects are being implemented on land, ranging from cesspool upgrades to erosion control. At the same time, coral reef monitoring programs are being designed specifically to assess pollution impacts. To date, $1.3 million has been identified for LAS projects, which include feral animal control, fire management, technical assistance for areas transitioning from agricultural to residential use and a workshop to identify indicators of impacts to coral reefs across the Pacific.

To address public health and environmental risks from untreated wastewater in cesspools, EPA has banned large-capacity cesspools serving 20 or more people per day. Construction of new large-capacity cesspools was banned on April 5, 2000 and existing ones must be upgraded or closed by April 5, 2005. Approximately 30,000 large-capacity cesspools in Hawaii will be affected by this ban.

One outcome of current land development pressures is a movement on all of the islands to preserve open space and beaches. The counties, along with local land trusts and conservation organizations, have purchased and preserved major coastal land parcels.

Addressing Overfishing

The DAR has undertaken a number of measures to improve the management of fisheries resources, including changes to minimum size limits for certain resource species, initiation of marine recreational fisheries surveys, evaluation and expansion of MPAs, and changes to commercial reporting forms. Other management measures have included the use of stock enhancement based on aquaculture for a few highly prized species and artificial reefs to improve the catch of some coastal fisheries species in a few select locations. A tag-and-release program initiated by DAR has involved over 850 volunteer anglers and has increased public awareness about fish biology and conservation.

DAR has begun discussions on revisions to the bag limits for certain species and has held a series of public meetings to discuss the regulation of gill nets. DAR is also considering size and harvest regulations for additional species. Additional work and revisions to the MPA program are also being proposed to enhance fisheries resources.

DAR and NOAA Fisheries are leading the effort to create a three-year LAS for coral reef fisheries. The LAS incorporates stakeholder input and defines the state's strategy for coral reef fisheries management. LAS projects include stock assessment, life cycle studies, refinement of data collection and analysis, and outreach and education. The LAS will be used as a starting point to create a coral reef fisheries management plan for Hawaii's nearshore reefs. The goal of the LAS is to work towards the development of an integrated fishery management plan to promote sustainable harvest using an ecosystem-based approach.

DLNR has been creating MPAs for over 35 years. The types of MPAs vary greatly, as do the biological and management considerations that were used to create these sites. State MPAs include:

- 11 MLCDs
- 18 FMAs
- 18 Bottomfish Restricted Fishing Areas
- Hawaii Institute of Marine Biology Research Reserve
- Ahihi Kinau Natural Area Reserve
- Kahoolawe Island Reserve

DAR administers the state's MLCD program, which is designed to conserve and replenish marine resources statewide (DLNR-DAR 1992; Table 9.10). DAR also manages the FMAs, Bottomfish Restricted Fishing Areas, and the Biology Research Reserve. Most of these sites were established to regulate the use of certain gear types and to limit conflicting uses. DAR initiated a regulatory review of current sites and will propose a new set of social/economic and biological criteria to manage existing sites and designate new sites through a public participation process.

Assessment of Efficacy of MLCDs

In order to properly assess the efficacy of existing MLCDs in Hawaii, it is necessary to: 1) map the distribution and characteristics (quality) of benthic habitats; 2) inventory and map the distribution of macroinvertebrates and fishes; and 3) define species habitat affinities in space and time. The CCMA-BT has developed digital benthic habitat maps (Figure 9.23) for most MLCDs and adjacent habitats that are being used to evaluate the efficacy of existing MLCDs, as well as develop criteria for future MLCD design (Friedlander and Brown, 2003a). The integrated mapping and monitoring of coral reef ecosystems and reef fish habitat utilization patterns have been conducted to support the Federally mandated MPA and essential fish habitat (EFH) initiatives. Using GIS technologies to couple the distribution of habitats and species habitat affinities enables the elucidation of species habitat utilization patterns for assemblages of animals at a scale that is commensurate with ecosystem processes. This integrated approach is useful in quantitatively defining EFH and defining biologically relevant boundaries of MPAs.

Of the six MLCDs examined to date, all have nominally higher fish biomass than similar adjacent hard bottom

Table 9.10. Summary of Hawaii MLCD characteristics. Levels of human use as classified by DAR (1992). Protection from fishing based on regulations, not on enforcement of these regulations. Source: Friedlander and Brown, 2003b.

MLCD	HECTARES	YEAR ESTAB.	USE	PROTECTION FROM FISHING	PERMITTED ACTIVITIES
OAHU					
Hanauma Bay	41	1967	High	High	Complete no-take
Pupukea[1]	71	2000	High	Mod	Pole and line from shore (2 lines only) Harvest of limu (seaweed) up to 2 lbs. Surround net for mackerel scad (Aug/Sep) Surround net for bigeye scad (Nov/Dec)
Waikiki	31	1988	High	High	Complete no-take
HAWAII					
Kealakekua Bay	127	1969	High	Mod	Pole and line – 60% of MLCD Thrownet – 60% of MLCD Mackerel and bigeye scad – 60% of MLCD Crustaceans – 60% MLCD
Wai Opae Tidepools	34	2003	High	High	Complete no-take No commercial activity
Lapakahi	59	1979	Low	Low	Pole and line – 90% of MLCD Throw net – 90% of MLCD Lift net for mackerel scad– 90% of MLCD
Waialea Bay	14	1985	Low	Low	Pole and line; Netting
Old Kona Airport	88	1992	Mod	Mod	Throw net from shore Pole & line from shore
LANAI					
Manele-Hulopoe	125	1976	Mod	Mod	Hook & line (shore) – 100% of MLCD All fishing except spear, trap, and net (other than thrownet) – 50% of MLCD
MAUI					
Molokini Shoal	31	1977	High	High	Trolling in 60% of MLCD
Honolua-Mokuleia Bays	18	1978	Mod	High	Complete no-take
Pupukea[1] – Established 1983, amended 2000					

habitats (Figure 9.33). The MLCDs also had higher values for most other fish assemblage characteristics (e.g., species richness, size, diversity), illustrating the effectiveness of these closures in conserving fish populations within these management units. Habitat complexity, quality, and size were important determinates of the effectiveness of these MLCDs with respect to their associated fish assemblages.

Recreational Use

A LAS is being developed to address the overuse and misuse of Hawaii's reefs by non-consumptive users. Statewide scoping meetings are soliciting input on the issues that should be addressed in the LAS. Develop-

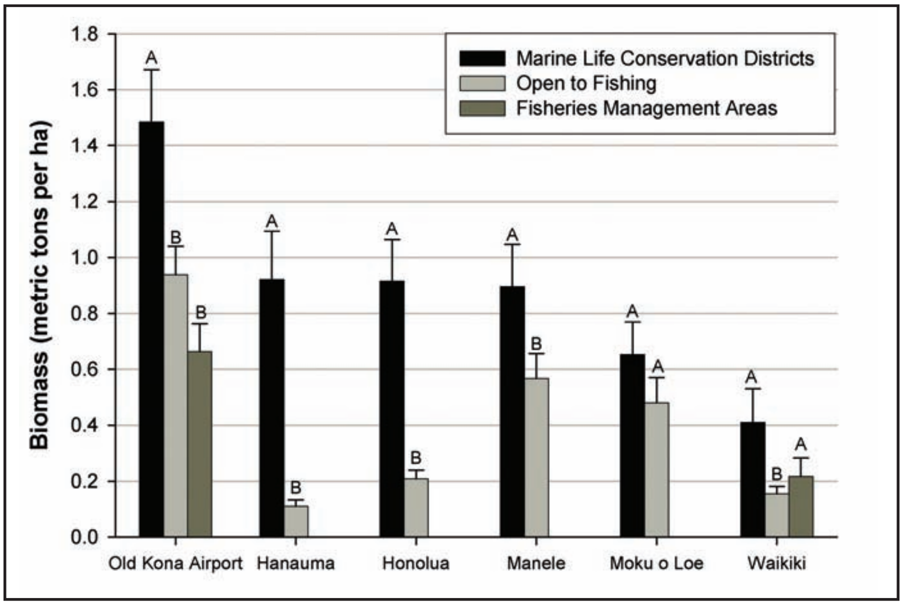

Figure 9.33. Comparison of fish biomass in MLCDs, FMAs, and areas open to fishing in the MHI. Management regimes with the same letter are not significantly different ($\alpha = 0.05$). Source: adapted from Friedlander and Brown, 2003a.

ment and implementation of the LAS will be overseen by a cooperative state/Federal steering committee. Additionally, DAR has undertaken a series of studies to assess the impacts of recreational use on the most heavily used sites to begin to better understand management actions needed to address these impacts.

OVERALL STATE/TERRITORIAL CONCLUSIONS AND RECOMMENDATIONS

Coral ecosystems in the MHI range from fair to excellent condition but are threatened by continued population growth, overfishing, urbanization, runoff, and development. Ocean outfalls, urban growth, and coastal developments (i.e., hotels, golf courses, etc.) are focal points for potential coral reef degradation. New technologies for extraction, offshore aquaculture, and bioprospecting raise concerns about the continued ability of management agencies to keep ahead of impacts to coral reef resources. There is clear evidence of overexploitation of many target food fishes and invertebrates. Key marine aquarium trade species have been heavily exploited with potential underreporting of harvest levels and insufficient enforcement, which compound problems for resource managers. Introduced aquatic alien species now threaten the structure and function of Hawaii's reefs and may outcompete endemic species. These introductions have caused complete phase shifts on some reefs.

However, significant progress has been made in mapping, monitoring, researching, and managing Hawaii's reefs. Habitat maps of the majority of the MHI provide a baseline for understanding the most critical areas for biodiversity and fisheries productivity. Research studies are improving the understanding of land-water interactions and how various stressors affect coral reefs, as well as which land-based mitigation measures are most effective. Monitoring programs are now documenting management effectiveness and improvements in ecosystem health and function. Improved socio-economic valuations of Hawaiian reef resources are fundamental for management and in seeking compensation for detrimental land-based activities (e.g., those causing sediment runoff) and/or ocean activities (e.g., ship groundings). Much of the data needed for decision-making has been obtained in recent years. Problems still remain with marine debris, but the local community is more aware and cooperative in removing it, especially from the MHI. Over the past several years, there has been tremendous success in removing a large portion (480 metric tons) of marine debris from the NWHI. The challenges of how to control the spread of alien species and eradicate them from Hawaiian reefs are just starting to be addressed, but the awareness of this threat has grown substantially in the past few years and funding is being made available to address this threat.

Studies have demonstrated that Hawaiian MPAs can effectively promote recovery of heavily exploited fish stocks without significant declines in areas outside of MPAs. FRAs along the West Hawaii coastline have successfully reduced conflicts between collectors and other resource users, promoted a sustainable fishery, and enhanced aquarium fish populations. The success of the FRAs in West Hawaii is likely to increase as aquarium fishes grow and mature within these protected areas and further replenish nearby reefs.

A new outreach campaign called Hawaii's Living Reef Program launched in 2004 is raising the public awareness of the importance of healthy coral reefs (Figure 9.34). Similar initiatives are underway to address impacts from land-based sources of pollution through Federal, state and community partnerships. The partnerships between management agencies, academia, non-governmental organizations, and user communities continue to develop, but will need ongoing financial and political support to succeed within the complex pattern of different coral reef habitats and human communities in the Hawaiian Archipelago.

Figure 9.34. Hawaii's Living Reef Program aims to raise public awareness of the importance of healthy coral reefs. As part of the campaign, educational slides like this will be shown at movie theaters around the state. Source: DAR.

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The State of Coral Reef Ecosystems of the Northwestern Hawaiian Islands

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INTRODUCTION AND SETTING

The Northwestern Hawaiian Islands (NWHI) consist of small islands, atolls, submerged banks, and reefs, and stretch for more than 2,000 km northwest of the high windward main Hawaiian Islands (MHI; Figures 10.1 and 10.2). From Nihoa and Necker Island (~7 and 10 million years old respectively) to Midway and Kure Atolls (~28 million years old), the NWHI represent the older portion of the emergent archipelago (Juvik and Juvik, 1998). The majority of the islets and shoals remain uninhabited, although Midway, Kure, Laysan Island, and French Frigate Shoals have all been occupied for extended periods over the last century by various government agencies.

The remoteness and limited reef fishing activities in the NWHI have resulted in minimal anthropogenic impacts. Large apex predators such as jacks and reef sharks are one of the most striking and unique components of the NWHI ecosystem. These top carnivores are no longer present in any abundance in the inhabited Hawaiian Islands. The NWHI flora and fauna include a large percentage of species that are endemic to the Hawaiian Islands, which are recognized for having some of the highest marine endemism in the world. The faunas of isolated oceanic archipelagos like the Hawaiian Islands represent species conservation hotspots that have become increasingly important due to the continual losses of biodiversity on coral reefs worldwide (DeMartini and Friedlander, 2004).

The NWHI represent important habitat for a number of threatened and endangered species. The Hawaiian monk seal is one of the most critically endangered marine mammals in the U.S. (1,400 individuals) and depends almost entirely on the islands of the NWHI for breeding and the surrounding reefs for sustenance. Over 90% of all sub-adult and adult Hawaiian green sea turtles found throughout Hawaii inhabit the NWHI. Seabird colonies in the NWHI constitute one of the largest and most important assemblages of seabirds in the world.

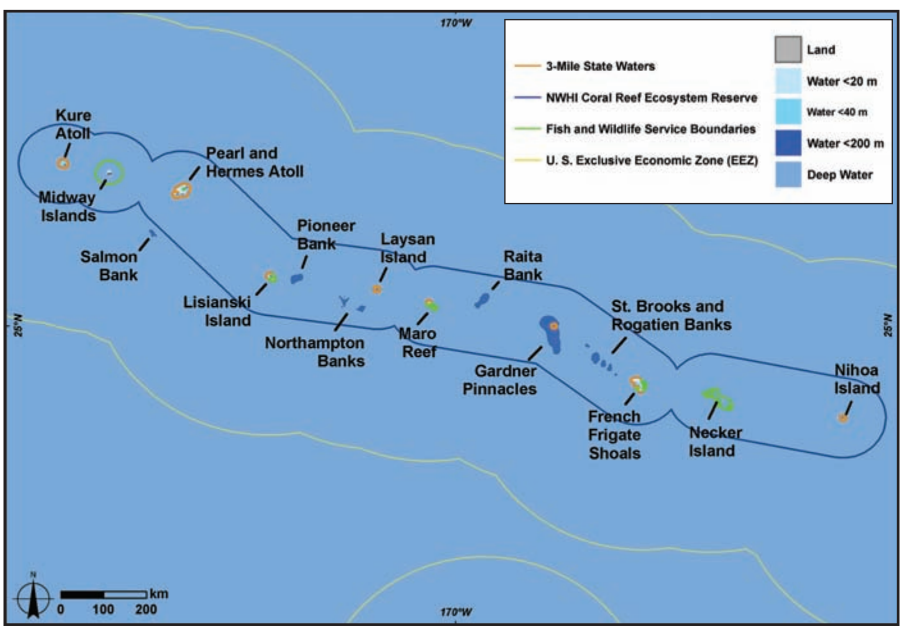

Figure 10.1. The Northwestern Hawaiian Islands, which extend across the north central Pacific, represent a vast, remote coral ecosystem that has been subjected to relatively minimal anthropogenic impacts. Map: A. Shapiro.

Despite their high latitude, similar numbers of coral species have been reported in the NWHI (57 spp.) compared to the MHI (59 spp.). Kure is the world's most northern atoll and is referred to as the Darwin Point, where coral growth and subsidence and erosion balance one another. Unlike the MHI where alien and invasive algae have overgrown many coral reefs, the reefs in the NWHI are free of alien algae and the high natural herbivory results in a pristine algal assemblage.

The reefs in the NWHI are among the few large-scale, intact, predator-

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7 NOAA Ocean Service, National Marine Sanctuary Program
8 U.S. Fish and Wildlife Service

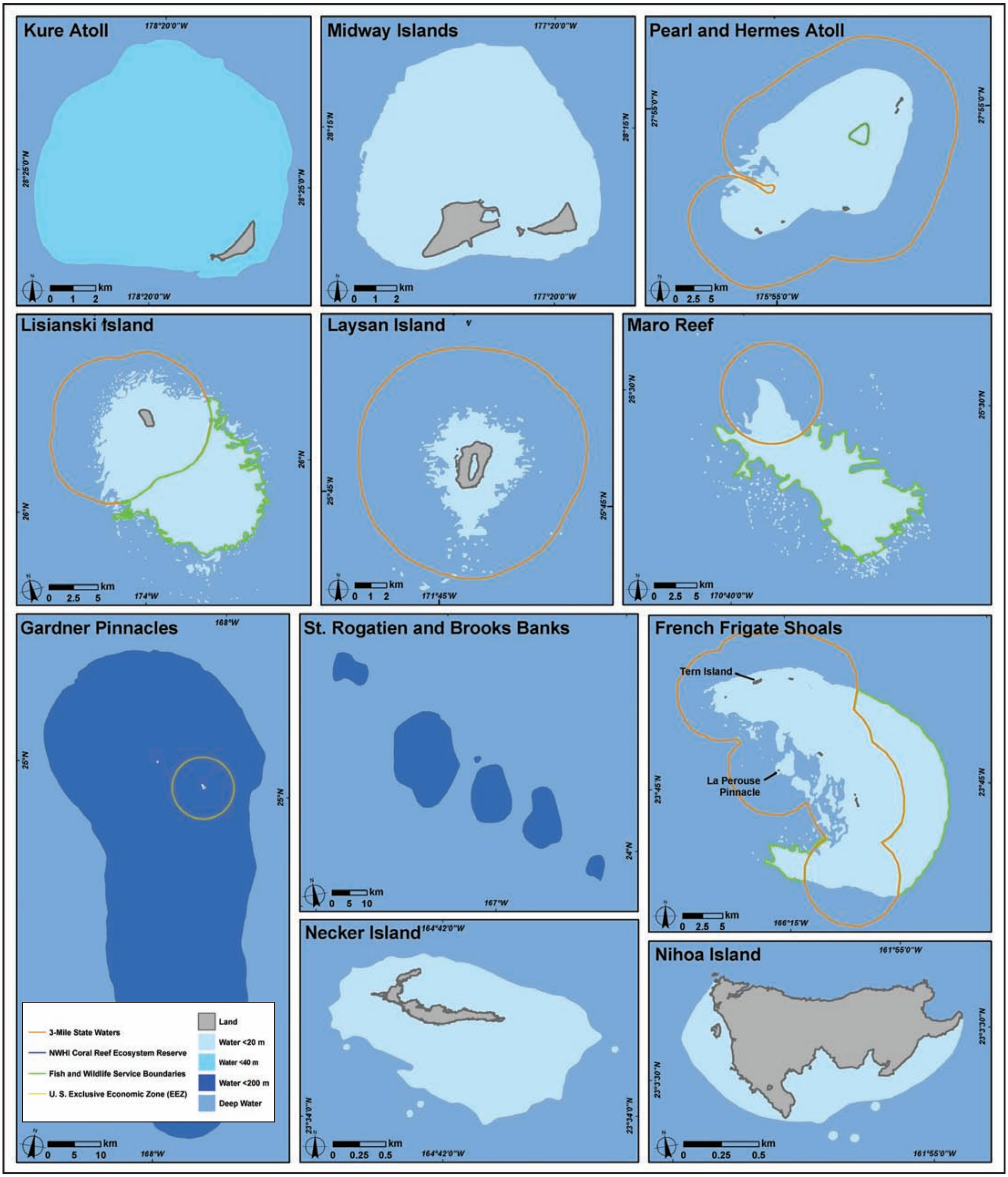


Figure 10.2. Locator map for the Northwestern Hawaiian Islands. Island abbreviations in figures and tables are as follows: Kure Atoll=KUR; Midway Atoll=MID, Pearl and Hermes Atoll=P&H; Lisianski Island=LIS; Laysan Island=LAY; Maro Reef=MAR; French Frigate Shoals=FFS; Gardner Pinnacles=GAR; Necker Island=NEC; Nihoa Island=NIH. Map: A. Shapiro.

dominated reef ecosystems remaining in the world and offer an opportunity to examine what could occur if larger more effective no-take marine reserves are established elsewhere (Friedlander and DeMartini, 2002). The nearly pristine condition of the NWHI allows scientists to study how unaltered ecosystems are structured, how they function, and how they can most effectively be preserved.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

The NWHI were impacted by mass coral bleaching during late summer 2002 (Aeby et al., 2003; Kenyon et al., in review). No records of mass coral bleaching in the NWHI exist before this time and it was previously thought that the NWHI was less susceptible to bleaching due to its high latitude location. The first documented bleaching event in the MHI was reported in 1996 (Jokiel and Brown, 2004). Bleaching was most severe at the three northern-most atolls (Pearl and Hermes, Midway, and Kure), with lesser incidences of bleaching at Lisianski Island and farther south in the NWHI. At the three northern atolls, bleaching was most severe on the backreef, moderate in the lagoon, and low on the deeper forereef (Table 10.1). Of the three coral genera that predominate at these atolls (*Porites, Montipora, Pocillopora*), *Montipora* and *Pocillopora* were most affected by bleaching (Figure 10.3), with lesser incidences observed in *Porites*. The average incidence of coral bleaching experienced in the backreef, forereef, lagoon, and channel closely corresponds to the composition of the dominant coral fauna in these zones coupled with its susceptibility to bleaching. Sea surface temperature (SST) data derived from both remotely sensed satellite observations as well as *in situ* buoys from the National Oceanic and Atmospherid Administration (NOAA) Coral Reef Early Warning System (CREWS) suggest that prolonged, elevated SST was a likely explanation for the bleaching response (Figure 10.4). This prolonged period of elevated SST coincided with a prolonged period of anomalously light wind speed, suggesting decreased wind and wave mixing of the upper ocean (Hoeke et al., 2004a, b). No significant bleaching was found the following year during surveys conducted in July 2003.

Table 10.1. Summary of towed-diver surveys conducted at the three northern-most atolls in the NWHI from September 20-28, 2002. NA=zone not surveyed at this atoll. Source: PIFSC-CRED, unpublished data.

	KURE	MIDWAY	P&H
Backreef (0.4 - 4.0 m depth)			
distance surveyed (km)	12.26	8.66	35.22
average % coral cover	10.19	11.26	10.20
average % coral bleached	64.09	77.41	66.14
Forereef *			
distance surveyed (km)	10.56	21.95	4.88
average % coral cover	6.72	1.59	5.89
average % coral bleached	14.35	15.04	75.38*
Central lagoon patch reefs (1.2 - 5.3 m depth)			
distance surveyed (km)	1.63	0	9.42
average % coral cover	18.57	NA	26.87
average % coral bleached	37.31	NA	36.81
Atoll barrier channel (6.5 - 15.8 m depth)			
distance surveyed (km)	0	6.58	2.65
average % coral cover	NA	1.46	5.16
average % coral bleached	NA	32.41	73.06
*Depth (m): 4.6-5.0 m at P&H; 9.0-16.5 m at MID and KUR			

Figure 10.3. Left panel shows *Montipora capitata* (bleached) and *Montipora turgescens* (lavender) on the northern backreef of Midway Atoll, September 2002. Right panel shows *Pocillopora meandrina* (bleached), with initial overgrowth by turf algae in the central patch reef of Kure Atoll, September 2002. Photos: J. Kenyon.

In late summer 2004, a second episode of mass coral bleaching was documented (Kenyon and Brainard, in review), as well as high mortality of *Montipora capitata* in backreef habitats at the three northern atolls. This second documented event, although milder in intensity than the 2002 event, shared numerous spatial and taxonomic patterns with the 2002 event. *In situ* temperature recorders that were deployed in July 2003 for 14 months showed that corals in shallow backreef and lagoon habitats experienced substantially more thermal stress during late summer 2004 than during 2003, exceeding local bleaching thresholds for as much as seven weeks. In both years, backreef sites at Pearl and Hermes Atoll experienced the highest incidences of bleaching.

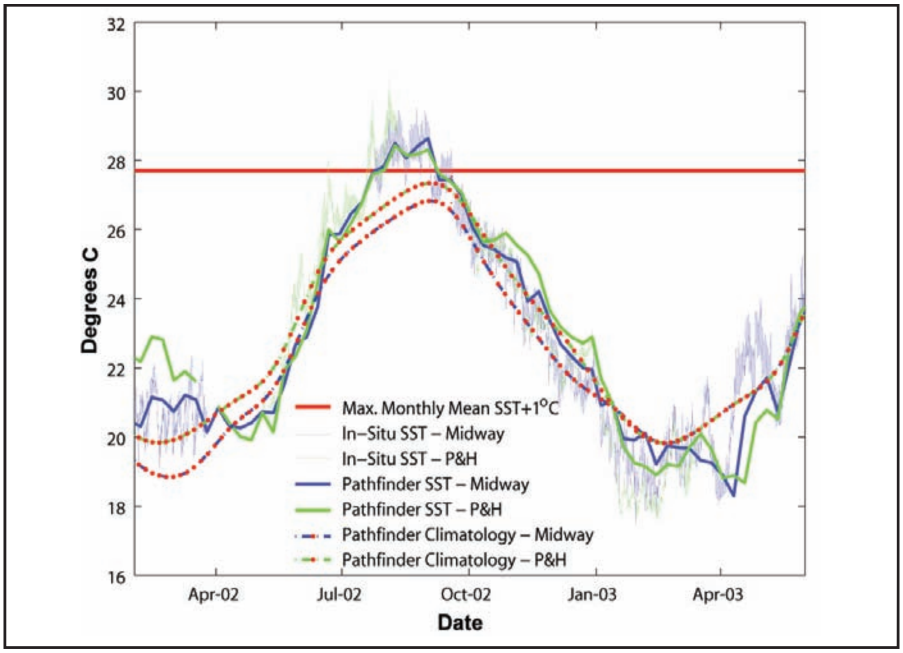


Figure 10.4. Satellite and *in situ* measurements at MID and P&H during 2002 and 2003, showing anomalously high SSTs at these northern atolls during the 2002 mass coral bleaching event. Both satellite Pathfinder SST and *in situ* SST at MID and P&H show values significantly exceeding long-term mean climatological values and the Coral Reef Watch bleaching threshold of maximum monthly mean SST plus 1° C. Source: Hoeke et al., 2004a, b.

Disease

There has been a worldwide increase in the reports of diseases affecting marine organisms. However, our ability to fully understand recent disease outbreaks is hampered by the paucity of baseline and epidemiological information on the normal disease levels in the ocean (Harvell et al., 1999). The NWHI is considered to be one of the last relatively pristine large coral reef ecosystems remaining in the world. As such, it provides the unique opportunity to document the normal levels of disease in a coral reef system exposed to limited human influence.

Little work had been done regarding coral disease in the NWHI with the exception of one study by Work et al. (2002) in which 16 sites were surveyed at French Frigate Shoals. They reported tumors on *Acropora* (Figure 10.5) as well as lesions associated with parasites, bacteria and fungi on a number of different coral species. During a multi-agency cruise conducted in September 2002, disease investigation was incorporated into the protocol and a characterization of coral disease was initiated. In July 2003, surveys were conducted, at 73

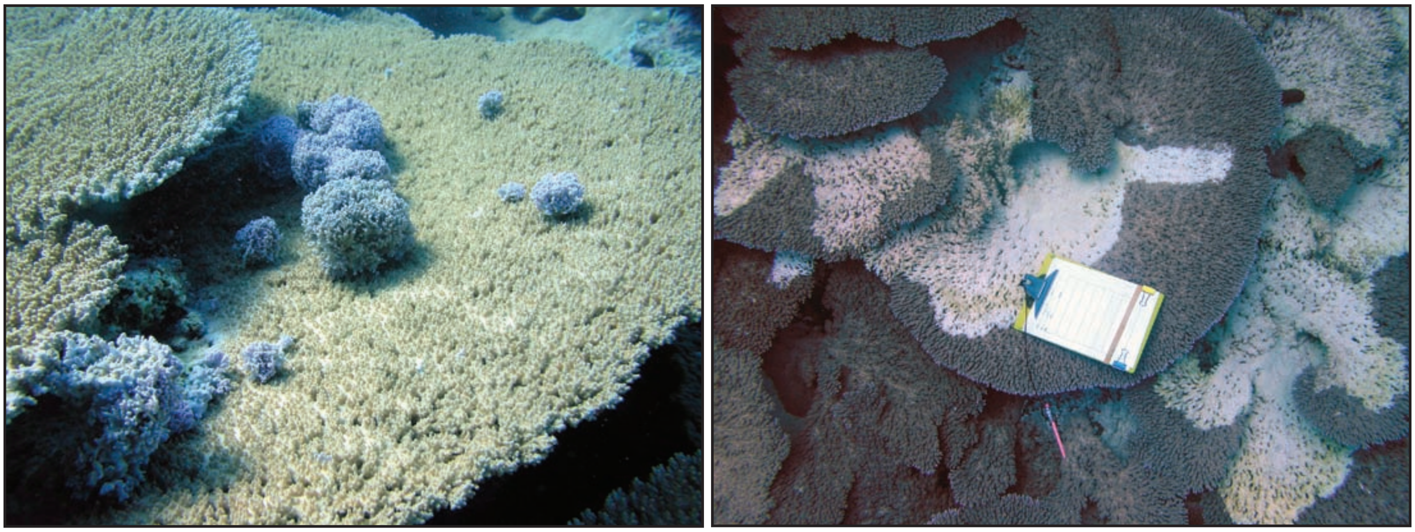


Figure 10.5. Two examples of disease in *Acropora cytherea* colonies in the NWHI. Left photo shows a colony of *A. cytherea* with tumors; the colony in the right photo shows signs of severe tissue loss in FFS. Photos: G. Aeby.

sites throughout the NWHI, to quantify and further characterize coral disease. During this survey, evidence of coral disease was found at very low levels at 68.5% of the sites across all regions. The most common disease was *Porites* trematodiasis caused by the digenetic trematode, *Podocotyloides stenometra* (Aeby, 1998). This disease was widespread (57.5% of the sites) and is known to exclusively affect *Porites* spp. coral. Numerous other conditions were also observed but at much lower frequency of occurrence (1.4%-16.4% of the sites). The majority of the observed disease signs were distinct from what has been previously described from other coral reef systems. Numbers of colonies affected by *Porites* trematodiasis were not enumerated but other types of conditions were found to be present at low levels. The overall average prevalence of disease (no. diseased colonies/total no. colonies) was estimated at 0.5% (range 0-7.1%). A disease outbreak at one site at French Frigate Shoals resulted in massive tissue on large acroporid table corals (Aeby, in review; Figure 10.5b).

Coral genera were found to exhibit differences in types of conditions and prevalence of disease (Figure 10.6). Pocilloporids, which are one of the most common types of corals found on the reefs of the NWHI, seemed comparatively resistant to disease. Only a single colony of *Pocillopora* with disease signs was found out of more than 6,000 colonies searched (prevalence=0.016%). In contrast, Acroporids make up less than 5% of the coral community yet showed the greatest damage due to disease and the highest prevalence of disease (prevalence=2.7%). Studies are planned to further investigate and monitor the incidence of coral diseases in the NWHI.

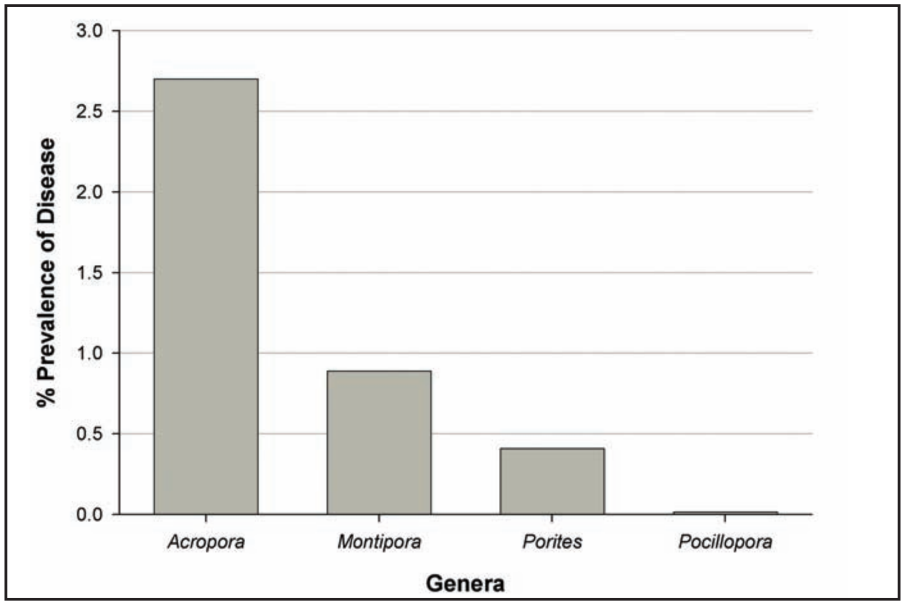


Figure 10.6. Differences in overall prevalence of disease among coral genera in the NWHI. Source: G. Aeby, unpublished data.

Storm and Wave Events

Tropical Storms

The coral reef ecosystems of the NWHI are only rarely in the path of tropical storms and hurricanes. On average, between four and five tropical cyclones are observed annually in the Central Pacific. This has ranged from zero, most recently in 1979, to 11 in 1992 and 1994. Few tropical storms that develop in the region become hurricanes (Figure 10.7) and those that do tend to be relatively weak. Both of the hurricanes nearing the NWHI since 1979 were category 2 on the Saffir/Simpson scale (maximum windspeeds of 96-110 mph) or weaker. Hurricane Patsy (in 1959) was the strongest hurricane reported

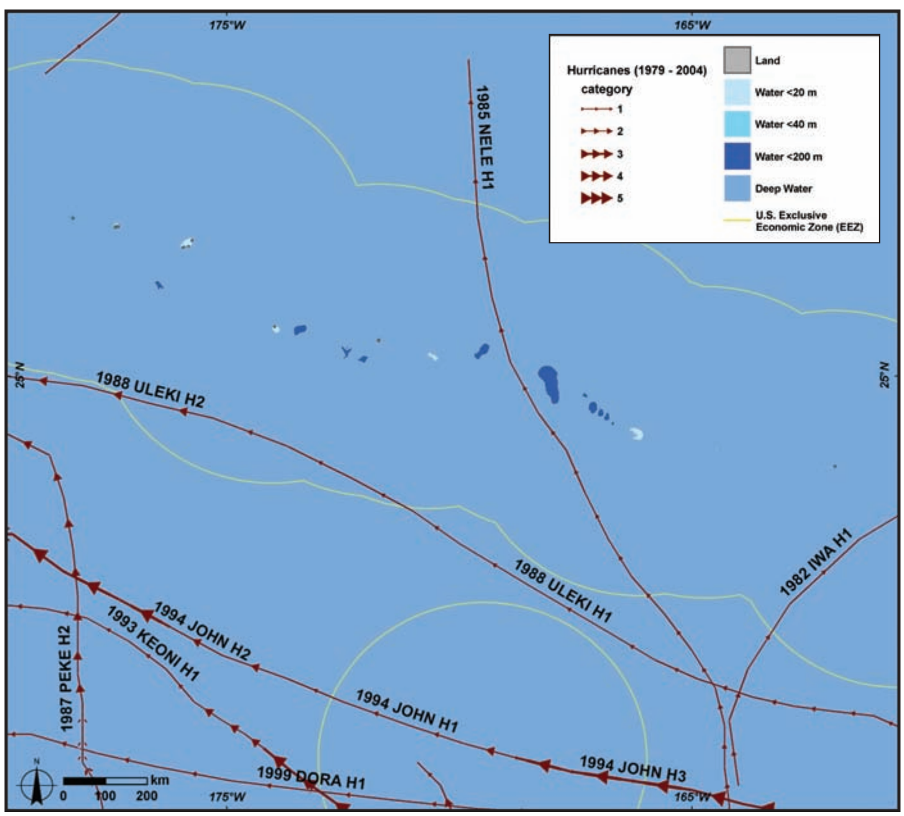


Figure 10.7. The path and magnitude of storms passing near the NWHI from 1979-2004. Year of storm, storm name and storm strength on the Saffir-Simpson scale (H1-5) are indicated for each. Map: A. Shapiro. Data: NOAA Coastal Services Center.

for the NWHI in the past 50 years, with wind speeds exceeding 100 knots as it approached and passed between Midway and Kure Atolls. None of the other hurricanes reported to have occurred in the NWHI have had winds exceeding 100 knots.

The impacts of these tropical storm events on the coral reef ecosystems of the NWHI are not documented. Though not observed, any damage to reef habitats associated with these storms would have been caused primarily by extreme wave energy events. No significant tropical storms have been observed in the NWHI since Hurricane Nele passed near Gardner Pinnacles in 1985. In summary, tropical storms represent a potential, but infrequent, threat to the coral reefs of the NWHI.

Extratropical Storms and Significant Wave Events

While the impacts of tropical storms on the coral reef ecosystems of the NWHI are relatively rare, the impacts of large wave events resulting from extratropical storms passing across the North Pacific each winter are thought to be significant. Most large (5-10+ m) wave events approach the islands and atolls of the NWHI from the west, northwest, north, and northeast, with the highest energy generally occurring from the northwest sector. The southern sides of most of the islands/atolls of the NWHI are exposed to fewer and weaker wave events. Average wave energy and wave power (energy transferred across a given area per unit time) is generally very high (~1.3 watts per meter, or W/m) between November and March and relatively low (~0.3 W/m) between May and September (Figure 10.8). October and April are generally transition months between the high energy winter months and the low energy summer months. In addition to mean wave power values increasing during the winter months, it is particularly noteworthy that the average maximum wave power during the winter months, associated with these storm events, is typically between 8 and 10 W/m. These extreme wave events (10+ m waves) subject the shallow water coral reef communities to at least one order of magnitude more energy than the typical winter waves. As such, these extreme wave events are believed to play a fundamental role in forming and maintaining biogeographic (spatial and vertical) distributions of corals, algae, and fishes of the coral reef ecosystems of the NWHI.

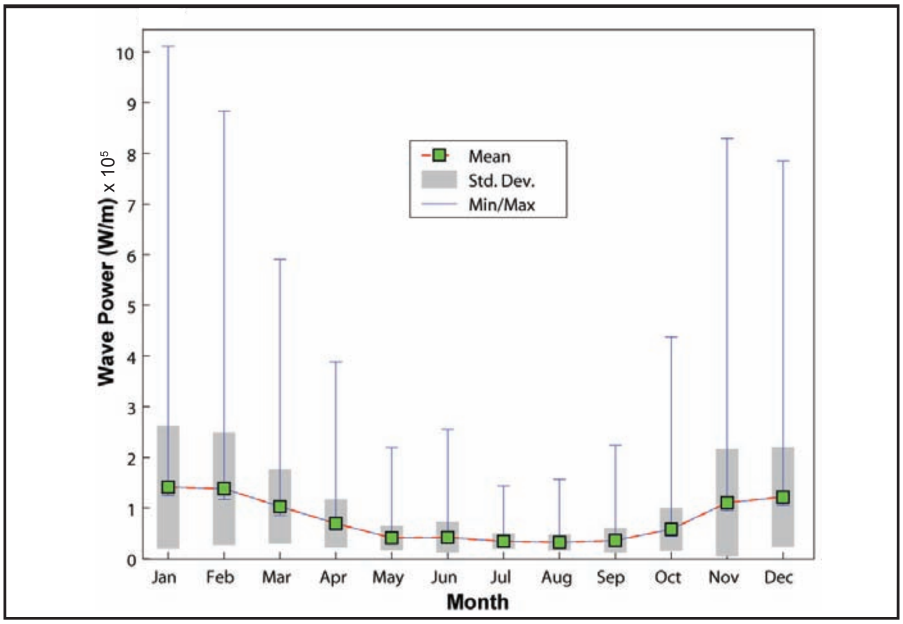


Figure 10.8. Climatological values of wave power (W/m) derived from NOAA buoy # 51001 located near NIH from 1981 to 2003. Green squares=monthly means; Shaded rectangles=standard deviation; Range bars=maximum and minimum monthly means. Data: NOAA National Data Buoy Center.

Coastal Development and Runoff

Previous land development and disturbance in the NWHI consisted of guano mining at Laysan Island a century ago, naval base construction at Midway and French Frigate Shoals during the first half of the 20th century, and U.S. Coast Guard (USCG) LORAN station construction and operation at Kure and French Frigate Shoals for several decades following World War II (WWII). The affected islands are coralline, small, porous, and generate little runoff and soil erosion. During recent decades there has been very little land development except small-scale conversion of abandoned USCG buildings on Tern Island at French Frigate Shoals and Green Island at Kure to wildlife research stations.

In-water development was limited to dredging of navigation channels for the naval bases at Midway and French Frigate Shoals during the middle of the 20th century. The only recent coastal construction at any of the NWHI has been the repair of the seawall protecting Tern Island's small runway and buildings and construction of a small boat ramp at French Frigate Shoals in 2004. This project is now completed and marine environments monitored before construction were re-monitored in late 2004. Construction impacts were minimal, and removal of derelict sheet piling in the area eliminated injury and death to endangered monk seals, threatened green sea turtles, and migratory seabirds that had previously become trapped.

The Midway Naval Air Station supported several hundred to several thousand soldiers and dependents during the pre- to post- WWII era before Midway was transferred to the U.S. Fish and Wildlife Service (USFWS) in 1996. Human population levels have been very small during the past several decades elsewhere in the NWHI, with only a few workers and volunteers now at the permanent wildlife stations at Laysan, French Frigate Shoals, and Midway, and the seasonal wildlife camps at Kure, Lisianski, and Pearl and Hermes. Due to the lack of any coastal development in the NWHI, runoff-induced impacts to nearshore reefs are non-existent.

Coastal Pollution

While no National Pollutant Discharge Elimination System (NPDES) permits or other industry permits were present in the NWHI, there has been a diverse history of use including: guano mining, fishing camps, USCG LORAN stations, U.S. Navy airfields and bases, and various Cold War missions. This history of use has left a legacy of contamination on many of the atolls. Contamination at all these sites includes offshore debris such as batteries (lead and mercury), transformers, capacitors, and barrels of chemical waste. Uncharacterized, unlined landfills remain on all of these islands. Specific known areas of contamination are the following:

Kure and French Frigate Shoals both have point sources of polychlorinated biphenyls (PCBs) due to former USCG LORAN stations. While the USCG has mounted cleanup actions at both sites, contamination remains and is found in island soils and in nearshore sediments and biota.

French Frigate Shoals and Pearl and Hermes were both used for WWII seaplane refueling. This activity is suspected to have been a source of petroleum contamination during operations.

Midway Atoll was the site of a U.S. Navy airfield. Before transfer to the U.S. Department of the Interior in 1996, the Naval installation was part of the Base Realignment and Closure (BRAC) that identified and cleaned up numerous contaminated sites throughout the Atoll. Contamination identified and remediated included petroleum in the groundwater and nearshore waters, pesticides (e.g., DDT) in the soil, PCBs in soil, groundwater, and nearshore sediments and biota, metals such as lead and arsenic in soil and nearshore waters, and unlined, uncharacterized landfills. See the BRAC documents for a complete inventory (http://www.defenselink.mil/brac/). While most of the known areas were remediated, several areas warrant continued monitoring for potential releases. Since closure, the Navy has returned on several occasions for further remediation.

Plutonium from the aboveground nuclear tests at Johnston Atoll in the 1960s has been detected in corals at French Frigate Shoals, 700 miles to the north. Finally, floating debris is a constant source of potential contamination to the islands and surrounding waters. A container of the pesticide carbofuran is suspected to have washed ashore at Laysan and killed many invertebrates. Named the 'Dead Zone', the area remained a hazard on the Island from 1987 until remediated by the USFWS in 2002. Debris continues to wash ashore on all of the islands and can cause localized adverse impacts. At Laysan, debris washed ashore or found in the surf over the last year has included unmarked bottles, military flares, a barrel marked diisocyanate (a carcinogen), and petroleum.

Tourism and Recreation

Tourism, sport fishing, recreational boating, and diving are not compatible with protection of fish and wildlife and their habitats in the Hawaiian Islands National Wildlife Refuge, and therefore are not permitted. Uses, such as research, that improve management of fish and wildlife are regulated through Special Use Permits issued by the USFWS. Midway Atoll National Wildlife Refuge (NWR) promotes visitor use including diving, snorkeling, beachgoing, nature photography, guided tours, birding, historical tours, and catch-and-release sport fishing. Visitor use in recent years, however, has been limited by the lack of routine, affordable air charter service to transport visitors to and from Midway Atoll NWR.

Fishing

Fishing and other resource extraction in the NWHI have been mostly limited to two commercial fisheries: the ongoing NWHI bottomfish fishery, and the now-closed NWHI lobster trap fishery. The bottomfish fishery has targeted several species of deepwater (generally >130-200 m) snappers (Lutjanidae) and one endemic species of epinepheline grouper (Serranidae) out of a total of a dozen common Bottomfish Management Unit Species (BMUS; WPFMC, 2004). This fishery is divided into two management zones: the Mau zone, which is closer to the MHI, and the more distant Hoomalu zone. The lobster trap fishery, which had historically targeted only the endemic Hawaiian spiny lobster, *Panulirus marginatus*, began targeting the non-endemic slipper lobster, *Scyllarides squammosus*, in 1998. The NWHI lobster trap fishery closed in 2000 because of growing uncertainty in the population models used to assess stock status (DeMartini et al., 2003).

Relatively few BMUS are conspicuous members of the shallow-reef ecosystem (<100 m) in the NWHI: amberjack (*Seriola dumerili*), although frequently caught while targeting other deep-slope species, are not retained; giant trevally (*Caranx ignobilis*), while the most abundant of the BMUS on shallow reefs (Friedlander and DeMartini, 2002), are neither caught nor sold in large numbers (WPFMC, 2004). Only two species, green jobfish (*Aprion virescens*) and the endemic Hawaiian grouper (*Epinephelus quernus*), occur in shallow reef habitats and also contribute substantively to NWHI Bottomfish landings (WPFMC, 2004), with jobfish by far the more abundant of these two species on shallow NWHI reefs (Friedlander and DeMartini, 2002). Existing time series data for Mau and Hoomalu Zone landings per trip (untargeted catch per unit effort [CPUE]) suggest no obvious pattern of temporal change for jobfish or for Hawaiian grouper in the Mau Zone, although there is a declining trend in CPUE for Hawaiian grouper in the Hoomalu Zone (Figure 10.9). A more accurate CPUE metric (targeted catch per unit of effort) is not available because species-specific effort data are lacking (R. Moffitt, pers. comm.).

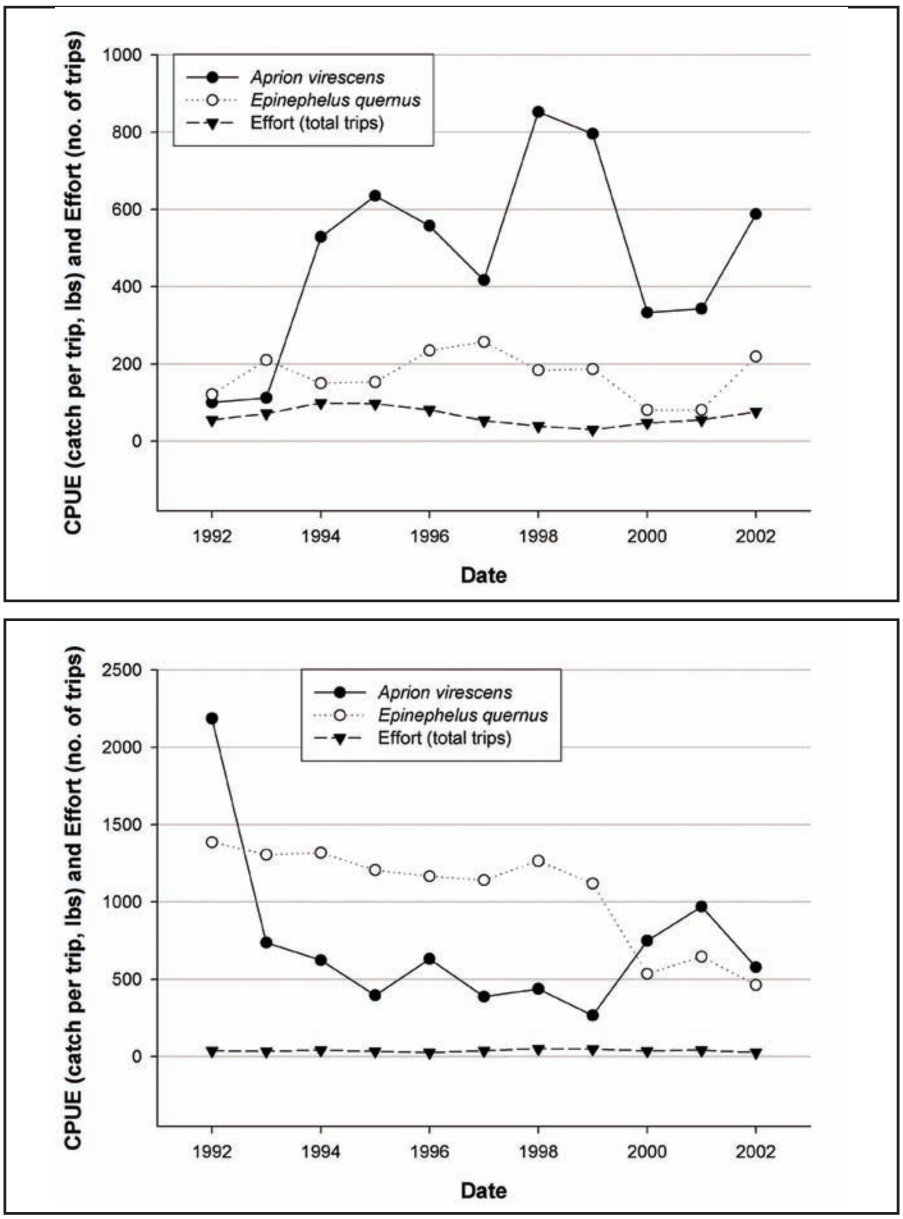


Figure 10.9. Time series of landings per trip in the Mau (upper panel) and Hoomalu (lower panel) zones for jobfish (*Aprion virescens*) and for Hawaiian grouper (*Epinephelus quernus*). Total (untargeted) effort (no. of trips) is also noted. Source: Western Pacific Fisheries Management Council, 2004.

CPUE data for the fishery-dependent NWHI lobster trap fishery and for fishery-independent lobster research surveys suggest successive half order of magnitude decreases in abundance between the early 1980s-early 1990s and between the early-to-late 1990s, respectively (Figure 10.10; DeMartini et al., 2003).

Other sources of resource extraction in the NWHI have been either nonexistent or brief, low impact, or both. There has never been a precious coral fishery in the NWHI (the fishery in the MHI has been inoperative since 2001). Small-scale (one boat), short-lived (single season) commercial fishing using bottom longlines to catch reef sharks was conducted at French Frigate Shoals and nearby banks in the year 2000. During one 21-day fishing trip, the vessel caught 990 sharks in the NWHI consisting mainly of sandbar shark, *Carcharhinus plumbeus* (69%), Galapagos shark, *Carcharhinus galapagensis* (18%), and tiger shark, *Galeocerdo cuvier* (10%) (Vatter, 2003). Extraction of shallow reef fishes in the NWHI for the ornamental trade has been almost non-existent due to their relatively inaccessible location and the establishment of the NWHI Coral Reef Ecosystem Reserve (CRER) in January 2001. Extraction of food and aquarium fish by recreational fishers has similarly been protected (and recently prohibited in Federal waters) and is currently being proposed for closure in State waters. Collections of voucher and other research specimens of shallow-water reef fishes, corals, other invertebrates, and algae in the NWHI has been periodic (typically late summer) and of trivial magnitude (less than several hundred pieces weighing less than a few tens of kilograms in aggregate, per year). All such activity continues to be regulated by NWR Special Use Permits, which are issued only to qualified researchers by the USFWS, and State of Hawaii Scientific Collecting Permits.

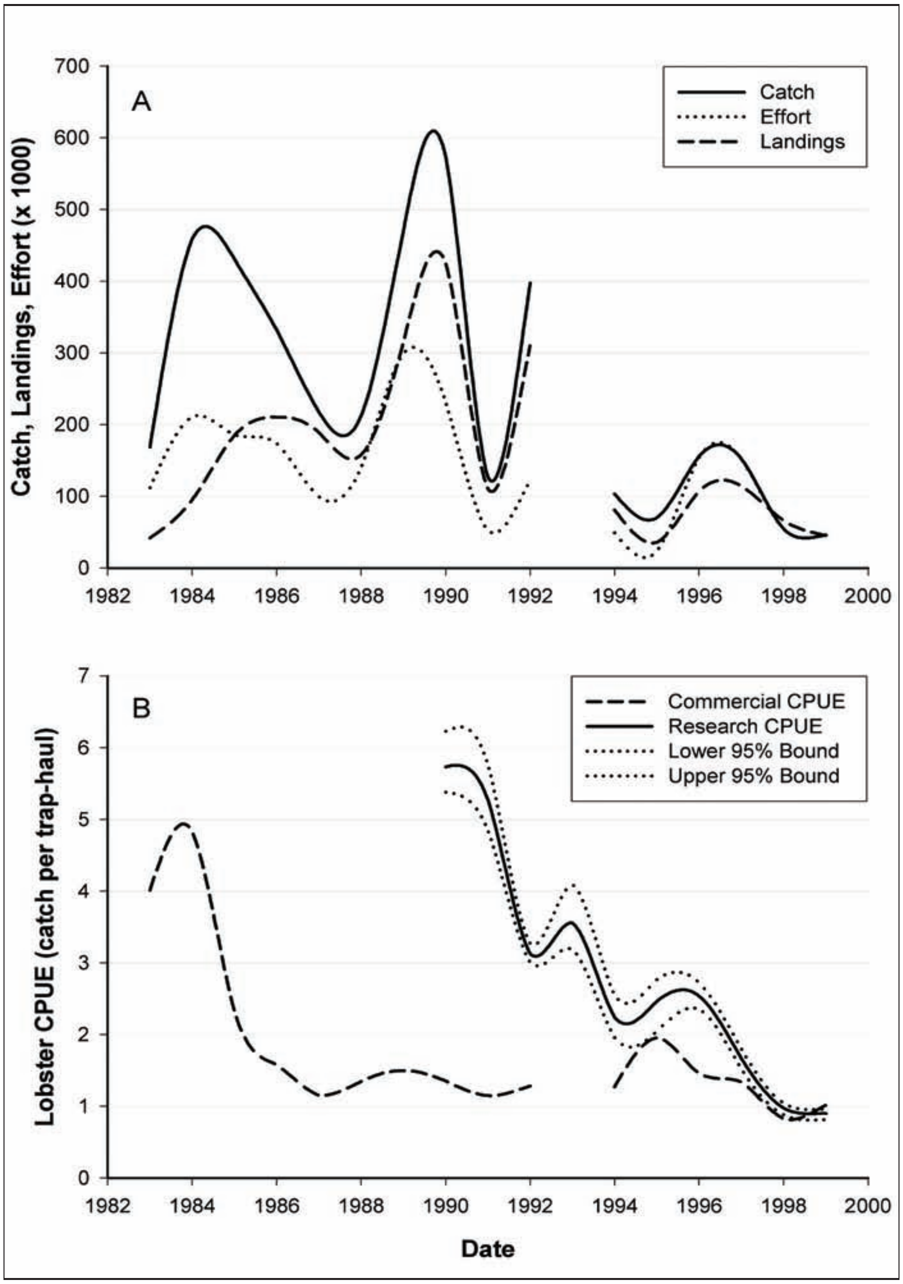


Figure 10.10. Time series plots of the NWHI commercial trap catch. Upper panel: Hawaiian spiny lobster landings (no. of lobsters x 1000), and effort (no. of trap-hauls x 1000); Lower panel: Total spiny lobster CPUE at Necker Bank, during the 1983-1999 comercial fishing seasons and as assessed on 1988-1999 lobster research cruises. Source: DeMartini et al., 2003.

Trade in Coral and Live Reef Species

Several species of reef fish found in the NWHI are highly desirable in the live aquarium fish trade. Of these, the endemic masked angelfish (*Genicanthus personatus*, Figure 10.11) is the most prized (R. Pyle, pers. comm.). Although two attempts have been made in recent years to access the NWHI to collect *Genicanthus* for the aquarium trade outside of Federally protected waters, the logistical and financial challenges of mounting such collecting trips and the difficulty of transporting live fish back to market in good condition have precluded any further efforts to obtain these fish.

Recently, the Waikiki Aquarium has spawned and reared masked angelfish in captivity (Debelius et al., 2003). With the feasibility of aquaculture of this species demonstrated, it is unlikely that a cost-effective commercial fishery for this species will ever exist in the NWHI. Other desirable aquarium species found in the NWHI, such as the Japanese angelfish (*Centropyge interrupta*, Figure 10.11) are not endemic, are available from more accessible localities for the aquarium trade, and have also been spawned and reared in captivity.

Figure 10.11. Left photo shows Endemic masked angel (*Genicanthus personatus*), and right photo shows Japanese angelfish (*Centropyge interrupta*). Both are valuable aquarium fish species. Photos: J. Watt.

Commercial harvesting of live coral for the aquarium trade is not known to have occurred in the NWHI and is now illegal or unauthorized within the NWHI CRER and the two NWRs and is also illegal within State waters. Table coral (*Acropora cytherea*) and several congeners are essentially absent in the MHI but are common at French Frigate Shoals and neighboring reefs in the NWHI (Grigg et al., 1981; Grigg, 1981; Maragos et al., 2004). However, *A. cytherea* is also common at many readily accessible locales throughout the Indo-Pacific region, and it is unlikely that an economically viable and legal fishery for live corals could exist in the remote NWHI. Still, one dead specimen of *A. cytherea* attributed to the NHWI was available for sale on eBay™ in 2002.

Ships, Boats, and Groundings

The NWHI region has a wide variety of submerged artificial structures including shipwrecks, aircraft wrecks, submerged landings, and unexploded ordinance. The systematic investigation of these objects in the NWHI began in 2002. Currently there are 52 known shipwrecks in the region, including rafts, whaling vessels, navy frigates, tankers, and modern fishing boats. Approximately 12 vessels have been located. In addition there are 67 known plane losses in the region, mainly naval aircraft from WWII, although only two have been located. Some of these ship and aircraft wreck sites fall into the category of war graves associated with major historic events. Unexploded ordinance and debris also exists in discrete locations.

Wrecks of historic sailing vessels in high energy environments are considered artifact “scatter sites”, and do not pose an immediate or critical threat to their surroundings. The preservation and management of heritage resources are mandated by state and Federal laws. More modern shipwrecks, such as the fishing vessels *Hoei Maru #5* and *Paradise Queen II* at Kure, or the tanker *Mission San Miguel* lost at Maro Reef, are greater threats to reef ecosystems. NOAA’s Damage Assessment Center maintains a list of sites for the NWHI. Mechanical damage from the initial grounding, subsequent re-deposition of wreck material by storm surge, fishing gear damage to reef and species, and fuel/oil or hazardous contents are all issues to be considered in protecting the integrity of the environment. Understanding the difference between historic wrecks and modern wrecks is crucial to proper (and legal) remediation and restoration efforts.

Marine Debris

Marine debris, mostly derelict fishing gear from distant fisheries around the Pacific Rim, is one of the greatest anthropogenic impacts to the reefs of the NWHI. These large nets damage corals and create an entanglement problem for monk seals, seabirds, and other marine organisms. Since 1996, the NOAA Fisheries Pacific Islands Fisheries Science Center (PIFSC), has led a highly successful multi-agency effort to remove and recycle over 329 metric tons of derelict fishing gear and other marine debris from the coral reef ecosystems of the NWHI (Table 10.2). The PIFSC Coral Reef Ecosystem Division (CRED) collaborates with NOAA’s National Ocean Service, NWHI Ecological Reserve, State of Hawaii, City and County of Honolulu, USFWS, USCG, U.S.

Table 10.2. Marine debris collection (kg) in the NWHI since 1996. Source: PIFSC-CRED.

REEF	1996/1997	1998	1999	2000	2001	2002	2003	TOTAL
KUR				3,298	23,516	1,567	1,227	**29,608**
MID			9,091	7,457			18,620	**35,168**
P&H	2,223		8,676	9,866	30,501	92,955	83,030	**227,251**
LIS			5,444	2,035	830	1,087	3,589	**12,985**
LAY					1,075	1,231	2,155	**4,461**
FFS	2,145	7,500	2,145		5,625	432	2,246	**20,093**
Total	**4,368**	**7,500**	**25,356**	**22,656**	**61,547**	**97,272**	**110,867**	**329,566**

Navy, University of Hawaii, Sea Grant, Hawaii Metals and Recycling, Honolulu Waste Disposal, and other local agencies, businesses, and non-governmental partners. Additional shore- and land-based recovery of derelict fishing gear was conducted in cooperation with the NOAA monk seal field camp, State of Hawaii, and USFWS. The primary goals of these efforts have been to assess, document, and remove derelict fishing gear from the coral reef ecosystems of the NWHI. In addition, strategic research has been conducted to better understand the dynamics of marine debris, particularly accumulation rates and estimates for specific sites labeled High Entanglement Risk Zones (HERZ) for endangered Hawaiian monk seals (*Monachus schauninslandi*). Marine debris survey and collection activities have been conducted at Kure, Midway, Pearl and Hermes, Lisianski, Laysan and French Frigate Shoals.

The past and current marine debris removal operations have targeted the accumulation in the NWHI over the past several decades, with tremendous success in both the direct removal of debris from the ecosystem and increasing public awareness of the issue. Based on the amount removed to date, it is estimated that at most, 1,000 tons of debris have accumulated in the NWHI over the past several decades. Assuming accumulation rates have been relatively constant over the past four decades, long-term average accumulation rates are approximately 25 tons per year. At Kure, annual towboard surveys of the HERZ along the northeastern edge of Green Island elicited evidence of marine debris accumulation (2002: 63 nets/km^2; 2003: 73 nets/km^2).

Until substantial efforts are made to significantly reduce the sources of debris and until debris can be effectively removed at sea, similar amounts are expected to continue accumulating indefinitely in the reef ecosystems of the NWHI.

Aquatic Invasive Species

Aquatic invasive species in the NWHI have only recently become an issue of interest, which has been driven by survey efforts in the MHI. The status of the taxonomy of many non-coral marine invertebrate groups is not fully developed for the NWHI and this does not allow comprehensive species inventories to be produced, although efforts to correct this are presently underway. In addition, when large-scale faunal surveys began in shallow water coral reef habitats in the NWHI in 2000 only two expeditions with such a focus had ever been to the area during the previous 100 years.

The data concerning marine aquatic invasive species in the NWHI was collected from a single focused marine invasive species survey by the Bishop Museum at Midway and from multidiscipline efforts conducted under the auspices of the Northwestern Hawaiian Islands Rapid Assessment and Monitoring Program (NOWRAMP) in 2000 and 2002, and the PIFSC-CRED efforts in 2000, 2002, and 2003.

Results of these efforts have recorded a total of eleven aquatic invasive marine invertebrate, fish, and algal species in the NWHI. Table 10.3 shows the species, their native ranges, their present status in the NWHI, and the hypothesized or documented mechanism of their introduction. The magnitude of the problem of aquatic invasive species is far greater in the MHI than the NWHI. Efforts in the NWHI should be focused on minimizing the likelihood of these remote habitats being exposed to aquatic invasive species through anthropogenic means. This can be achieved by outreach and education directed towards all activities that have the potential for acting as mechanisms of transport.

Table 10.3. Marine invasive species in the NWHI. Sources: Zabin et al., 2003; Godwin, 2002; DeFelice et al., 2002; Godwin, 2000; DeFelice et al., 1998.

SPECIES	TAXA	NATIVE RANGE	PRESENT STATUS IN NWHI	MECHANISM OF INTRODUCTION
Hypnea musciformis	Algae	Unknown; Cosmopolitan	Not Established; in drift only (MAR)	Intentional introduction to MHI (documented)
Diadumene lineata	Anemone	Asia	Unknown; on derelict net only (P&H)	Derelict fishing net debris (documented)
Pennaria disticha	Hydroid	Unknown; Cosmopolitan	Established (P&H, LAY, LIS, KUR, MID)	Fouling on ship hulls (hypothesized)
Balanus reticulatus	Barnacle	Atlantic	Established (FFS)	Fouling on ship hulls (hypothesized)
Balanus venustus	Barnacle	Atlantic and Caribbean	Not Established; on vessel hull only (MID)	Fouling on ship hulls (documented)
Chthamalus proteus	Barnacle	Caribbean	Established (MID)	Fouling on ship hulls (hypothesized)
Amathia distans	Bryozoan	Unknown; Cosmopolitan	Established (MID)	Fouling on ship hulls (hypothesized)
Schizoporella errata	Bryozoan	Unknown; Cosmopolitan	Established (MID)	Fouling on ship hulls (hypothesized)
Lutjanus kasmira	Fish	Indo-Pacific	Established (NIH, NEC, FFS, MAR, LAY, and MID)	Intentional introduction to MHI (documented)
Cephalopholis argus	Fish	Indo-Pacific	Established (NIH, NEC, FFS)	Intentional introduction to MHI (documented)
Lutjanus fulvus	Fish	Indo-Pacific	Established (NIH and FFS)	Intentional introduction to MHI (documented)

Eleven species of shallow-water snapper (Lutjanidae) and grouper (Serranidae) were purposefully introduced to the main islands of the Hawaiian Archipelago in the late 1950s and early 1960s. Two snappers, the bluestripe snapper (*Lutjanus kasmira*) and the blacktail snapper (*L. fulvus*), and one grouper, the peacock grouper (*Cephalopholis argus*), are well-established and have documented patterns of colonization along the island chain (Randall, 1987).

Bluestripe snappers have been by far the most successful fish introduction to the Hawaiian coral reef ecosystem. From some 3,200 individuals introduced on the island of Oahu in the 1950s, the population has expanded its range widely and has been reported as far north as Midway in the NWHI (~2,400 km; Figure 10.12.). These records suggest a dispersal rate of about 33-130 km/yr. The other two species have only been recorded as far north as French Frigate Shoals and are present in much lower numbers than bluestripe snappers.

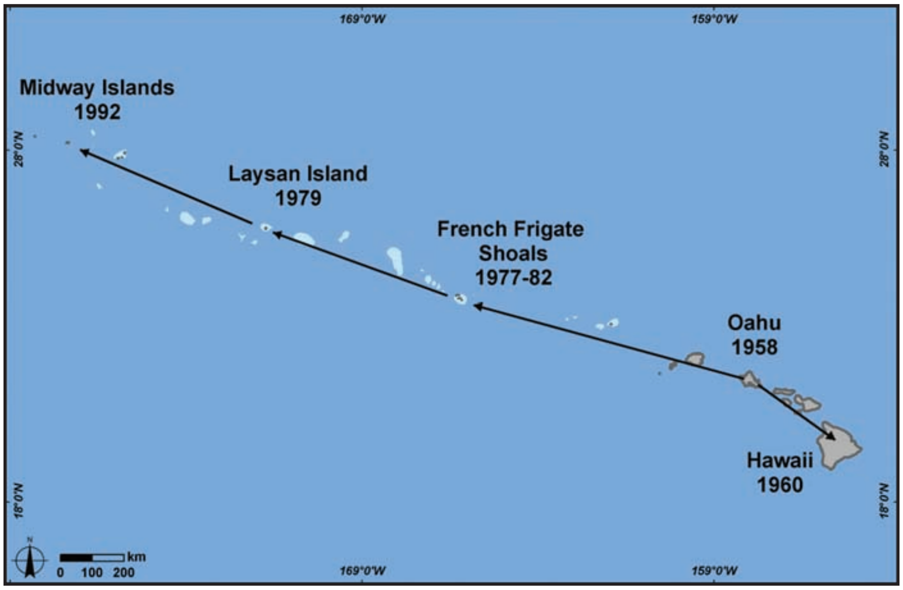


Figure 10.12. The spread of bluestripe snapper, *Lutjanus kasmira*, throughout the Hawaiian archipelago. Map: A. Shapiro. Source: Sladek-Nowlis and Friedlander, 2004.

Security Training Activities

Areas between Kauai and Nihoa are sometimes subjected to closure when missile tests are conducted at the Pacific Missile Testing Range on Kauai.

Offshore Oil and Gas Exploration

No offshore oil or gas exploration occurs in Hawaii.

CORAL REEF ECOSYSTEMS—DATA-GATHERING ACTIVITIES AND RESOURCE CONDITION

Description of Coral Reef Monitoring, Research and Assessment Activities

The monitoring programs that are currently collecting data in the NWHI are listed in Table 10.4. Many of the locations where monitoring has occurred recently are shown in Figure 10.13.

Table 10.4. Monitoring programs in the NWHI.

MONITORING PROGRAM	OBJECTIVES	YEAR EST.	FUNDING	AGENCIES
Northwestern Hawaiian Islands Reef Assessment and Monitoring Program	Monitor fishes, algae, coral and other invertebrates	2000	NOAA, USFWS, HCRI	PIFSC-CRED, DAR, USFWS, UH, NOS, numerous other institutions
Monk Seal Forage Base Study	Track the temporal dynamics of the shallow-reef fish forage base of monk seals	1992-2000	NOAA	PIFSC
Marine debris program	Oceanographic conditions and the rate of marine debris accumulation	1996	NOAA	PIFSC-CRED, UH, USFWS, DAR, USCG
Oceanography program	Water chemistry, circulation patterns	2000	NOAA	PIFSC-CRED, UH
Fishery independent lobster monitoring	Monitor lobster using fishery-independent sampling	1983	NOAA	PIFSC
Fishery Monitoring and Economics Program	Fisheries catch and effort statistics	1948	NOAA	PIFSC, DAR
Marine mammal research program	Monitor and assess reproductive subpopulations	1985	NOAA	PIFSC, USFWS
Marine turtle research program	Monitor selected sea turtle breeding sites	1973*	NOAA, USFWS	PIFSC, USFWS
Seabird monitoring	Monitor selected nesting seabird species	1978 (Albatross annually)	USFWS	USFWS
Coral monitoring	Monitoring of coral at permanent sites	2000	HCRI, USFWS	USFWS, PIFSC-CRED

PIFSC – Pacific Islands Fisheries Science Center
CRED – Coral Reef Ecosystem Division, PIFSC, NOAA Fisheries
DAR – Hawaii Division of Aquatic Resources, Department of Land and Natural Resources
USFWS – U.S. Fish and Wildlife Service
NOS – NOAA Ocean Service
UH – University of Hawaii
HICRI – Hawaii Coral Reef Initiative
*USFWS personnel stationed at French Frigate Shoals since 1978 to monitor turtle breeding sites.

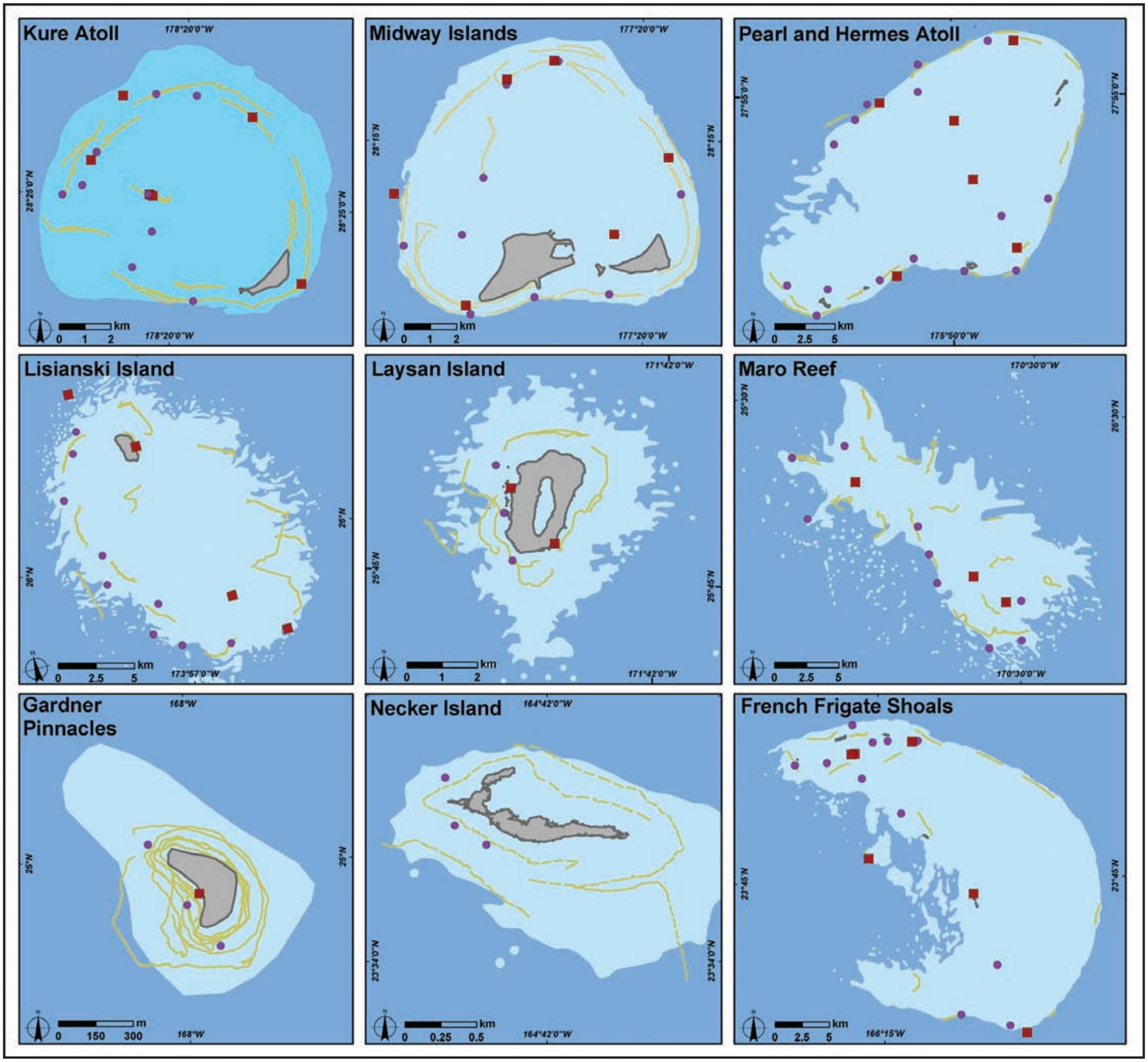
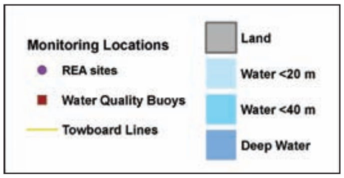


Figure 10.13. Monitoring locations in the NWHI. Map: A. Shapiro.



OCEANOGRAPHIC CONDITIONS AND WATER QUALITY

The health, functioning, and biogeography of the coral reef ecosystems of the NWHI are affected by the oceanographic conditions to which the fish, algae, corals, and other invertebrates of the ecosystem are exposed. These biological components depend on the time-varying ocean currents, waves, temperature, salinity, turbidity, nutrients, other measures of water quality, and other oceanographic conditions. As these conditions change, so do the health, distribution, and species diversity of each reef community. Table 10.5 provides a list of long-term oceanographic and water quality monitoring programs in place in the NWHI. Figure 10.14 shows the station locations of many of these monitoring systems.

Ocean Currents

Ocean currents transport and distribute larvae among and between different atolls, islands, and submerged banks of the NWHI, and also provide the mechanism by which species are distributed to and from the MHI, as well as far distant regions. The relatively low species diversity and high endemism of the NWHI are the result of the relative oceanographic isolation of the Hawaiian Archipelago. Ocean currents are measured and monitored in the NWHI in many different ways (Table 10.4). Since 1990, ocean current profiles along the Ha-

Table 10.5. Long-term oceanographic and water quality monitoring programs in the NWHI. Source: PIFSC-CRED.

SYSTEM	VARIABLES MONITORED	DATES	AGENCY
Deepwater CTD* - 10 sites (NIH, NEC, FFS, GAR, MAR, LAY, LIS, P&H, MID, KUR)	temperature, salinity, dissolved oxygen, and chlorophyll versus depth to a depth of 500 m	May 1998 - present	PIFSC-CRED
Shallow-water CTD* - multiple sites each island/atoll	temperature, salinity, turbidity	Sept. 2001 - present	PIFSC-CRED
Coral Reef Early Warning System (CREWS) Buoys - 4 Standard (P&H, MAR, KUR), 1 Enhanced – (FFS)	Standard: temperature (1 m), salinity, wind, atmospheric pressure, Enhanced: Std plus ultraviolet radiation, photosynthetic active radiation	Oct. 2001 - present	PIFSC-CRED
Sea Surface Temperature (SST) Buoys – 4 (NEC, LAY, LIS, MID)	Temperature at 0.5 m	Oct. 2001 - present	PIFSC-CRED
Subsurface Temperature Recorders (STR) – 22	Temperature at depths between 0.5 m and 5 m	Oct. 2002 - present	PIFSC-CRED
Ocean Data Platforms (ODP) – 2 (NEC, MID)	temperature, salinity, spectral directional wave motion, current profiles	Oct. 2002 - present	PIFSC-CRED
Wave and Tide Recorders (WTR) – 4 (P&H, KUR)	spectral wave motion, tides, temperature	July 2003 - present	PIFSC-CRED
Drifter Buoys	temperature, surface circulation (location)	2001 (6), 2002 (10), 2003 (8)	PIFSC-CRED
Autonomous Profiling Explorer (APEX) Floats	temperature, surface circulation (location)	2002 (6)	PIFSC-CRED
Tide Gauges	tidal fluctuations, sea level	FFS=1974-present, MID=1947-present	UH Sea Level Center
Wave Monitoring Buoys	wave height & period, wind speed & direction, atmospheric pressure, temperature	1980 - present	NOAA National Weather Service, National Data Buoy Center
Satellite Remote Sensing	sea surface temperature, winds, sea surface height, ocean color	SST -1981 SSH – 1992 Wind – 1995 Ocean Color - 1994	NOAA Satellites and Information, Hawaii Coastwatch
Model Fields	waves / surface circulation		NOAA National Weather Service, Wave Watch 3 Naval Research Laboratory, Navy Coastal Ocean Model

* CTD: Conductivity, Temperature and Depth

waiian Archipelago have been measured using acoustic Doppler current profilers (ADCP) aboard the NOAA ships *Townsend Cromwell* (1990 to 2002) and *Oscar Elton Sette* (2003 to present) during routine transects along the archipelago to support an array of scientific cruises for PIFSC. Based on 10 years of ADCP data during the period 1990 to 2000, Firing et al. (2004a) demonstrate that upper ocean currents in the NWHI are highly variable in both speed and direction, being dominated by eddy variability. Averaged over time, the resultant mean flow of the surface waters tend to flow predominantly from east to west in response to the prevailing northeast tradewinds (Figure 10.15). The lack of coral reef ecosystems to the east, or upstream, of the Hawaiian Archipelago and the generally low biodiversity to the east explains the low species richness and high endemism. Surface Velocity Program (SVP) current drifters and autonomous profiling explorer (APEX) drifters have also been deployed in the NWHI by PIFSC annually since 2001. These SVP and APEX drifters provide indications of the Lagrangian (or water-following) flow, thereby representing potential larval pathways. Similar to the ADCP measurements, the drifters show significant eddy variability and a general surface flow from east to southwest (in 2001-2002) and northwest (in 2003) (Figure 10.16). Interestingly, two of the six APEX drifters deployed near Nihoa and Necker in 2001 were advected close to Johnston and then moved back northward toward the NWHI, suggesting the larval link between Johnston and the NWHI (Firing et al., 2004a). Spatial maps of ocean currents in the vicinity of the NWHI are also computed from satellite observations of sea surface height from the TOPEX Poseidon and JASON altimetric satellites (Polovina et al., 1995). In recent years, the PIFSC has also deployed ADCP moorings at Southeast Brooks Bank (1998-1999), Necker (2003-2004) and Midway (2003-2004) to look more closely at temporal variability of ocean currents over submerged banks and reef habitats in the NWHI.

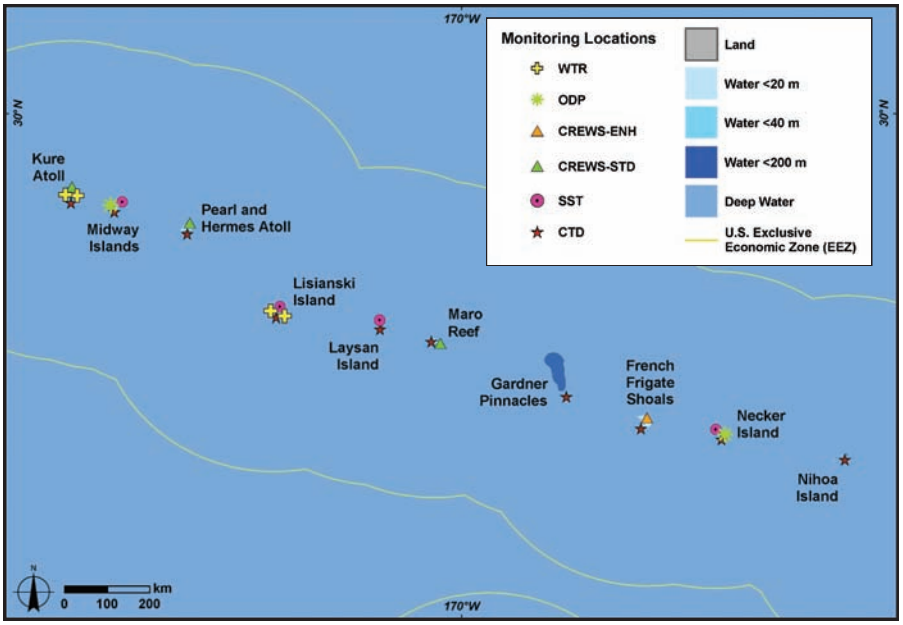


Figure 10.14. Long-term oceanographic monitoring stations in the NWHI. Wave and Tide Recorder (WTR) stations are indicated by yellow crosses. Ocean Data Platform (ODP) locations are indicated by green asterisks. Enhanced CREWS stations are indicated by orange triangles. Standard CREWS stations are indicated by green triangles. SST buoys are indicated by purple circles. Permanent deepwater CTD stations are indicated by red stars. Source: Hoeke et al., 2004a, b.

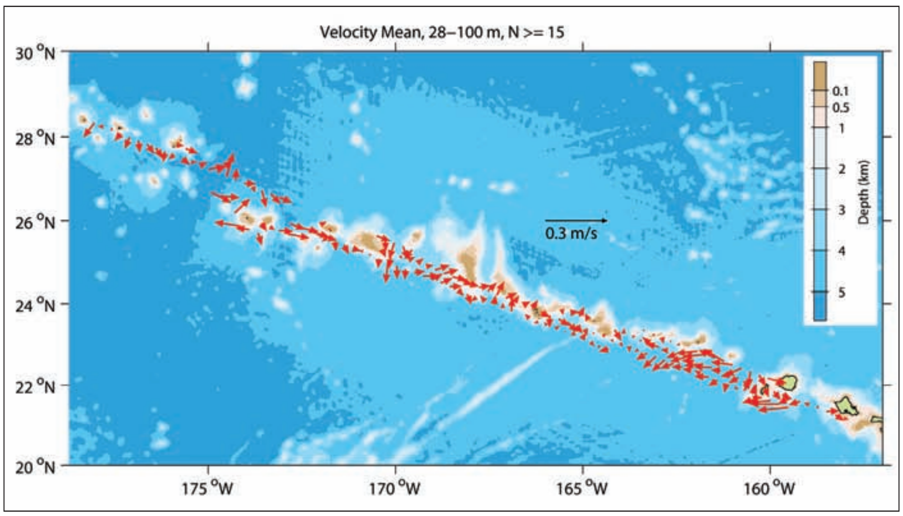


Figure 10.15. ADCP data from 1990 to 2000 averaged over time. The upper ocean currents in the NWHI are highly variable in both speed and direction, being dominated by eddy variability. The resultant mean flow of the surface waters tends to flow predominantly from east to west in response to the prevailing northeast tradewinds. Source: Firing et al., 2004a.

Ocean Waves

Among each of the islands, atolls, and submerged banks of the NWHI, the distributions of species of corals and algae, and their associated fish and invertebrate assemblages are often determined not only by the ocean currents, but also by the exposure to ocean waves. Many species of corals and algae can survive in sheltered

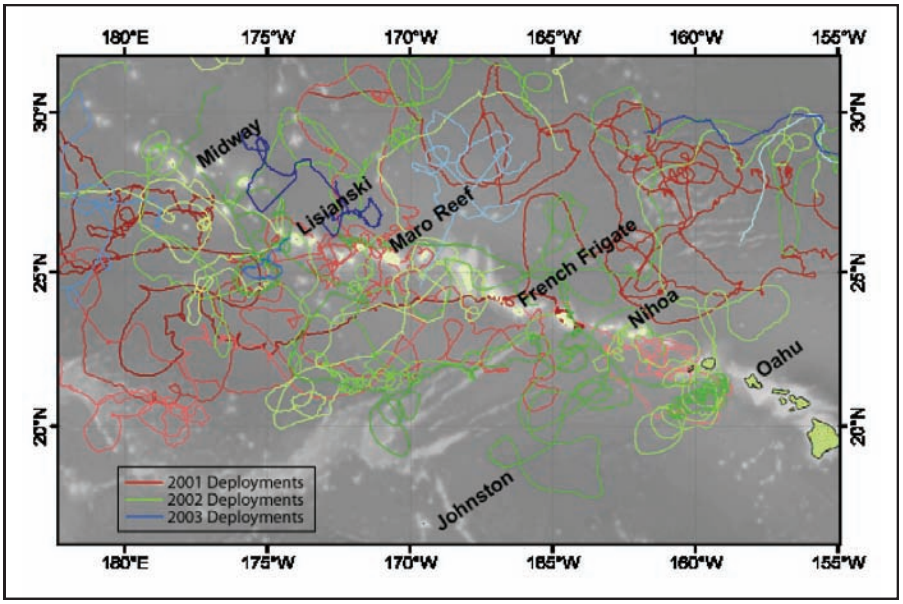


Figure 10.16. Satellite-tracked drifter tracks from SVP drifters deployed along the NWHI in 2001 (reds), 2002 (greens), and 2003 (blues). Source: Firing et al., 2004b.

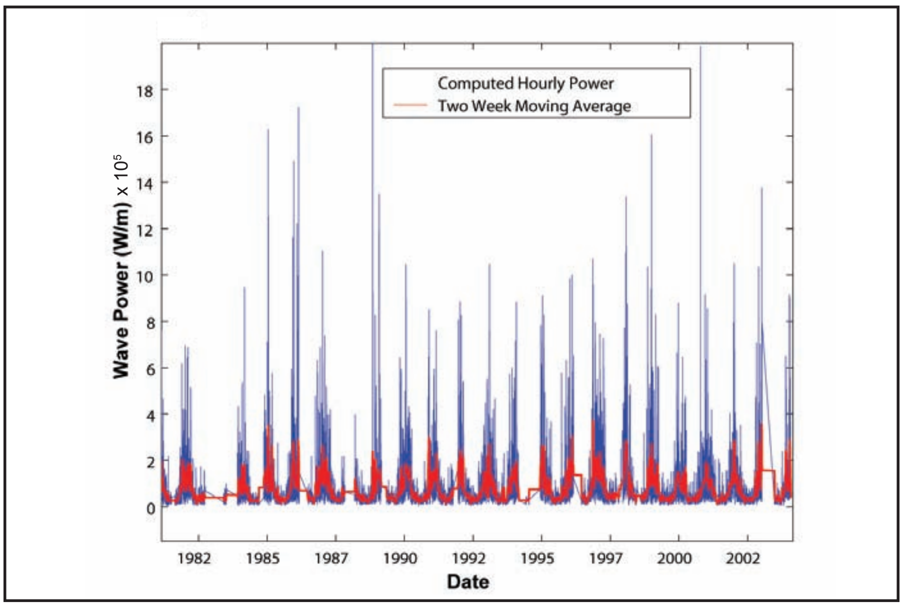


Figure 10.17. Time series of wave power computed from wave data from NOAA Buoy #51001 located near Nihoa Island in the NWHI. Data courtesy of NOAA Data Buoy Center. Source: Brainard et al., 2004.

or quiescent habitats. Other species can survive or even thrive in the high-energy habitats of the surf zones on the northwestern facing reefs that are exposed to tremendous waves caused by winter storms across the North Pacific. The less hardy species cannot survive the pounding by these large winter waves.

Significant wave events vary over interannual (between year) and decadal time scales (Figure 10.17). Interannually, some years experience greater or lesser amounts of cumulative wave energy or numbers of extreme wave events than other years. This temporal variability of wave power allows expansions and retractions of the spatial and vertical ranges of the some species during relatively quiescent and turbulent years, respectively. Over the past 20 years, wave measurements at NOAA buoy 51001 (near Nihoa Island in the NWHI) show a pattern of anomalously high numbers of extreme wave events during the periods 1985-1989 and 1998-2002 and anomalously low numbers of extreme wave events in the early 1980s and the period 1990-1996. This apparent decadal variability of wave power is possibly related to well-documented Pacific Decadal Oscillation (PDO) events, which are a mode of North Pacific climate variability at multi-decadal time scales that has widespread climate and ecosystem impacts (Mantua et al., 1997). Studies have shown decadal oscillations of various components of NWHI ecosystems (lobsters, monk seals, seabirds, etc.) relate to larger scale climate shifts across the North Pacific (Polovina et al., 1995).

Ocean temperatures

While coral bleaching can be caused by a wide range of environmental variables acting alone or in combination (Jokiel and Brown, 2004), the predominant cause of increasing incidences of coral bleaching globally is believed to be anomalously warm water temperatures (Jokiel and Coles, 1990; Kenyon et al., in review). Because of the significant influence of temperature on coral reef ecosystem health, observations of temperature in the NWHI are collected by a wide array of instruments and platforms, including satellite remote sensing of SST using Advanced Very High Resolution Radiometer (AVHRR), moored surface buoys and subsurface temperature recorders, closely-spaced conductivity-temperature-depth profiles (CTD casts) in shallow water/nearshore reef habitats, broadly-spaced shipboard deep water CTD casts to depths of 500 m, and satellite-tracked SVP drifters (Table 10.5).

The coral reefs of the NWHI are exposed to large seasonal temperature fluctuations, particularly Kure, Midway, and Pearl and Hermes Atolls at the northwestern end of the archipelago. SSTs at these northerly atolls range from less than 18°C in late winter of some years (17°C in 1997) to highs exceeding 28°C in the late summer months of some years (29°C in 2002) (Figure 10.18). Compared with most reef ecosystems around the globe, the annual fluctuations of SST of about 10°C at these northerly atolls is extremely high. While the summer temperatures are generally similar along the entire NWHI, the warmest summer temperatures tend to occur at the three northernmost atolls, presumably caused by reduced mixing due to weaker winds (situated closer to the center of the North Pacific high pressure ridge) and decreased circulation due to large shallow water lagoons (Brainard et al., 2004; Hoeke et al., 2004a, b). The winter temperatures tend to be 3-7°C cooler at the northerly atolls than at the southerly islands and banks as the subtropical front migrates southward. These cooler winter temperatures are thought to reduce coral growth rates.

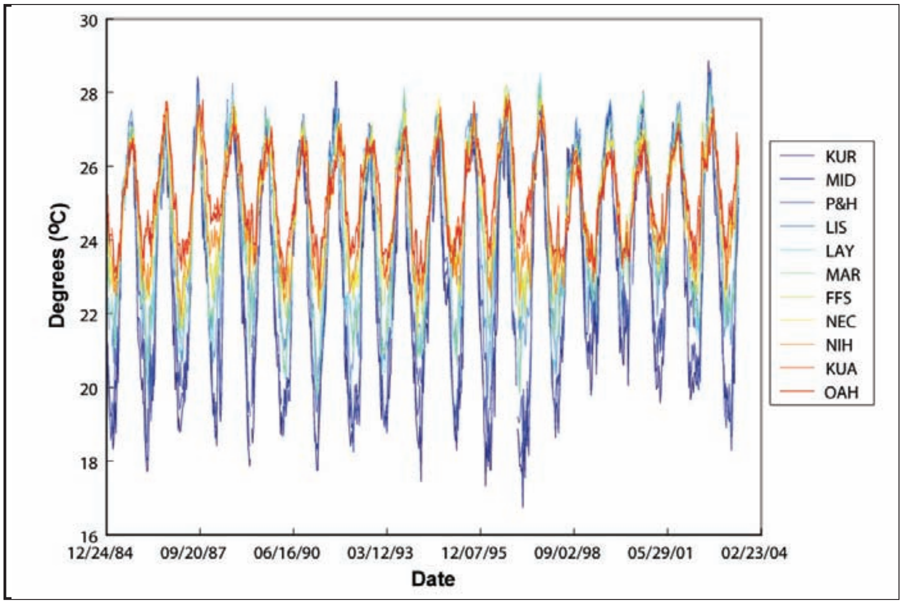


Figure 10.18. Time series of Pathfinder SST at key islands and atolls of the NWHI from KUR to Oahu (OAH) between 1984 and 2004. Blue colors=northerly atolls and red colors=Kauai (KUA) and OAH in the Main Hawaiian Islands. Data provided by NOAA Satellites and Information, Hawaii CoastWatch. Source: Hoeke et al., 2004b.

In addition to the strong annual cycle, SST observations show significant interannual and decadal variability (Figure 10.18). The highest summer maximum SSTs at the northern atolls occurred during the summers of 1987, 1991, and 2002, possibly suggesting a teleconnection with El Niño Southern Oscillation (ENSO) events. Winter minimum temperatures at the northern atolls appear to oscillate over a longer time period, as indicated by a significant warming of winter SSTs beginning in 1999 and lasting for several years (Brainard et al., 2004).

During the period between July and September 2002, ocean temperatures along the Hawaiian Archipelago were anomalously warm (Figure 10.19). According to NOAA's Coral Reef Watch Program, temperatures exceeded the coral bleaching threshold for four consecutive Degree Heating Weeks. As discussed elsewhere in this report, this resulted in widespread mass coral bleaching of many species of coral in shallow water habitats, particularly at the three northernmost atolls. While warming is common during the late summer months, this extreme warming event, and the resulting coral bleaching is believed to have been caused by anomalously low wind speeds during the period (Hoeke et al., 2004a, b).

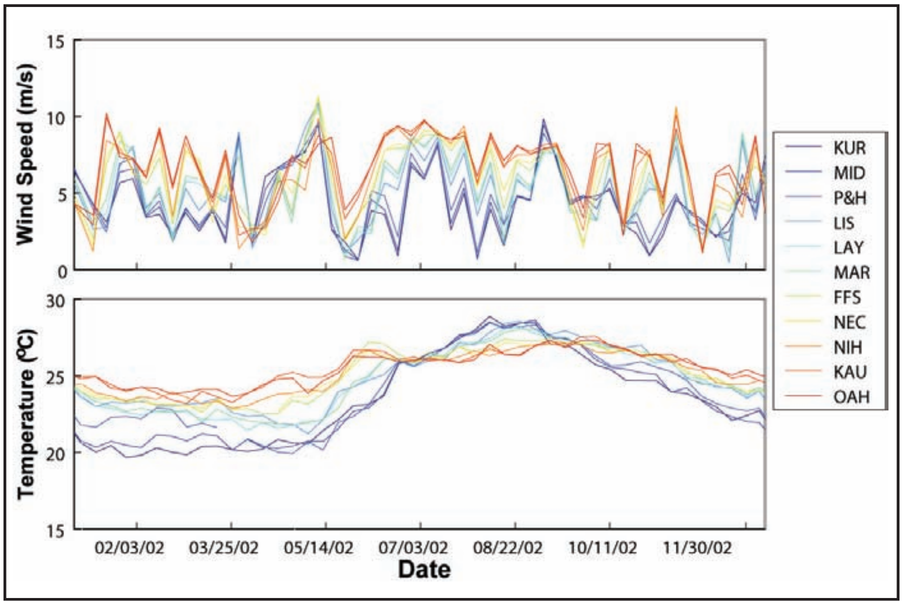


Figure 10.19. Satellite-derived wind speed and SST along Hawaiian Archipelago from Oahu (OAH) to KUR during 2002. The warming event associated with the 2002 coral bleaching followed periods of light winds at the northernmost atolls. Source: Hoeke et al., 2004a, b.

Nutrients

Satellite observations of ocean color from the National Aeronautics and Space Administration's (NASA) Sea-viewing Wide Field-of-view Sensor (SeaWiFS) reveal a significant chlorophyll front associated with the subtropical front, with high chlorophyll north of the front and low oligotrophic waters south of the front. These observations reveal significant seasonal and interannual migrations of the front northward during the summer months and southward during the winter months (Seki et al., 2002). The southward migration of the subtropical front generally brings these high chlorophyll waters to intersect the northern portions of the NWHI. During some years, these winter migrations of the subtropical front extend southward to include the southern end of the NWHI. Additional evidence suggests decadal scale movements in the southward extent of the subtropical front. During periods when high chlorophyll waters intersect the NWHI, overall productivity of the effected reef ecosystems is expected to be elevated. Changes across many trophic levels of the NWHI ecosystem are believed to be associated with these migrations (Polovina et al., 1995).

BENTHIC HABITATS

CORAL

Coral abundance, distribution, condition, biodiversity, and population structure in the NWHI were surveyed at more than 536 sites between 2000 and 2003. Several techniques were used: towed diver video surveys each averaging approximately 2 km in length, rapid ecological assessments (REA) each covering between 1000-5000 m^2 per site, photo-quadrat/video surveys at permanently marked 50-100 m transects, settlement and recruitment studies at six of the NWHI, and directed observations on coral disease, predation, and bleaching at all of the NWHI except Nihoa. Initially, the REA protocols focused on video-taping two 25 m transects at each site and visually inventorying species and estimating their relative abundance in broader surrounding areas. In 2002, the protocols were revised to shift towards *in situ* quantitative coral population data collection along the first two 25 m transects. The revised REA protocols are described in Maragos et al. (2004) and were used during the 2002 and 2003 surveys.

Coral species inventories and distribution from REAs

REA surveys at 465 discreet sites on 11 reefs in the NWHI inventoried coral species, their relative abundances, and their distributions during 2000-2002. Surveys (462) around the 10 islands were in depths of ≤20 m, and three surveys on the submerged Raita Bank were in depths of 30-35 m. Results include 11 first records for stony coral species in the Hawaiian Archipelago, and 29 species range extensions to the NWHI. Several species may be new to science. There are now 57 stony coral species known in the shallow subtropical waters of the NWHI (Table 10.6), similar to the 59 shallow and deepwater species known in the better-studied and more tropical MHI. Coral endemism is high in the NWHI: 17 endemic species (30%) account for 37-53% of the relative abundance of stony corals visually estimated on each reef of the NWHI. Three genera (*Montipora, Porites, Pocillopora*) account for 15 of the 17 endemic species and most of the endemic abundance. Seven *Acropora* species (Figure 10.20) are now known from the central NWHI despite their near absence from the MHI. Coral abundance and diversity are highest at the large open atolls of the central NWHI (French Frigate, Maro, Lisianski/Neva Shoal) and decline gradually through the remaining atolls to the northwest (Pearl and Hermes, Midway and Kure). Stony corals are also less abundant and diverse off the exposed basalt islands to the southeast (Nihoa, Necker, La Perouse, Gardner), where soft corals (*Sinularia, Palythoa*) are more abundant. Exposure to severe wave action appears to limit coral development off these small islands and surrounding deep platforms. Temperature extremes and natural accumulation of lagoon sediments may contribute to decline of coral species and abundance at the northwestern end of the chain, based on the REA survey results.

Table 10.6. Checklist of stony corals reported from the NWHI, including 2000-2002 REA surveys. Source: Maragos et al. 2004.

ACROPORIDAE	
++ j	*Acropora cerealis* (Dana, 1846)
J	*A. cytherea* (Dana, 1846)
++ j	*A. gemmifera* (Brook, 1892)
J	*A. humilis* (Dana, 1846)
++ j	*A. nasuta* (Dana, 1846)
+ j	*A. paniculata* (Verrill, 1902)
j	*A. valida* (Dana, 1846)
*? j	*Montipora capitata* (Dana, 1846)
* v	*M. dilatata* (Studer, 1901)
* ++	*M.* cf. *dilatata* (Studer, 1901)
*	*M. flabellata* (Studer, 1901)
* j	*M. patula* (Verrill, 1864)
* + j	*M.* cf. *incrassata* (Dana, 1846)
++ j	*M. tuberculosa* (Lamarck, 1816)
* +	*M. turgescens* (Bernard, 1897)
	M. verrilli (Vaughan, 1907)
AGARICIIDAE	
	Pavona clavus (Dana, 1846)
*? j	*P. duerdeni* (Vaughan, 1907)
j	*P. maldivensis* (Gardiner, 1905)
j	*P. varians* (Verrill, 1864)
v j	*Leptoseris hawaiiensis* (Vaughan, 1907)
j	*L. incrustans* (Quelch, 1886)
+ j	*L. scabra* (Vaughan, 1907)
+	*Gardineroseris planulata* (Dana, 1846)
BALANOPHYLLIIDAE	
+	*Balanophyllia* sp.
+	*Cladospammia* cf. *eguchii* (Wells, 1982)
DENDROPHYLLIIDAE	
+	*Tubastraea coccinea* (Lesson, 1829)
FAVIIDAE	
+	*Leptastrea agassizi* (Vaughan, 1907)
++	*L. bewickensis* (Veron & Pichon, 1977)
* ++	*L.* cf. *Favia hawaiiensis* (Vaughan 1907)
++	*L.* cf. *pruinosa* (Crossland, 1952)
j	*L. purpurea* (Dana, 1846)
j	*Cyphastrea ocellina* (Dana, 1846)
FUNGIIDAE	
j	*Fungia scutaria* (Lamarck, 1801)
++	*F. granulosa* (Klunzinger, 1879)
+ j	*Cycloseris vaughani* (Boschma, 1923)
POCILLOPORIDAE	
* r	*Pocillopora* cf. *cespitosa* var. *laysanensis* (Vaughan,1907)
j	*P. damicornis* (Linnaeus, 1758)
j	*P. eydouxi* (Edwards & Haime, 1860)
	P. ligulata (Dana, 1846)
j	*P. meandrina* (Dana, 1846)
* +	*P. molokensis* (Vaughan, 1907)
* ++	*P.* cf. *capitata* (Verrill, 1864)
PORITIDAE	
*	*Porites brighami* (Vaughan, 1907)
*	*P. compressa* (Dana, 1846)
* +	*P. duerdeni* (Vaughan, 1907)
* +	*P. evermanni* (Vaughan, 1907)
j	*P. lobata* (Dana, 1846)
*	*P. rus* (Forskal, 1775)
* ++	*P. hawaiiensis* (Vaughan, 1907)
+	*P.* cf. *annae* (Crossland, 1952)
	P. cf. *solida* (Forskål, 1775)
SIDERASTREIDAE	
+	*Psammocora explanulata* (Horst, 1921)
+ j	*P. nierstraszi* (Horst, 1921)
+ j	*P. stellata* (Verrill, 1864)
* +	*P. verrilli* (Vaughan, 1907)

Notes:
+ New range record for the NWHI (previously known in main Hawaiian Islands).
++ New range record for Hawaii as a whole.
j Hawaiian species also reported at Johnston Atoll.
r reported only at Raita Bank and now considered endemic at the species level.
v reported by Vaughan (1907) at Laysan but not during present study.
* species endemic to Hawai‘i and northern but Line Islands (including Johnston).
*? considered endemic to Hawai‘i and Line Islands here and by Maragos (1995), not by Veron (2000).

Figure 10.20. A large table coral, *Acropora cytherea*, thrives near a permanent monitoring site at French Frigate Shoals. Photo: J. Watt.

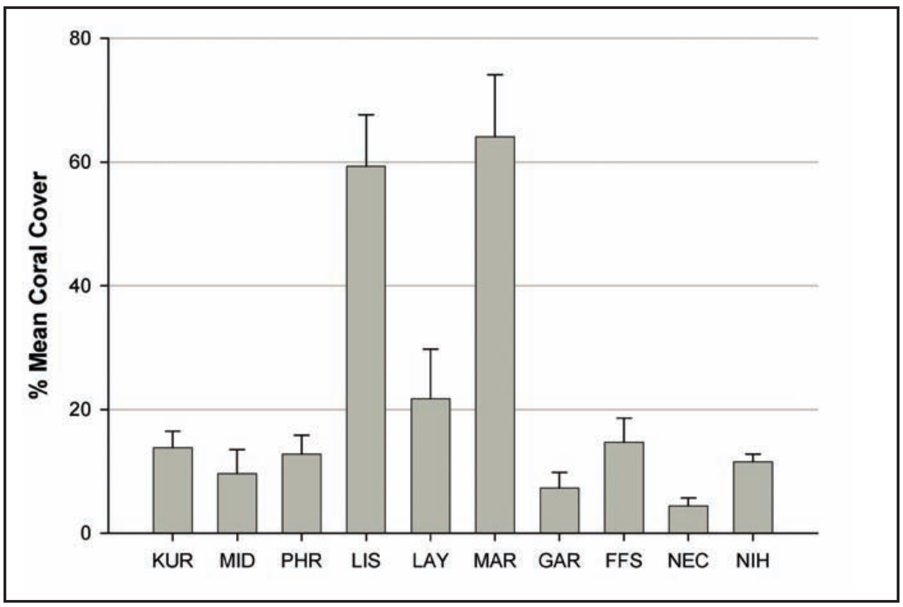


Figure 10.21. Differences in coral cover among regions within the NWHI. REA surveys were conducted at 173 sites in 2002. Coral cover was calculated from size frequency data of colony counts within transects. Data are mean and standard error. Source: PIFSC-CRED, unpublished data.

Coral Community Structure

REA surveys were conducted at 173 sites across the NWHI in 2002. Based upon these surveys it was found that coral cover varies greatly across the NWHI. Most regions have low coral cover while Maro Reef and Lisianski having comparatively high coral cover (Figure 10.21). Grigg (1983) reported similar results with the exception of higher coral cover reported from French Frigate Shoals. However, his study was based on a much smaller and spatially limited number of sites. It was also found that coral cover varied among reef zones (Table 10.7), thus estimates of coral cover would vary greatly depending on where the surveys were conducted. The reef zone with the highest coral cover varied among regions with no consistent pattern emerging. Coral community structure also differed across the regions (Table 10.8) but overall *Porites, Pocillopora,* and *Montipora* were the dominant genera.

Coral monitoring at permanent transects

Methods

Permanent monitoring sites were selected to cover representative shallow-water (<20 m) coral reef habitats. With only an hour of ship's time every other year devoted to each survey, it was important that sites be conveniently located and safely approached from offshore. Several sites at Pearl and Hermes and French Frigate Shoals were installed to monitor the effects of a ship grounding and a future sea wall construction project, respectively. A total of 11 transects were established at French Frigate Shoals, 10 at Midway Atoll, eight at P&H, three each at Maro Reef and Lisanski/ Neva Shoal, two each at Laysan and Nihoa, and one each at Gardner Pinnacles and Necker. The availability of small skiffs at the permanently occupied field stations at Midway and French Frigate Shoals contributed to the greater number of transects there.

At each site, photoquadrats were taken along 50 m or 100 m transects. To date 1,938 photoquadrats at 48 transects have been collected and partially analyzed. Digital video was also taken along most transects.

Results and Discussion

Monitoring of corals was established at 41 permanently marked transects at nine of the NWHI (except Kure) from 2000-2002, supplementing 2002-2003 monitoring efforts at REA sites. Six of the sites at French Frigate Shoals and two at Midway were resurveyed in 2002. Repetitive surveys at the same reefs using the same methods allows more precise detection of changes in coral and macroinvertebrate populations over time. The principal advantage of fixed sites is reduced spatial variability relative to temporal variability, provided that the original transects are precisely relocated and resurveyed. The principal disadvantage is the extra time required for installing permanent markers during the initial survey and relocating, repairing, or replacing lost markers during subsequent surveys. Permanently marked transects are particularly useful for tracking changes in sessile benthos such as individual coral colonies over many years. Analyses are still in progress and discussion here is limited to the results of initial baseline surveys.

Table 10.7. Differences in coral cover within different reef zones in the NWHI. Numbers represent the average coral cover (%) + standard error. Coral cover calculated from size frequency data of colonies within transects. Data based on REA surveys in 2002. NS=not sampled. Source: PIFSC-CRED, unpublished data.

	REEF ZONE			
	SHELF	FOREREEF	BACKREEF	LAGOON
NIH	11.5 (1.3)	NS	NS	NS
NEC	4.4 ± 1.3	NS	NS	NS
FFS	8.2 ± 6.6	7.6 ± 3.2	12.0 ± 3.5	24.1 ± 9.7
GAR	7.3 ± 2.5	NS	NS	NS
MAR	NS	64.1 ± 10.0	NS	NS
LAY	21.7 ± 8.0	NS	NS	NS
LIS	50.0 ± 12.1	73.2 ± 11.2	NS	24.5±
P&H	NS	13.3 ± 3.1	5.0 ± 2.7	20.7 ± 11.0
MID	2.7 ± 2.2	2.1 ± 0.63	30.6 ± 12.1	0.98 ± 0.41
KUR	20.2 ± 11.7	8.9 ± 2.0	12.3 ± 3.6	19.9 ± 5.3
mean	**15.8 (5.5)**	**28.2 (12.9)**	**14.9 (5.4)**	**18.0 (4.4)**

Table 10.8. Coral community structure within the NWHI. Numbers represent the average composition (%) by genera based on colony counts within belt transects conducted in 2002. The three most abundant genera are highlighted (bold type) within each region. Source: PIFSC-CRED, unpublished data.

	NWHI	KUR	MID	P&H	LIS	LAY	MAR	GAR	FFS	NEC	NIH
	# REA SITES PER ISLAND	21	31	32	22	10	14	6	29	6	2
CORAL GENERA	*Acropora*	0	0	0	0.4	0	2.6	0.06	**8.8**	0	0
	Cyphastrea/Leptastrea	**3.2**	3.3	**13**	**12**	8.5	4.2	**2.5**	3.2	0.4	1.1
	Fungia/Cycloceris	0.1	0.15	0.4	7.2	0	0.5	0	0.2	0	0
	Montipora	1.8	**15**	3.2	**35**	**14**	**18**	1.1	3.3	**4.3**	**4.8**
	Pocillopora	**41**	**27**	**28**	3.5	**12**	**9.9**	**11**	**19**	**28**	**34**
	Porites	**54**	**53**	**52**	**41**	**65**	**54**	**81**	**63**	**68**	**60**
	Pavona	0.2	0.43	1.9	3.5	0.9	5.7	1.9	1.9	0	0
	Psammocora	0	0.38	0.9	1	0	0.1	0.45	0.1	0	0
	Other stony coral	0	0	0	0	0	0	0	0.1	0	0
	Soft coral/anemones	0	0.92	1	0	0.3	4.9	1.94	2.5	0	0

Live coral cover was quite variable ranging from 0.37% to 48.34% at the monitoring transects (Table 10.9). The highest values were concentrated at ocean reef sites sheltered from heavy tradewinds and large winter swell from the Northwest Pacific and at most lagoon sites, except the low values at sites near Tern Island at French Frigate Shoals which have a history of chronic disturbance from dredging filling, fuel spills, and other contamination since WWII. The lowest live coral values were concentrated at ocean facing reefs off Nihoa, Necker, Gardner, and Laysan Islands, which are more exposed to large waves and swells from any direction. Lisianki Island is protected by Neva Shoal, which might explain the higher coral cover there.

Moreover, sites with large mean coral diameters positively correlated with those of high coral cover. However, sites with large frequencies (numbers of corals per square meter) did not correlate with high coral cover. Sites with the highest diversity of corals (numbers of coral types per transect) showed no strong correlations with other parameters. Many of these sites were situated where there was greater habitat variety and some shelter from heavy swells and wave action.

Table 10.9. Summary of NWHI coral monitoring data at permanently marked sites. C=central, N=north, S=south, E=east, W=west, lag=lagoon, tip=end of perimeter reef. Source: Maragos and Veit, 2004.

ATOLL/ ISLAND	# OF SITES	REEF LOCALE	YEAR	# CORAL TYPES/ TRANSECT	TRANSECT AREA (m^2)	% CORAL COVER	CORAL FREQ. #/m^2	CORAL MEAN DIAM.-cm
FFS	1	N tip	2001	5	25	20.7	2.8	25
FFS	2	N tip	2002	5-8	72	11.5-23.1	2.3-7.7	19-23
FFS	1	NE lag	2001	4	35	25.9	3.4	42.4
FFS	2	NE lag	2002	3-4	73	29.1-34.7	1.6-2.9	32.6-76.2
FFS	3	N lag	2002	3-4	119	0.4-1.6	1.5-1.9	5.3-8.7
FFS	1	N ocean	2001	4	38	11.6	14.2	11.6
FFS	1	N ocean	2002	3	51	12.5	11.7	13.3
FFS	1	NC lag	2001	6	36	8.6	4.6	12.3
FFS	1	NC lag	2002	3	45	6.7	8	9.3
FFS	1	central lag	2001	5	33	24.1	8.5	19.9
FFS	2	central lag	2002	2-4	69	14.6-28.8	6.2-7.1	16.1-30.3
FFS	1	S tip	2001	8	36	31.6	5.1	25.5
FFS	1	S tip	2002	2	16	46.1	3.3	43.6
GAR	1	W side	2002	3	20	4.3	10	8.9
LAY	2	W lag	2002	4	62	4.2-7.4	5.6-9.5	7.7-11.0
LIS	1	S fringing	2002	2	51	4.8	1,0	14.5
LIS	1	E ocean	2002	1	51	45.8	1.8	57.4
LIS	1	N fringing	2002	2	51	15.5	5.1	22.9
MAR	1	W lag	2001	3	34	3.7	3.8	10.9
MAR	1	SE ocean	2002	3	17	26	4.6	29.6
MAR	1	NW tip	2002	3	24	48.3	6.4	36.4
MID	3	N&W lag	2002	2-3	154	29.6-40.6	1.5-2.0	46.6-53.2
MID	5	E lag	2002	2-4	152	0.49-12.5	1.4-4.5	6.8-22.6
MID	2	S lag	2002	2	80	4.4-5.1	2.8-12.2	8.0-14.7
NEC	1	S ocean	2002	2	57	5.2	9.1	8.4
NIH	2	S&W side	2002	2-4	57	0.6-7.9	3.2-4.3	2.4-18.0
P&H	4	SE ocean	2000	2-5	271	6.2-8.9	3.0-7.7	11.0-21.1
P&H	1	W ocean	2002	4	62	5.7	3.2	15.5
P&H	1	S pass	2002	3	54	1.8	1.1	14.4
P&H	1	S lag	2002	3	37	2.1	1.8	11.7
P&H	1	C lag	2002	2	55	19.8	4.6	25.65

Towed-diver surveys

Since 2000, 333 towed-diver surveys have been conducted in the NWHI by PIFSC-CRED (Kenyon et al., 2004; Figure 10.22). During each survey, two divers maneuver separate boards that are equipped with digital video or still camera, as well as temperature and depth recorders, while being towed behind a small boat. The tow path is concurrently recorded by a global positioning system (GPS) receiver onboard the boat, to which a layback model is applied to more accurately map the position of the recorded imagery. Percent cover of salient benthic categories is quantified by whole-image analysis of still frames sampled at 30-second intervals. Towed-diver surveys bridge a gap between large-scale mapping efforts using satellite data and small-scale traditional belt transects or roving diver assessments, providing a mesoscale spatial assessment of reef habitats.

Towboard results

At French Frigate Shoals, where the greatest quantity of towed-diver survey benthic imagery has been analysed to date, three coral genera – *Porites, Pocillopora,* and *Acropora* – account for more than 93% of total coral cover throughout the atoll, while their relative percent cover, densities, and size distributions vary according to geomorphic and geographic location within the atoll system. Preliminary results from other atoll systems in the NWHI (Pearl and Hermes, Midway, and Kure) similarly reveal differences in total coral cover and the relative abundance of coral genera based upon zone (forereef, backreef, or lagoon) and geographic location. *Porites* and *Pocillopora* dominate the coral cover at these three northern atolls, with *Montipora* frequently co-dominating in the relatively protected backreef zone.

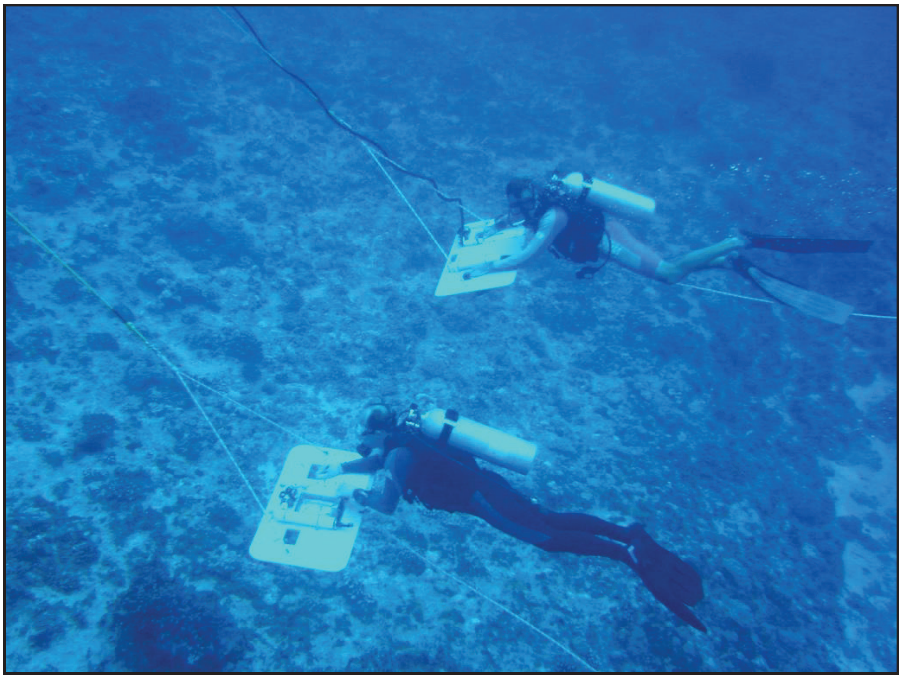
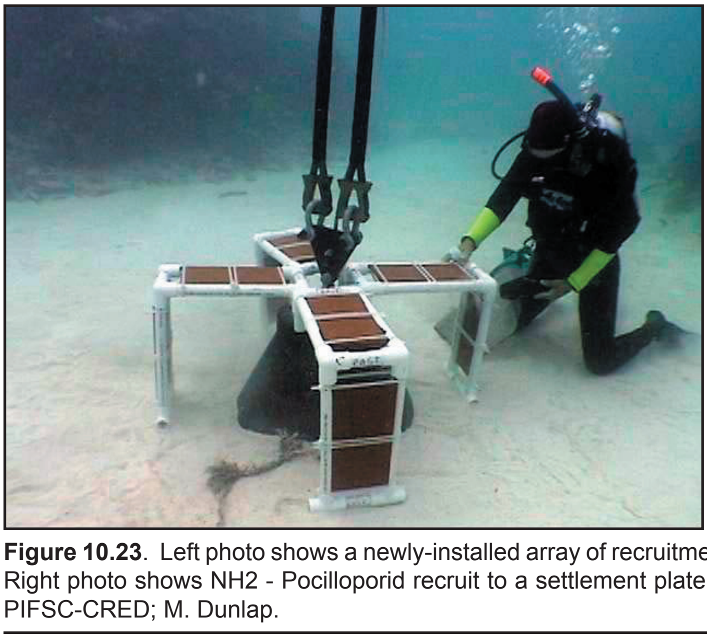


Figure 10.22. Photo of towboard divers surveying a reef in the NWHI. Photo: PIFSC-CRED.

Coral settlement and recruitment

In fall 2001, settlement plates were attached to the base of CREWS moorings at each of French Frigate Shoals, Maro Reef, Lisianski, Pearl and Hermes, Midway, and Kure (Figure 10.23A) to assess larval recruitment and enable coupling of biological data with physical data collected by the buoys. The plates have been collected and fresh plates installed at roughly one-year intervals since that time in order to examine them for settlement by calcareous organisms. After recruitment plates were collected, all calcareous organisms present on the collected plates were counted and measured (Figure 10.23B).

Coral recruits were present at all locations, but Maro had the highest density (270 recruits/m^2/year versus the next highest at Kure of 43 recruits/m^2/year) and a larger mean coral diameter (2.67 mm versus the next largest at Lisianski of 2.05 mm) than other plates. The recruitment rate at Maro is the highest rate yet recorded in the Hawaiian Archipelago. Recruits were identified from the families Acroporidae, Pocilloporidae, and Poriti-



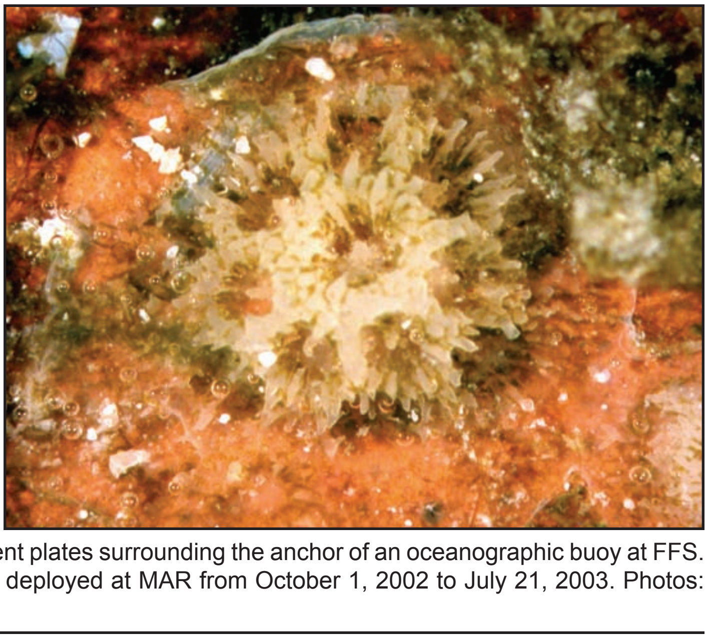


Figure 10.23. Left photo shows a newly-installed array of recruitment plates surrounding the anchor of an oceanographic buoy at FFS. Right photo shows NH2 - Pocilloporid recruit to a settlement plate deployed at MAR from October 1, 2002 to July 21, 2003. Photos: PIFSC-CRED; M. Dunlap.

dae, with Pocilloporids constituting up to 90% of the recruits. Lowest coral settlement occurred at Midway (7 recruits/m^2/year), followed by Pearl and Hermes (18 recruits/m^2/year). Coral recruits were more abundant on the undersides (horizontal) and insides (vertical) of plates at five of the six locations. While low settlement at those sites could be a reflection of naturally low recruitment, numbers may have been affected by an August 2002 bleaching event at the three northern atolls. Annual deployment and collection of plates will address whether low recruitment at these locations is typical or associated with bleaching events, as well as many recruitment questions important to management.

ALGAE

Until recently, algal collections from the NWHI were solely qualitative, intermittent, and often biased towards large, macroscopic species (Reinbold, 1899; Lemmerman, 1905; Howe, 1934; Buggeln, 1965; Tsuda, 1965, 1966; Balazs, 1979). Abbott (1989) listed all known algae reported from historic collections, and added considerable detail to our knowledge of microscopic turf and epiphyte species; however, she acknowledged that a paucity of collections from the NWHI undoubtedly underrepresented the true algal diversity present in these ecosystems. Additionally, many collections were made from drift algae or off lobster traps, disassociating the algae from any data about the environments they inhabit. To ameliorate this problem, expeditions to the NWHI over the past five years have focused on *in situ* sampling of algal diversity, and five recent works have greatly increased our phycological knowledge. Abbott (1999) and Abbott and Huisman (2004) thoroughly examined numerous red, brown, and green algal collections from the NWHI, and Vroom et al. (in press, a,b) completed a detailed study of marine algae from 57 sites at the French Frigate Shoals and increased the number of known algae from this atoll system by over 380%. Okano et al. (in prep.) examined 28 sites from the lagoon at Kure Atoll and documented 92 algal species, and Vroom and Page (in press) completed a multivariate analysis of algal percent cover along the entire NWHI chain. Because of these studies, 355 species of algae are now known from the NWHI chain (Table 10.10).

From an algal perspective, the NWHI contain many unique habitats and even several endemic species new to science which have recently been described (Figure 10.24; Abbott and McDermid, 2001, 2002; Vroom and Abbott, 2004a, b). Additionally, the NWHI contain a large number of Indo-Pacific algal species not found in the MHI. Among these, *Halimeda velasquezii*, represents one of the most common algal species in the NWHI. Expeditions during 2000-2002 found reproductive individuals of *H. velasquezii* for the first time (Vroom and Smith, 2003), allowing scientists to begin addressing ecologically-based algal questions for common species in the NWHI.

Table 10.10. Numbers of algal species currently known from the NWHI. Source: Abbott 1989, 1999; Vroom et al., in press, a,b.

Red algae	204
Brown algae	59
Green algae	92

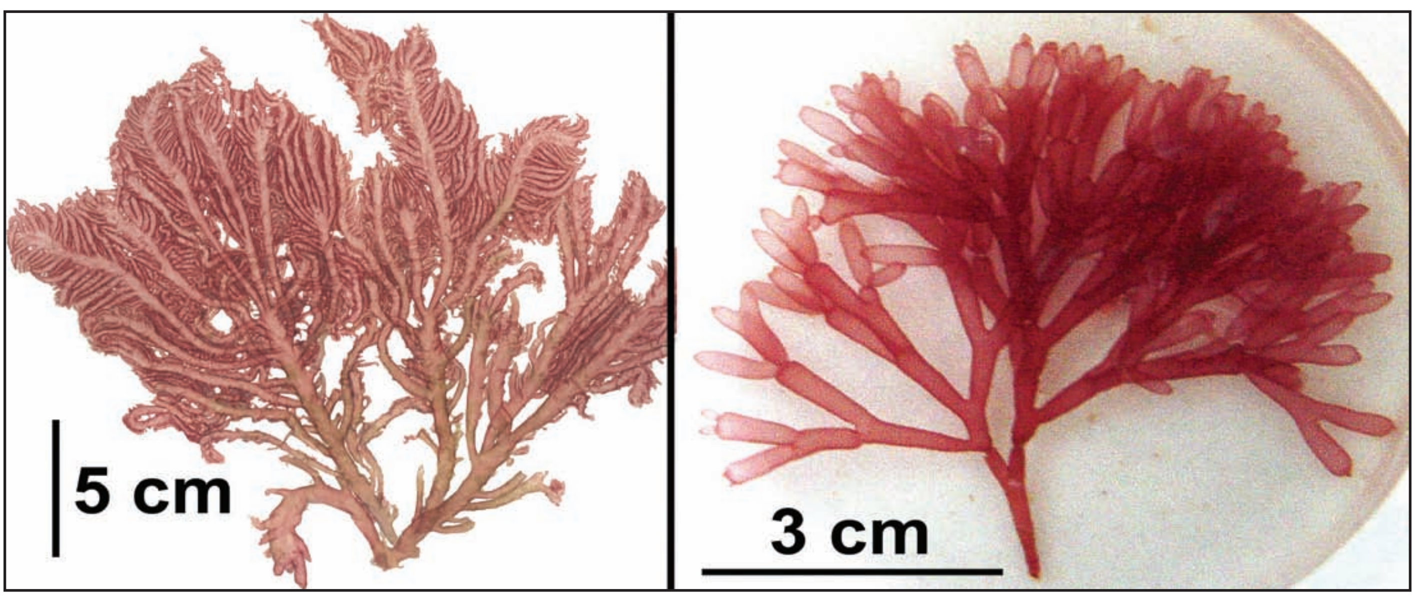


Figure 10.24. *Acrosymphtyon brainardii* (left) and *Scinaia huismanii* (right) are two newly described species of red macroalgae from FFS that are endemic to the NWHI. Photos: P. Vroom.

Quantitative baseline assessments of algal cover began on all NWHI in 2002 using a protocol devised specifically for remote tropical reef ecosystems (Preskitt et al., 2004). Detailed photoquadrat analysis combined with voucher specimens and field notes allowed for percent cover determination of algae and invertebrates at the species level. Analyses from French Frigate Shoals and Pearl and Hermes (Vroom et al., in press, a,b; Vroom et al., in prep.) have found that algal dominated reefs are normal for many of the healthy ecosystems of the NWHI. Expansive forereef and backreef regions are characterized by approximately 15% macroalgal cover while coral cover is less than 8%. Only select lagoonal and patch reef regions exhibited coral cover greater than macroalgal cover. This differs drastically from the generally held belief that healthy tropical reef ecosystems should be dominated by scleractinian coral species. Turf algal meadows were the most common component of essentially all benthic habitats and covered every non-living substrate except sand.

Multivariate analyses of 28 sites from the French Frigate Shoals using the Preskitt method allowed seven distinct biogeographical zones to be interpreted based on substrate-type and algal/invertebrate species composition (Figure 10.25; Vroom et al., in press, a,b). The largest biogeographical group was located on the closed, eastern side of the atoll system and characterized by high densities of the green macroalga *Microdictyon setchellianum*. The area surrounding La Pérouse Pinnacle on the open, western side of the atoll contained the highest crustose coralline algal cover at the atoll. Most lagoonal regions contained sand patches or broad regions of algal turf where macroalgae such as *Halimeda velasquezii, Turbinaria ornata,* and *Asparagopsis taxiformis* were very common. Oceanographic monitoring studies conducted concurrently with algal sampling suggested that water motion may be a major factor in defining algal distribution at the French Frigate Shoals. Multivariate percent cover studies similar to the one completed for the French Frigate Shoals are currently underway for Pearl and Hermes and Lisianski. Baseline assessment data for all other NWHI are in-hand, and available for future analyses.

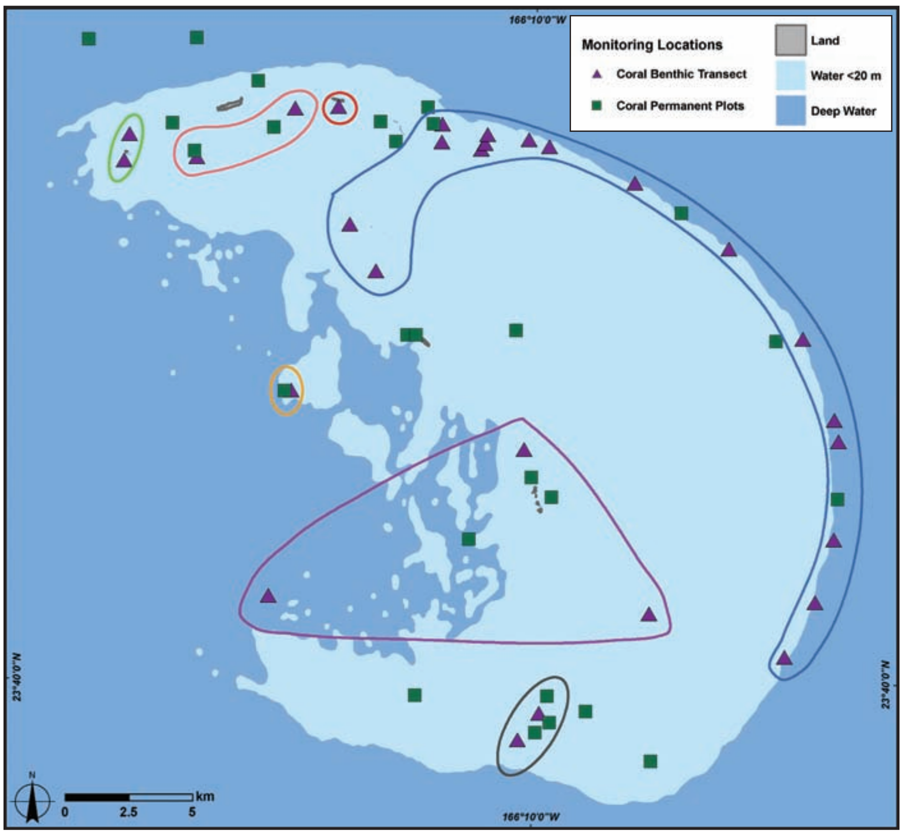


Figure 10.25. Map of FFS with seven biogeographical groups outlined in different colored lines. Biogeographical groups were determined, in part, through multivariate analysis of benthic species cover. Source: Vroom et al., in press, a,b.

Algal monitoring in the NWHI is still in its infancy. Rapid archipelago-wide studies found no significant differences in the prevalence or relative abundance of algal genera between research expeditions conducted in 2002 and 2003 (Vroom and Page, in press). Annual revisits to established sites throughout the NWHI will enable long-term data sets to be established that may reveal change over years or decades if environmental or anthropogenic changes occur. Analysis of similarity (ANOSIM) tests using Primer (Clarke and Warwick, 2001) revealed algal prevalence and relative abundance on reefs surrounding each island to differ more than comparisons among islands as a whole (Vroom and Page, in press). This is not surprising considering the number of different habitat types within a single island system (forereef, backreef, patch reef, etc.).

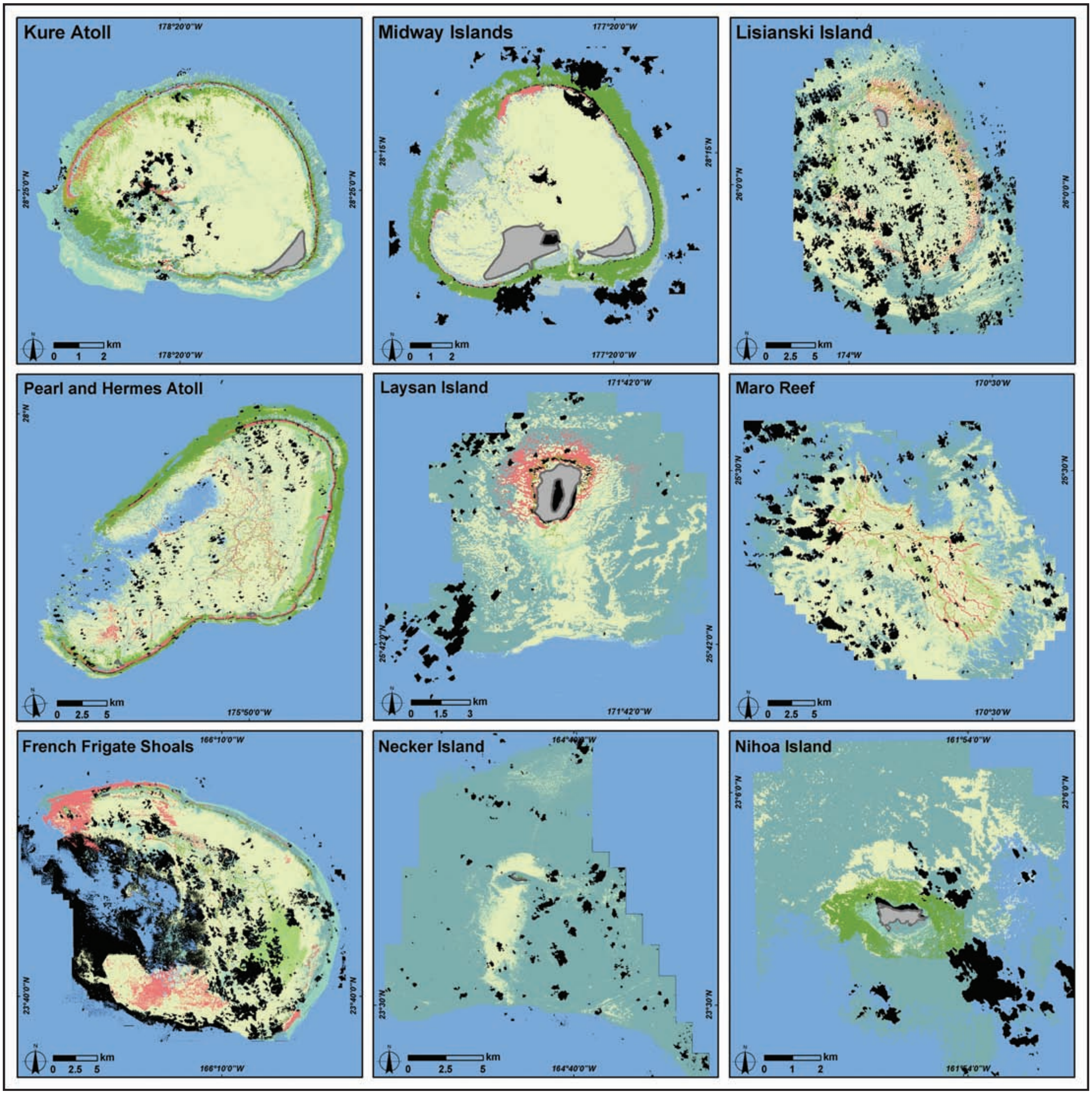
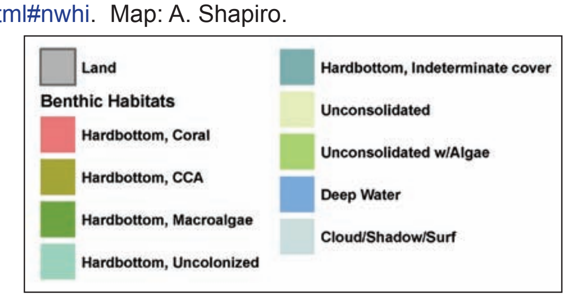


Figure 10.26. Nearshore benthic habitat maps were developed in 2003 by NOAA based on supervised classification of IKONOS satellite imagery. For more info, see: http://ccmaserver.nos.noaa.gov/rsd/products.html#nwhi. Map: A. Shapiro.



BENTHIC HABITAT MAPPING

In 2003 NOAA's CCMA released an atlas of digital maps depicting the shallow-water benthic habitats of the Northwestern Hawaiian Islands and several related products (Figure 10.26). The maps and derived bathymetry products were generated from IKONOS satellite imagery and classified using a hierarchical classification system that accounts for both geomorphologic structure and biotic cover. Despite difficulties associated with conducting ground validation in this remote area, accuracy estimates suggest that the maps, which were derived primarily through spectral analysis, are approximately 72% accurate for the major habitat classes (NOAA, 2003). A multibeam mapping project and other benthic habitat characterization techniques are being employed by PIFSC-CRED to generate similar and complimentary products.

ASSOCIATED BIOLOGICAL COMMUNITIES

FISH

Methods

NOAA Fisheries conducted quantitative monitoring of shallow-reef fishes in the NWHI during the 1990s to track the temporal dynamics of the shallow-reef fish forage base of monk seals (Monk Seal Forage Base Study, or MSFBS) at French Frigate Shoals in 1992 and Midway in 1993 (DeMartini et al., 1996). Stations were resurveyed at sites established by James Parrish and Hawaii Cooperative Fisheries Research Unit co-workers during the 1980s. Starting in 1995, annual sampling was conducted in late summer-early fall to control for seasonal effects by surveying shortly after most fish settlement. DeMartini et al. (2002) provides a comprehensive summary of the spatial and temporal patterns of shallow reef fishes at these two atolls during this period.

In late 2000, the Northwestern Hawaiian Resource Assessment and Monitoring Program (NOWRAMP) was established to assess the entire (ecosystem-level) resource base at all 10 emergent reefs and shallow (<20 m) shoals within the NWHI. Friedlander and DeMartini (2002) describe sampling and analysis designs in detail for the assessment-phase studies.

Both series of fish monitoring studies utilized *in situ* diver observations to tally fishes, by 1-10 cm (total length, TL) size classes, on belt transects of defined widths and lengths. On NOWRAMP surveys, length frequency data for larger, rarer fishes were augmented by timed (five-minute) tallies made within circular (10 m fixed radius) "stationary point count" plots. NOWRAMP surveys also included a "roving diver" component that provided species-presence data. The total search area at stations averaged 3,000 m^2 (DeMartini and Friedlander, 2004). As a separate but complementary effort on NOWRAMP surveys, pairs of divers were towed for an average of 50 minutes by motorized skiff (mean 2.66 km tow length) to estimate densities of large apex predators (Figure 10.27) at a necessarily much larger spatial scale (DeMartini et al., in press).

For the MSFBS, a total of nine stations (four outside, five inside the lagoon) were visited at French Frigate Shoals and at Midway on each survey. For the NOWRAMP surveys, three to about 20 stations were visited per reef on each cruise; and three major habitats (fore reef, back reef, lagoon patch reef) were used as major sampling strata. Stations were randomly located within strata selected based on relative exposure (i.e., windward, leeward) in order to increase spatial coverage and separate habitat- and reef-specific attributes. Total sampling effort (number of stations) during the assessment phase at each of the 10 reefs was proportional to total reef area and ranged from 10 at tiny Gardner Pinnacles to 74 at the largest atolls (French Frigate Shoals, Pearl and Hermes).

Figure 10.27. Large apex predators, such as sharks (left panel) and jacks (right panel), are abundant in the NWHI and dominate the ecosystem in terms of biomass. Large predators are conspicuously absent from most of the other jurisdictions in this report. Photos: J. Watt.

Results and Discussion

Initial insights into new baseline patterns of NWHI reef fish distribution and abundance are provided by DeMartini et al. (1996). Differences between French Frigate Shoals and Midway in the relative abundance of herbivores and carnivores and in the distribution of fish numbers and biomass among barrier reef and lagoon patch reef habitats were first noted. The major conclusion reached in this study was that reasonable statistical power (80% probability of rejecting a false null hypothesis) for detecting a large but less-than-catastrophic (50%) change in shallow-reef fish density would be attainable using a decade-long series of annual surveys only if species were pooled into higher taxonomic or trophic categories for analyses.

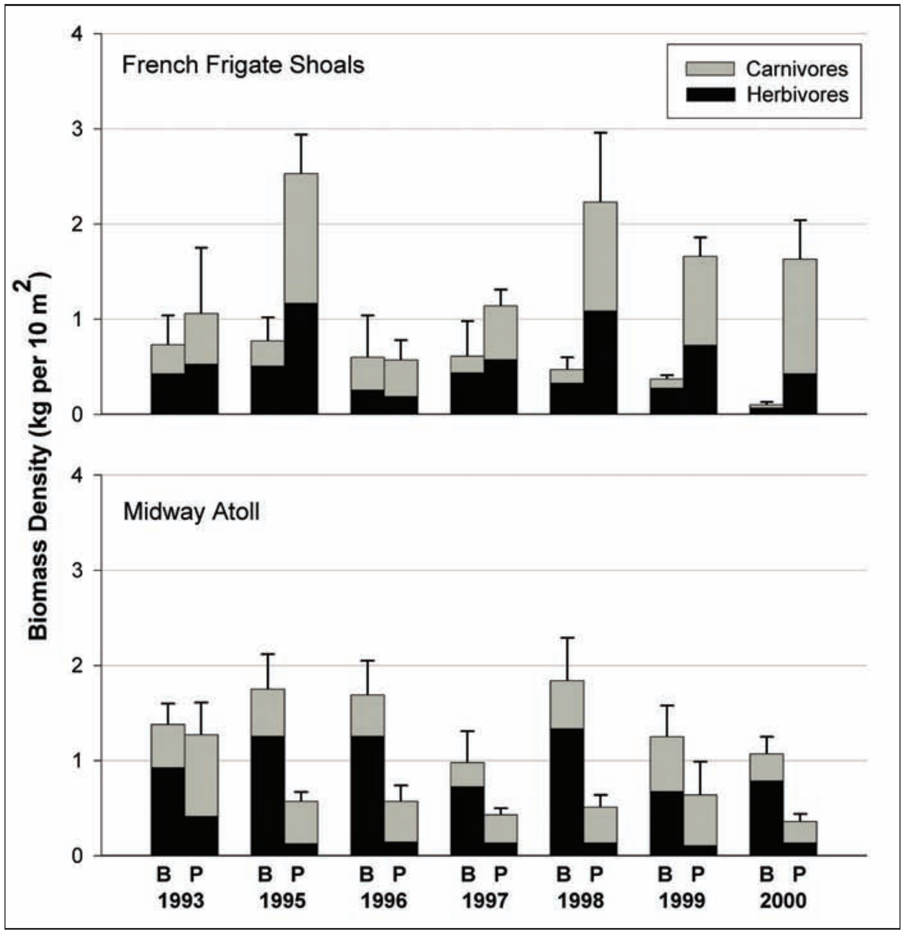


Figure 10.28. Biomass densities of herbivores (solid histograms) and carnivores (diagonals) at FFS and MID in 1992 (FFS only), 1993 (MID only), and 1995-2000 (both sites), in barrier (B) and patch (P) reef habitats. Standard errors are noted for total (herbivore plus carnivore) fishes. Source: DeMartini et al., 2002.

General results and conclusions related to the monitoring conducted by the MSFBS have been discussed by DeMartini et al. (2002). Briefly restated, these are: 1) There were no discernible temporal changes in the biomass densities of either herbivorous or carnivorous reef fishes at either French Frigate Shoals or Midway during the 1990s (Figure 10.28); 2) There was a consistently higher recruitment of young-of-year (YOY) life-stages of fishes at Midway Atoll versus French Frigate Shoals during the 1990s despite generally greater densities of older-stage fishes at French Frigate Shoals (Figure 10.29); and 3) Both giant trevally (*Caranx ignobilis*) and bluefin trevally (*C. melampygus*) were more frequently encountered and more abundant at French Frigate Shoals versus Midway, and the magnitude of this general difference increased (as giant trevally sightings decreased) subsequent to 1996 (Figure 10.30), at which time a recreational catch-and-release fishery was begun at Midway after the Midway Naval Air Station was closed and the atoll became a USFWS NWR (DeMartini et al., 2002).

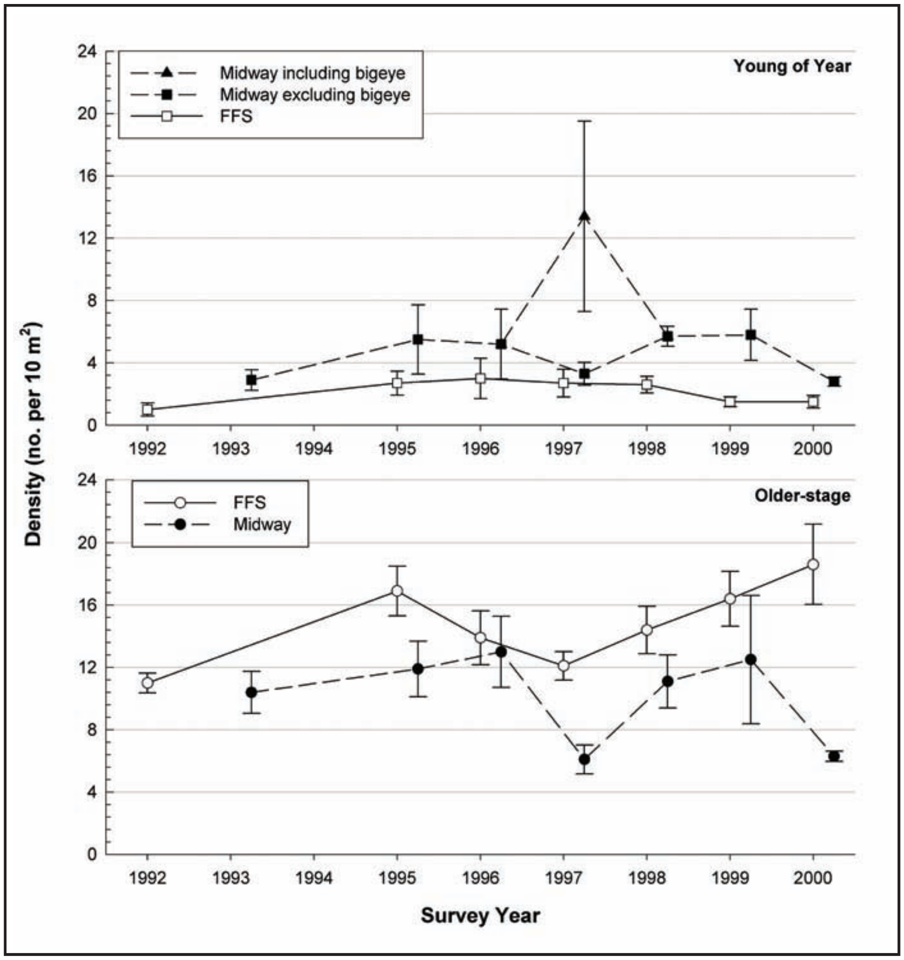


Figure 10.29. Time series of the estimated mean numerical density of YOY and older-stage fishes of all taxa at FFS and MID during each survey year. Each vertical bar represents 1 standard error (SE) of the estimated survey year grand mean for both major habitats. Source: DeMartini et al., 2002.

A comparison between the fish assemblages in the NWHI and MHI was conducted following sampling in 2000 across both regions (Friedlander and DeMartini, 2002). Grand mean fish standing stock in the NWHI was more than 260% greater than in the MHI across similar habitats (Figure 10.31). The most striking difference was the abundance and size of large apex predators (primarily sharks and jacks) in the NWHI compared to the MHI. More than 54% of the total fish biomass on forereef habitats in the NWHI consisted of apex predators, whereas this trophic level accounted for less than 3% of the fish biomass in the MHI. In contrast, fish biomass in the MHI was dominated by herbivores (55%) and small-bodied lower-level carnivores (42%). Most of the dominant species by weight in the NWHI were either rare or absent in the MHI and the target species that were present, regardless of trophic level, were nearly always larger in the NWHI.

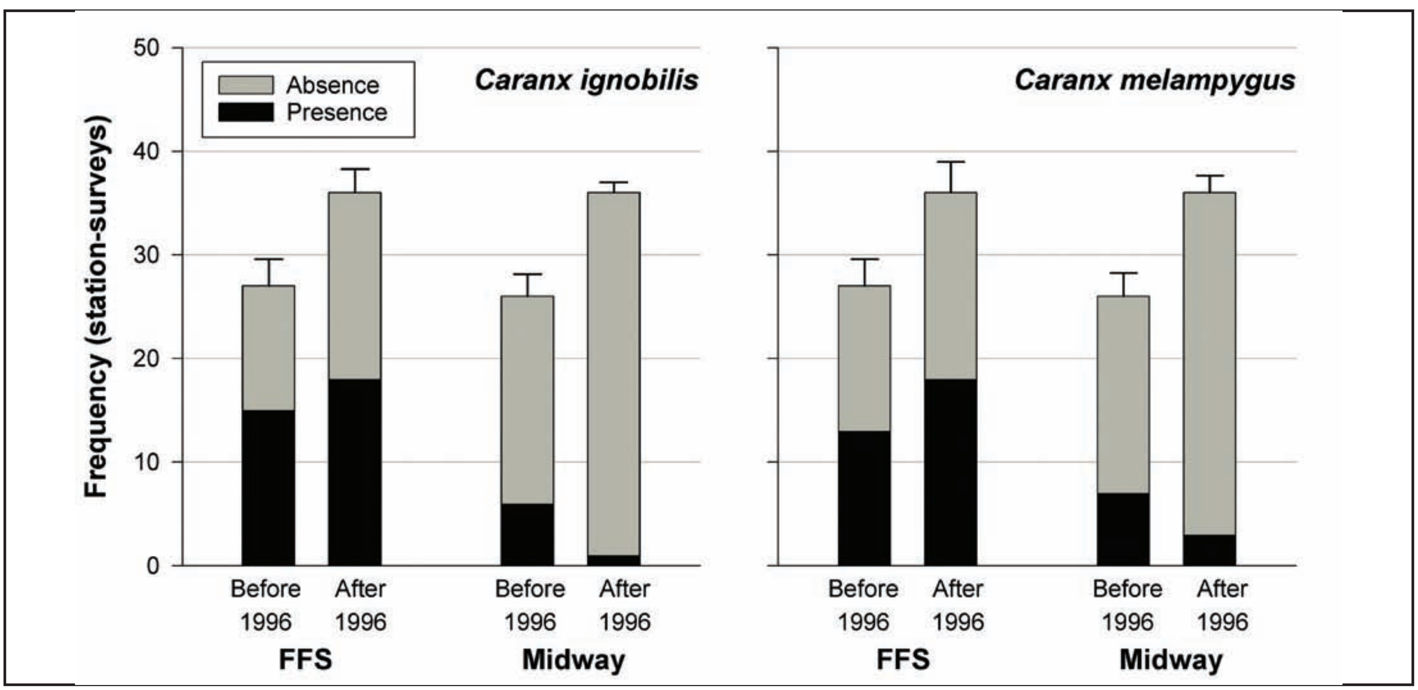


Figure 10.30. Relative presence-absence of giant trevally (*Caranx ignobilis*) and bluefin trevally (*C. melampygus*) at FFS and MID stations during 1992 (FFS) or 1993 (MID) through 1995-2000 pooled. The stacked presence-absence bars indicate species subtotals up to and including 1996 ("Before") versus after 1996 ("After") at each site. Vertical lines atop histogram bars are 1 SE. Source: excerpted from DeMartini et al., 2002.

Several assessment-focused studies complement the contemporary monitoring program described below. DeMartini (2004) recognized the importance of back reef, lagoon patch reef, and other sheltered (wave-protected) habitats as nursery areas for juvenile reef fishes in the NWHI. This study, based on re-analyses of some of the data collected for the MSFBS, contributes substantially to development of both "essential fish habitat" and "habitats of particular concern" which recognize the greater per-unit-area value of atolls due to their larger proportion of sheltered habitats.

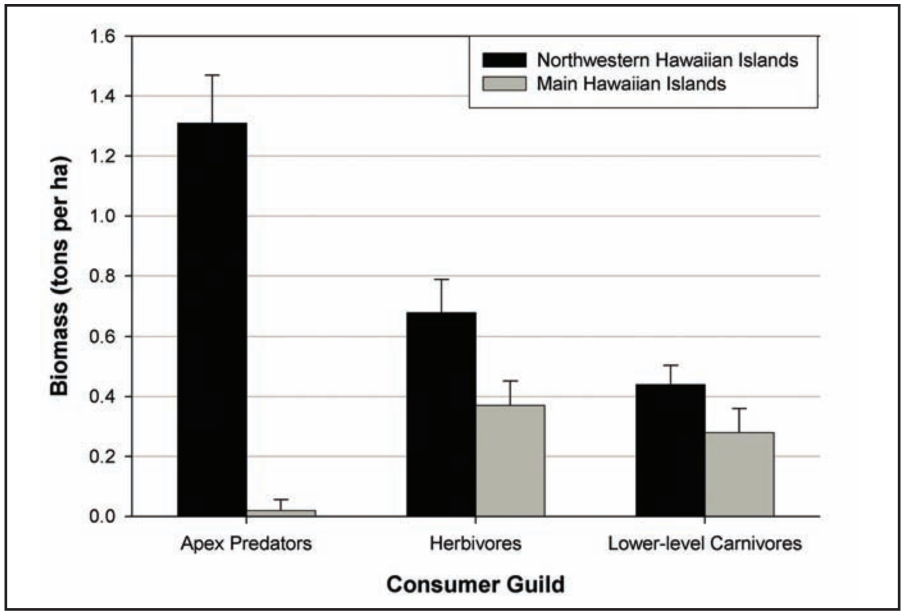


Figure 10.31. Comparison of the biomass in major trophic guilds between the MHI and the NWHI. Source: Friedlander and DeMartini, 2002.

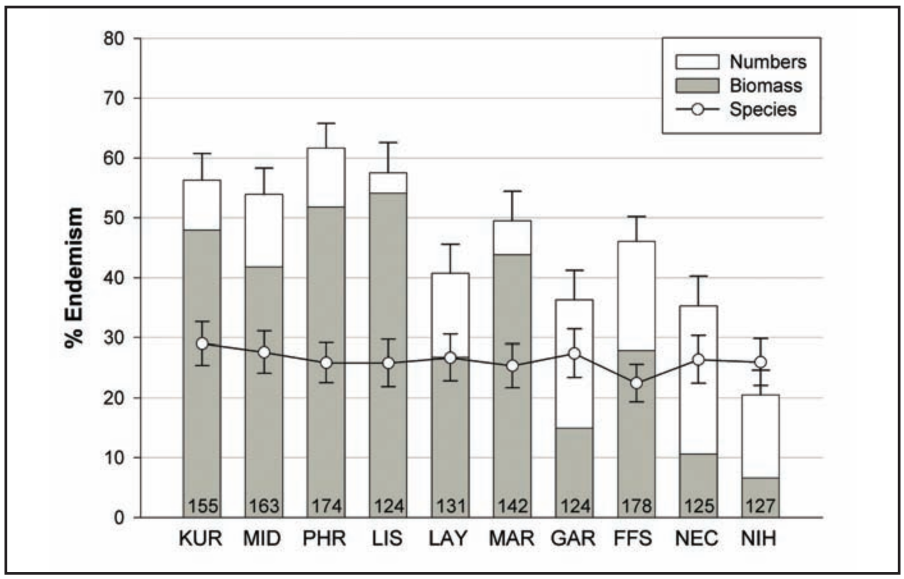


Figure 10.32. Various measures of percentage endemism (based on species presence-absence, and on numerical and biomass densities) at each of ten emergent NWHI reefs, illustrating patterns of endemism with latitude-longitude. Presence-absence data are indicated by line graph and density data by histograms. Species richness (number of species) is noted by numbers at base of histograms. Source: DeMartini and Friedlander, 2004.

Important to biodiversity concerns is the markedly high endemism of shallow reef fishes in the NWHI. Percentage endemism based on the typical species-presence criterion is about one-fifth higher (30% vs 25%) in the NWHI versus MHI (DeMartini and Friedlander, 2004). The MHI value is indistinguishable from present estimate of 23% for Hawaiian fishes based on comprehensive specimen sources including market sampling, poison stations, and museum collections (Randall, 1998). Endemism is even more strongly expressed in terms of standing stock per unit area–both biomass (mean 37%) and especially numerical (mean 52%) densities–in the NWHI, and increases with latitude throughout the Hawaiian Archipelago even though species-presence-based measures of endemism lack latitudinal pattern within the NWHI (Figure 10.32; DeMartini and Friedlander, 2004). These recent observations of a latitudinal effect on standing stock-based endemism were foreshadowed by an analogous pattern observed previously at French Frigate Shoals and Midway (DeMartini, 2004).

Size structure data collected during the initial NOWRAMP assessment provided insights into the effects of apex predators on their shallow-water reef fish prey. Protogynous (female-to-male sex-changing) labroid fishes (wrasses and parrotfishes, especially the latter), the adult sexes of which conspicuously differ in body coloration, are the preferred prey of *C. ignobilis*, the dominant apex predator on shallow NWHI reefs (Sudekum et al., 1991; Friedlander and DeMartini, 2002). At the three northernmost atolls of the NWHI, body sizes at coloration (sex) change of labroids are larger, and overall size distributions are skewed larger in labroids and other prey fish species at Midway (Figure 10.33), where jacks are fewer, compared to two nearby atolls (Kure and Pearl and Hermes) where jacks are more abundant (DeMartini et al., in press). These latter observations have significant implications for reef fish management in the Hawaiian Archipelago. First, *in situ* observations,

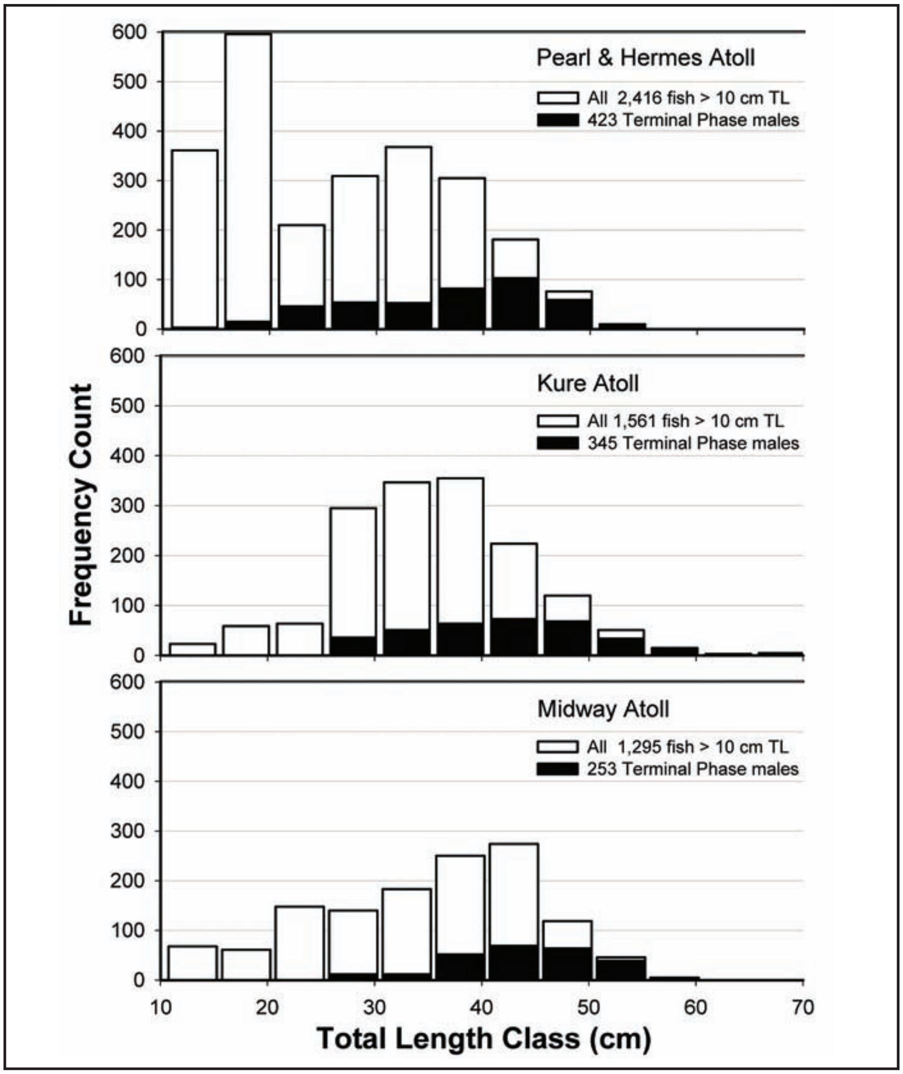


Figure 10.33. Body size (TL) frequency distributions of eight species of sexually dimorphic, sex-changing labroids (four parrotfishes, four wrasses) at (A) P&H, (B) KUR, and (C) MID in the far northwestern NWHI, during Sept.-Oct. periods of 2000 and 2002. Terminal-phase (sex-changed) males are indicated by fills within histogram bars. Source: DeMartini et al., in press.

Table 10.11. Non-coral invertebrate species identified to date in the NWHI.

PORIFERA	**23**	**ARTHROPODA**	
CNIDARIA		Pycnogona	3
Hydrozoans	10	Cirripedia	9
Scyphozoans	2	Peracarids	76
Anthozoans	13	Decapods	125
PLATYHELMINTHES	**5**	**ECHINODERMATA**	
NEMERTEA	**1**	Asteroids	11
BRYOZOA	**39**	Ophiuroids	26
BRACHIOPODA	**1**	Echinoids	21
SIPUNCULIDA	**1**	Holothuroids	17
ANNELIDA	**52**	**UROCHORDATA**	**25**
MOLLUSCA			
Gastropods	310		
Bivalves	66		
Cephalopods	2		
TOTAL=838			

instead of gonadal examination, can be used to estimate size at sex change, an important parameter for stock assessment. Second, prey size frequency distributions can be used as an effective proxy for predation intensity (predator abundance) when assessing functional change on NWHI coral reefs as part of an ecosystem-based approach to management (DeMartini et al., in press).

NON-CORAL INVERTEBRATES

Prior to efforts in 2000, there had been only two large-scale expeditions to the NWHI for the purpose of marine faunal surveys. The first was the Albatross Expedition in 1902 in which a variety of species were collected and deposited at the Smithsonian Institution's National Museum of Natural History. A second effort was the Tanager Expedition in 1923, which was organized by the U.S. Department of Agriculture and the Bishop Museum.

Recent efforts since 2000 have collected a large amount of non-coral marine invertebrate material (Table 10.11), much of which remains to be definitively identified. To date, a number of new species have been recorded for the Hawaiian Archipelago and some species might prove to be endemic to the NWHI. Mollusks, crustaceans, and echinoderms dominate the non-coral invertebrate fauna in the NWHI, which is typical for most coral reef communities. These cryptic fauna are more abundant in the NWHI than the MHI, although remote locations of the MHI that are not heavily impacted by anthropogenic stressors are comparably abundant (DeFelice et al., 2002). Species data for non-coral invertebrates is incomplete and collaboration with taxonomic experts throughout the world is in progress.

HAWAIIAN MONK SEAL

The Hawaiian monk seal (*Monachus schauinslandi*) is the only endangered pinniped occurring entirely within U.S. waters. Its current population is estimated at 1,300 seals, a decrease of about 60% since the 1950s. Counts declined about 5% per year from 1985 to 1993, remained relatively stable through 2000, and declined again in 2001. When compared historically, the monk seal beach count abundance index reached record lows for 2001, 2002, and 2003 (Figure 10.34).

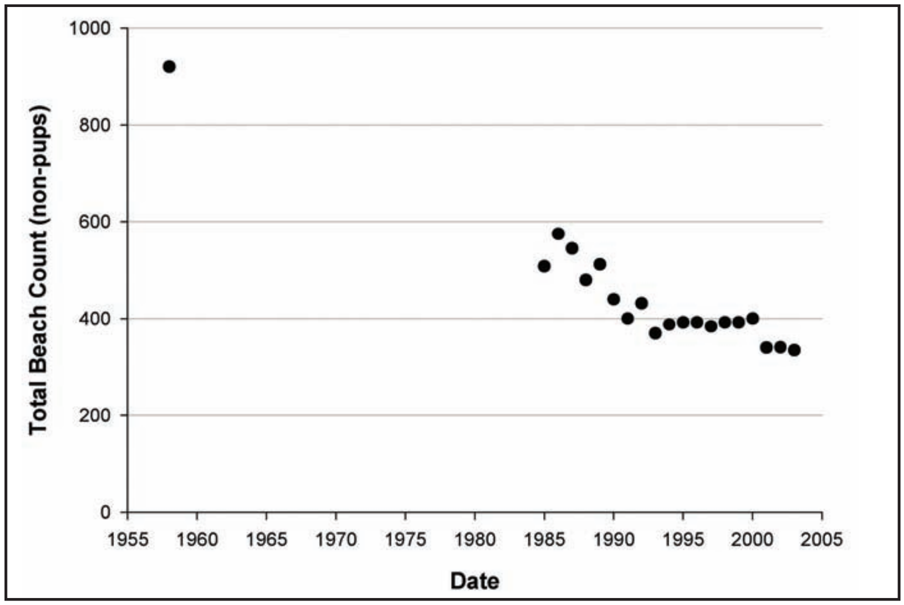


Figure 10.34. Historical trend in beach counts (non-pups) of Hawaiian monk seals at the six main reproductive subpopulations. Source: Antonelis et al., in review.

Population trends have been variable at the six main reproductive subpopulations in the NWHI. In recent years overall pup production and juvenile survival have decreased at most sites. The largest subpopulation is at French Frigate Shoals where counts of non-pups have dropped by 60% since 1989, and the age distribution has become severely inverted due to high juvenile mortality over the last decade. Future abundance trends will likely depend upon whether predicted losses at French Frigate Shoals are countered by gains at other locations. Monk seals occur throughout the Hawaiian Archipelago, and although most are found in the NWHI, a small but increasing number haulout and pup in the MHI. They commonly occur on isolated beaches for resting, molting, parturition, and nursing offspring, and forage on demersal and benthic prey. Past and present sources of anthropogenic and natural impacts to monk seals include hunting during the1880s, disturbance (e.g., active and post WWII military activities), entanglement in marine debris, direct fishery interaction prior to establishment of the 1991 Protected Species Zone in the NWHI, predation by sharks, aggression by adult male monk seals, and reduction of habitat and prey due to environmental change. Assessment and mitigation of factors limiting population growth are ongoing challenges and primary objectives of the monk seal recovery effort.

HAWAIIAN GREEN SEA TURTLE

The green turtle (*Chelonia mydas*) is the most abundant large marine herbivore and has a circumtropical distribution with distinct regional population structures. Globally, the green turtle has been subject to a long history of human exploitation with some stocks now extinct and others in decline. The Hawaiian green sea turtle or honu (Figure 10.35) comprises a spatially disjunct metapopulation with numerous distinct foraging grounds within the 2,200 km span of the Hawaiian Archipelago.

The principal rookery for the Hawaiian green sea turtle is located on sand islands at French Frigate Shoals which accounts for >90% of all nesting within the Hawaiian Archipelago. The main rookery island at French Frigate Shoals is East Island where

Figure 10.35. Greater than 90% of the Hawaiian green sea turtles' principal nesting areas are located on the sand islands of FFS. Photo: J. Watt.

at least 50% of all French Frigate Shoals nesting occurs. Nesting females exhibit strong island fidelity, and the Hawaiian green sea turtle stock has been continuously monitored for several decades. Annual surveys of the number of female green turtles coming ashore to nest each night have been conducted at East Island since 1973.

Green sea turtles in U.S. waters have been protected under the Federal Endangered Species Act since 1978. From the mid-1800s until about 1974, the Hawaiian stock was subject to human exploitation such as turtle harvesting at foraging grounds, harvesting of nesters and eggs, and nesting habitat destruction.

The long-term trends based on a population model for the East Island nester abundance illustrates two main features: a dramatic increase in abundance over the 30-year study and substantial fluctuations in the number of annual nesters (Figure 10.36). Such fluctuations are characteristic of green turtle nesting populations and reflect a variable proportion of females in the population that breed each year in response to spatially correlated ocean-climate variability. The Hawaiian green sea turtle stock is clearly recovering after more than 25 years of protecting their nesting and foraging habitats in the Hawaiian Archipelago.

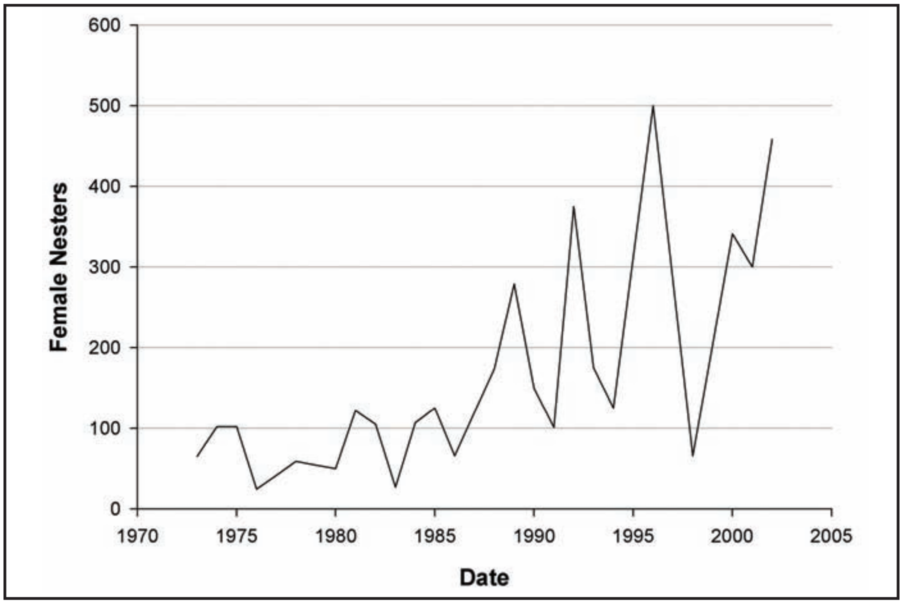


Figure 10.36. Nester abundance shown as the number of female green sea turtles nesting each year at East Island from 1973 to 2002. Source: Balazs and Chaloupka, 2004.

PEARL OYSTERS

The population of black-lipped pearl oysters, *Pinctada margaritifera*, at Pearl and Hermes Atoll were discovered in 1927 and heavily harvested. Conservative estimates indicate that approximately 150,000 oysters were either exported or killed during the harvest. An expedition in 1930 to assess the population post-harvest found 480 pearl oysters, and estimated 100,000 oysters remaining on the reef. More recent surveys in 1969, 1996, and 2000 found only a few oysters and it was assumed that the population had not recovered since the harvest.

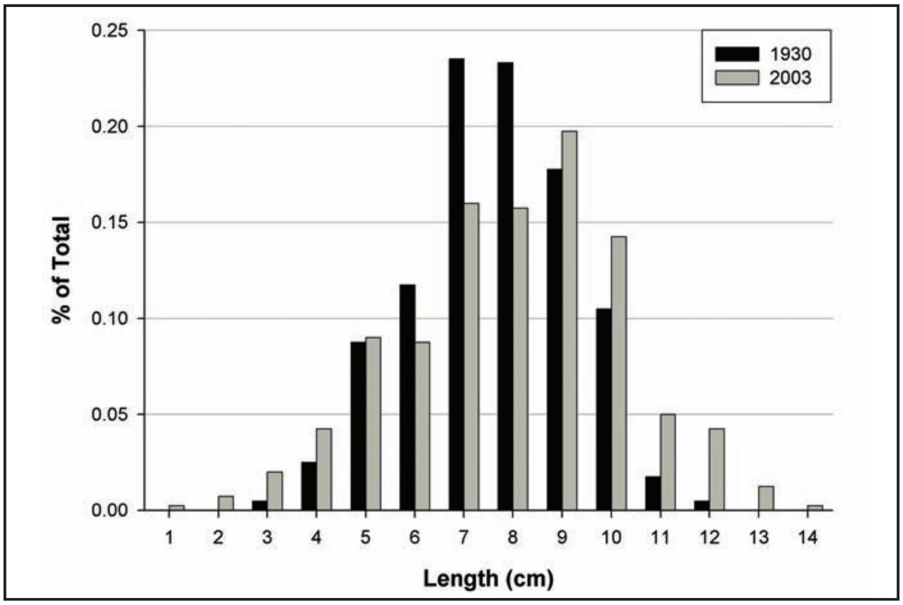


Figure 10.37. Pearl oyster size frequency distribution at P&H in 1930 and 2003. Source: Keenan et al., in review.

In 2003, the NOAA Fisheries-led multi-agency marine debris removal team spent several months conducting surveys at Pearl and Hermes that included documenting sightings of pearl oysters (Keenan et al., in review). Over 1,000 individuals were documented and mapped in this sampling effort. The average size of pearl oysters in the 2003 surveys was larger than the 1930 surveys (Figure 10.37). The number of individuals and the size structure from recent surveys may reflect a recovery of the population 70 years after harvest ceased and/or a more thorough sampling effort relative to previous surveys.

SEABIRDS

Seabird colonies in the NWHI constitute one of the largest and most important assemblages of seabirds in the world, with approximately 14 million birds (5.5 million breeding annually) representing 21 species. More than 95% of the world's Laysan and Black-footed albatross nest here. For several other species such as Bonin petrel, Christmas shearwater, Tristram's storm-petrel, and Grey-backed tern, the NWHI supports colonies of global significance. The last complete inventory of NWHI breeding populations was done between 1979 and 1984. Population trends since then have been derived from more intensive monitoring at three islands. Population trends in the NWHI are stable or increasing for most species but there is concern for a few, especially the albatross.

Annual reproductive success (proportion of chicks fledged per egg laid) of Laysan albatross, *Diomedea immutabilis*, and Blackfooted albatross, *D. nigripes*, at French Frigate Shoals in the NWHI indicates strong coherence between the two species that is especially evident during two years of very low reproductive success (1984 and 1999) (Figure 10.38; Seki, 2004). Both years of low reproductive success occurred about one year after major ENSO events. Other seabird species such as Red-footed boobies, *Sula sula*; Red-tailed tropicbirds, *Phaethon rubricauda*; and Black noddies, *Anous tenuirostris*, also exhibited very low reproductive success in 1998-99, but not in 1984.

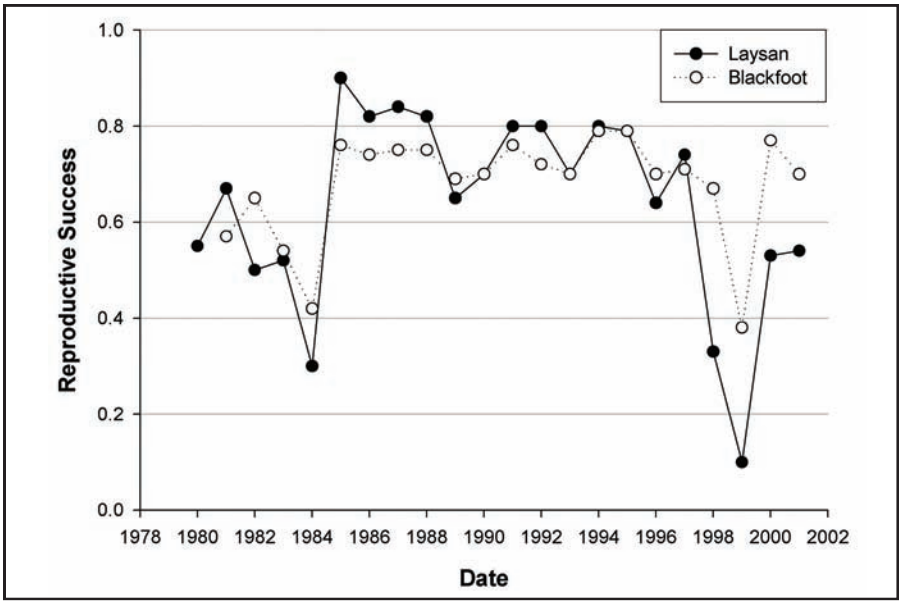


Figure 10.38. Temporal trends in the reproductive success of Black-footed and Laysan albatrosses monitored at FFS from 1980 to 2001. Source: Seki, 2004.

The conservation status of Hawaiian seabirds was assessed as part of the North American Waterbird Conservation Plan. Eleven of the 21 species were classified as highly imperiled or high conservation concerns at the broad scale of the plan (eastern North Pacific, western North Atlantic, and Caribbean). At the regional scale (Pacific Islands) six species were included in these highest concern categories: Laysan, Black-footed and Short-tailed albatross; Christmas shearwater; Tristram's storm-petrel; and Blue noddy. Greatest threats to seabirds in the NWHI are introduced mammals and other invasive species, fishery interactions, contaminants, oil pollution, and climate change. Over the past 20 years, active management in the NWRs and Hawaii State Seabird Sanctuary has included eradication of rodents (*Rattus rattus* at Midway and *R. exulans* at Kure); eradication or control of invasive plants; coordination among NOAA Fisheries, Fishery Management Councils, industry, and conservation organizations to reduce fishing impacts; and cleanup of contaminants and hazards at former military sites. The NWHI are unique in being one of the largest marine protected areas in the world, established in 1909 for the express purpose of protecting seabirds. Early protection and active management have resulted in large, diverse, and relatively intact seabird populations.

The estimated 14 million seabirds residing in the NWHI are primarily pelagic feeders that obtain the fish and squid they consume by associating with schools of large predatory fish such as tuna and billfish (Fefer et al., 1984). While both the predatory fish and the birds are capable of foraging throughout their pelagic ranges, which encompass the entire tropical ocean, the birds are most successful at feeding their young when they can find schools of predatory fish within easy commuting range of the breeding colonies. Recently fledged birds, inexperienced in this complex and demanding style of foraging, rely on abundant and local food resources to survive while they learn to locate and capture prey. Ashmole and Ashmole (1967) and Boehlert (1993) suggest that the circulation cells and wake eddies found downstream of oceanic islands may concentrate plankton and therefore enhance productivity near islands, thus allowing higher tuna populations locally.

Johannes (1981) describes the daily migrations of skipjack tuna and yellowfin tuna to and from the waters near islands and banks. Conservation of these tunas in the vicinity of seabird colonies will enhance the birds' ability to provide adequate food for their offspring. Wake eddies also concentrate the larvae of many reef fishes and other reef organisms and serve to keep them close to reefs, enhancing survivorship of larvae and recruitment of juveniles and adults back to the reefs. For at least four of the 21 seabird species breeding in the NWHI (brown noddies, black noddies, white terns, and brown boobies), significant proportions (33%-56%) of their diet originate from the surrounding coral reef ecosystem (Ashmole and Ashmole, 1967; Harrison et al., 1983; Diamond, 1978).

Overall Condition and Summary of Analytical Results

The remoteness and limited reef fishing activities that have occurred in the NWHI have resulted in minimal anthropogenic impacts. Large apex predators such as jacks, reef sharks, and amberjacks are one of the most striking and unique components of the NWHI ecosystem. These top carnivores are seldom encountered nowadays in the inhabited Hawaiian Islands.

The flora and fauna of the NWHI include a large percentage of species that are endemic to the Hawaiian Islands. The faunas of isolated oceanic archipelagos like the Hawaiian Islands represent species conservation hotspots that have become increasingly important due to the continual losses of biodiversity on coral reefs worldwide. The NWHI represent important habitat for a number of threatened and endangered species. The Hawaiian monk seal is one of the most critically endangered marine mammals in the U.S. (1,400 individuals) and depends almost entirely on the islands of the NWHI for breeding and the surrounding reefs for sustenance. Over 90% of all sub-adult and adult Hawaiian green sea turtles found throughout Hawaii come from the NWHI.

Despite their high latitude location, nearly as many species of coral have been reported from the NWHI (57) compared with the MHI (59). Kure is the world's most northern atoll and is referred to as the Darwin Point, where coral growth and subsidence/ erosion balance one another. Unlike the MHI where alien and invasive algae have overgrown many coral reefs, the reefs in the NWHI are free of alien algae and the high natural herbivory results in a pristine algal assemblage.

Spatial and temporal variability of key oceanographic processes influence the structure, function, and biogeography of the NWHI coral reef ecosystem. Although currents in the region are dominated by eddy-energy, there is a weak mean flow from the MHI towards the NWHI. Preliminary drifter observations suggest local retention at the northern atolls, supporting observations of increased endemism upchain. Wintertime temperature minima (17-20°C) and summetime maxima (27-29°C) are greater at the northern end of the chain compared with the MHI. Observations of an intermittent eastward-flowing Subtropical Countercurrent in the region between French Frigate Shoals and Gardner Pinnacles support the hypothesis of a genetic gateway to the archipelago from the central Pacific.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Administrative jurisdiction over the islands and marine waters is shared by NOAA, USFWS, and the State of Hawaii. Eight of the 10 NWHI (all except Kure and Midway Atolls) have been protected by what is now the Hawaiian Islands National Wildlife Refuge (HINWR) established by President Theodore Roosevelt in 1909. The Refuge includes all land and reef areas to 20 fathoms off Necker Island and to 10 fathoms off the remaining seven islands.

The State of Hawaii manages the Kure Atoll Wildlife Refuge and all waters around each of the islands and atolls from 0-3 miles except Midway. The State has recently proposed regulations that would create the NWHI Marine Refuge. The new NWHI Marine Refuge would: 1) require an entry permit for any activities within State waters; 2) prohibit fishing of any kind at Kure Atoll, Pearl and Hermes Atoll, Lisianski Island, Laysan Island, Maro Reef, Gardner Pinnacles, French Frigate Shoals, and Necker Island; 3) prohibit fishing of any kind from 0-10 fathoms in State waters surrounding Nihoa Island; 4) allow for Native Hawaiian cultural gathering; 5) prohibit engaging in any activity, including the anchoring of a vessel that can or does result in damaging or destroying coral, and; 6) prohibit engaging in any activity not authorized by this regulation. These proposed rules are undergoing final review and will be enacted into law sometime in early 2005. The State also issues commercial fishing permits to all fishermen fishing in the NWHI and landing their catch in Hawaii. The State maintains the data base on effort and landings that are used by the management agencies for fisheries management decisions.

NOAA Fisheries has also designated 10 areas from the shore to 20 fathoms in the NWHI as critical habitat for the Federally endangered Hawaiian monk seal, although this designation does not include any restrictions of activities. Commercial fishing in the NWHI within 100 m depth targets mostly bottomfish and previously lobsters, each of which is managed separately by the NOAA Fisheries through fishery management plans developed by the Western Pacific Regional Fishery Management Council. Both of these fisheries are limited entry with fewer than 20 vessels allowed to operate in each fishery. Presently, there are fewer than 10 vessels active in the bottomfish fishery. The lobster fishery has been closed by NOAA Fisheries since 2000 due to uncertainties in the lobster population model parameters used to accurately estimate the exploitable lobster population.

Except for Midway, the NOAA Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve (CRER), established in 2000 by President Clinton (Executive Order 13178 and amended with Executive Order 13196 in January 2001), extends protection and Federal jurisdiction beyond the offshore boundaries of State waters to a maximum distance of 50 nm (see Figure 10.1). Midway is outside both State of Hawaii and CRER jurisdiction and since 1996 has been under USFWS administration as the Midway Atoll NWR, affording protection to all reefs and islands at the atoll. This large reserve area, 2,200 km in length and 3-50 nautical miles (6-93 km) from shorelines, is managed by the Secretary of Commerce and may be designated as a National Marine Sanctuary. Executive Order 13178 also established caps on commercial fishing and 15 Reserve Preservation Areas in which extractive use is prohibited with limited exceptions. The Reserve boundaries lie seaward of the jurisdictional areas of the Hawaiian Islands NWR, Midway Atoll NWR, and State of Hawaii boundaries, mandating that all three agencies cooperate fully for effective protection of all NWHI and coral reefs.

Except for Kure and Midway, recreational and commercial fishing activities are prohibited within the 10-fathom isobath of the eight islands (and inside 20 fathoms around Necker) within the Hawaiian Islands NWR managed by the USFWS. Kure Atoll currently falls under State jurisdiction, and fishing is permitted on its shallow reefs. Under the State's proposed new marine refuge regulations, fishing will no longer be allowed within State waters at Kure. Midway Atoll NWR sponsored a catch-and-release sportfishery between 1996 and 2002, but all ecotourism activities including sport fishing have been greatly reduced due to funding shortfalls to operate the refuge associated transportation, housing facilities and utilities.

OVERALL STATE/FEDERAL CONCLUSIONS AND RECOMMENDATIONS

With coral reefs around the world in decline, it is extremely rare to be able to examine a coral reef ecosystem that is relatively free of human influence and consisting of a wide range of healthy coral reef habitats. The remoteness and limited activities that have occurred in the NWHI have resulted in minimal anthropogenic impacts. The region represents one of the few large-scale, intact, predator-dominated reef ecosystems remaining in the world and offers an opportunity to examine what could occur if larger more effective no-take marine reserves are established elsewhere. The high proportion of endemic species and unique mix of tropical and sub-tropical assemblages has identified the NWHI as a global biodiversity hotspot. The NWHI are critically important to a number of wide-ranging species such as seabirds, turtles, monk seals, and sharks (Figure 10.39). Strong ecological linkages are provided by these and a few other organisms for the transfer of energy and nutrients among ecosystems.

The nearly pristine condition of the NWHI allows us to understand how unaltered ecosystems are structured, how they function, and how they can most effectively be preserved. The NWHI provide an unparalleled opportunity to assess how a "natural" coral reef ecosystem functions in the absence of major human intervention. These reefs consist of discreet ecological subunits that can be used as replicates to examine large-scale ecological processes, while the scale of the existing fisheries allows for adaptive management strategies that can address questions related to stock decline and recovery. The NWHI represents a baseline in which to understanding natural fluctuations and measure the success of existing management regimes elsewhere. Lessons learned from the NWHI can be used to help develop more effective management strategies in the MHI and other ecosystems. The NWHI should not only be conserved for their intrinsic value, but also for their value to hedge against fisheries collapses and as a model for ecosystem-based management.

Figure 10.39. Seabirds, such as these Brown noddy terns and Brown booby at P&H (left photo), rely on the NWHI for nesting, feeding and breeding. The critically endangered Hawaiian monk seal (right photo) is an intergral component of the NWHI ecosystem. Photos: J. Watt.

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The State of Coral Reef Ecosystems of American Samoa

Peter Craig[1], Guy DiDonato[2], Douglas Fenner[3], Christopher Hawkins[4]

INTRODUCTION AND SETTING

American Samoa is a U.S. Territory located approximately 4,200 km south of Hawai'i. It is the southernmost of all U.S. possessions and the only U.S. jurisdiction in the South Pacific. American Samoa comprises seven islands (five volcanic islands and two coral atolls) with a combined land area of approximately 200 km^2 (Figure 11.1). The five volcanic islands, Tutuila, Aunu'u, Ofu, Olosega, and Ta'u, are the major inhabited islands of American Samoa. Tutuila, the largest island, is also the center of government and business. Ofu, Olosega, and Ta'u, collectively referred to as the Manu'a Islands, are 107 km east of Tutuila. Two outer islands, Rose Atoll and Swains Island, are approximately 259 km and 327 km from Tutuila, respectively. Rose Atoll is uninhabited and is managed as a National Wildlife Refuge (NWR) by the U.S. Fish and Wildlife Service (USFWS), while Swains Island is inhabited by a subsistence population of approximately 10 people.

The islands range in size from the populated high island of Tutuila (138 km^2) to the uninhabited and remote Rose Atoll (4 km^2). The total area of coral reefs (to the 100 m depth) in the Territory is 296 km^2. Due to the steepness of the main islands, shallow water habitats around the islands are limited and consist primarily of fringing coral reefs (85% of total coral reef area) with a few offshore banks (12%) and two atolls (3%). The fringing reefs have narrow reef flats (50-500 m); depths of 1000 m are reached within 2-8 km from shore.

Coral reefs in American Samoa support a high diversity of Indo-Pacific corals (over 200 species), fishes (890 species), and countless invertebrates. In recent years the corals have demonstrated considerable resilience following a series of natural disturbances, including four hurricanes in the past 18 years, a devastating crown-of-thorns starfish invasion in 1978, and several recent bleaching events. Following each disturbance, the corals eventually recovered and grew to maintain the structural elements of the reefs. However, because serious overfishing has occurred, the Territory's coral reef ecosystem cannot be considered healthy based on the resilience of the corals alone. Furthermore, climate change impacts such as warm-water coral bleaching and coral disease are becoming increasingly apparent and pose a major, repetitive impact to the structure and function of local reefs. Additionally, the Territory's high population growth rate (2.1% per year) continues to strain the environment with issues such as extensive coastal alterations, fishing pressure, loss of wetlands, soil erosion and coastal sedimentation, solid and hazardous waste disposal, and pollution.

1 National Park of American Samoa
2 American Samoa Environmental Protection Agency
3 American Samoa Department of Marine and Wildlife Resources
4 American Samoa Coral Reef Initiative

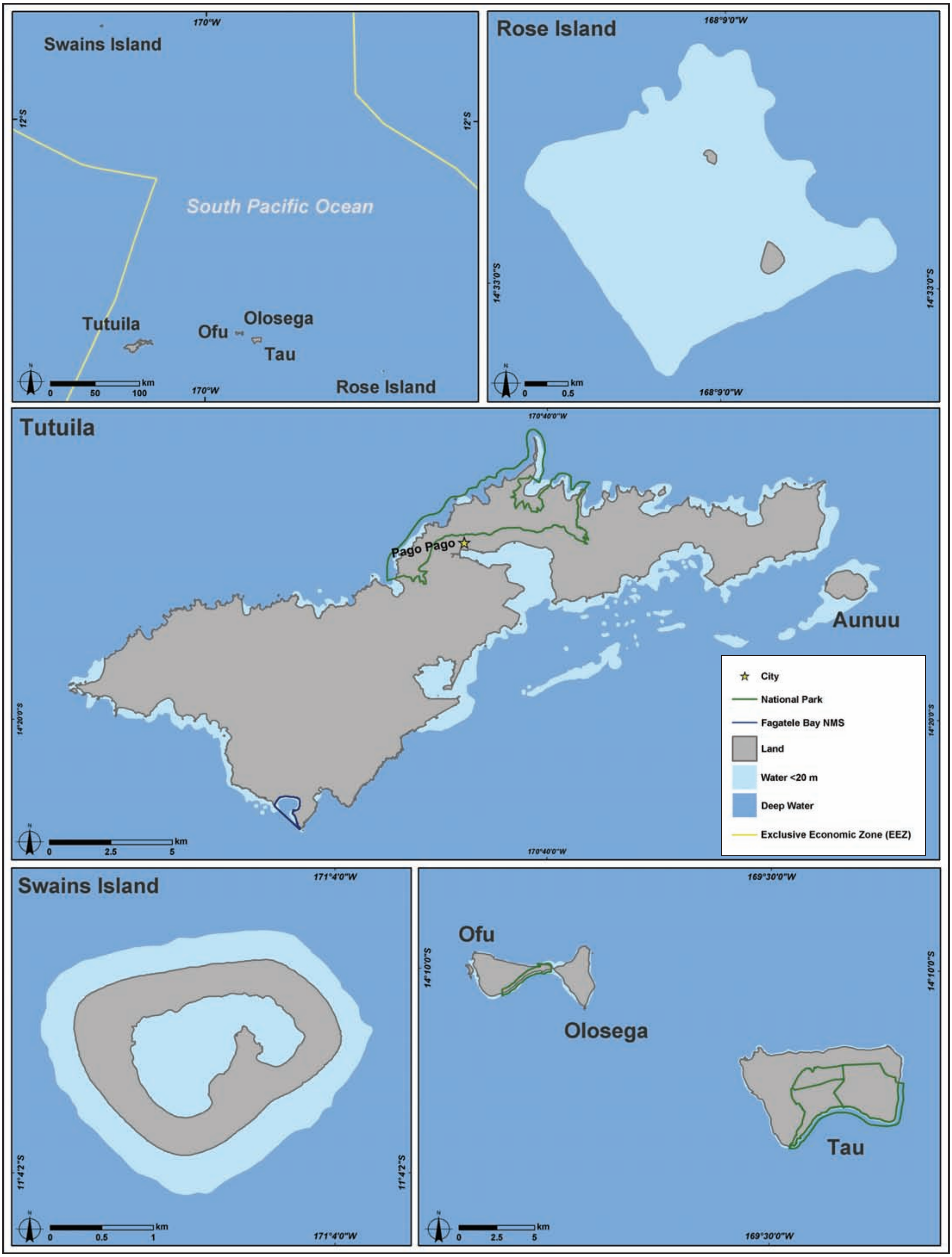


Figure 11.1. Map of the locations in American Samoa mentioned in this chapter. Map: A. Shapiro.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSES

Climate Change and Coral Bleaching

Global warming and climate change will impact coral reefs in at least two ways. First, these impacts increase water temperatures which can stress or kill corals; second, they increase the level of dissolved CO_2 in sea water which may reduce the growth rate of corals and promote erosion of the reef itself. Despite the remote oceanic location of American Samoa, it is apparent that CO_2 (a primary greenhouse gas) is steadily increasing (Figure 11.2). In recent years, some coral bleaching has been observed annually on local reefs, and bleaching was particularly widespread and prolonged (four months) in 1994, 2002, and 2003 (Figure 11.3A). However, systematic assessments of the degree of bleaching, species affected, and percent recovery/mortality is generally not available for the Territory.

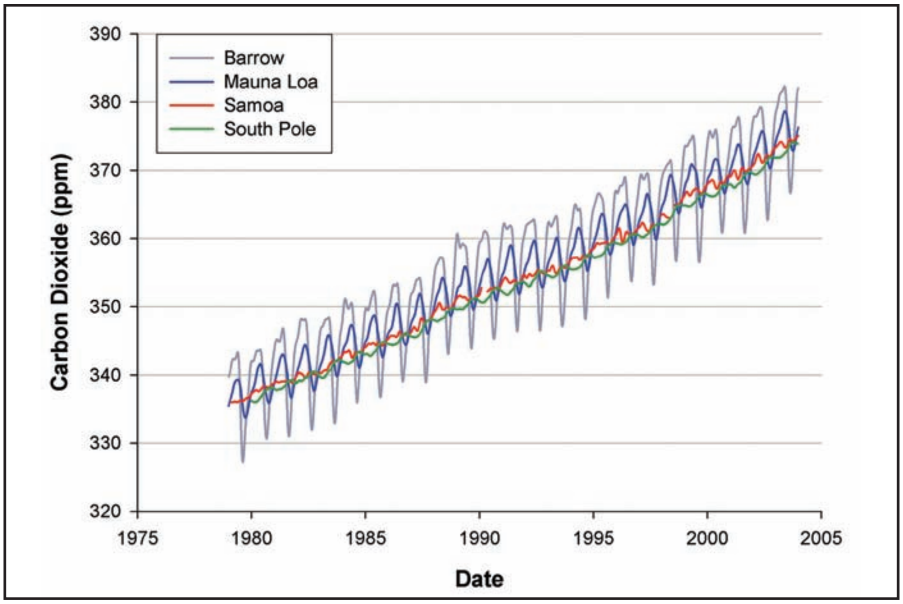


Figure 11.2. Increase of atmospheric CO_2 in American Samoa, Hawaii, and the North and South Poles. Source: NOAA Climate Monitoring and Diagnostic Laboratory.

Diseases

During bleaching episodes in 2002 and 2003, formerly rare coral diseases were commonly seen (Figure 11.3B,C). At present, there is a lack of consistent descriptive terminology for Pacific coral diseases, but what has been observed seems similar to that called 'white syndrome' in the Great Barrier Reef. Coral tumors have also been observed on local reefs.

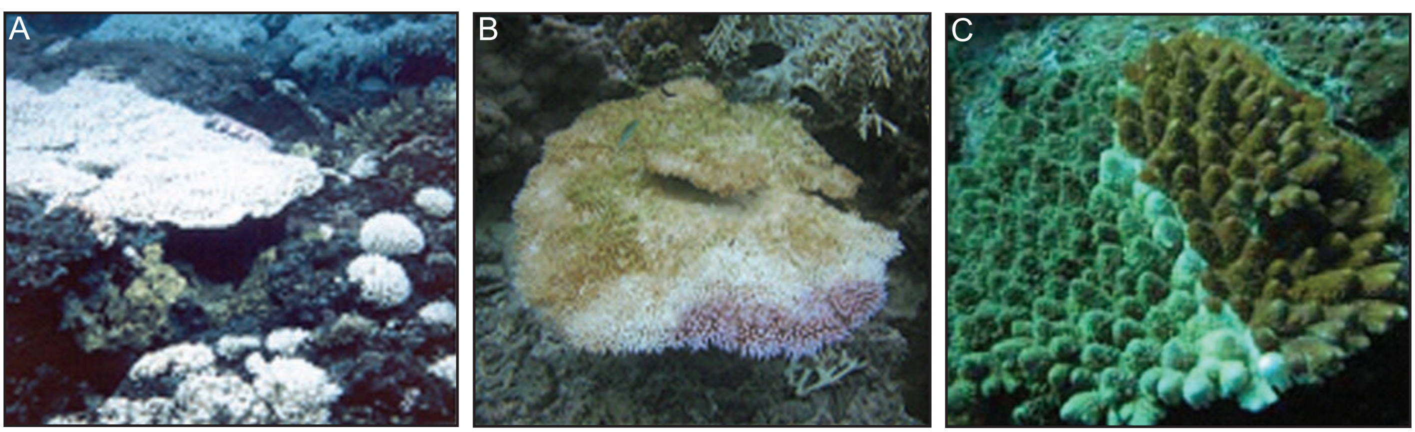


Figure 11.3. Images of bleached (A) and diseased (B, C) acroporid corals. The disease is similar to the 'white syndrome' seen in the Great Barrier Reef, and generally results in a three-tiered appearance: a healthy-colored section, a white zone of recently dead polyps, and a dead area that has been colonized by epiphytic algae. Photos: P. Craig.

Tropical Storms

Tropical storms and cyclones are a natural occurrence in the South Pacific region. American Samoa has been hit by four cyclones in the past 18 years (1986, 1990, 1991, 2004). The 1986 cyclone was especially damaging to the Manu'a Islands, the 1990 and 1991 cyclones caused heavy damage throughout the Territory, while the recent cyclone in 2004 appears to have been less severe, causing the loss of perhaps 10% of reefs on the northern sides of the islands. During the latest cyclone (Figure 11.4), there was relatively little rainfall, so the massive sedimentation and nutrient enrichment that caused widespread growths of epiphytic algae after the 1991 cyclone did not occur.

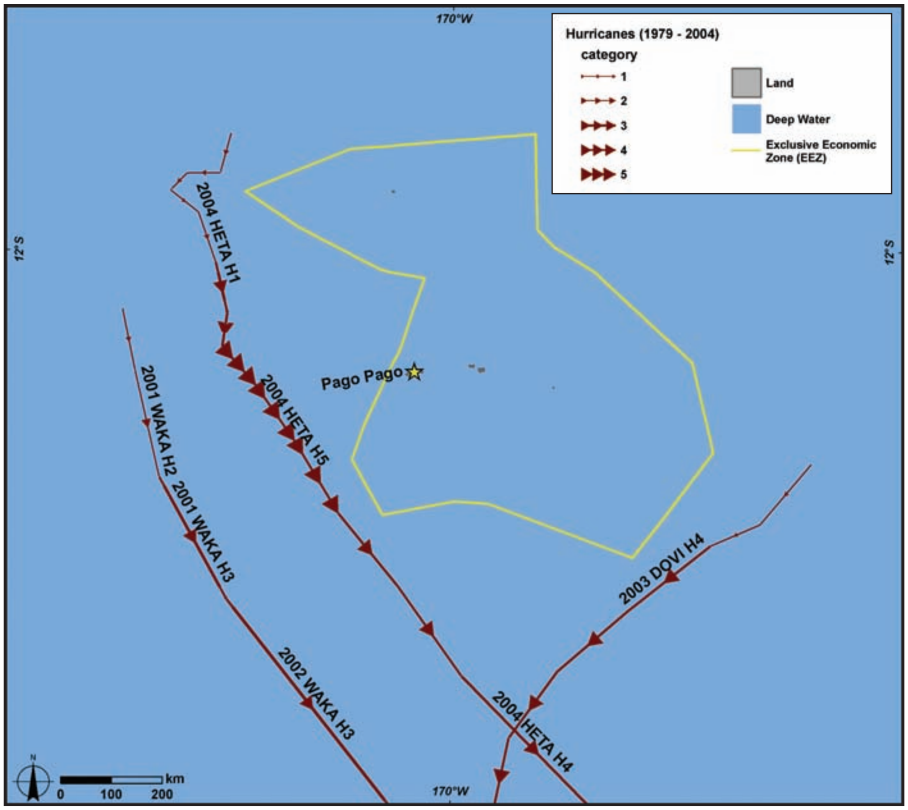


Figure 11.4. A map showing the paths and intensities of tropical cyclones passing near American Samoa from 1979-2004. Year of storm, storm name and storm strength on the Saffir-Simpson scale (C1-5) are indicated for each. Map: A. Shapiro. Source: http://weather.unisys.com/hurricane, Accessed 1/10/05.

Coastal Development and Runoff

Most of the population of American Samoa resides on Tutuila. However, only approximately one-third of the land area has a slope of less than 30%. As a result, the population density of the island is 1,350 people per km^2, which surpasses the population density of Manhattan in New York City, even though the island is semi-rural and the tallest structures are two stories high. This density has placed considerable demands on American Samoa's coastal areas. Though all of the Territory's lands are within the coastal zone, most of the land favorable for development lies immediately adjacent to the coast (Figure 11.5). Several hundred land-use permit applications are received per year, a majority of which are approved with conditions.

Figure 11.5. Development pressure often occurs at locations adjacent to sensitive habitats, such as the mangrove forests and coral reefs that occur near this harbor. Photo: American Samoa Coastal Management Program.

Figure 11.6 Heavy rains can cause flooding, which transports sediment, nutrients, and pollutants into coastal waters. Photo: C. Hawkins.

Coastal Pollution

Pollution from human activities has directly impacted the coastal resources of American Samoa, with the most obvious evidence of this in Pago Pago Harbor. Historical industrial, commercial, and military activity in the harbor led to coastal pollution that degraded water quality and local reef habitats. In recent years, the regulation of commercial and industrial facilities in Pago Pago Harbor has reduced coastal pollution, and monitoring has tracked dramatic improvements in water quality (see 'Water Quality' section). Limited evidence suggests that harbor reef habitats may be recovering as well.

Point source pollution, which has been successfully identified and mitigated, has been replaced by nonpoint source pollution as the primary pollution in coastal areas (Figure 11.6). Runoff from impervious surfaces directly impacts coastal areas, while island streams transport elevated levels of nutrients to coastal areas. Nutrient sources to local streams include faulty or improperly constructed septic tanks and concentrated animal waste from small family-owned pigsties. Streams entering coastal waters carry large amounts of sediments and nutrients, as many homes and businesses are located along them. The flow can be heavy during rainfalls, since the topography is steep. Exacerbating this is the amount of impermeable surface that has been constructed along the low, flat coastal lands.

Local streams also serve as temporary waste receptacles, and this debris causes unsightly trash deposits in the nearshore coastal areas. The island's main road runs along the water's edge and has historically been a convenient place to dump unwanted debris. In addition, vegetation clearing for crops often occurs on lands with slopes greater than 30%, which in turns leads to excessive erosion. As a consequence, most villages in the Territory have experienced major flooding, stream sedimentation, and impacts to reef ecosystems.

Tourism and Recreation

There is relatively little tourism in American Samoa and it appears that it will be some years before the Territory enters the mainstream of South Pacific tourism, as has nearby Fiji (400,800 tourists in 2003; Fiji Tourism, http://www.bulafiji.com/Industry.asp?lang=EN&sub=0156, Accessed 5/2/05). For example, the annual number of visitors to the National Park of American Samoa is currently estimated to be only 1,000 on Tutuila Island, 1,000 on Ofu Island, and 20 on Ta'u Island. Perhaps half of these tourists use marine areas of the park for swimming, snorkeling, or scuba diving. There are also few pleasure boats – about 30 anchor in Pago Pago Harbor during the cyclone season, but none are found elsewhere in the Territory. Tournaments for pelagic sport fish (e.g., tuna, marlin, etc.) occur sporadically, with some 20 small local vessels competing to catch the largest fish. Over the years there has also been a slight increase in numbers of villagers participating in recreational fishing along island shorelines; however, their numbers are low and only a few are seen during a drive around the island.

Fishing

There are two types of fisheries that harvest coral reef fishes and invertebrates: 1) subsistence fishing by villagers, which is usually a shoreline activity using a variety of gear, such as rod and reel, spear guns, gillnet, and gleaning; and 2) artisanal fishing by free-divers who spear fish, and small-boat fishers who jig for bottomfish around the steeply sloping islands. Most of these fish are sold at local stores. Subsistence fishing has been declining over the past two decades (Coutures, 2003) as a result of the gradual change from a subsistence to a cash-based economy. A third type of fishery focuses on pelagic fishes, especially tuna. The pelagic fishery includes small longline boats and large commercial boats that deliver tuna to the local canneries.

Coral reef fish and invertebrate resources have declined in abundance. Harvested species such as giant clams and parrotfish are overfished, and there has been heavy fishing pressure on surgeonfish (Craig et al., 1997; Page, 1998; Green and Craig, 1999). Groupers, snappers and jacks seen on the reef are smaller and less abundant than in the past. In addition, most village fishers and elders believe that numbers of fish and shellfish have declined (Tuilagi and Green, 1995). During an extensive survey in February 2004 of coral reefs in American Samoa, divers from the National Oceanic and Atmospheric Administration (NOAA) noted an unusually low abundance of large fishes and sharks around the main islands in the Territory (R. Brainard, pers. comm.). In response to this decline, a ban on scuba-assisted fishing was implemented in 2001.

Trade in Coral and Live Reef Species

Attempts to get coral reef products to off-island markets occur periodically, but there has been little development in these efforts, primarily due to the high cost of getting fresh or live shipments to markets in Hawaii and beyond, as well as the limited and frequently delayed flight schedule from the Territory to Hawaii (generally two or three flights per week).

Ships, Boats, and Groundings

In the past decade, 10 groundings of fishing vessels, all large (>30 m) foreign-flagged longliners, occurred in the Territory. Nine occurred in Pago Pago Harbor during Hurricane Val in 1991 and their rusting hulls remained on the reefs for nine years. They were finally removed in 2000, due to actions taken by the U.S. Coral Reef Task Force. The tenth longliner ran aground in 1993 at Rose Atoll, a NWR, spilling a full fuel load, fishing lines and other metal debris onto the atoll. Follow-up studies indicate that significant damage occurred to the atoll, with the loss of about 30% of the atoll's foundation of crustose coralline algae and a community shift from a coralline algae substrate to one of fleshy blue-green algae, most likely due to iron enrichment (Green et al., 1998). USFWS personnel removed most of the debris during several cleanup trips to the atoll, but the community shift is still visible 11 years later, as evidenced by a recent NOAA site visit (R. Brainard, pers. comm.).

Marine Debris

Marine debris is not presently a major problem except in the industrialized Pago Pago Harbor. In addition to a 57-year old sunken ship (*U.S.S. Chehalis*) in the harbor that may still contain a fuel load, the shallow and deep harbor bottom is littered with fuel barrels, car batteries, and other debris. Outside of the harbor, most debris sighted in coastal waters derives from household garbage (aluminum cans, plastic bags, disposable diapers) that is thrown into the island's creeks, though some larger items, such as refrigerators and fuel tanks, are occasionally seen drifting or beached.

Aquatic Invasive Species

Although Pago Pago Harbor has been a major shipping port for over 50 years, a recent survey of introduced marine species found that relatively few alien species have propagated in the Territory, with most being restricted to the inner portions of the harbor (Coles et al., 2003). Altogether, 28 non-indigenous or cryptogenic species were detected during this survey: bryozoans (6), hydroids (6), amphipods (4), tunicates (2), barnacles (2), algae (2), bivalves (2), sponge (1), polychaete (1), isopod (1), ophiuroid (1). However, none appeared to be invasive or is known to be invasive at sites outside of American Samoa. Most of these alien species occur in Hawaiian harbors and many are widely distributed around the world.

Security Training Activities

No security training activities occur in the Territory.

Offshore Oil and Gas Exploration

No oil and gas exploration activities occur in the Territory.

Other

Population growth has been identified as a major threat to coral reefs in the Territory (Figure 11.7). The current population of 63,000 is increasing at a rapid rate of 2.1% per year. Most people in the Territory (96%) live on the south side of Tutuila Island, where growth continues to strain the environment, causing chronic problems such as extensive coastal alterations, fishing pressure, loss of wetlands, soil erosion and coastal sedimentation, solid and hazardous waste disposal, and pollution.

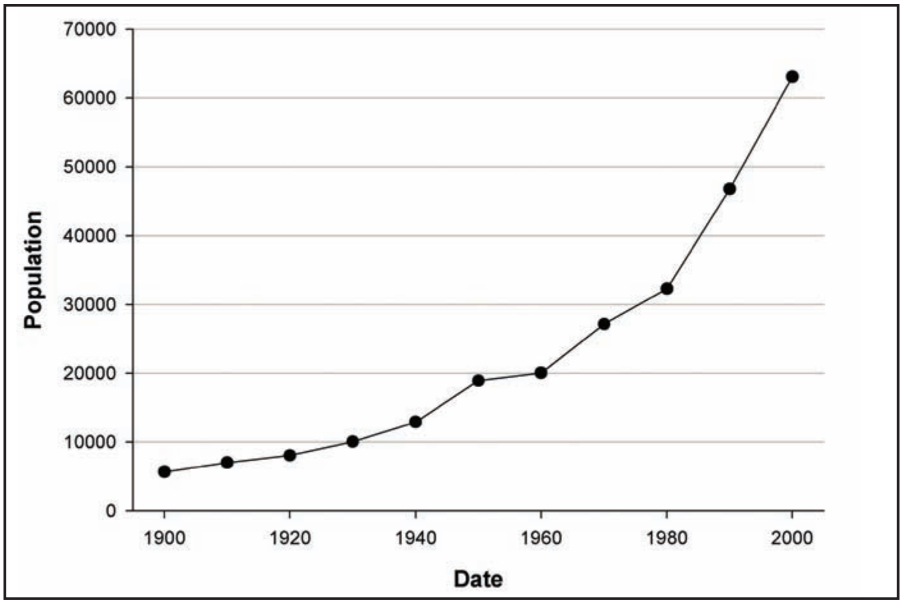


Figure 11.7. Population growth in American Samoa. Source: U.S. Census.

CORAL REEF ECOSYSTEMS-DATA GATHERING ACTIVITIES AND RESOURCE CONDITION

American Samoa has a long history of coral research and monitoring activities. For example, the Aua Transect is the oldest known coral reef transect still being surveyed, and the second oldest monitoring program in the world (Green et al., 1997; Green, 2002); Fagatele Bay has been monitored for over 20 years (Green et al., 1999). However, there has not been an integrated monitoring program established in the Territory to determine overall coral reef ecosystem status and trends. Thus, a working group was created in 2003 to establish such a program, with the American Samoa Coastal Management Program (ASCMP) supporting the initial funding of a Territorial coral reef monitoring coordinator to lead this effort. In addition, the Department of Marine and Wildlife Resources (DMWR) has begun to develop an agency-oriented program of long-term coral reef monitoring, and has hired a coral reef monitoring ecologist. The first year of monitoring is set to begin in January 2005 (Table 11.1, Figure 11.8).

Table 11.1. Parameters to be included in the Territorial Coral Reef Monitoring Program.

1. Coral Condition	Disease, bleaching, % cover
2. Algal Condition	% cover, type
3. Fish	Species abundance (grouper, snapper, parrotfish)
4. Macro-invertebrates	Abundance (giant clam, lobsters, crown-of-thorns)
5. Water Quality	Temperature, nutrients (N, P), light transmission
6. Anthropogenic	Debris, damage
7. Weather	Air temperature, sun/cloud, wind

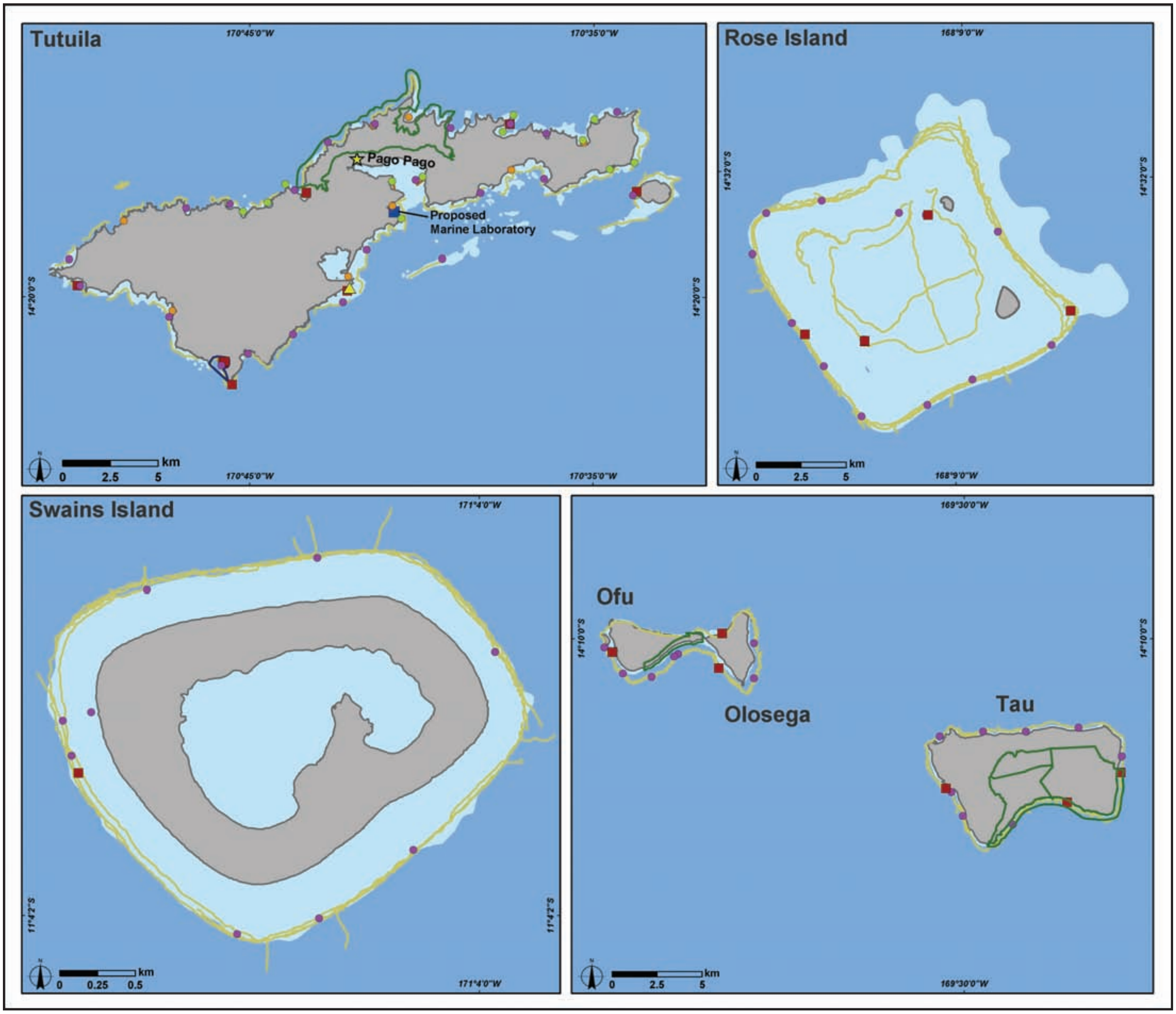
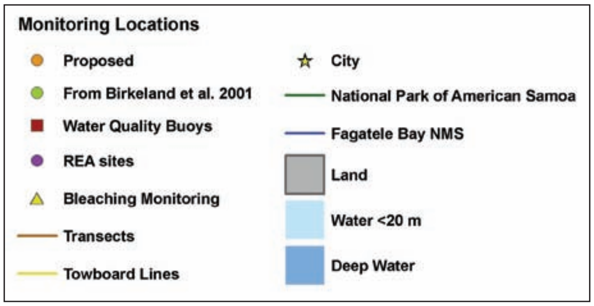


Figure 11.8. Monitoring program sites on Tutuila and Aunu'u Islands. Map: A. Shapiro; Sources: T. Curry, ASCMP; Birkeland et al., 2004; PIFSC-CRED.



In addition to those activities listed in Table 11.2, funding from the U.S. Coral Reef Task Force and other sources has made various studies possible, and data from these studies may provide the baseline for repetitive analyses.

Bishop Museum Introduced Marine Species Survey

A survey of marine organisms (macroinvertebrates, benthic macroalgae, fish) was conducted in Pago Pago Harbor, Fagatele Bay National Marine Sanctuary, the National Park on Tutuila Island, and other core sites to detect introduced marine species (Coles et al., 2003).

Table 11.2. Agency/organization-specific activities that provide information about coral reef health. Note: not all listed activities can be considered monitoring.

PROJECT	AFFILIATION	LOCATION	YEAR BEGUN	FREQUENCY	STATUS
Aua Transect	Territorial	Aua Village	1917	Completed twice	Ongoing
Fagatele Bay Monitoring	Fagatele Bay National Marine Sanctuary	Fagatele Bay	1985	Approx. every 5 years	Ongoing
Market Survey	DMWR	Tutuila	1994	Intermittent	Ongoing
Inshore Creel Survey	DMWR	South shore of Tutuila	1978	Daily	Ongoing
Vital Signs	National Park of American Samoa	National Park waters	2004	Annual	
U.S. EPA Environmental Monitoring and Assessment Program	National Park of American Samoa	Territorial waters	2004	To be decided	
American Samoa Research and Monitoring Program	PIFSC-CRED	Territory-wide	2002	Every 2 years	Ongoing
Stream/beach Monitoring	American Samoa Environmental Protection Agency (ASEPA)	Tutuila-wide	2002	Weekly	Ongoing
Soft Coral Survey	National Park of American Samoa	Utulei Village	1917	Completed twice	Ongoing
ASEPA	ASEPA	Tutuila-wide	2003	Bi-annual	
NPSP Program	ASEPA	Selected watershed sites on Tutuila	2003	Annual	

Monitoring of Biological Populations and Oceanographic Processes

In February-March 2002 and February 2004, the NOAA's Pacific Island Fisheries Science Center, Coral Reef Ecosystem Division (PIFSC-CRED) conducted comprehensive, multidisciplinary assessments of the coral reef ecosystems around Rose Atoll and Tutuila, Aunuu, Tau, Ofu, Olosega, and Swains Islands. Spatial and temporal monitoring of biological populations (fish, coral, algae, macro-invertebrates) and oceanographic processes (current, temperature/salinity profiles, bio-acoustic surveys) were conducted to document natural conditions and to detect possible human impacts to these ecosystems. Detailed bathymetric maps were completed for Tutuila and the Manua Islands. Results of these studies will be included in the next reporting effort.

Coral Disease Surveys

Two disease studies were completed in American Samoa between 2002 and 2004. The first was a broad disease survey around Tutuila and the Manu'a Islands (Work and Rameyer, 2002). The second survey was recently led by Dr. Greta Aeby (Aeby and Work, in prep.) with the intent of linking coral disease to water quality there as well as to wider-Pacific coral disease distributions.

Lobster Survey

In 2003, a survey of the artisanal lobster fishery in American Samoa was conducted (Coutures, 2003). Results indicate that landings are small but overfishing does not seem to be occurring. Additionally, the report outlines several management recommendations.

Algae Survey

A study was conducted in 2003 to inventory the algae of American Samoa (Skelton, 2003). The study surveyed 26 sites on Tutuila, Anuu, Ofu, and Olesega and documented the presence of 237 species of algae and two species of seagrass in the Territory.

Economic Valuation Study

A comprehensive economic valuation study of American Samoa's coral reefs was completed by Spurgeon et al. in 2004. Salient results of this study will be included in the next reporting effort.

WATER QUALITY

Pago Pago Harbor Water Quality Monitoring

Water quality in inner Pago Pago Harbor was determined from samples collected at several stations. Samples collected at multiple depths at each station were averaged, and the annual estimates of water quality parameters (e.g., total nitrogen, or TN, total phosphorus, or TP, chlorophyll a, or chl a) were calculated from station means. Field sampling is now performed only twice annually, once in the tradewinds season (June-October) and once in the non-tradewinds season (November-May).

Coastal Water Quality Sampling

The recent coastal sampling conducted in collaboration with the American Samoa Environmental Protection Agency (ASEPA) and the National Park of American Samoa followed the methods and approach of the U.S. Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program. Within the Territory's coastal region (up to one-quarter mile out from the coast), 50 randomly selected sites were sampled for a standard suite of parameters. In addition to a standard hydrographic profile, grab samples of water at the surface, middle, and bottom of the water column were processed and analyzed for standard nutrients (TN, TP, ammonium, nitrate/nitrite, phosphate), chl a, and suspended solids. Where possible, sediments were collected with a modified Van Veen grab and analyzed for grain size, total organic carbon, organics, and metals. Fish were also collected at those stations and analyzed for tissue contaminants. Field methods are detailed in a U.S. EPA publication (2001).

Stream Monitoring

There are approximately 140 perennial streams on Tutuila, comprising nearly 420 stream km. The large number of streams precludes a census approach to monitoring, so ASEPA instead relies on random stream selection to quantify the range of stream ecological conditions. Streams are initially classified into four groups according to local population density as an indicator of the potential human impact on local streams. Streams from each class are pooled and then several are selected randomly for intensive monitoring.

In the first year, eight streams were selected, two from each of four watershed classes. Each stream was visually assessed using methods based on the U.S. EPA's Rapid Bioassessment Protocols (Barbour et al., 1999). The following variables were evaluated for each stream: epifaunal substrate/available cover, embeddedness, sediment deposition, channel flow status, channel alteration, and riparian vegetative zone width. After the initial habitat assessment, streams were then monitored at a monthly or near-monthly frequency for water hydrography (temperature, pH, dissolved oxygen, turbidity), water chemistry (TN, TP, nitrate, ammonium), and bacterial contamination (*Enterococcus*).

After the first year, a new pool of streams was selected from the four classes. These streams were visited and monitored monthly, and their habitats were assessed visually.

Beach Monitoring

In 2003, ASEPA monitored 16 beaches in Pago Pago Harbor, the center of industry and commerce on Tutuila Island. At weekly intervals, water samples (0.5 L) were collected in sterile bottles at water depths no less than knee level of the technician, independent of tidal height. Samples were stored in coolers for transport and returned to the laboratory within two hours of collection. *Enterococci* were enumerated using Enterolert® and most probable number methods. Enterolert® utilizes chromogenic substrate technology to enumerate indicator bacteria. *Enterococci* numbers were then compared to the American Samoa's legal Water Quality Standards (WQS) to determine compliance.

Results and Discussion

Craig et al. (2000) suggested that American Samoa's oceanic waters demonstrate excellent quality, and there are no indications that oceanic water quality has since changed. Furthermore, the water quality problems that emerged in Pago Pago Harbor during the 1970-80s have greatly improved, based on chl a, TN, and TP levels (Figure 11.9).

However, the picture is less clear in other coastal areas of the Territory, as there are very few data from the near coastal regions of American Samoa. This will soon be remedied, as the National Park of American Samoa and ASEPA recently finished a collaborative, comprehensive coastal water quality survey around Tutuila and the Manu'a Islands. This survey used a probabilistic design to sample the waters from the coastline to one-quarter mile offshore. This study will provide the first Territory-wide data on water quality in the near coastal areas.

The data currently available indicate that streams in densely populated areas of Tutuila exhibit higher nutrient levels (e.g., TN, TP) than streams in less-populated areas. These streams transport nutrients to the near shore and reef flat areas. The effects of these nutrients on coral reef ecosystems in American Samoa are unknown. Weekly beach monitoring at 16 recreational beaches in 2003 demonstrated that the Territory's beaches often exceed the WQS for *Enterococcus* (Figure 11.10). Likely sources of this contamination include improper treatment and disposal of both human and animal waste.

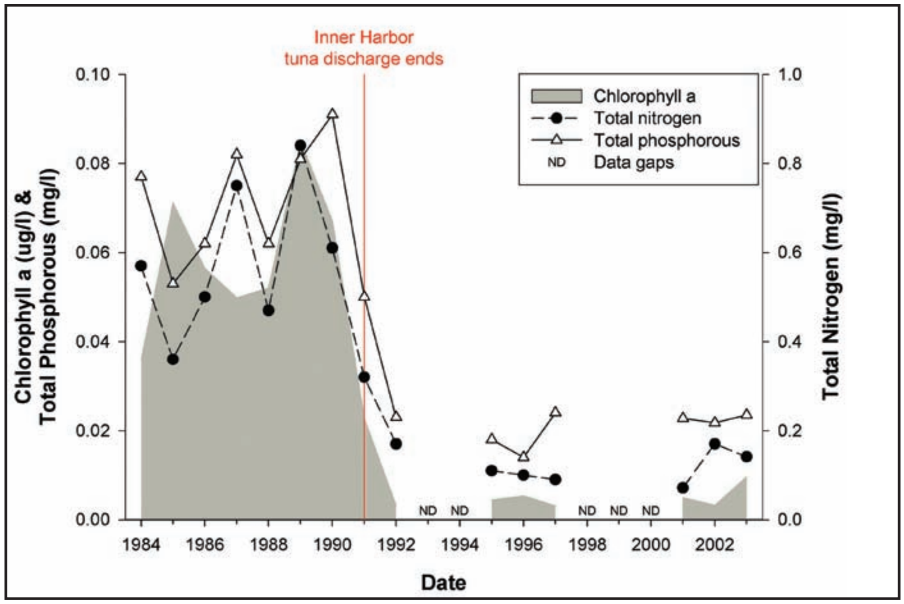


Figure 11.9. Water quality in inner Pago Pago Harbor greatly improved after tuna canneries were required to modify their waste disposal processes in 1991. Source: ASEPA.

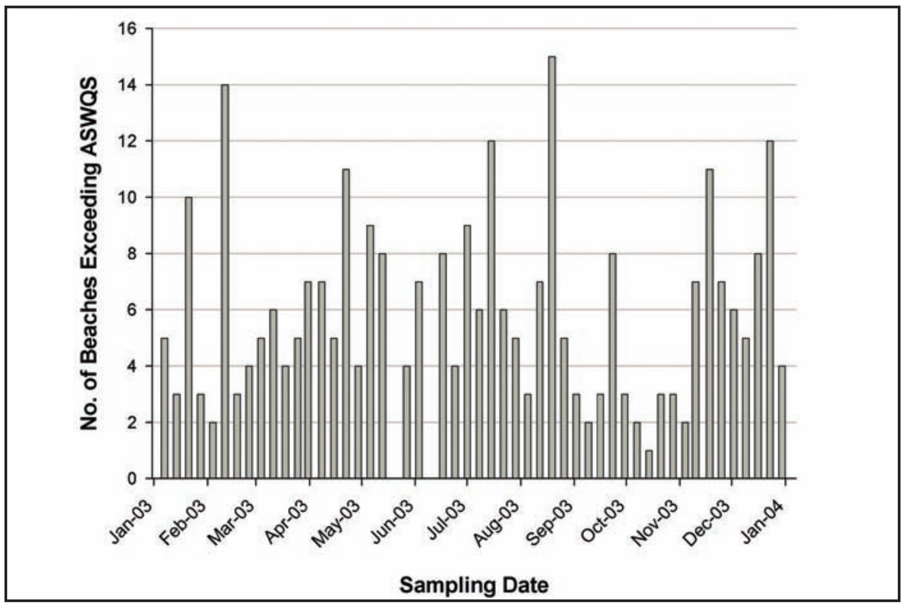


Figure 11.10. Number of local recreational beaches exceeding the American Samoa WQS as detected by the ASEPA weekly beach monitoring program conducted throughout 2003. Source: ASEPA.

BENTHIC HABITATS

Surveys and monitoring have occurred in Tutuila, including Pago Pago Harbor and Fagatele Bay, and in the smaller Manu'a Islands. Most studies have concentrated on hard corals, but soft corals have been surveyed as well. Monitoring of coral bleaching events has recently begun. The many disparate studies are brought together here for the first time to discern trends in coral populations in American Samoa**.**

HARD CORALS

Very Long-Term Monitoring of Pago Pago Harbor, The Aua Transect

Methods

Transects in Pago Pago Harbor, started in 1917 by Mayor (1924) and Cary (1931) and resurveyed by Cornish and DiDonato (2004), involved counting colonies of hard and soft corals within large (25 x 25 ft) plots along a transect line. Most of the sites have been destroyed by dredging and filling, but a few have survived and been re-surveyed several times. Re-surveys used the same methods with 1 m^2 plots. Green (2002) and Birkeland et al. (2004) used a point-intercept method along 50 m transects and recorded substrate categories (Green, 2002). Transects were at 10 m depth, except in Fagatele Bay where transects were laid at 3 m, 6 m, and 9 m depths and on the reef flat. At each transect meter mark, substrate was recorded in four categories and 24 subcategories under the tape and 1 m to each side. Fenner (2004) estimated the proportion of bleached staghorn coral colonies at the Airport Lagoon during a one-hour swim following the same approximate route.

Results and Discussion

Extensive studies by the Carnegie Institute of Washington D.C. between 1917 and 1920 (Mayor, 1924) provide excellent baseline data from which to determine changes over time for coral reefs in Pago Pago Harbor. Re-surveys of the 1917 transect have provided quantitative information on trends at the reef at Aua over 83 years, the longest quantitative reef monitoring anywhere (Mayor, 1924; Dahl and Lamberts, 1977; Dahl, 1981; Birkeland and Green, 1999; Birkeland and Belliveau, 2000). A 28% decline in average number of colonies per square meter was noted in 1973, with a substantial decline (30%) between 1973 and 1980 (Figure 11.11). A total decline of 78% in average number of corals per square meter between 1917 and 2001 indicates that natural and anthropogenic disturbances in Pago Pago Harbor have contributed to degradation in reef conditions. Eutrophication from tuna cannery discharges between 1954 and 1991 may have been a major factor, as well as nearby road and other infrastructure construction. The 1978 crown-of-thorns starfish (*Acanthaster planci*) outbreak may also have contributed to the sharp decline between 1973 and 1980. The mass coral bleaching in 1994 might have contributed to further decline. Cyclones are unlikely to have caused much damage to these corals due to their protected location within the harbor.

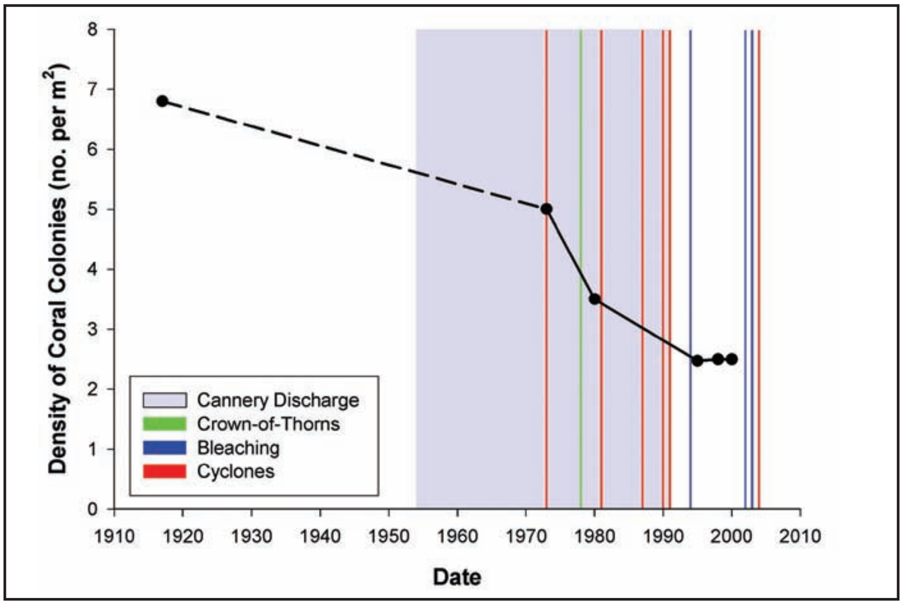


Figure 11.11. The number of hard coral colonies on the Aua Transect, in Pago Pago Harbor, American Samoa from 1917 to 2000. Sources: Mayor, 1924; Dahl and Lamberts, 1977; Dahl, 1981; Birkeland and Green, 1999; Birkeland and Belliveau, 2000.

Long-Term Monitoring in Tutuila

Long-term monitoring of corals at selected sites around Tutuila Island has been ongoing since 1982. While this is not a holistic, multi-agency driven effort, the purpose of this survey is to determine any substantial changes over the last several decades. Reefs within the Territory have been heavily impacted by a series of natural and anthropogenic events (crown-of-thorns starfish outbreaks, tropical cyclones, water quality degradation, etc.). Recent studies have shown that corals are slowly recovering after massive disturbances in the late 1980s and early 1990s (Birkeland et al., 2004; Green, 2002).

A series of reef surveys starting in the early 1980s by Fisk and Birkeland (Fisk and Birkeland, 2002) and then Green (1996, 2002) provides data on the trends in hard coral cover around Tutuila during this period. In the early to mid-1980s, hard coral cover was increasing on Tutuila. A mass crown-of-thorns outbreak in 1978 killed many corals, so the increases in the early to mid-1980s are likely to be recovery from that event (Figure 11.12). A series of three tropical cyclones followed, and the cyclones in 1990 and 1991 were severe. A mass bleaching event in 1994 also killed corals. When coral cover was measured again in 1995, coral cover had been reduced to the lowest levels yet seen. When coral cover was measured in 1996, a small improvement was seen, and when it was measured again in 2001, strong gains and the highest observed coral cover was recorded. A slight decline was found in 2003 in a separate survey by Houk et al. (in press). According to the limited data available, coral cover conditions at previously surveyed sites are currently at good levels.

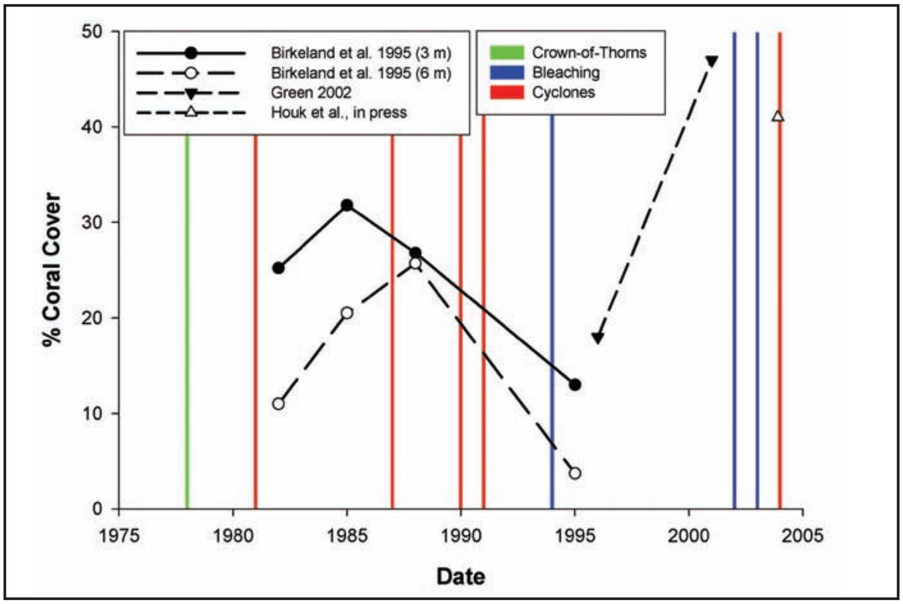


Figure 11.12. Hard coral cover trends for Tutuila from three studies show periods of recovery interrupted by events causing mortality. Sources: Birkeland et al., 1997; Green, 2002; Houk et al., in press.

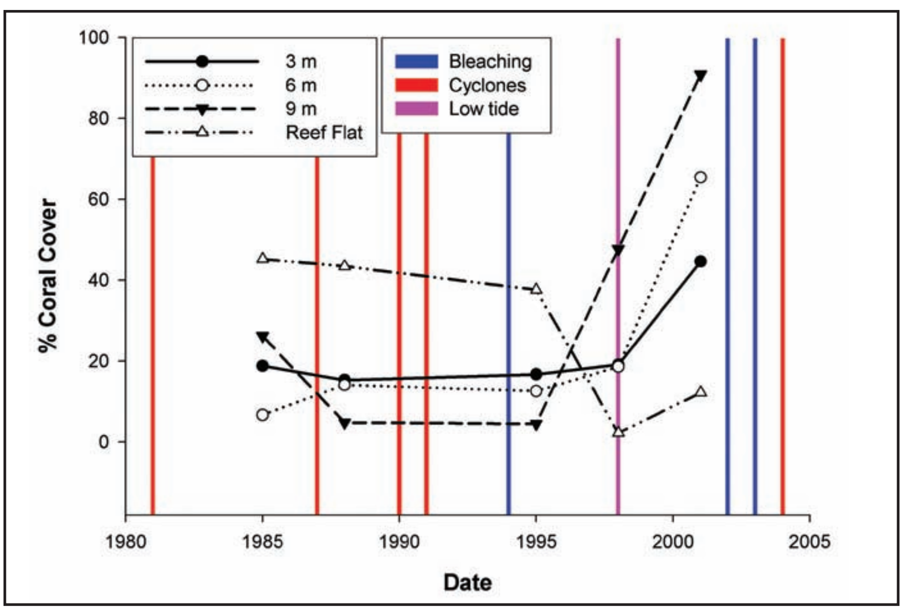


Figure 11.13. Hard coral cover trends for Fagatele Bay, Tutuila. Source: Birkeland et al., 2004.

Long-Term Monitoring in Fagatele Bay (Tutuila)

Hard corals have been monitored in Fagatele Bay for nearly 20 years. Figure 11.13 shows trends in live hard coral cover at four different depths from 1985 through 2001. Coral cover was low at 3 m, 6 m, and 9 m depths from 1985 through 1995, then showed strong increases, particularly at the end of this period. The increases in 2002 were strongest in deep water and weakest in shallow water. Live coral on the reef flat showed a very different pattern, having the highest cover from 1985 to 1995, and then dropping to low levels in 1997 and 2002. Thus, corals on the reef slope at 3-9 m show one pattern, and corals on the reef flat show a different pattern.

The reef flat and reef slope are very different habitats and may be exposed to different events. The fact that coral on the slope stayed low from 1985 to 1995 suggests that a series of events may have kept coral cover low. There were three cyclones during this period and one bleaching event, and all of these disturbances may have combined to suppress coral recovery. After 1995, coral cover on the reef slope recovered dramatically, similar to the recovery observed on Tutuila as a whole (Figure 11.13). The loss of live hard corals from the reef flat after 1995 may be attributable to a low-tide event that caused mass-mortality in reef flat corals in 1998. The Aua Transect is a reef flat within the harbor, showing a similar downward trend (Figure 11.11). Unfortunately, while periodic re-surveying can reveal trends, it is often unable to pinpoint the causes of those trends.

The data for Tutuila as a whole (Figure 11.12) and Fagatele Bay specifically (Figure 11.13) are consistent in showing an increase in coral cover from 1996 to 2002 and is supported by informal observations suggesting that the coral populations are recovering from past events. The most recent data available was gathered during the 2002 and 2004 PIFSC-CRED surveys. Towed diver surveys were conducted around a large part of Tutuila, and visual estimates of coral cover recorded. The average live coral cover recorded was 31% in 2002 and 19% in 2004. Measurements from video taken by the same towed divers found 29% cover for 2002, which is close to the 31% found by visual estimate. This is significantly less than seen in Figures 11.12 and 11.13, but the area covered was quite different (wide ranging tows along reef versus transects at a few selected sites, and twice as much area covered by tows in 2004 than in 2002). It is likely that the lower percentages in the towed-diver surveys were due to the inclusion of areas of low coral cover, while the transects were on reefs within areas of relatively high coral cover. Thus, the data are not comparable (even the two towed-diver surveys are not comparable), and indeed these percentages from the towed-diver surveys are lower than data from transects from other studies conducted at about the same time (Green, 2002; Houk et al., in press).

Short-Term Monitoring of Coral Bleaching

Major events such as tropical cyclones, mass coral bleaching, and crown-of-thorns outbreaks have not been monitored in the past. However, a new program to monitor corals that are particularly susceptible to bleaching has begun. The DMWR has begun monitoring bleaching in staghorn corals (*Acropora* spp.) in the Airport Lagoon on Tutuila. Water temperatures in enclosed lagoons are higher on sunny days during low tide when circulation is reduced. Approximately 50% of the staghorn corals in the Airport Lagoon have been killed by bleaching caused by high temperatures in the summers of 2001 and 2002. A bleaching event also occurred in 2004, following a period of sea surface temperatures (SST) that nearly reached the bleaching threshold (Figure 11.14). Lagoon water, however, reached higher temperatures than SST in the adjacent ocean. Bleaching peaked by March 28, and later subsided. Corals were only partially bleached and bleaching was confined to enclosed lagoons. This monitoring provided an early warning of the bleaching event and real-time data on the course of bleaching. Such monitoring of major events will allow the identification of the causes of some major shifts in reef communities. This mild bleaching might now be expected as the normal summer bleaching. However, temperature records show that Hurricane Heta (early January 2004) caused a sharp decrease in water temperature that reset the summer warming process that was underway. The result was lower temperatures than would otherwise have occurred and less bleaching. The previous two summers resulted in severe bleaching with some coral deaths; this may be more typical in future summers as well.

In summary, hard corals have declined significantly in Pago Pago harbor, particularly in recent years. Outside the harbor, hard corals have been impacted by a series of major events, including a crown-of-thorns outbreak, several cyclones, and several mass coral bleaching episodes. These major events have caused declines in hard corals, although they have shown significant recovery. Outside the harbor, hard corals are considered to be in their best condition since the crown-of-thorns outbreak in 1978.

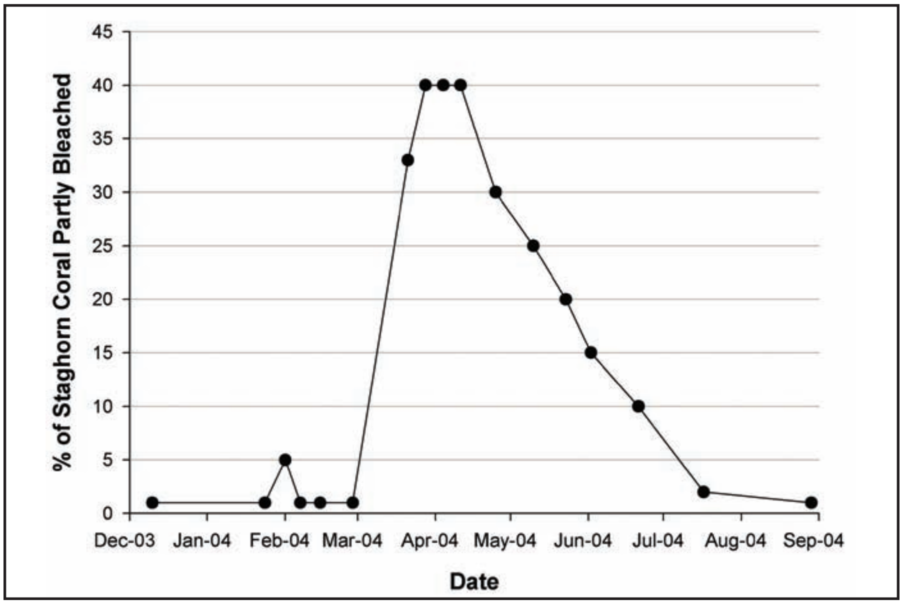


Figure 11.14. The course of a mild bleaching event in 2004, as measured in staghorn corals in a partly enclosed lagoon on Tutuila. Source: Fenner, 2004.

SOFT CORALS

Soft corals were first measured during the 1917 studies in Pago Pago Harbor by Mayor and Cary. This is the world's oldest quantitative coral reef transect data. Cary's transect site at Utulei was re-surveyed by Cornish and DiDonato (2004). The live soft coral cover drastically declined since 1917 (Figure 11.15). Many activities have occurred in Pago Pago Harbor during this period, including the construction of two large tuna canneries in 1954 and 1963. The tuna canneries discharged increasing volumes of wastewater into the harbor, causing eutrophication until discharges were moved outside the harbor and nutrient levels declined. Tuna cannery discharges occurred for about a decade before the 1973 measurement. Other events impacting the marine environment of American Samoa during this time were a major crown-of-thorns outbreak in 1978, a series of cyclones, and a series of mass coral bleaching events. The crown-of-thorns outbreak would not have affected soft corals directly, as these starfish do not prey on soft corals. However, the death of many hard corals may have reduced competition for space. Hurricanes damage both hard and soft corals, and mass coral bleaching can kill both hard and soft corals. The large number of significant events during this 87-year period does not allow the identification of the cause of soft coral decline at this location.

A second series of soft coral studies focused on Mayor's 1917 Aua Transect in Pago Pago Harbor, which was re-surveyed in 1973, 1980, and 1996 (Figure 11.16). This series of studies also found a drastic decline in soft corals in the harbor. However, the addition of the 1973 and 1980 studies in this series showed that the drastic decline was restricted to the period between 1973 and 1980, because soft coral numbers actually increased from 1917 to 1973. Although eutrophication is suspected, the cause of the drastic decline in soft corals cannot be determined from this data. Significant variation in soft coral abundance may have occurred during the long gaps between surveys.

Preliminary results from the 2004 PIFSC-CRED cruise indicated that there were several locations on reef fronts around Tutuila where soft corals were common. Thus, soft corals are not extinct around the Island, and the drastic decline seen in the harbor may be restricted to that area. If so, that would support the suggestion that the decline was caused by local events, such as eutrophication related to tuna cannery wastewater discharge.

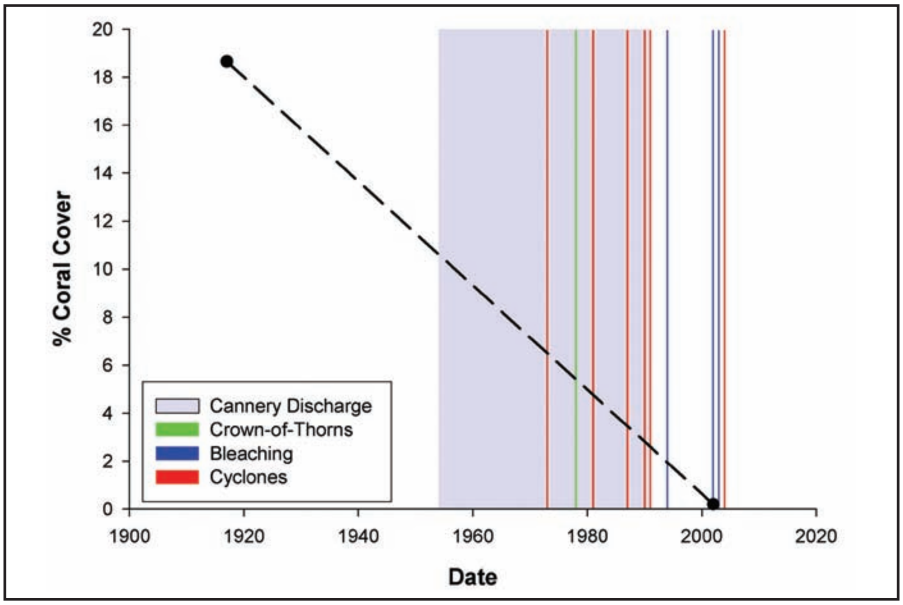


Figure 11.15. A 2003 re-survey of Mayor's 1924 soft coral survey in Utulei, Pago Pago Harbor, shows that almost no colonies remain at the site. Note the occurrence of bleaching events before and after the re-survey. Source: Cornish and DiDonato, 2004.

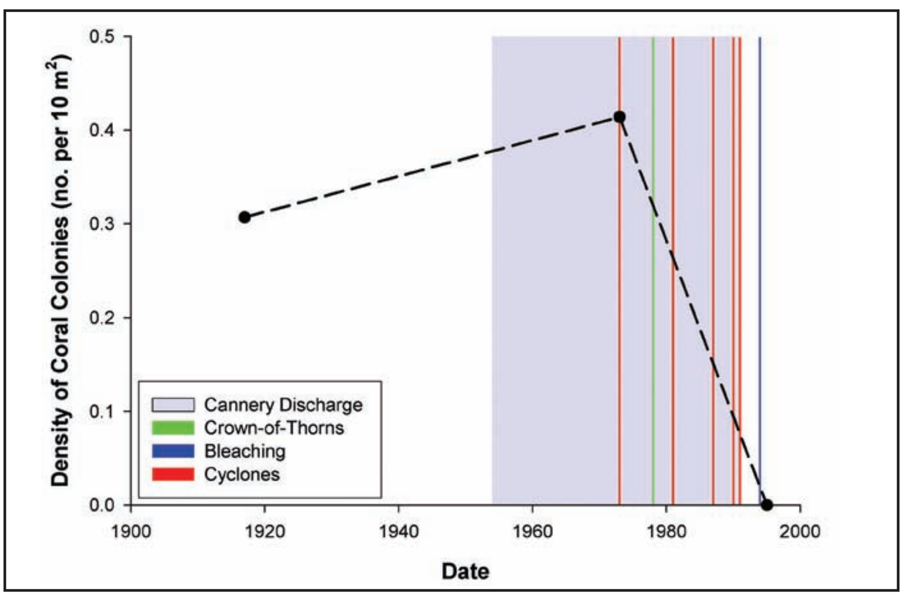


Figure 11.16. Soft coral colony monitoring at Aua Transect. Note cyclone and bleaching events between second and third data points. Sources: Mayor, 1924; Dahl, 1981; Green et al., 1997.

Benthic Habitat Mapping

NOAA's Center for Coastal Monitoring and Assessment, Biogeography Team (CCMA-BT) initiated a nearshore benthic habitat mapping program in Guam, American Samoa and the Commonwealth of the Northern Mariana Islands in 2003. IKONOS satellite imagery was purchased from Space Imaging, Inc. for all three jurisdictions and used to delineate habitat polygons in a geographic information system (GIS). Habitat polygons were defined and described according to a hierarchical habitat classification system consisting of 18 distinct biological cover types and 14 distinct geomorphological structure types. The project, which was completed in 2004, mapped 71.5 km^2 of nearshore habitat in the islands and produced a series of 45 maps that are currently being distributed via a print atlas, CD-ROM, and on-line at http://biogeo.nos.noaa.gov/products/us_pac_terr/. A summary map (Figure 11.17), where polygons have been aggregated into major habitat categories, depicts the geographical distribution of reefs and other types of benthic habitats in American Samoa (NOAA, 2005).

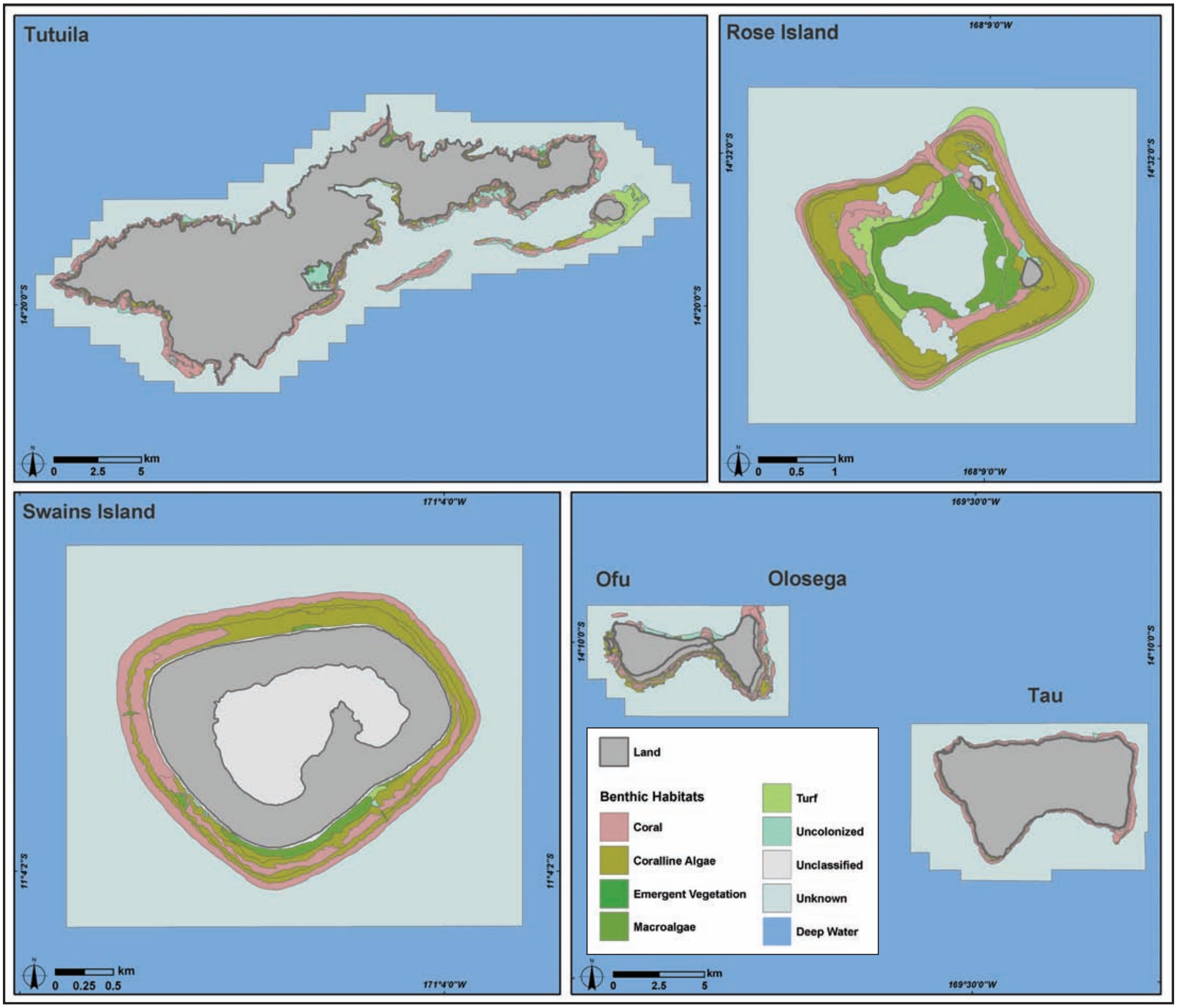


Figure 11.17. Nearshore benthic habitat maps were developed in 2004 by CCMA-BT based on visual interpretation of IKONOS satellite imagery. For more info, see: http://biogeo.nos.noaa.gov. Map: A. Shapiro.

ASSOCIATED BIOLOGICAL COMMUNITIES

This section focuses primarily on reef-associated fishes because of their importance as food to the islanders as well as the significant impact that fishing has had on fish populations. Available information about other reef-associated communities (macro-invertebrates, marine mammals, sea turtles, seabirds) is limited.

FISH

The coral reef fish fauna in American Samoa was diverse (890 species), amounting to approximately twice the number of fish species on Hawaiian and Caribbean reefs. Few marine endemic species are thought to exist in American Samoa due to widespread dispersal of their pelagic larvae.

Reef fish are harvested in both subsistence and artisanal fisheries on the five main islands in the Territory. Artisanal fishing includes both nighttime free-divers who spear reef fish and small boat fishers who target deepwater bottomfish. There is currently no export of coral reef fish to off-island markets or the aquarium trade. Some fishing also occurs at the two small and remote atolls in the Territory: Swains Island and Rose Atoll. Swains Island is inhabited by about 10 residents. Rose Atoll is uninhabited and a NWR, but anecdotal evidence indicates that poaching has occurred, at least in past years.

As described below, two trends in these fisheries are: 1) subsistence fishing has been declining steadily over the past two decades (Coutures, 2003) as villagers shift from a subsistence to cash-based economy; and 2) coral reef fish and invertebrate resources have declined significantly in abundance and size due most likely to overfishing. Regarding the latter point, it is important to recognize that coral reefs and the fish populations they support are quite limited in the Territory due to the small size of the islands and their steeply sloping sides that drop quickly into water depths of 4-5 km, thus providing relatively limited areas of shallow water habitats. For example, the five main islands in the Territory (where most fishing occurs) have only 125 km^2 of coral reef eocsystems in the depth zone of 0-50 m. Another way to visualize this size limitation is that a small boat can circumnavigate the connected islands of Ofu and Olosega in about one hour.

Two types of monitoring programs in American Samoa document different aspects of the fish community. Underwater visual surveys (fisheries-independent surveys) describe the kinds of fish observed by divers on the reef. Extensive underwater visual surveys were conducted throughout the Territory in 1996, 2002, and 2004 (Green, 2002; Schroeder, unpublished data).

Annual surveys of fish harvests or creel surveys (fisheries-dependent surveys) document the actual species and quantities of fish extracted from the reefs. The DMWR has monitored artisanal bottomfish catches since 1982, but annual harvests by artisanal night-divers and subsistence fisheries have been monitored only intermittently.

Underwater Visual Surveys

Methods

Fish were counted along three to five replicated belt transects (3 x 50 m) set at 10 m depths on reef slopes (Green, 2002). These transect dimensions were used because they yield the most precise estimate of abundance for highly mobile, diurnal species such as wrasses. Fish sizes were estimated visually. A restricted family list excluded species that were very small, nocturnal, or cryptic in behavior (e.g., gobies, blennies, cardinalfish). Fishes were surveyed by three passes along each transect, counting different species in each pass. The first count was of large, highly mobile species which are most likely to be disturbed by the passage of a diver (such as parrotfishes, snappers, and emperors). The second count was of medium-sized mobile families (including most surgeonfishes, butterflyfishes, and wrasses) which are less disturbed by the presence of a diver. The third count was of small, site-attached species (mostly damselfishes) which are least disturbed by the presence of a diver. Since surveys were conducted throughout the year, these comparisons were made based on adult fishes only to avoid the temporal effects of recruitment on the data. Adults were defined as individuals that were more than one-third of the maximum total length (TL) of each species. Individuals less than one-third maximum TL were considered juveniles that had recruited during the previous year.

Results and Discussion

Territory-wide fish surveys document that there are few large fish left on the reefs around the five main islands, a strong indication that populations have been overfished (Craig and Green, 2004). Figure 11.18 shows the pooled lengths of all surgeonfish, unicornfish, parrotfish, snappers, emperors, groupers, jacks, and sharks sighted during extensive surveys at 10 m depths on the reef slope. Few fish were 40 cm or larger in TL. These data were derived from belt transects measuring 3 x 50 m. When wider transects (20 x 50 m) were used to focus on species that are wary of divers and/or are particularly vulnerable to exploitation due to the large sizes they can attain (70-200 cm), the same pattern emerges (Figure 11.19). These include sharks, maori wrasse, and several large species of parrotfish, but virtually none was bigger than 50 cm, despite a considerable sampling effort (27 sites sampled, 99 transects in total). This does not represent a sudden change; comparison of surveys from 1996 (Green, 2002) and 2004 (R. Schroeder, pers. comm.) indicate that local reefs have had few large fish for at least eight years. Birkeland et al. (1997) note the tremendous loss of spawning potential this can represent since one large female red snapper (61 cm) has the spawning potential of 212 smaller females (42 cm).

Additionally, the 2002 PIFSC-CRED survey shows that densities of large fish (≥20 cm TL) in the main islands (Tutuila and Manu'a) were much lower than in the remote atolls (Rose and Swains), which in turn were much lower than in the unfished Northwestern Hawaiian Islands (NWHI; Figure 11.20).

The six-fold decrease in fish densities between the Territory's main islands and remote atolls support the case that reefs on the main islands are overfished. While comparisons

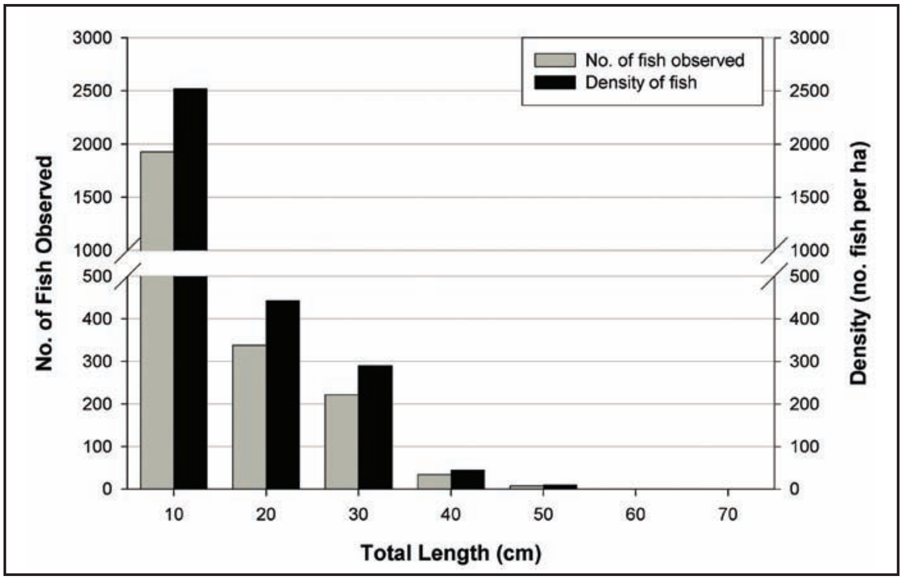


Figure 11.18. Lengths of standing stocks of targeted fishes at 17 sites on Tutuila in 2002. Source: Green, 2002.

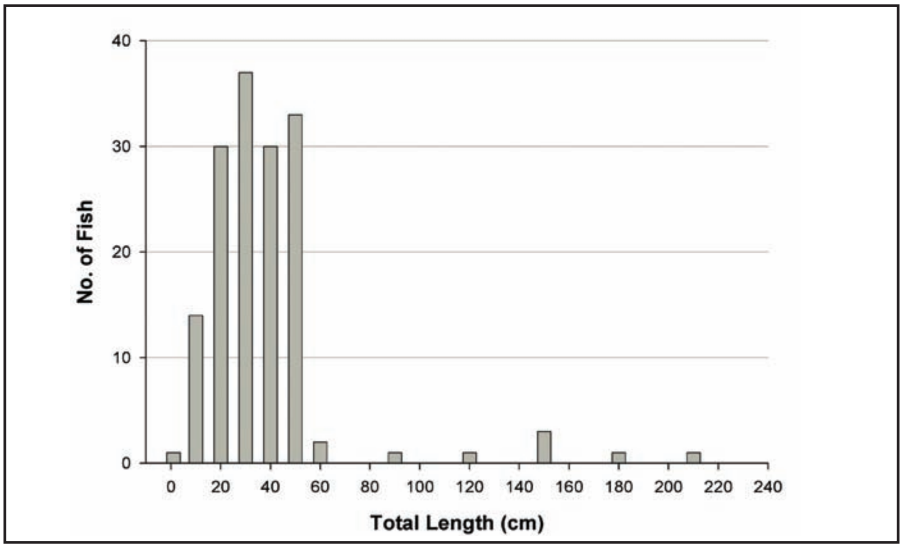


Figure 11.19. Lengths of large and vulnerable species (sharks, maori wrasse, large parrotfish spp.) at 27 sites in American Samoa. Source: Green, 2002.

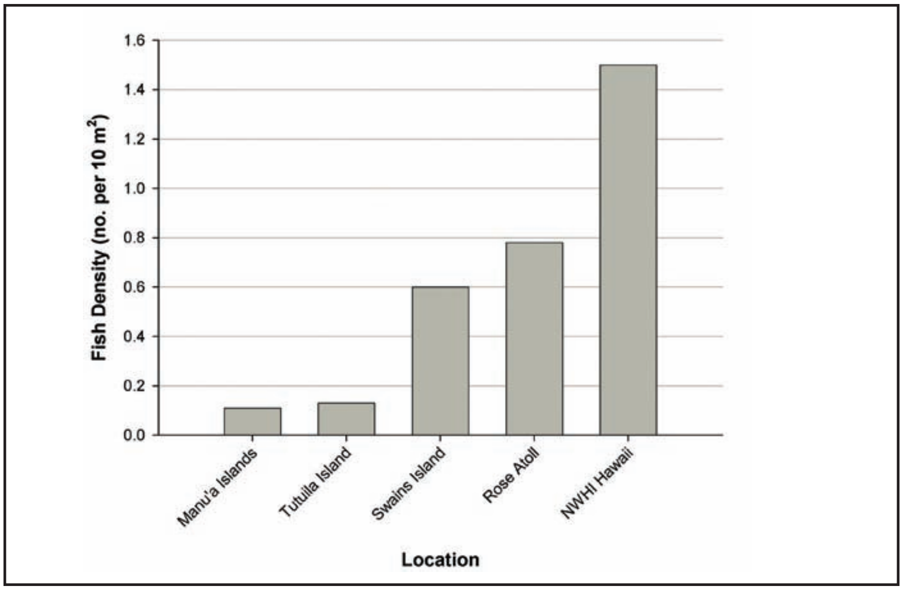


Figure 11.20. Densities of large fish in American Samoa and the NWHI in 2002. Source: R. Brainard, pers. comm.

with the unfished NWHI are speculative, they do suggest the potential magnitude of the loss of large fish in American Samoa.

Despite the low numbers and small sizes of fish, American Samoa is fortunate that the reefs still have an abundance of small herbivorous surgeonfish and parrotfish, which helps prevent a phase shift from reefs characterized by a high abundance of crustose coralline algae to reefs with abundant large fleshy algae.

Fish Harvest Surveys (Creel Surveys)

Annual catches of coral reef fish have declined in both the subsistence and artisanal fisheries, but for somewhat different reasons. The subsistence fishery is primarily a shore-based effort that harvests numerous fish and invertebrate species such as surgeonfish, parrotfish, goatfish, snappers, groupers, jacks, octopus, polychaetes (*Palolo viridis*), and spiny lobsters (Craig et al., 1993).

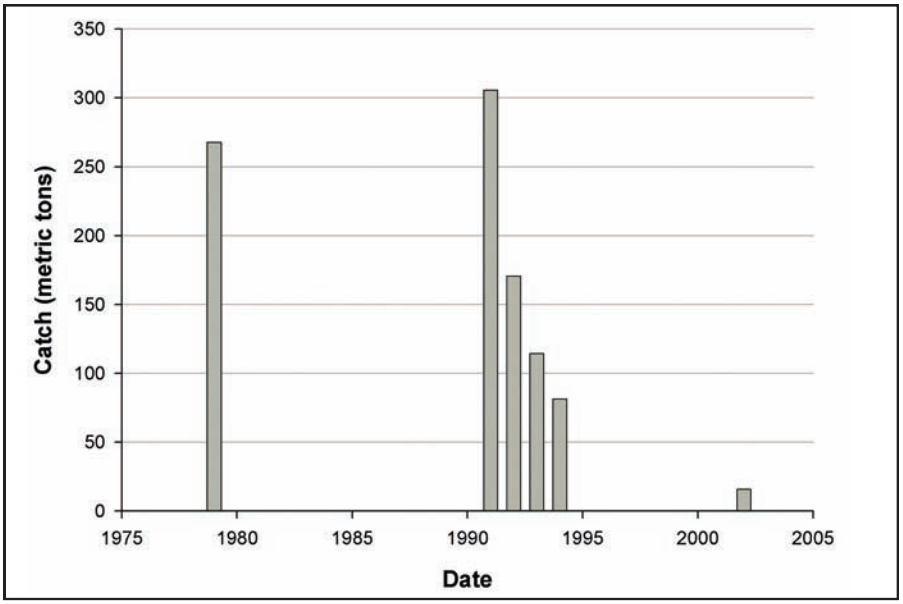


Figure 11.21. Subsistence harvest on Tutuila Island. Years with no catches were not monitored. Source: DMWR, unpublished data.

Subsistence catches in Tutuila have declined substantially over the past 25 years (Figure 11.21), primarily due to lifestyle changes in the Territory. The necessity for subsistence fishing is giving way to a cash-based economy with many villagers now employed in government offices and canneries. Although the catch per unit of effort has not changed greatly, the per capita catch has declined dramatically (Figure 11.22). This sentiment was also expressed by local fishers who felt that fish abundance had declined around Tutuila Island (Tuilagi and Green, 1995). However, in the outer islands of Manu'a, the per capita catch was much higher at 73 kg/person (Craig et al., 2004).

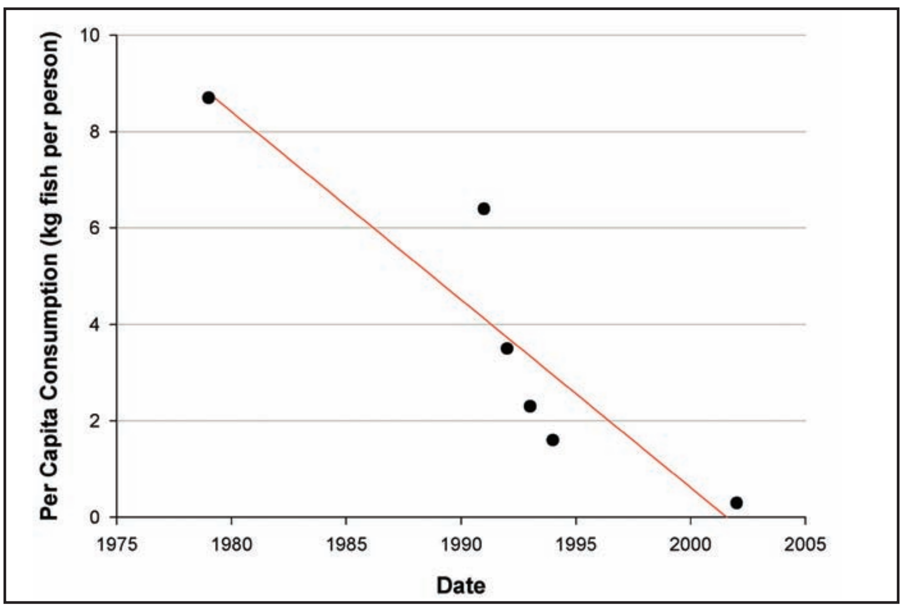


Figure 11.22. Per capita consumption of fish in the subsistence fishery of Tutuila Island. Source: DMWR, unpublished data.

Artisanal fisheries include two different fishing efforts on coral reefs. The first is nighttime spear fishing in shallow waters, and the fish are sold in local stores. Long-term trends show a period of low activity in the early 1990s due to hurricanes in 1990 and 1991, and then a buildup in the mid-1990s as the night divers doubled their catch by switching from free-diving to diving with scuba gear, which greatly improved their catch rates (Figure 11.23).

This fishery began to decline in 2000 which suggests that it had exceeded a sustainable catch. In 2001, the DMWR banned the use of scuba gear for fishing, which resulted in a drop in harvest levels to pre-scuba catch levels.

The second artisanal fishery targets deepwater snappers and groupers (bottomfish). Bottomfish fishing flourished briefly in the early 1980s when the fishery was subsidized, but it declined thereafter when the subsidies were discontinued and the few available fishing grounds were fished out (Itano, 1991; Figure 11.24). In 2001, many of the remaining bottomfish boats converted to longline fishing for albacore.

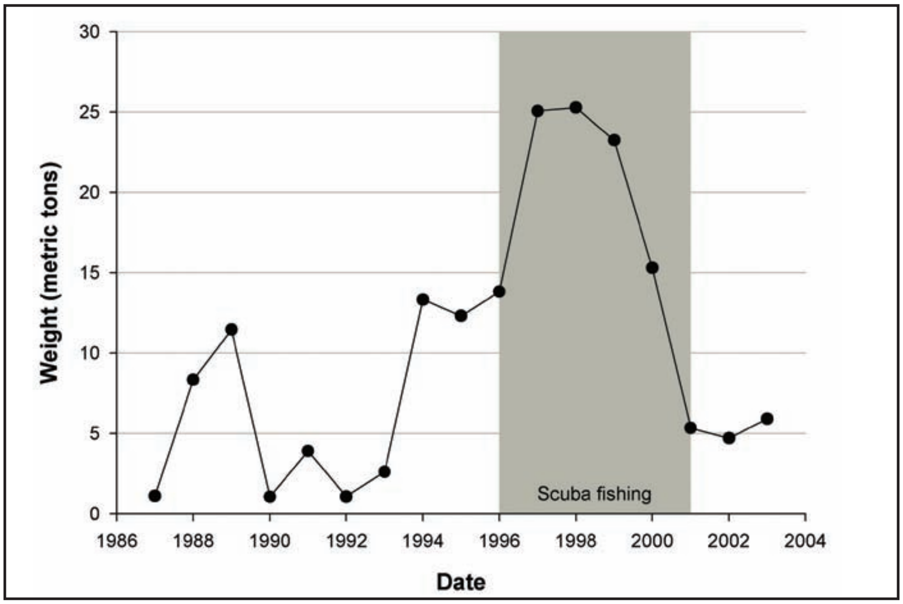


Figure 11.23. Catch of reef fish (surgeonfish and parrotfish) by night-divers on Tutuila Island. Source: DMWR, unpublished data.

MACROINVERTEBRATES

Limited information about macroinvertebrates exists for the Territory. The harvested invertebrates (octopus, lobster, palolo, etc.) are generally listed in catch reports for subsistence and artisanal fisheries. Most show no clear trends, although giant clams (*Tridacna* spp.) are in lowest abundance around the populated islands (Green and Craig, 1999). Spiny and slipper lobsters have been recently described by Coutures (2003). Crown-of-thorns starfish have been rare around Tutuila Island since their massive invasion in 1978; a low but persistent population inhabits the Manu'a Islands.

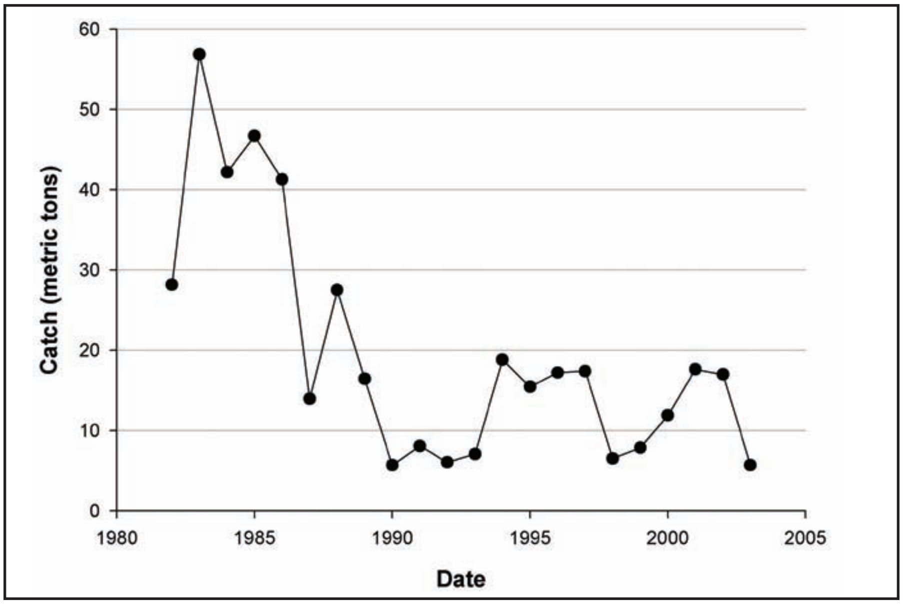


Figure 11.24. Annual catch of bottomfish. Source: DMWR, unpublished data.

SEA TURTLES

Sea turtle populations are in serious decline, both locally and throughout the South Pacific due to harvest, habitat loss of nesting beach habitats and incidental catches in fishing gear (Craig, 2002). Their depletion has been so significant that coral reef biologists often have to be reminded that turtles had formerly been an important component of the coral reef ecosystem. The hawksbill turtle is listed as "threatened" and it is rapidly approaching extinction in the South Pacific, according to the USFWS/NOAA Fisheries Turtle Recovery Plan Team (RPT). The RPT concluded that the status of this species is clearly of the highest concern for the Pacific and it was recommended that immediate actions be taken to prevent its extinction. The RPT further found that green sea turtles (outside Hawaii) have seriously declined and should probably be listed as "endangered" rather than "threatened." In American Samoa, a few turtles are still killed or have their eggs collected for food. In 2003, a sanctuary for sea turtles and marine mammals was established in the territorial waters of American Samoa (0-3 miles offshore) to help publicize this conservation issue.

MARINE MAMMALS

Southern stocks of humpback whales migrate to American Samoa to calve and mate, primarily in September and October. Their numbers are low but unknown, and they are listed as "endangered." Other marine mammals, such as sperm whales and spinner dolphins, occur here but little is known about them. In 2003, a sanctuary for sea turtles and marine mammals was established in the territorial waters of American Samoa to help protect species and publicize this conservation issue.

SEABIRDS
Seabirds that feed in the nearshore coastal waters of American Samoa include Brown boobies and noddies, while other seabirds may contribute nutrients to coastal waters from their cliffside nests. The first Territory-wide survey of seabirds was conducted in 2000 (O'Connor and Rauzon, 2003).

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

The American Samoa Government coordinates all of its territorial coral reef management activities through the Coral Reef Advisory Group (CRAG). This group comprises both territorial and Federal agencies including the American Samoa Government Department of Commerce (which includes the ASCMP and Fagatele Bay National Marine Sanctuary, Figure 11.25), DMWR, ASEPA, the American Samoa Community College, and the National Park of American Samoa. These agencies collaborate to plan and implement actions related to the management of the Territory's coral reefs.

Figure 11.25. Fagatele Bay National Marine Sanctuary. Source: K. Evans.

Each agency within the CRAG has specific projects and programs that enhance the quality of marine habitats, regulate activities on coral reefs, promote awareness, or facilitate research into various aspects of coral reef science. Recently, CRAG members adopted a threat-based approach (as outlined in the U.S Coral Reef Task Force's Puerto Rico Resolution) to identifying key problems on American Samoa's reefs. In tandem with this, the CRAG has also created four three-year action strategies to address the issues of overfishing, global climate change, land-based sources of pollution, and population pressure.

The U.S. Coral Reef Initiative has been instrumental in supporting the Territory in its coral reef conservation activities. The annual Coral Conservation Grant Program has provided managers and scientists in American Samoa with tools, staff, funds, and equipment with which to accomplish key research and management projects. Three programs have benefited greatly from this support: the Marine GIS Program, MPA Program, and Coral Reef Monitoring Program.

Marine GIS Program
GIS activities range from basic map production for DMWR programs (e.g., Fishery Management Program, MPAs) and other CRAG agencies, to more complex spatial analysis of fisheries data, spatial data production, conversion and maintenance, and GIS software customization and development for the above purposes. The use of GIS and mathematical algorithms for the design of the MPAs Network has been investigated locally and brought to the attention of American Samoa's MPA Program. New benthic habitat mapping data and classification schemes were acquired from the CCMA-BT. In addition, multibeam data collected during the NOAA survey in selected shallow areas (<30 m) are being used to test the accuracy of an algorithm to derive bathymetry from IKONOS satellite images.

In collaboration with ASEPA, maps of assessment categories of water quality for streams, wetlands, and ocean shoreline for Tutuila and Manu'a Islands have been developed. A geo-dataset containing all ASEPA and related agency monitoring stations and their attributes is being developed.

Marine Protected Areas Program

Marine Protected Areas (MPAs) are increasingly being relied on as a precautionary form of protection. Community-based MPAs are also increasing throughout the Pacific. In response to the need for a more coordinated approach, the importance of regional networking, and most importantly, the realization that the existing MPAs are doing very little to enhance ecosystem function or protect species, American Samoa is developing an MPA Program within the DMWR and supported by the CRAG. The program focuses on coordinating existing MPAs (Figure 11.26), developing new ones, and creating a territorial master plan to guide MPA management and development, proper management of community-based and territorial MPAs, coordination between local and federal initiatives (i.e. National Park, National Marine Sanctuary), and regional networking, primarily between American Samoa, Samoa, and Fiji.

Figure 11.26. The Nu'uuli Pala Special Management Area is a resource that will be incorporated into the American Samoa MPA Program. Photo: T. Curry.

Table 11.3. Coral reef area contained within MPAs in American Samoa. Only Rose Atoll is a long-term, no-take MPA. Source: P. Craig, pers. obs.

ISLAND	MPA	MPA SIZE (km²)	POTENTIAL CORAL REEF AREA (km²)	
			0-150'	0-300'
Tutuila	Fagatele Bay NMS	0.7	0.6	0.7
	National Park	6.6	6.1	6.6
	Community-based	1	1	1
Ofu	Vaoto Marine Park	0.4	0.4	0.4
	National Park	1.5	1.5	1.5
	Community-based	0.1	0.1	0.1
Ta'u	National Park	4.8	1.9	4.8
Rose Atoll	Rose Atoll NWR	158.1	9.9	11.6
Totals		**173.2**	**21.5**	**26.7**

In 2003, NOAA's Pacific Services Center in Hawaii, collected data for the Territory's section of the Marine Managed Areas National Inventory (Table 11.3). This effort was assisted by the American Samoa Department of Commerce, the DMWR, and the Territory's Coral Reef Initiative. The data are currently being collated and will be available on-line in the near future at http://www.mpa.gov.

Coral Reef Monitoring Program

With the recent addition of two staff positions to establish and run the Coral Reef Monitoring Program, American Samoa will implement an integrated coral reef monitoring plan in 2005. This program will assist individual agency monitoring efforts, as well as the Community-based Fisheries Management Program at the DMWR. For the first time, the Territory will have a single point of reference and contact for monitoring activities, as well as a centralized database.

American Samoa Marine Laboratory

The American Samoa Government has recently completed a facility plan for a marine laboratory. This plan is comprehensive, and includes detailed cost estimates for construction, operation, and maintenance, as well as recommendations for site selection. In addition, a conceptual rendition of the lab has been completed by a Hawaii-based architect and a business/marketing plan has been developed in partnership with the Small Business Development Center at the American Samoa Community College.

American Samoa has never had a marine laboratory capable of supporting quality research by local agencies or visiting scientists and professionals. This has made it difficult to conduct the research that the American

Samoa Government would like to pursue. Without a facility with which to attract qualified scientists, timely and responsive coral reef management has been hindered.

Though American Samoa is fortunate to receive support from the Federal government for marine and coastal protection efforts, Pacific islands such as Guam, Palau, and Hawaii have been able to attract numerous high caliber researchers. In turn, their cumulative body of work has contributed greatly to increased knowledge of coral reef ecosystems, with increased and jurisdictional management effectiveness as a result.

The proposed marine laboratory would serve three main purposes. First, the American Samoa Government will have a facility that can be utilized by local agencies with an interest in marine conservation efforts (i.e., coral reef science, research, and monitoring). The laboratory will provide wet and dry labs, storage and office space, tanks for holding marine organisms, and facilities for aquaculture research and development. Second, the laboratory will serve as an educational institution, 'ao'aoga o le gataifale' in Samoan, associated with the Marine Science Program at the American Samoa Community College, to provide students with research experience and lab facilities for their projects. The marine lab may also be involved in networking with other marine education initiatives for Pacific Island groups. Third, the laboratory will serve as a research base to attract scientists that are funded both domestically and internationally, who might not otherwise have considered American Samoa due to the lack of local facilities. Local agencies are increasingly receiving requests for support from scientists wishing to conduct marine research in the Territory.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

The status of coral reefs in American Samoa is mixed. There are notable improvements, but other serious problems persist. Generally, corals are in good condition, having recovered from massive cyclone damage in 1991. More recent but moderate damage occurred during Hurricane Heta in 2004, but given the observed resilience of corals in the Territory and the generally low level of anthropogenic stressors (e.g., low recreational use), regrowth is expected over the next several years. Another noteworthy improvement is the removal of 10 shipwrecks off local reefs. There has also been a marked improvement in water quality in Pago Pago Harbor.

Local reefs, however, have been seriously overfished and few large fish remain. Genuine consideration needs to be given to reducing overall catches and developing effective MPAs that provide long-term protection to harvested species. Despite the resiliency of corals mentioned above, scientists are observing increases in coral bleaching and mortality, as well as areas heavily impacted by coral diseases, which have historically been rare.

Management Strategies

Progress in coral reef management has been made in several areas. Significant regulatory action has included a ban on scuba-assisted fishing, as well as the establishment of a sanctuary for sea turtles and marine mammals in all territorial waters. Interagency management efforts have been focused more clearly through local action strategies (LAS) that address overfishing, land-based pollution, population growth, and climate change. Each LAS includes steps to address the problems and a timeline for doing so. Progress is also being made to develop both a coordinated territorial monitoring program and a territorial network of MPAs. Coordinators for both of these projects are now on staff.

Gaps

Funding. A common management problem on small Pacific Islands is how to best balance the limited funding opportunities. Because a department's professional staffing may be small, it is often necessary to hire personnel through coral reef grant programs. The difficulty is twofold. First, the remaining funding may not be adequate to conduct projects, and more importantly, it is difficult to eventually transfer these positions to local funding, thus their long-term continuation is not assured.

Enforcement. Enforcement of regulations that protect coral reefs and associated habitats and fisheries has not been adequate for several reasons. First, political and judicial support has not been forthcoming. Violators have historically not been pursued, or if caught, received a ‘slap on the wrist.’ Second, management has not prioritized this issue until recently, and none of the Territory’s MPAs, from Federal to village level, have an effective enforcement presence. Third, the lack of a coherent and long-term funding source to create an adequately sized enforcement staff has yet to be identified. In addition, funding must also be found to ensure that enforcement operations conducted on boats are safe. While American Samoa does have a U.S. Coast Guard presence, the USCG station does not possess the capabilities for water-based rescue or assistance, and there is no radio system in place in the Territory to support patrol activities. Finally the conservation enforcement officers that American Samoa does have are generally in need of more comprehensive training. For example, the DMWR Conservation Enforcement Division lacks a formal training program for entry level conservation enforcement officers.

Training. Coral program staff in American Samoa have improved greatly over the past several years, thanks largely to the U.S. Coral Reef Task Force. However, as the Territory is an isolated island group, few opportunities are available for in-service training for these staff. Ensuring that everyone can attend at least one appropriate conference or training per year is an expensive proposition, given the airfare and per diem costs. However, its value is manifest.

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The State of Coral Reef Ecosystems of the U.S. Pacific Remote Island Areas

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INTRODUCTION AND SETTING

The U.S. Pacific Remote Island Areas (PRIAs) are nine sovereign Federal territories that straddle the equator in the central Pacific. All are single reef ecosystems that are a part of a large central Pacific biogeographic and geological province consisting mostly of ancient low reef islands and atolls (Figure 12.1; Stoddart, 1992). Six of the PRIAs are atolls or atoll reefs: Johnston Atoll (16˚N, 169˚W), Palmyra Atoll (5˚53´N, 162˚05´W), Kingman Reef (6˚25´N, 162˚23´W), which constitute the three northernmost of the U.S. Line Islands; Rose Atoll (14˚S, 168˚W), the easternmost of the Samoan Islands; Wake Atoll (20˚N, 155˚W), the northernmost of the Marshall Islands; and Midway Atoll (28˚N, 177˚W), near the northwestern end of the Hawaiian Archipelago. The remaining three PRIAs are low reef islands within one degree latitude of the equator: Jarvis Island (00˚S, 160˚W), in the central U.S. Line Islands, Howland Island (00˚18´S, 160˚01'W); and Baker Island (00˚13´N, 176˚38´W), the two northernmost of the U.S. Phoenix Islands. All except Wake and Johnston are National Wildlife Refuges (NWRs) administered by the U.S. Fish and Wildlife Service (USFWS) and all fall under co-jurisdiction of the U.S. Department of Interior (DOI) and the U.S. Department of Commerce (DOC), except Johnston, which is managed by the U.S. Department of Defense, and Palmyra, which is under the joint jurisdiction of DOI, DOC, and The Nature Conservancy.

Although all nine are outside the political jurisdiction of other U.S. Pacific States and Territories (Hawaii, American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands [CNMI]), Rose and Midway Atolls are geographically a part of American Samoa and Hawaii, respectively. For organizational purposes, Midway Atoll is mostly treated in the chapter on the Northwestern Hawaiian Islands (NWHI), and Rose Atoll is partially covered in the chapter on American Samoa. Swains Island (14˚S, 168˚W), the northernmost island in American Samoa, is also a remote reef island but it is not technically a PRIA because it falls under the jurisdiction of the Territory of American Samoa.

All of the PRIAs were uninhabited at the time of their discovery by Americans and Europeans over the past two centuries, although Polynesians (and Micronesians, in the case of Wake) probably visited all of the islands periodically over many centuries to harvest fish and wildlife. The U.S. claimed most of the islands via the Guano Act of 1856. Except for Palmyra, Kingman and Rose, the PRIAs lie within arid zones of the tropical Pacific, with insufficient groundwater and rainfall to support continuous human habitation. Moreover, Kingman, lacks vegetated islets, and the land area at Rose is too small and vulnerable to storms to allow habitation. Although Palmyra is certainly capable of supporting human settlements, it is unclear as to why it remained uninhabited during recent centuries. The lack of human habitation allowed the coral reef ecosystems of the PRIAs to remain completely pristine until the early 20th century. Even today all lie beyond the influence of urban centers, associated pollutants, and major shipping lanes.

Most of the PRIAs were materially modified during the World War II (WWII) era: the U.S. constructed and occupied military bases at Johnston, Palmyra, Wake, Midway, and Baker, while Kingman, Jarvis, and Howland were also briefly occupied or utilized during the war era. With the closure of the military base at Johnston in early 2004, only Wake Atoll remains an active U.S. military base. The seven NWRs in the PRIAs were established between 1924-2001, and all are presently no-take island and marine protected areas (MPAs) except Palmyra, on which limited catch and release sport fishing for bonefish and offshore pelagic catch for local consumption are allowed.

1 NOAA Fisheries, Pacific Islands Fisheries Science Center
2 U.S. Fish and Wildlife Service
3 University of Hawaii, Joint Institute for Marine and Atmospheric Research
4 Bishop Museum
5 Department of Land and Natural Resources, Division of Aquatic Resources
6 University of Hawaii, Hawaii Institute of Marine Biology
7 NOAA Fisheries, Pacific Islands Regional Office

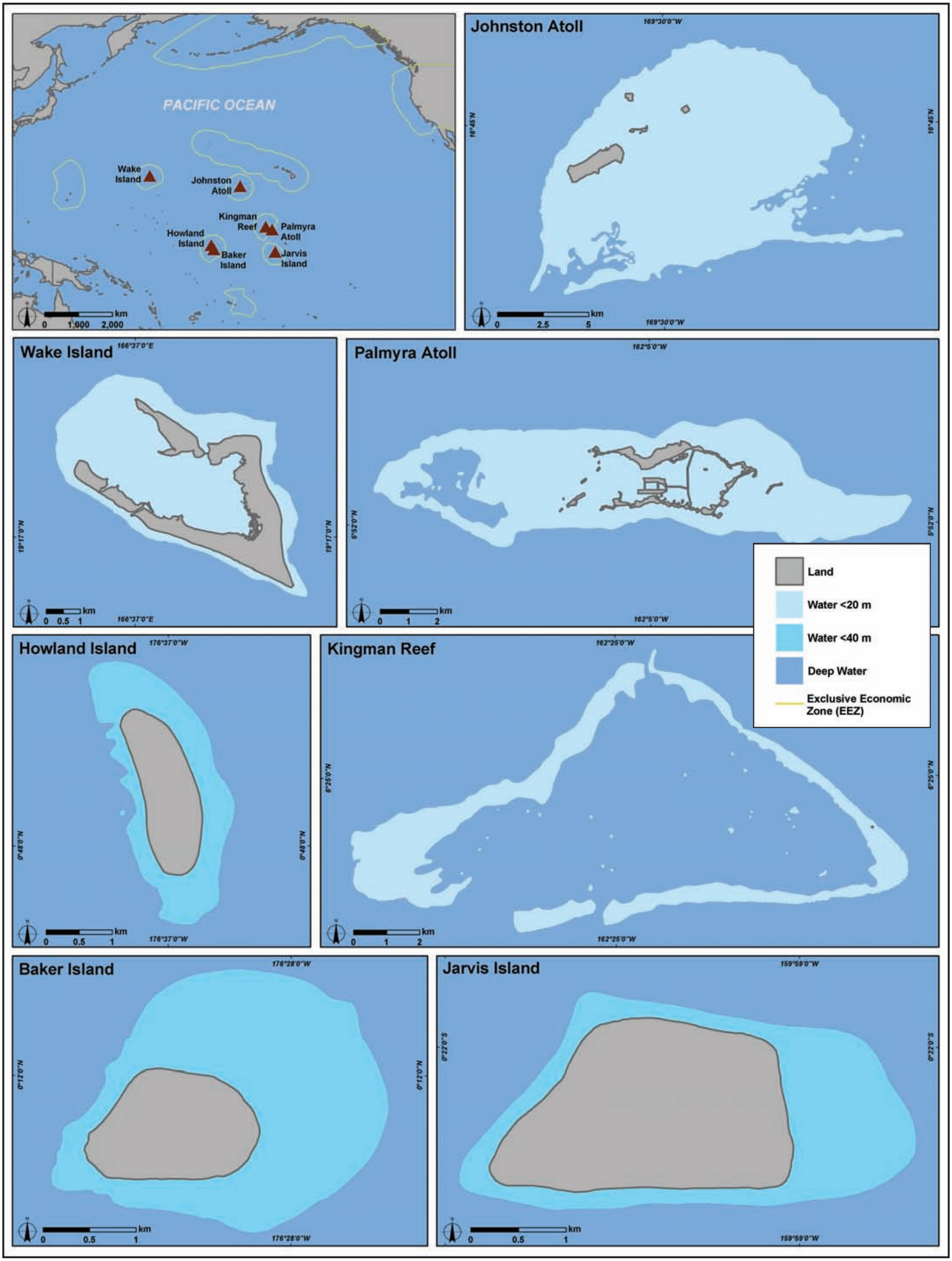


Figure 12.1. Locator map for the Pacific Remote Insular Areas (PRIAs). Map: A. Shapiro.

Ocean currents transport and distribute larvae among and between different atolls and islands, and particularly in the Pacific equatorial region, define sea surface temperatures (SSTs) and available nutrient regimes. The North Equatorial Current (NEC), Equatorial Counter Current (ECC), Equatorial Undercurrent or Cromwell Current (EUC), and South Equatorial Current (SEC) provide the mechanism by which many species are distributed among the PRIAs, nearby central Pacific islands, the main Hawaiian Islands (MHI), as well as other distant regions.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

Federally sponsored coral reef surveys conducted between 1979-2004 reveal that all PRIAs have experienced coral bleaching during the past 25 years. Pre-2000 observations by Maragos (1979, 1994) include reports and photographs of localized coral bleaching of the ocean reefs at Wake in mid-1979 and mass coral bleaching in progress at Rose off all reefs to depths of 25 m in April 1994. NOAA and USFWS scientists who visited Wake in 1998 did not report any bleaching. Several USFWS visits and surveys of Rose between 1995-1999 and recent surveys of Rose in 2002 and 2004 sponsored by the National Oceanic and Atmospheric Administration (NOAA) reveal that corals are still recovering from a mass bleaching event of 1994. Coral bleaching was also reported at Johnston and Kingman in the 1990s (P. Jokiel, pers. comm.). The four NOAA and USFWS-sponsored expeditions to Baker, Howland, Jarvis, Kingman, and Palmyra between 2000-2004 strongly suggest that mass bleaching occurred within the few years before 2000, and that corals have remained in recovery phase since then. Additional evidence on recent bleaching at Palmyra reveal that the reefs off the broad western reef terrace at Palmyra supported thriving *Acropora* staghorn coral thickets in 1987 (Maragos, 1988) that died and degenerated to rubble deposits by November 1998 (Molina and Maragos, 1998). The distribution of large *Porites* heads and numerous small *Pocillopora* coral heads present on the terrace in late 1998 suggest mass coral bleaching in the mid-1990s rather than coral mortality caused by storm waves at Palmyra.

During 12 benthic surveys at Johnston Atoll in January 2004, mild bleaching of relatively few coral colonies were found at eight of the 12 sites. Mild bleaching was observed on *Montipora patula, M. capitata,* and *Acropora cytherea*.

During much of June through December 2002, both remotely sensed and *in situ* measurements of SST around Jarvis Island, Baker Island, and Howland Island were extremely high, at times 2˚C or more above maximum mean conditions, for prolonged periods (Figure 12.2). Prolonged temperature anomalies such as these have been implicated in most widespread coral bleaching events. Due to their remote nature, these reefs were not surveyed during or immediately after this period of SST increase. Biological monitoring by experienced scientists in early 2004 did not yield visual evidence that widespread coral mortality had occurred in the wake of a possible bleaching event in 2002.

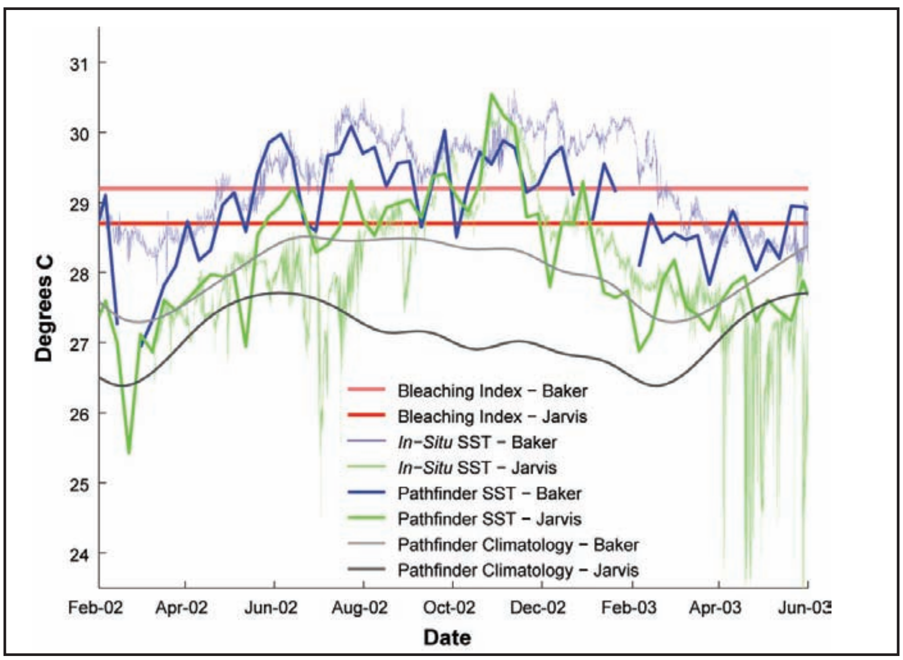


Figure 12.2. Satellite and *in situ* temperatures at Baker and Jarvis Islands during 2002 and 2003 showing anomalously high SST. Both satellite Pathfinder SST (Baker – thick blue line, Jarvis – thick green line) and *in situ* temperatures (z~=-15 m) at Baker (thin blue line) and Jarvis (thin green line) show values significantly exceeding long-term mean climatological values (Baker–light gray line, Jarvis–dark gray line). Coral Reef Watch bleaching threshold of maximum monthly mean SST plus 1°C are included for reference. Source: Brainard et al., 2004.

Diseases

Johnston Atoll

In January 2004, surveys were conducted at 12 sites at Johnston Atoll to quantify and characterize coral disease. Surveys were limited to sites within the lagoon due to harsh weather conditions. Signs of coral disease were evident at 92% of the sites surveyed. The average prevalence of disease (no. of diseased colonies/total no. of colonies) was estimated at 3.1%, which is higher than what has been reported for the NWHI (average estimated prevalence=0.5%; Aeby, NWHI chapter). Types of diseases included growth anomalies on *Acropora* and *Montipora*, white syndrome on the table coral, *Acropora cytherea*, *Montipora* tissue loss syndrome, and *Montipora* patchy tissue loss. These diseases have also been observed in the NWHI. One disease that has not yet been found in the NWHI was *Montipora* ring syndrome, where affected corals have abnormal growths with tissue death in the center producing a ring-like lesion (Figure 12.3). Work et al. (2001) found similar disease signs at Johnston Atoll during a qualitative assessment of coral disease.

Figure 12.3. *Montipora patula* from Johnston Atoll with abnormal growths, January 2004. Photo: G. Aeby.

Howland and Baker Islands

A qualitative assessment of coral disease was conducted at six sites around Howland Island and six sites around Baker Island during January 2004. The corals were found to be in good condition with few colonies having any signs of disease. Small patches of denuded skeleton were frequently observed on acroporids and seemed to be associated with damselfish (*Plectroglyphididon* sp.) activities.

Tropical Storms

In general, the PRIAs of Johnston, Kingman, Palmyra, Jarvis, Howland, and Baker experience low frequencies of tropical storm events, although occurrences at Johnston are much more common than the other areas. These islands and atolls are located in between the major eastern and western Pacific tropical storm centers, which are most active in late summer and early fall (Figure 12.4). Most storms that develop off the coast of Mexico and head west undergo cyclolysis (storm death) or spin off northwards before reaching the longitude of the PRIAs. Cyclogenesis (storm formation) to the west/northwest of the PRIAs produces tropical depressions and storms that head away from the PRIAs toward the western Pacific. Additionally, due to their proximity to the equator, the U.S. Line and Phoenix Islands are located out of the path of almost all tropical cyclones of any intensity. No tropical cyclones of any magnitude have been observed within the Exclusive Economic Zones (EEZs) of Howland, Baker, or Jarvis Island in the past 60 years. Three cyclones have been observed in the Kingman/Palmyra EEZ. However, only one of these three, Ekeka in 1992, reached wind speeds in excess of 60 knots (Figure 12.4).

Because Johnston is located at a higher latitude than the other areas, it is subjected to a greater degree of tropical storm activity, catching storm systems out of the eastern Pacific center that travel between 10 and 20 degrees latitude. As a result, Johnston experiences a higher frequency of tropical storm events than both the U.S. Line and Phoenix Islands to the south and the NWHI to the north. Significant hurricanes that have passed near Johnston since 1979 include Hurricane John in 1994, Hurricane Keoni in 1993, and Hurricane Keli in 1984 (Figure 12.4).

While the impacts of these tropical storm events on coral reef ecosystems in the PRIAs are not documented, any damage to reef habitats associated with these storms would have been caused primarily by extreme wave energy events. In summary, tropical storms represent a moderately frequent disturbance event experienced by coral reefs at Johnston Island, potentially influencing physical and biological reef structure, although certainly not to the degree experienced by reefs and terrestrial environments in the western Pacific. Kingman, Palmyra, Jarvis, Howland, and Baker, on the other hand, are rarely, if ever, directly subjected to significant tropical storms and hurricanes.

Significant Wave Events

While the direct impacts of tropical storms on the coral reef ecosystems of most of the PRIAs islands and atolls are relatively rare, the impacts of large wave events resulting from distant tropical and extratropical storms may be significant. Episodic events with wave heights around 2-3 m and periods of 15-20 seconds occur at frequent intervals throughout the year in the equatorial PRIAs (Baker, Howland, Jarvis, Palmyra, and Kingman). Although this is an order of magnitude less than NWHI wintertime wave events, the equatorial PRIAs are much less seasonal in terms of wave energy and these relatively more moderate events occur throughout the year (Figure 12.5). These events generally approach this area from the northeast through the northwest during the boreal winter, from the southwest in the boreal summer, and to a smaller extent, from the west during the northern hemisphere's typhoon season. The wave climate of Johnston Atoll is likely very similar to that of the NWHI and MHI, with a large number of extremely energetic events in the wintertime and very consistent, moderate waves in the summer.

These episodic wave events subject the shallow-water coral reef communities to a great deal more energy than the average energy level. As such, wave climate likely plays a

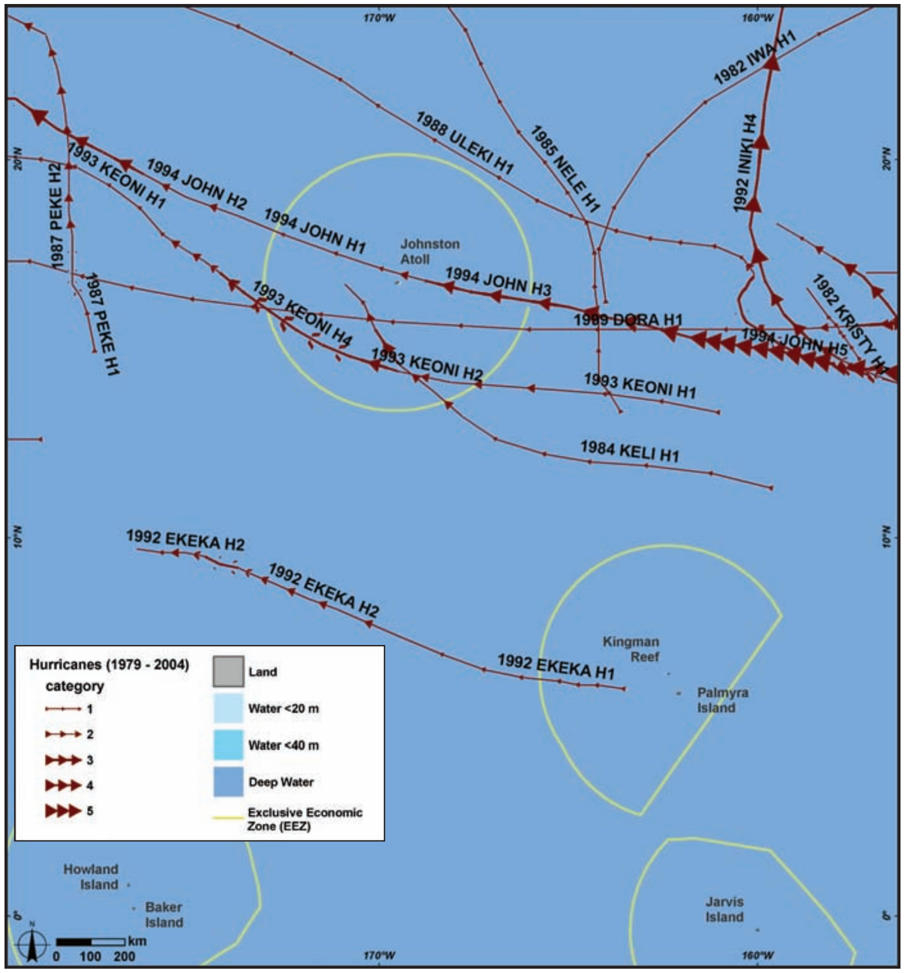


Figure 12.4. A map showing the paths and intensities of tropical storms passing near the PRIAs, 1979-2004. Year of storm, storm name and storm strength on the Saffir-Simpson scale (H1-5) are indicated for each. Map: A. Shapiro. Source: NOAA Coastal Services Center.

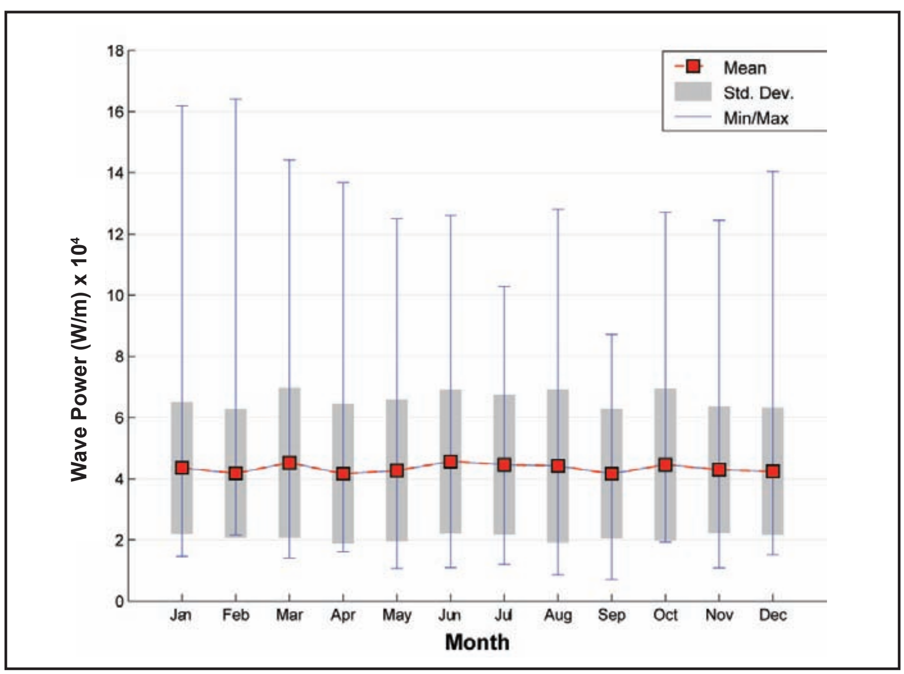


Figure 12.5. Climatological values of wave power (W/m) derived from NOAA Buoy #51028 located along the equator at 154°W near Christmas Island from 1997-2004. Source: NOAA National Data Buoy Center.

fundamental role in forming and maintaining biogeographic (spatial and vertical) distributions of corals, algae, fishes, and invertebrates of the coral reef ecosystems of the PRIAs.

Coastal Development and Runoff

There has not been any coastal development in the PRIAs since the W.W.II era. An atoll research station at Palmyra is being proposed and coordinated by The Nature Conservancy and the USFWS that will be funded by foundations and several participating research institutions and universities. During the past year, all but a few of the Johnston Atoll buildings and facilities were demolished by the U.S. Department of Defense (DoD) prior to the closure of the military base there in early 2004.

Surface runoff is nearly non-existent in the PRIAs. Most of the PRIAs lie within the arid zone of the tropical central Pacific, one (Kingman Reef) lacks permanent land, and all have porous carbonate soils characteristic of atolls and low reef islands. The paved runways at Wake, Midway, and Johnston are designed as catchments for collecting rainfall as a source of freshwater. The PRIA runways at Palmyra, Jarvis, Howland, and Baker have deteriorated or lie within an arid zone, and all are incapable of collecting rainfall and generating surface runoff.

Coastal Pollution

The military bases at Palmyra, Midway, and Johnston Atolls housed up to several thousand military personnel for periods exceeding a decade or more, thus generating sewage pollution and various toxic and hazardous chemicals, and leaving behind abandoned fuels, solvents, and numerous contaminants. The DoD's Defense Environmental Restoration Program funded the draining and demolition of underground fuel storage tanks at Palmyra and some burning of fuel in drums at Howland and Baker in the late 1980s, but many contaminants remain, especially at Johnston and Palmyra. Johnston was also the site of post-war high atmospheric nuclear testing, storage of chemical munitions, and stockpiling of Agent Orange defoliants, all of which released contaminants to the atoll environment. Although the Johnston Atoll Chemical Agent Disposal System completed the task of destroying all chemical agents and associated fuels and explosives in 2003, nuclear waste, dioxins, and other chemical contaminants have not been removed. The USFWS is presently urging the DoD to conduct additional cleanup of military contaminants and toxics at Johnston as part of an acceptable transfer of the atoll to USFWS management.

Coral monitoring data collected off the northwest coast of Baker in 2000-2004 showed evidence of impacts from a nearby W.W.II military debris dump, including periodic dieback of *Acropora* corals (Figure 12.6) and proliferation of cyanobacteria characteristic of sites generating dissolved iron from corroding metallic debris. Additional eco-toxicological studies at the sites are now being proposed.

The status of military contamination and pollution at Wake Atoll could not be assessed at this time.

Tourism and Recreation

The 2004 termination of military activities at Johnston Atoll permanently closed all sport-fishing activity at the atoll. Presently, The Nature Conservancy sponsors and promotes compatible ecotourism activities at Palmyra Atoll, including

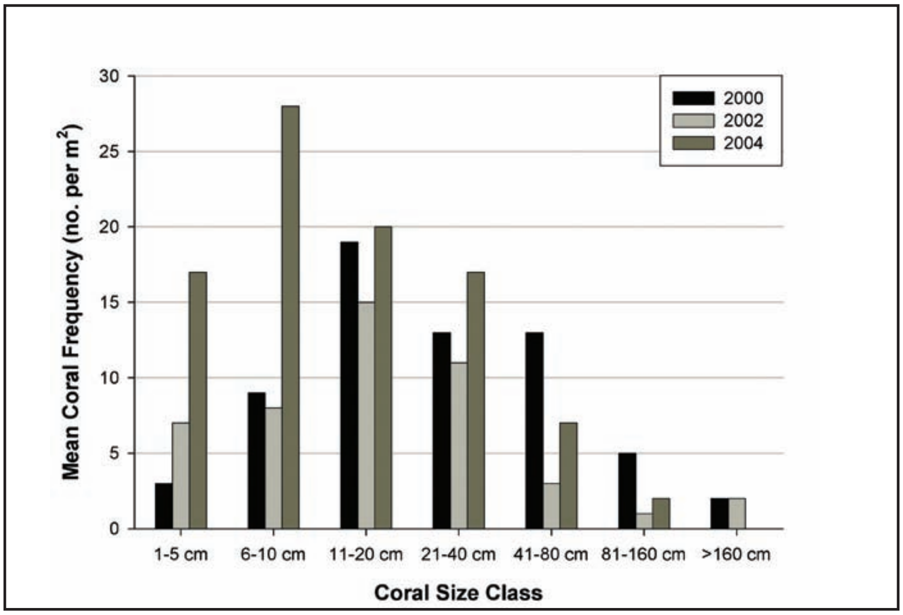


Figure 12.6. Evidence of periodic *Acropora* dieback at USFWS permanent monitoring site BAK-5P near the abandoned WWII military ocean dump site off the northwestern coast of Baker Island. Source: Maragos and Veit, 2004.

a) catch-and-release sport-fishing for lagoon bonefish, b) blue water sport-fishing of offshore pelagic species, with catch limited to what can be consumed on the island, c) sport diving, d) snorkeling, e) hiking, f) beach-going, g) touring historic sites, and h) birding. Aside from Palmyra, all other central Pacific NWRs are closed to commercial fishing. Access to any NWR requires a Special Use Permit issued by the NWR manager. Permits are granted only for actions compatible with the conservation and protection of fish, wildlife, and vegetation inhabiting the refuges. The military facility at Wake Atoll allows sport diving, beach-going, touring historical sites, and other recreational activities for resident DoD workers and some visitors, although Wake is not a tourism destination.

Fishing

The islands and surrounding waters of Howland, Baker, and Jarvis; Kingman Reef; and most of Palmyra Atoll are currently NWRs under the management of the USFWS. Fishing and unauthorized entry in these waters are prohibited; however, current levels of poaching are largely unknown. Anecdotal evidence of possible fishing activity includes the presence of fishing lines entangled on the reef >50 m deep, as seen on NOAA's Pacific Island Fisheries Science Center-Coral Reef Ecosystem Division's (PIFSC-CRED) towed-optical assessment device video surveys in 2004. The Nature Conservancy owns one-third of Palmyra, primarily for ecotourism (e.g., catch-and-release fishing for bonefish [*Albula* spp.] in the lagoon). In recent years, occasional trips have been made by Hawaii-based fishing vessels to Kingman and Palmyra for coastal sharks (fining) and bottomfish. There is also recent anecdotal evidence of occasional fishing at Kingman and Palmyra (e.g., Fijian fishers on tuna boats based out of San Francisco). However, it is presently not possible to quantify such effort or catch, nor whether by foreign vessels or passing yachts. Johnston Atoll is under the control of the U.S. military with overlay status as a NWR. Recreational and subsistence fishing is regularly practiced by the temporary workers on the island. Based on a survey during the late 1980s, catch was dominated by soldierfish (Holocentridae). Other fish taken included bigeyes (Priacanthidae), flagtails (Kuliidae), mullet (Mugilidae), goatfish (Mullidae), jacks (Carangidae), parrotfish (Scaridae), and surgeonfish (Acanthuridae). It was also common for island residents to regularly ship coolers of fish and corals to Hawaii; however, this practice has recently been prohibited.

Trade in Coral and Live Reef Species

Trade in live reef organisms in the Pacific is primarily for live food fish and ornamental aquarium species, including colorful fish, corals, other invertebrates, and "live rock." Total value of the trade exceeds $1 billion (USD) per year (Barber and Pratt, 1997; Sadovy and Vincent, 2002). Large species of fish, such as humphead wrasse (*Cheilinus undulatus*), large groupers (Serranidae) and emperors (Lethrinidae) are captured and ordered live in upscale restaurants, primarily in Southeast Asia (e.g., Hong Kong), where prices can exceed $100 (USD) per kg. The practice can be harmful as sodium cyanide is often used to facilitate capture, resulting in mass mortality of coral reef communities. Targeted large fish are characteristically long-lived and can be rapidly depleted locally. This results in collection operations moving eastward from Southeast Asia in search of more productive reefs (e.g., Micronesia and the Marshall Islands). There is no evidence to date that live reef fish harvesters have reached the PRIAs. Any such take would be illegal as these areas are no-take NWRs, with one (Wake) under control of the U.S. military. However, the targeted species/sizes do occur at these islands, which are remote and largely unprotected due to the lack of enforcement. The long transport distance of live product to Asian markets may render these U.S. islands economically unfeasible for operations, with the possible exception of Wake Atoll, an active, occupied military base.

There is currently no known live reef ornamental fishing operating in the PRIAs. However, some export of live corals was documented in the 1980s from Johnston Atoll to Hawaii, though DoD and USFWS cooperatively eliminated this activity thereafter. The DoD closed its operations at Johnston in 2004, and the atoll is again an uninhabited NWR. As such it is now vulnerable to unauthorized collection by fishers from nearby Hawaii (1,500 km to the northwest) because of the present lack of on-site enforcement and surveillance.

Ships, Boats, and Groundings

All the PRIAs are uninhabited except for several caretakers and students at Palmyra and DoD workers at Wake. Periodic transports call at Wake to offload supplies, food, and fuel. Otherwise, ship traffic is limited to: a) NOAA oceanographic research vessels every one to two years to all PRIAs except Wake; b) irregularly scheduled supply vessels to Palmyra; and c) unauthorized fishing vessels near the uninhabited NWRs. Tour ships do not call at any of the PRIAs except periodically at Palmyra Atoll.

All PRIAs are vulnerable to ship groundings since most are low lying, poorly chartered, and lack beacons and aids to navigation. Wake suffered a major tanker grounding and fuel spill in the mid-1970s. All of the PRIAs except Wake, Johnston, and Palmyra are rodent-free, due to the concerted rodent eradication efforts of the USFWS and specialists over the past three decades. However, ship groundings always run the risk of re-introducing rodents and other alien species that can decimate native wildlife and vegetation. Fuel spills from ruptured vessels run the risk of mass kills of nearshore marine life, migratory shore birds, sea turtles, and resident seabirds. Dissolved iron from corroding wreckage can also fuel localized outbreaks of invasive cyanobacteria that can displace native species and smother reef building organisms.

Marine Debris

Fishing nets and anthropogenic objects were recorded during towed-diver surveys by the PIFSC-CRED in 2001, 2002, and 2004 in the U.S. Line and Phoenix Islands. During the 2004 season, there was no notable debris accumulation at Howland, Baker, Jarvis, Palmyra, and Kingman. Several anchors and chains are present off the northwestern anchorage of Baker, which served as a temporary forward Allied Forces air base during the W.W.II assault on Tarawa Atoll. After the battle, Baker was abandoned and military debris and material was dumped off the northwestern anchorage.

Long-line gear was encountered at all sites. The majority of the noted debris from Howland, Baker, and Jarvis during all three survey years consisted of encrusted anchors and chains, probable remnants from their guano mining past. In 2004, one large fishing net was found along a previously surveyed 2002 track on the southern forereef zone of Kingman Reef. This net, with an estimated size of 6 m by 12 m, was not noted during the 2002 season. Although the density of nets encountered during towed-diver surveys is low, nets have been seen during each survey year.

Having served as a Pacific military base for refueling during WWII, nuclear testing in the 1960s, and chemical storage and disposal in the 1970s and 1980s, Johnston Atoll contained the majority of marine debris noted during towed-diver surveys in the U.S. Line and Phoenix Islands. Over 200 anthropogenic objects were seen and recorded. Documented items include tires, bottles, metal racks, barrels, steel pipes, frames, and cables.

Aquatic Invasive Species

The efforts by the PIFSC-CRED and the USFWS sponsored Pacific Biological Survey performed by the Bishop Museum, both based in Hawaii, have provided information concerning marine alien species in the PRIAs. Documentation of marine alien species occurred through regular survey and monitoring activities by the PIFSC-CRED in 2002 and 2004. These surveys involved 27 sites at the U.S. Phoenix Islands, 33 sites at the U.S. Line Islands, and 12 at Johnston Atoll. An intensive inventory focusing on marine alien species was conducted at 11 sites at Johnston Atoll by the Bishop Museum.

Compiled data from these efforts reveal that marine alien species exist in these remote islands and that 85% are at either Johnston or Palmyra Atoll. Both of these sites were active military installations with many of the alien species reaching the atolls via the hulls and ballast waters of arriving vessels. These two remote atolls have experienced the greatest physical alteration historically and the majority of alien species documented are associated with these altered habitats. A compiled list from the combined efforts is provided in Table 12.1, including species name, native range (if determined) and a status of either alien or cryptogenic. The cryptogenic term refers to species of unknown status that are most likely introduced. Comparable data for Wake Island, an active military base, are not available.

Table 12.1. List of marine alien species reported from the PRIAs since 2000. Source: Godwin and Vroom, unpublished data.

SPECIES	NATIVE RANGE	STATUS IN PRIAs
Sponge species 1 (Unidentified)	Undetermined	Cryptogenic, Palmyra Atoll only
Sponge species 2 (Unidentified)	Undetermined	Cryptogenic, Palmyra Atoll only
Pennaria disticha (hydroid)	W. Atlantic	Alien
Branchiomma nigromaculata (polychaete)	Undetermined	Cryptogenic, Johnston Atoll only
Armandia intermedia (polychaete)	Indo-west Pacific, Atlantic	Cryptogenic, Johnston Atoll only
Balanus amphitrite amphitrite (barnacle)	SW Pacific, Indian Ocean	Alien
Bugula vectifera (bryozoan)	Undetermined	Cryptogenic, Johnston Atoll only
Caulibugula dendrograpta (bryozoan)	Undetermined	Alien, Johnston Atoll only
Didymozoum triseriale (bryozoan)	Indo-Pacific	Cryptogenic, Johnston Atoll only
Halysis diaphana (bryozoan)	Undetermined	Cryptogenic, Johnston Atoll only
Ascidia sydneiensis (tunicate)	Undetermined	Alien, Johnston Atoll only
Diplosoma listerianum (tunicate)	Undetermined	Alien, Palmyra and Johnston Atolls
Microcosmus exasperatus (tunicate)	Undetermined	Alien, Johnston Atoll only

Marine alien species in these remote areas have just recently become an issue of interest, due to survey efforts in other parts of the tropical Pacific. Efforts should be focused on minimizing the likelihood of coral reef habitats being exposed to marine alien species through the spread of organisms already established in altered habitats and transport of new species from outside of the PRIAs. This can be achieved by management efforts directed towards all activities that have the potential for acting as mechanisms of transport, especially visiting ships and airplanes as well as the shoes and clothing of visitors.

Security Training Activities

Security training activities are not practiced at any of the NWRs in the PRIAs. Data are not available for Wake Atoll, which is currently an active military installation.

Offshore Oil and Gas Exploration

Offshore oil and gas exploration has never occurred, is not being contemplated, nor would it currently be feasible in the PRIAs. All are small low-lying atolls and reef islands surrounded by deep oceanic waters. The possibility of any commercial oil and natural gas formations is highly unlikely.

Other

Crown-of Thorns Starfish

Counts of the crown-of-thorns starfish (COTS), *Acanthaster planci*, were conducted around the U.S. Line and Phoenix Islands in 2001, 2002, and 2004 in conjunction with 50-minute towed-diver habitat surveys (see towed-diver method in the 'Benthic Habitat' section).

All 2001 and 2002 tows at Palmyra were resurveyed in 2004, and four new tows were added. Surprisingly, COTS were not observed at Palmyra in 2004, even though the survey efforts increased and they were recorded in 2001 and 2002 (Table 12.2). Aggregations of COTS were recorded by the USFWS and The Nature Conservancy divers in mid-2001 and 2002 off the southwestern terrace, but these apparently disappeared by 2004. COTS have yet to be observed by towed-divers at Baker, Jarvis, and Howland Islands.

Table 12.2. Total number of COTS recorded during towed-diver surveys and the total distance (km) surveyed in 2001, 2002, and 2004. Source: PIFSC-CRED, unpublished data.

LOCATION	2001		2002		2004	
	TOWED KM	COTS	TOWED KM	COTS	TOWED KM	COTS
Johnston Atoll	N/A	N/A	N/A	N/A	63.2	182
Howland Island	10.1	0	10.8	0	20.8	0
Baker Island	9.9	0	5.4	0	17	0
Jarvis Island	11.3	0	11.1	0	19.9	0
Palmyra Atoll	17.8	4	31	28	41.7	0
Kingman Atoll	26.6	140	27.4	378	37.8	752

In the 2004 survey year, COTS were recorded at Johnston Atoll and Kingman Reef (Table 12.2). For the 63.2 km of surveyed habitat at Johnston, divers recorded 2.9 COTS/km. The COTS were most noticeable at Kingman Reef where recorded sightings in 2004 increased 44% from 2002 and 160% from 2001. Towed-divers surveyed 26.6 km of habitat in 2001 and recorded 5.3 COTS/km. In 2002, 27.4 km of habitat was surveyed with 13.8 COTS/km and in 2004, 37.8 km of habitat was surveyed with 19.9 COTS/km (Figure 12.7). In addition to resurveying all 2001 and 2002 tows, two additional towed-diver surveys recorded 162 COTS, 21.5% of all recorded COTS at Kingman in 2004. The towed-diver estimating habitat reported that 13% of the coral habitat along those two tows appeared white due to COTS predation. Counts of COTS from towed-diver surveys typically underestimate abundance since juvenile and adult COTS may hide underneath plate corals and other structures.

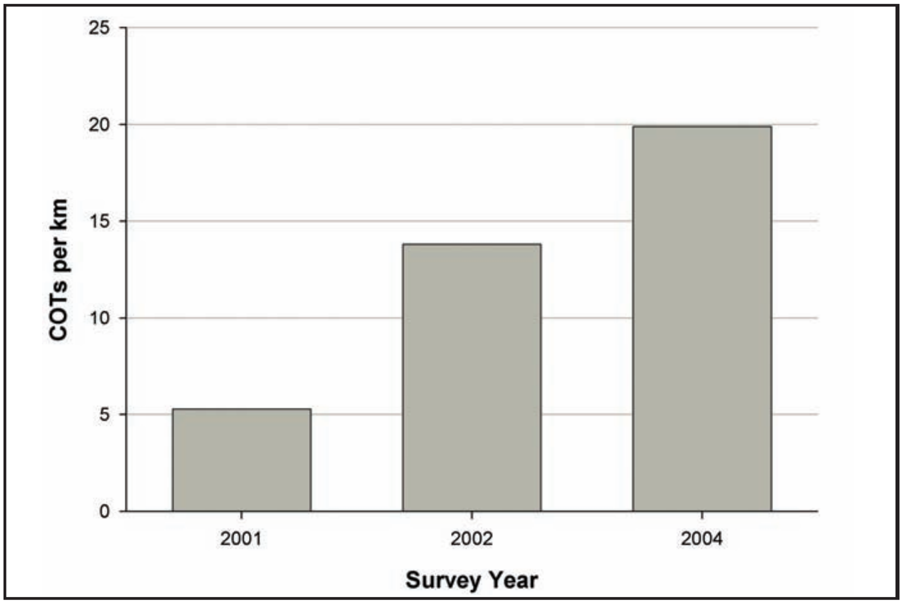


Figure 12.7. Recorded COTS per towed kilometer (km) at Kingman Reef in 2001, 2002, and 2004. Source: PIFSC-CRED, unpublished data.

Pacific Remote Island Areas

CORAL REEF ECOSYSTEMS—DATA GATHERING ACTIVITIES AND RESOURCE CONDITION

WATER QUALITY AND OCEANOGRAPHIC CONDITIONS

The health, functioning, and biogeography of the coral reef ecosystems of the PRIAs are primarily controlled by the oceanographic conditions to which fish, algae, corals, and other invertebrates of the ecosystem are exposed. This broad and diverse biological community is heavily influenced by time-varying ocean currents, waves, temperature, salinity, turbidity, nutrients, and other measures of water quality and oceanographic conditions. As these conditions change, so do the health, distribution, and species diversity of each reef community. Table 12.3 provides a list of long-term oceanographic and water quality monitoring programs in place in the central equatorial Pacific. Figure 12.8 shows the locations of many of these monitoring sites.

Table 12.3. Oceanographic monitoring systems in the PRIAs.

SYSTEM	VARIABLES MONITORED	DATES	AGENCY
Deepwater CTDs* at select locations near the islands	temperature, salinity, dissolved oxygen, and chlorophyll versus depth to a depth of 500 m	Feb. 1999 - present	PIFSC-CRED
Shallow-water CTD* - multiple sites each island/atoll	temperature, salinity, turbidity	Feb. 2001 - present	PIFSC-CRED
Coral Reef Early Warning System (CREWS) Buoys - 1 Enhanced – (Palmyra)	Enhanced: temperature (1 m), salinity, wind, atmospheric pressure, ultraviolet radiation, photosynthetic active radiation	Feb. 2002 - present	PIFSC-CRED
Sea Surface Temperature (SST) Buoys – 4 (Johnston, Howland, Jarvis, Kingman)	Temperature at 0.5 m	Feb. 2002 - present	PIFSC-CRED
Subsurface Temperature Recorders (STR) – 24	Temperature at depths between 0.5 m and 5 m	Feb. 2002 - present	PIFSC-CRED
Ocean Data Platforms (ODP) – 2 (Baker, Jarvis)	temperature, salinity, spectral directional wave motion, current profiles	Oct. 2002 - present	PIFSC-CRED
Wave and Tide Recorders (WTR) – 1 (Johnston)	spectral wave motion, tides, temperature	July 2003 - present	PIFSC-CRED
Tide Gauges	tidal fluctuations, sea level	?	NOAA Ocean Service, Pacific Tides Branch
Wave Monitoring Buoys – SE of Kiritami (Christmas) Island	wave height & period, wind speed & direction, atmospheric pressure, temperature	1997 - present	NOAA National Weather Service, National Data Buoy Center
Satellite Remote Sensing	sea surface temperature, winds, sea surface height, ocean color	SST -1981 SSH – 1992 Wind – 1995 Ocean Color - 1994	NOAA Satellites and Information, Hawaii Coastwatch
Model Fields	waves / surface circulation		NOAA National Weather Service, Wave Watch 3 Naval Research Laboratory, Navy Coastal Ocean Model

* CTD: Conductivity, Temperature, and Depth

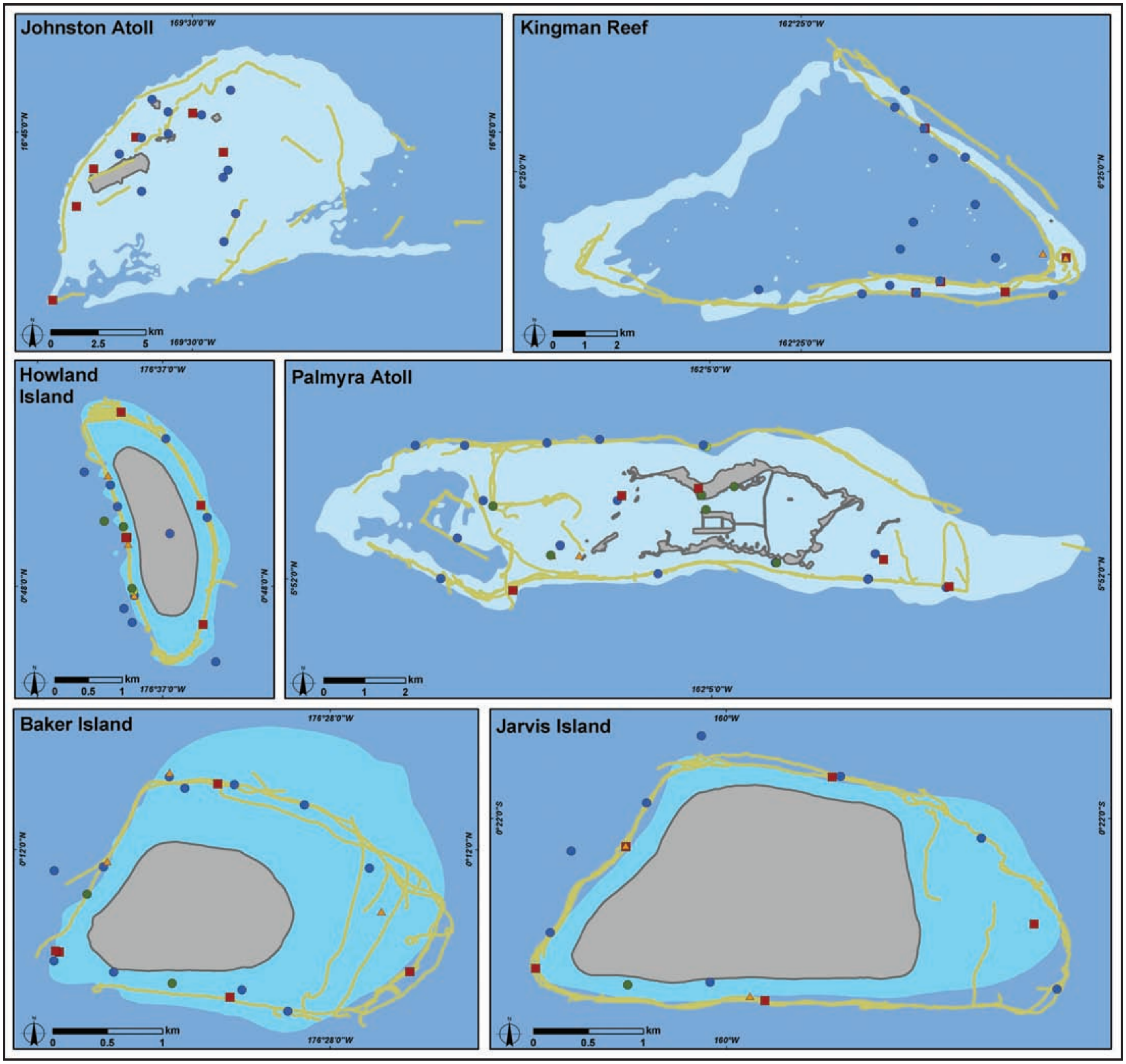
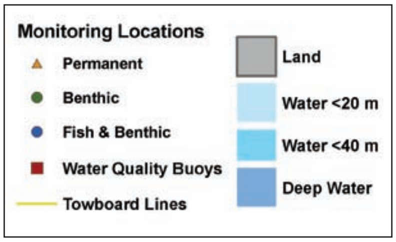


Figure 12.8. Monitoring locations in the PRIAs. Map: A. Shapiro. Source: PIFSC-CRED.



Ocean currents transport and distribute larvae among and between different atolls and islands, as well as define SSTs and available nutrient regimes. The equatorial region is home to several well-defined, though variable, currents: the NEC, ECC, EUC, and SEC. These currents are highly influential to the ecosystems of these islands and atolls: the ECC is the major pathway of larval transport and connectivity to regions of high biodiversity to the west; the deeper flowing EUC brings colder water and nutrient enrichment to islands nearest the equator (Figure 12.9); and the NEC and SEC are generally well mixed and nutrient poor. The magnitude and mean position of these current systems are highly dependent on El Niño/Southern Oscillation (ENSO), and ENSO-related changes to oceanographic conditions in this region are generally much greater than annual changes. Figure 12.10 shows this dependence; SST at all central Pacific PRIAs exhibit greater interannual variability and dependence on ENSO than seasonal changes, with the exception of Johnston Atoll which exhibits a more annual cycle similar to that experienced by the Hawaiian Archipelago.

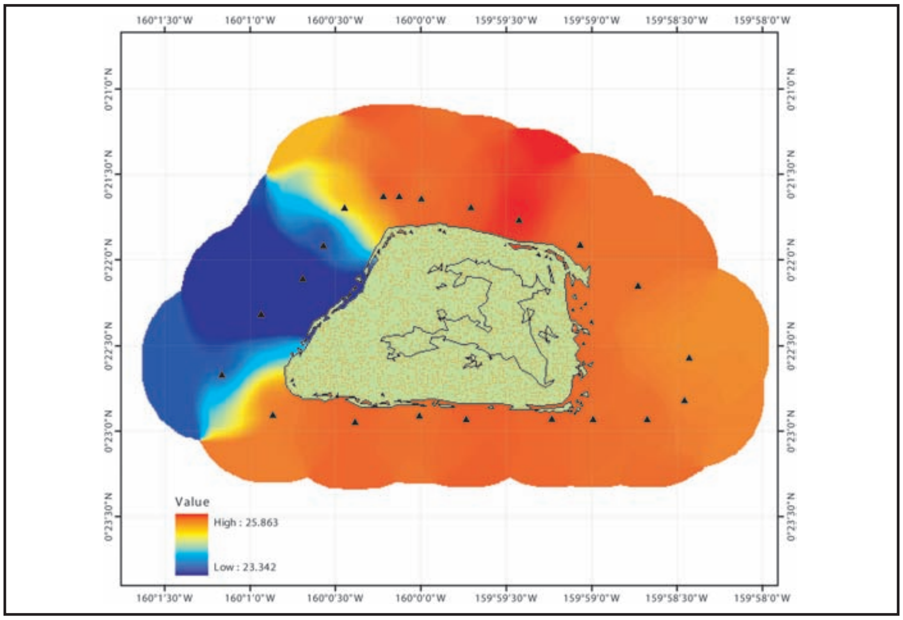


Figure 12.9. Upwelling of cooler, nutrient rich waters originating from the Equatorial Undercurrent near Jarvis Island. Upwelled waters influence fish assemblages and distributions, coral growth rates, and a number of other components of the local coral reef ecosystem. Source: Gove, 2005.

Starting in 1999, hydrographic measurements and oceanographic parameters near these island and atoll environments have been measured using shipboard acoustic Doppler current profilers (ADCP), deep and shallow water conductivity, temperature, and depth device (CTDs), and an array of instrument moorings aboard the NOAA ships *Townsend Cromwell* (1999, 2000, and 2001) and *Oscar Elton Sette* (2002 and 2004) during regular scientific cruises for the PIFSC-CRED. Based on data from these cruises, as well as other satellite derived and *in situ* data sources listed in Table 12.4, a number of physical/biological linkages have been observed:

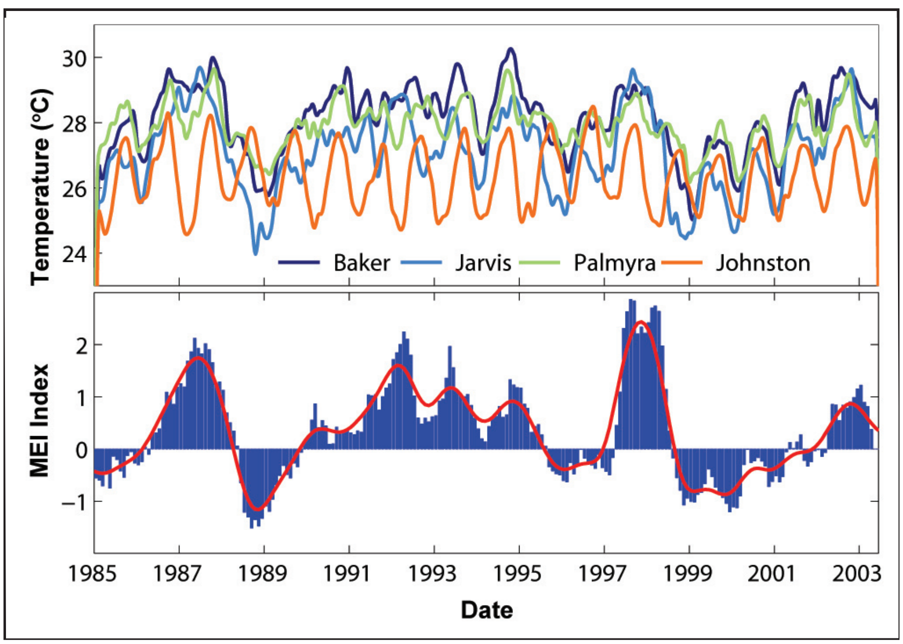


Figure 12.10. Relationship of NOAA Pathfinder derived SST with ENSO Multivariate Index (MEI) at the PRIAs of the central Pacific. Note Jarvis extreme dependence on ENSO contrasting with Johnston's annual cycle. Source: PIFSC-CRED, unpublished data.

- A link between areas of upwelling EUC water with benthic habitat composition and distribution of reef fishes, especially planktivores, at Jarvis and Baker islands;

- Extreme interannual variability of water temperatures, upwelling, and other mixing phenomena (connected with nutrient supply and primary productivity) at Jarvis and Baker and the dependence of this variability on the ENSO cycle;

- Evidence of weak but consistent upwelling along Palmyra Atoll's southern side and its connection to high biomass measured with bioacoustics; and

- Poor water circulation within Palmyra Lagoon and backreef areas and associated large diel variations in water temperature (Figure 12.11).

Continued monitoring and analysis of oceanographic conditions and ecological assessments are required to establish quantitative linkages between ecosystem health and the ever-changing physical environment.

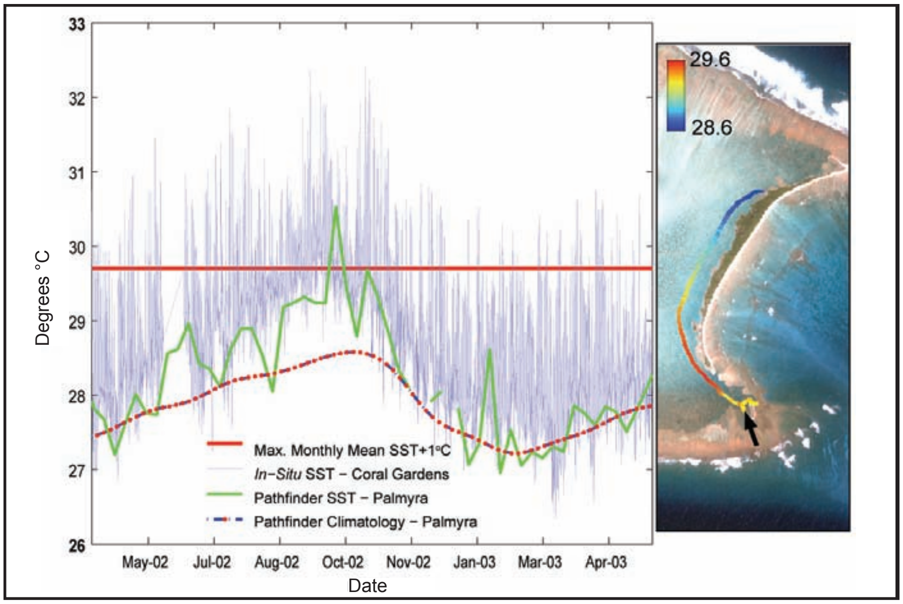


Figure 12.11. Water temperatures recorded by *in situ* STR and shallow water CTDs in a Palmyra backreef (commonly know as the Coral Gardens) as compared to pelagic, NOAA pathfinder SST. Black arrow on overview of CTD temperature track at right indicates position of the STR. Highly elevated daytime temperatures and spatial variation in water temperatures indicate poor circulation and a potentially greater risk of coral bleaching. Source: PIFSC-CRED, unpublished data.

BENTHIC HABITATS

CORALS

Several techniques have been used since 2000 by PIFSC-CRED and USFWS to assess and monitor coral biodiversity, distribution, abundance, population structure, and condition in the PRIAs including the U.S. Phoenix Islands (Howland and Baker); U.S. Line Islands (Jarvis Island, Johnston Atoll, Palmyra Atoll, and Kingman Reef); and American Samoa (Rose Atoll). These techniques include towed-diver surveys each averaging about 2 km in length, rapid ecological assessments (REA) each covering between 1,000-5,000 m^2 per site, photo-quadrat/video surveys at permanently marked 50-100 m transects, and recruitment studies at three of the islands/atolls.

Methods

Rapid Ecological Assessments

REAs are concurrently conducted by algal, coral, other invertebrate, and fish specialists along three 25 m transects (Figure 12.12). Between 2000 and 2002, 98 REA surveys at 78 sites were conducted to assess coral populations in the U.S. Phoenix and Line Islands. During these years, REA protocols focused on visually inventorying species and estimating their relative abundance in broader areas surrounding the transect lines using the DACOR (Dominant, Abundant, Common, Occasional, Rare) system. Assessment activities were initiated at Johnston Atoll in 2004, and 29 sites were resurveyed in the U.S. Phoenix and Line Islands (Table 12.4). Sites were selected so

Figure 12.12. A USFWS coral biologist and two NOAA fish biologists survey along the same transect lines at Kingman Reef. Photo: J. Kenyon.

as to initiate monitoring in locations for which previous qualitative and/or quantitative data were available. In 2004, protocols were revised to shift towards *in situ* quantitative coral population data collection. At each site, two of the three 25 m transect lines were videotaped for use in analyzing percent cover of primary benthic components and as a record of condition of the benthos. Each coral whose center fell within 1 m of the first two transect lines was identified to genus and assigned to one of seven size classes based on the estimated length (cm) of its longest diameter: <5, 6-10, 11-20, 21-40, 41-80, 81-160, and >160 cm. In addition, digital photographs were taken of coral species, including those within a broader area beyond the transect lines, to provide a more complete inventory of coral biodiversity at each site. The revised REA protocols are described in Maragos et al. (2004).

Table 12.4. Summary of coral assessment and monitoring activities conducted by PIFSC-CRED and USFWS in the PRIAs from 2000-2004. REA = rapid ecological assessment, TDS = towed-diver survey. Source: PIFSC-CRED, unpublished data.

	2000		2001		2002		2004	
LOCATION	**REA**	**TDS**	**REA**	**TDS**	**REA**	**TDS**	**REA**	**TDS**
Johnston Atoll	NA	NA	NA	NA	NA	NA	12	27
Howland Island	5	8	7	6	6	4	3	9
Baker Island	6	6	6	6	6	2	3	8
Jarvis Island	6	9	4	4	5	4	5	11
Palmyra Atoll	8	12	5	8	11	13	9	21
Kingman Reef	5	10	9	11	9	11	9	18

Towed-diver Surveys

Broad-scale assessment of the shallow-water (<30 m) benthic habitats around the U.S. Phoenix and Line Islands were conducted during 2000-2002 (110 surveys) and 2004 (67 surveys) (Table 12.4) by the PIFSC-CRED. Survey paths in 2004 attempted to replicate selected paths covered in other years to monitor for change, or to fill in gaps in areas not previously surveyed. Benthic towed-diver surveys were initiated at Johnston Atoll in 2004 (Table 12.4). During each survey, two divers maneuver separate boards equipped with a digital video or still camera and temperature and depth recorders, while being towed behind a small boat. The tow path is recorded by a global positioning system (GPS) receiver onboard the boat, and a layback model is applied to the data to more accurately map the position of the imagery. Percent cover of salient benthic categories is quantified by whole-image analysis of still frames sampled at 30-second intervals. Towed-diver surveys bridge a gap between large-scale mapping efforts using satellite data and small-scale traditional belt-transects or roving diver assessments, thereby providing a mesoscale spatial assessment of reef habitats.

Permanent Transects

At each permanent site, a 50 m surveyor's tape was laid along each transect alignment marked with stainless steel stakes installed at 5 m intervals. A 1 m^2 quadrat was laid sequentially and photographed along the entire transect at 1 m intervals for a total coverage of 50 m^2 per transect. These data will be later analyzed for the same parameters as the REA coral census data including percent coral cover, size class distribution, frequency, mean diameter, and generic diversity. More detailed information on the choice and installation of permanent transects is reported in the NWHI chapter of this report.

Recruitment Plates

In 2002, recruitment plates were attached to the base of Coral Reef Early Warning System moorings in the Palmyra Atoll and Kingman Reef (Figure 12.13) lagoons and to

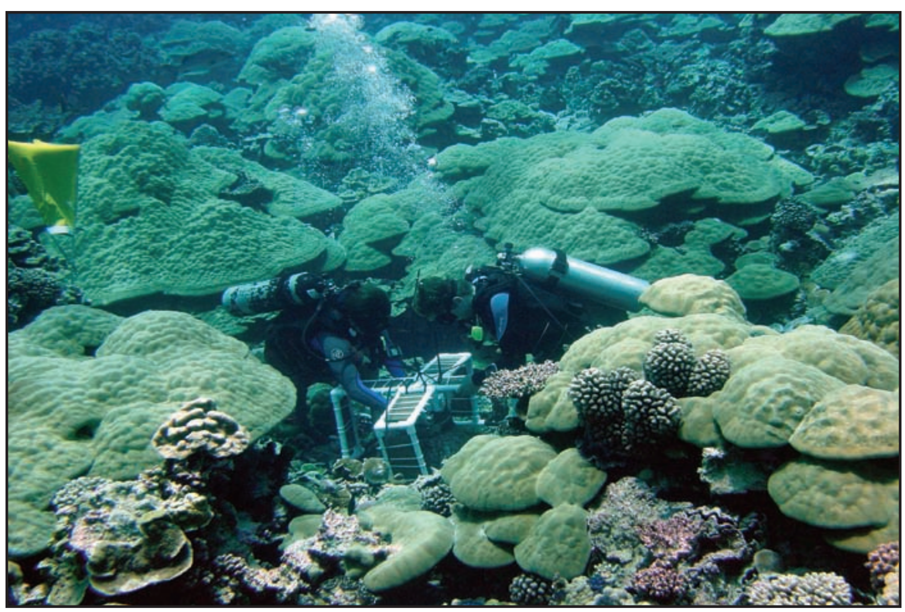


Figure 12.13. Divers install recruitment plates in the lagoon at Kingman Reef. Photo: K. Wong.

a subsurface ocean data platform at Baker Island to assess larval recruitment by calcareous organisms. Their deployment in physical association with the instrumented moorings will enable coupling of biological data with physical data collected by the instruments. Biennial collections and deployments of these plates will address levels of larval recruitment as well as spatial and temporal differences among the sampled areas.

Results and Discussion

Coral community structure from REA surveys

Following surveys conducted in 2000–2002, the coral fauna tallied for the U.S. Phoenix and Line Islands included: Baker (80 species), Howland (91 species), Jarvis Island (49 species), Palmyra Atoll (170 species), and Kingman Reef (155 species). Relative abundances of cnidarians occurring within belt-transects at sites surveyed in the U.S. Line Islands in 2004 is reflected in Table 12.5. Genera comprising more than 10% of colony abundance in each location are highlighted in bold type.

Table 12.5. Relative abundance of cnidarian colonies in the U.S. Line Islands, based on REA surveys at 23 sites conducted by PIFSC-CRED and USFWS in 2004. All cnidarian genera for which at least one colony was tallied in at least one location are listed.

	PERCENT OF CNIDARIAN FAUNA		
GENERA	JARVIS ISLAND	PALMYRA ATOLL	KINGMAN ATOLL
Acropora	0.10%	3.60%	1.10%
Alveopora	0.00%	0.00%	0.00%
Astreopora	0.00%	0.40%	0.80%
Cladiella	0.00%	0.00%	1.30%
Chryptodendrum	0.00%	0.10%	0.00%
Coscinaraea	0.10%	0.00%	0.00%
Dendronephthya	0.00%	0.40%	0.00%
Echinophyllia	0.00%	0.10%	0.40%
Favia	0.30%	5.60%	6.70%
Favites	0.90%	1.90%	1.60%
Fungia	2.70%	5.10%	**41.9%**
Gardineroseris	0.00%	0.00%	0.20%
Goniastrea	0.00%	0.20%	0.10%
Halomitra	0.00%	0.10%	0.00%
Herpolitha	0.00%	0.20%	0.40%
Heteractis/Stichodactyla	0.00%	0.10%	0.20%
Hydnophora	0.00%	2.00%	0.40%
Leptastrea	0.00%	0.20%	0.40%
Leptoseris/Pachyseris	0.80%	0.60%	0.10%
Lobophyllia/Symphyllia	0.00%	1.20%	0.10%
Merulina	0.00%	0.00%	0.10%
Millepora	1.50%	0.10%	0.00%
Montastraea	0.00%	1.00%	0.80%
Montipora	**20.0%**	4.70%	3.70%
Palythoa	0.00%	1.80%	0.10%
Pavona	9.90%	**11.0%**	1.10%
Platygyra	0.00%	1.40%	0.40%
Pocillopora	**50.4%**	**24.4%**	4.40%
Porites	1.00%	**16.9%**	**22.7%**
Psammocora	0.80%	0.40%	0.50%
Rhodactis	0.00%	0.00%	0.10%
Sandalolitha	0.00%	0.10%	0.00%
Sarcophyton	0.00%	5.90%	3.20%
Scapophyllia	0.00%	0.00%	0.10%
Sinularia/Lobophytum	9.90%	6.10%	5.80%
Stylaster/Distichopora	0.70%	0.80%	0.00%
Stylocoeniella	0.00%	0.00%	0.00%
Stylophora	0.00%	0.40%	0.10%
Tubastraea	0.80%	0.00%	0.00%
Turbinaria	0.00%	3.30%	1.40%
Total cnidarians counted	**1061**	**3684**	**5896**
Area surveyed (m^2)	**600**	**750**	**725**

Size class distributions of cnidarians for three of these locations in American Samoa are shown in Figure 12.14. Analyses of coral colony size-frequency distributions can reveal important characteristics of reef populations, and can be used as a tool to estimate the response of coral populations to the reef environment. These data will serve as a baseline to which future size class determinations at the same sites can be compared.

The total number of cnidarian corals and anemone species reported historically at the PRIAs and adjacent atolls are shown in Figure 12.15. The pattern clearly shows that coral and anemone species diversity is higher at Palmyra and Kingman, both in the path of the ECC. The ECC travels through much of the higher marine biodiversity region of the western Pacific and may be transporting larvae of additional species to the two reefs. The ECC and the two reefs may serve as important pathways and stepping stones for species dispersal to the atolls and reef islands of the central Pacific. The total number of cnidarian corals and anemone species reported at the PRIAs and adjacent atolls are shown in Figure 12.15.

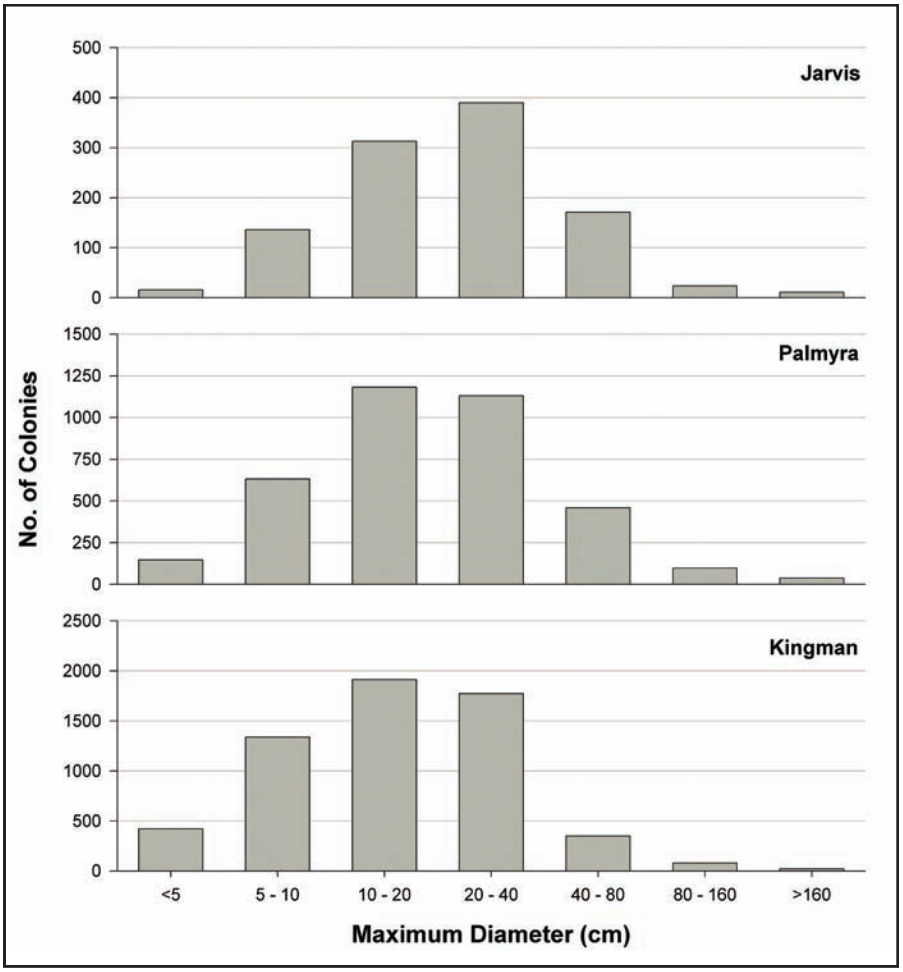


Figure 12.14. Size class distributions of cnidarians surveyed in REA belt-transects in the U.S. Line Islands during 2004. Source: PIFSC-CRED, unpublished data.

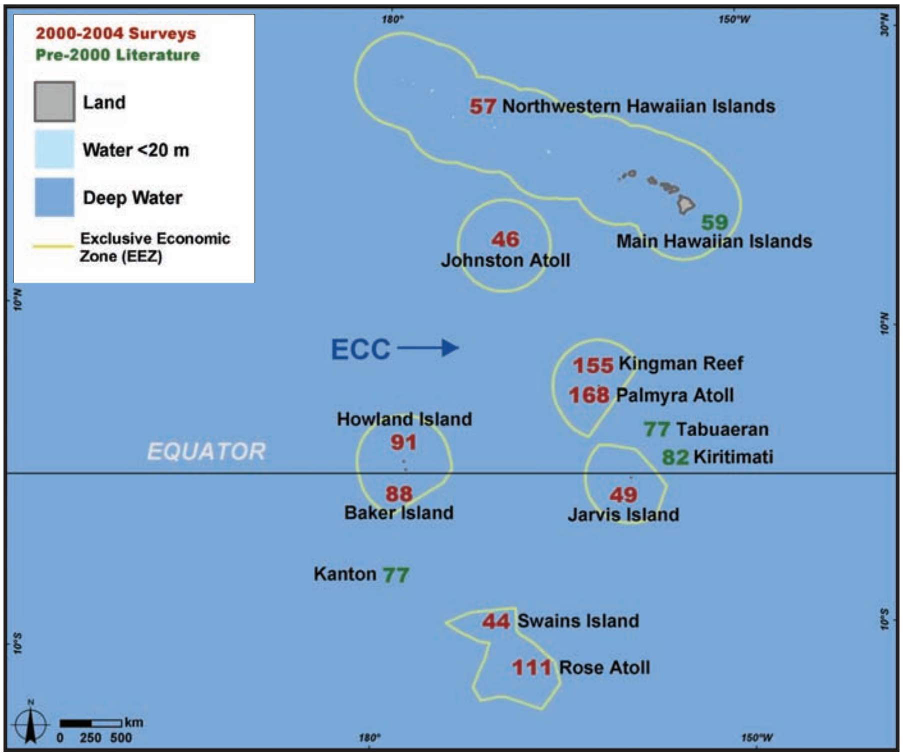


Figure 12.15. Coral and anemone species totals reported at all surveyed central Pacific reefs. Blue arrow shows the direction of the equatorial countercurrent (ECC). Sources: Maragos, 1974, 1995, 1997, 2004; Maragos and Jokiel, 1978, 1986; Maragos et al., 2003; Coles et al., 2000; J. Kenyon and S. Godwin, pers. comm.

Shift in coral community structure from 1999 to 2004

Forty permanent 50 m or 100 m transects were gradually established in the PRIAs, American Samoa, and the Marshall Islands between 1999 and 2004. These transects include nine sites each at Johnston and Rose; five sites at Palmyra; three sites each at Baker, Howland, Jarvis, Kingman, and Swains; and two sites at Ailinginae Atoll in the Republic of the Marshall Islands. Many of the older PRIA sites at Baker, Howland, Jarvis, Kingman, Johnston, Rose, and Palmyra have now been resurveyed up to three times through early 2004, providing an opportunity to track changes in coral community structure over a two to five year period at specific sites. Figure 12.16 documents the decline of *Acropora*, *Montipora,* and *Pocillopora* and the concomitant increase of *Porites* between 2000-2004.

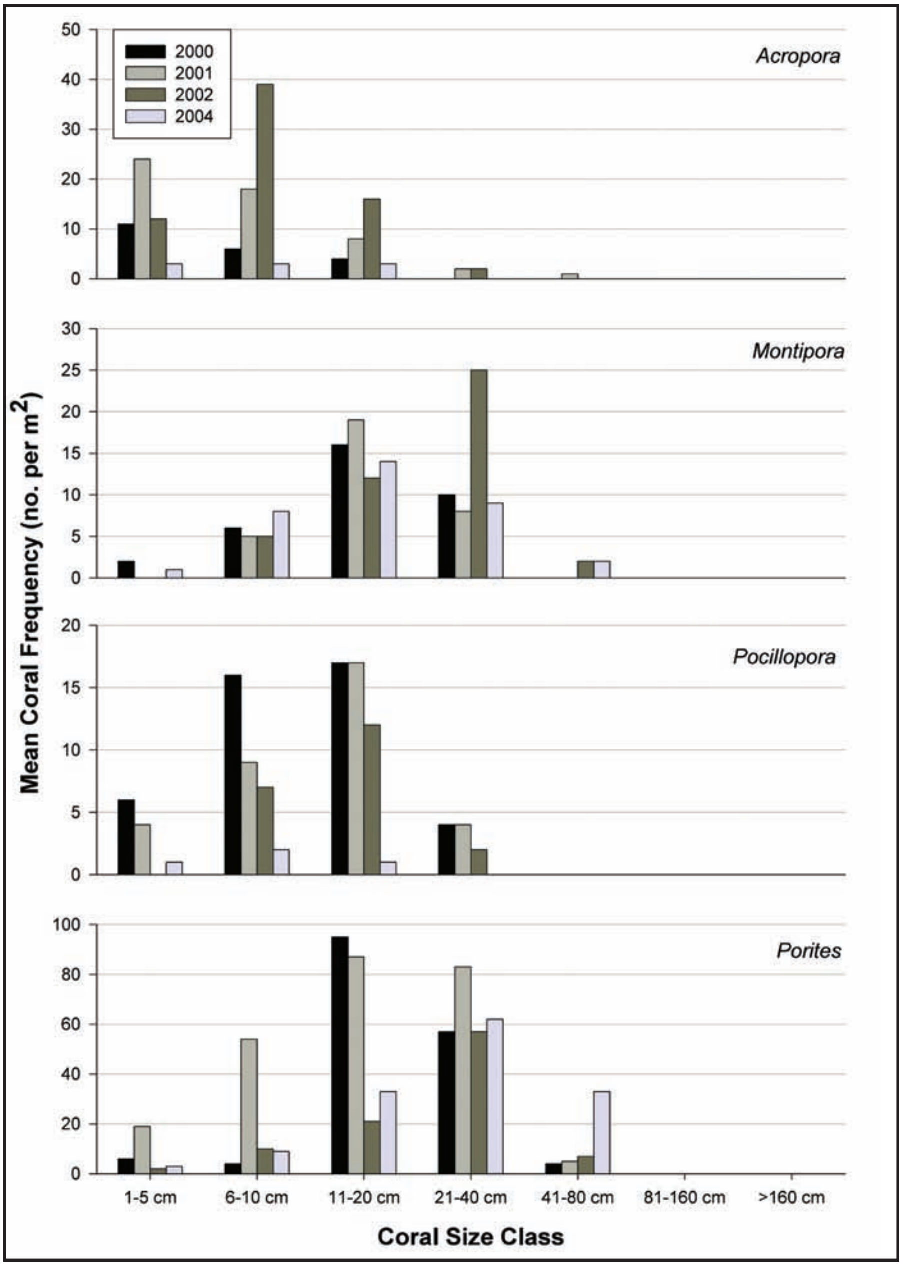


Figure 12.16. Coral size and abundance at Kingman Reef site 5P from 2000-2004. *Acropora*, *Montipora* and *Pocillopora* corals have declined, while *Porites* coral has shifted from small and numerous to large colonies. Source: Maragos and Veit, 2004.

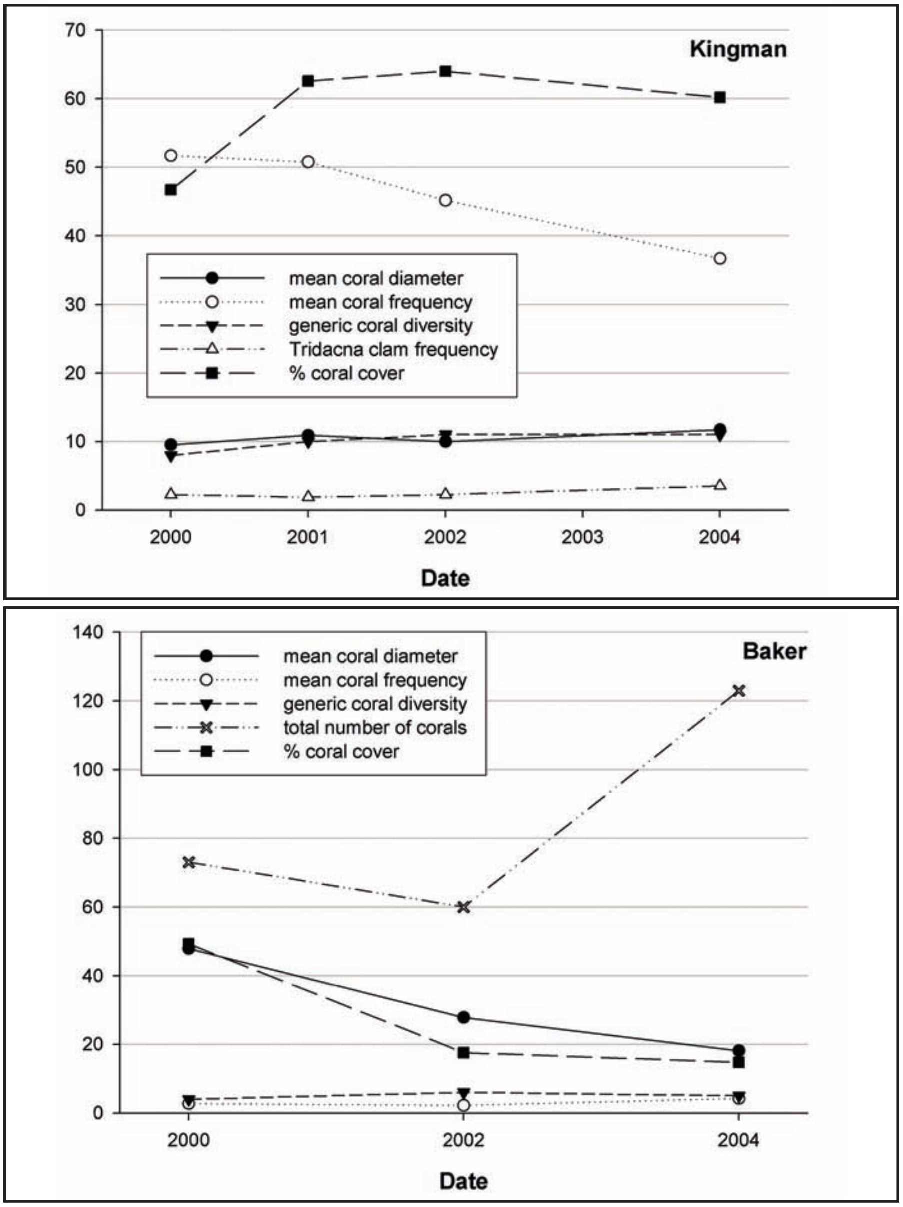


Figure 12.17. Summary of trends in mean coral diameter, mean coral frequency, generic diversity, coral percent cover, and *Tridacna* clam frequency at Kingman Reef site 5P (upper panel) and at Baker site 5P (lower panel) between 2000-2004. Source: Maragos and Veit, 2004.

Figure 12.17 provides representative examples of changes at two of the older monitoring sites, KIN-5P in the east shallow lagoon of Kingman Reef and BAK-5P at Baker Island, over the same time period. At the Kingman Reef site, the 2002 photoquadrats along the permanent transect showed numerous COTS (*Acanthaster*) feeding scars and two of the starfish actively feeding on corals. The photos and other observations show that many types of corals are potential prey for the starfish at Kingman but that incidence of predation was higher on *Pocillopora*, *Montipora* and *Acropora* than on *Porites* when all four groups are present (as was the case at site KIN-5P). The data show a gradual shift to larger more abundant *Porites* over the four years of monitoring, with COTS predation on the other coral groups likely contributing to this trend.

These examples represent the preliminary findings at just two of 40 permanent monitoring sites in the PRIAs and neighboring reefs. The findings are also consistent with those of Timmers (this report) that document the movement of COTS towards the eastern lagoon of Kingman Reef in 2002, based on towed-diver surveys at Kingman Reef, and illustrate the value of multiple strategies in assessing and monitoring coral reef life at remote sites where dive time and dive days per locale are extremely limited. Monitoring corals and conspicuous macroinvertebrates at permanently marked sites has the advantage of isolating temporal trends in a set area. Analyses of all permanent monitoring data will allow comparison to coral data collected at adjacent REA sites at each of the PRIAs and help elucidate larger-scale geographic and temporal trends for coral population dynamics in the PRIAs. The findings should help NWR managers focus on assessing and eliminating anthropogenic stressors at these vulnerable reefs.

ALGAE

Methods

Quantitative algal sampling performed by the PIFSC-CRED in the Pacific has been limited by four factors: short visits to each site (40-50 minutes/year), the inability of phycologists to work away from the "fish transects," only having one phycologist per benthic team, and the lack of expertise in the field. The techniques presented here were written by phycologists with first-hand experience from previous research missions, and give divers the ability to sample on and slightly away from the fish transect line, quickly record percent cover using photoquadrats, and sample species without the aid of trained phycologists. Advantages to these techniques include:

• One person analyzes all images for analytical consistency, which minimizes error associated with having multiple divers with varying levels of expertise subjectively determining percent cover in the field;

• Fish transects are usually laid at a constant depth. Previous phycologists have been frustrated by seeing large amounts of algae growing in shallower water a short distance away from the fish transect, and being unable to sample those areas because of sampling constraints placed on the benthic team. This method allows phycologists to move off the main transect into shallower water; and

• Specimens collected from each photoquadrat will allow for easier species determination, including analysis of epiphytes.

Because no quantitative algal sampling has ever occurred on the PRIAs before the PIFSC-CRED research expeditions, it is impossible to tell how the present state of the reefs compares to past conditions. However, the lack of obvious algal blooms or alien species on the reefs combined with high percent covers of crustose coralline algae and moderate abundance of macroalgae suggests that these reef systems are very healthy.

Results and Discussion

Historically, algal collections from the U.S. Line and Phoenix Islands were solely qualitative, intermittent, and often biased towards large, macroscopic species (Dawson et al., 1955; Dawson, 1959; Tsuda and Trono, 1968). South et al. (2001) added considerable detail to our knowledge of microscopic turf and epiphyte species of islands relatively close to the U.S. Phoenix Islands; however, the paucity of algal collections from U.S. equatorial islands undoubtedly underrepresents the true algal diversity present in these ecosystems. To ameliorate this problem, PIFSC-CRED expeditions to American Samoa over the past four years have focused on *in situ* sampling of algal diversity. Most data have not been thoroughly analyzed and are stored at the PIFSC-CRED office in Honolulu.

From an algal perspective, the US equatorial islands contain many unique habitats and are likely to contain endemic species new to science. Expeditions during 2001-2004 addressed ecologically-based algal questions for common species in the PRIAs for the first time. Additionally, quantitative baseline assessments of algal cover using a protocol devised specifically for remote tropical reef ecosystems (Preskitt et al., 2004) were conducted. Detailed photoquadrat analysis combined with voucher specimens and field notes will allow for percent cover determination of algae and invertebrates at the species level. Oceanographic monitoring studies conducted concurrently with algal sampling will aid in defining algal distributional patterns throughout the US equatorial islands. Baseline assessment data for all of the U.S. Line and Phoenix Islands are in-hand and available for future analyses.

Algal monitoring in the U.S. equatorial islands is still in its infancy. Biannual visits to established sites throughout the U.S. Line and Phoenix Islands will enable long-term data sets to be established that may reveal change over years or decades if environmental or anthropogenic changes occur. Preliminary monitoring results have helped determine the relative abundance of algal genera (Table 12.6).

Table 12.6. Algae of Johnston Atoll, Howland Island, Baker Island, Jarvis Island, Palmyra Atoll, and Kingman Atoll. Bold numbers indicate the number of photo-quadrats in which an alga occurred; italicized numbers indicate the alga's relative abundance (rank) in relation to other algae occurring in the same photo-quadrat. Standard deviation of island averages are given in parentheses. Asterisks indicate algae found during the random swim that did not occur in photo-quadrats sampled. Source: Page and Preskitt, 2004.

	JOHNSTON ATOLL AVERAGE	HOWLAND ISLAND AVERAGE	BAKER ISLAND AVERAGE	JARVIS ISLAND AVERAGE	PALMYRA ATOLL AVERAGE	KINGMAN REEF AVERAGE
GREEN ALGAE						
Avrainvillea		**8.33 (11.79)** *4.17 (0.24)*			**11.46 (14.04)** *4.68 (0.8)*	**9.26 (19.30)** *4.88 (0.99)*
Bryopsis	*		**11.11 (16.39)** *3.9 (0.36)*			*
Caulerpa	**12.50 (19.62)** *3.15 (1.30)*	**6.25 (7.98)** *5 (0)*			**3.13 (6.20)** *5 (1.41)*	**3.70 (4.39)** *4.25 (0.96)*
Codium				**1.39 (3.4)** *5*		
Dictyosphaeria	**2.77 (4.10)** *4.75 (1.26)*	**2.08 (4.17)** *5*	**5.56 (6.8)** *4 (1)*	**5.56 (8.61)** *4.75 (0.35)*	**26.04 (23.75)** *4.05 (1.03)*	**9.26 (12.11)** *5 (0.41)*
Halimeda	**10.42 (17.81)** *3.08 (0.44)*	**33.33 (19.25)** *3.21 (0.57)*	**26.39 (38.16)** *3.17 (0.58)*	**27.78 (12.55)** *3.65 (0.38)*	**70.83 (26.35)** *2.82 (0.61)*	**71.3 (28.29)** *2.72 (0.47)*
Microdictyon						**34.26 (28.7)** *4.01 (0.68)*
Neomeris					**1.04 (2.95)** *4*	**29.63 (22.86)** *4.38 (0.59)*
Valonia				**5.56 (13.61)** *3.5*	**3.13 (4.31)** *4.67 (0.58)*	**5.56 (8.33)** *4.33 (0.58)*
Ventricaria	**4.17 (9.73)** *2.67 (1.15)*					**0.93 (2.78)** *7*
RED ALGAE						
Amphiroa						
Chrysymenia	**0.69 (2.41)** *5*					
Dasya	*					
Galaxaura			**4.17 (10.21)** *4.67*		**12.5 (35.36)** *3.58*	
Haloplegma	*					
Halymenia						
Hypnea						
Jania			**1.39 (3.4)** *3*			**3.7 (8.45)** *5.83 (0.24)*
Laurencia			**16. 67 (16.67)** *3.63 (1.03)*			
Peyssonnelia			**4.17 (6.97)** *3.75 (1.77)*	**2.78 (4.3)** *3 (1.41)*	**5.21 (6.2)** *3.75 (0.96)*	**11.11 (16.67)** *3.83 (0.82)*
Wrangelia		**37.5 (19.84)** *3.73 (0.36)*				
branched coralline	**11.81 (23.42)** *2.17 (0.58)*		**5.56 (10.09)** *2.67 (0.94)*	**12.5 (23.42)** *3.32 (0.25)*	**1.04 (2.95)** *3*	**16.67 (23.94)** *3.33 (0.84)*
crustose coralline	**48.61 (29.69)** *2.25 (0.50)*	**97.92 (4.17)** *1.54 (0.32)*	**81.94 (20.01)** *1.97 (0.79)*	**91.67 (7.45)** *1.87 (0.47)*	**93.75 (9.71)** *1.7 (0.24)*	**83.33 (20.83)** *2.15 (0.35)*
BROWN ALGAE						
Dictyota	**2.27 (7.54)** 2.67 (1.89)	*	**36.11 (33.61)** *3.15 (0.6)*	**5.56 (13.61)** *4.25*	*	
Lobophora	**11.81 (20.56)** 3.08 (0.67)	**64.58 (28.36)** *2.62 (0.54)*	**66.67 (39.09)** *2.24 (0.99)*	**69.44 (25.09)** *2.86 (0.89)*		
orange crust					**65.63 (34.05)** *2.99 (0.63)*	**13.89 (18.63)** *4.02 (0.99)*
Turbinaria					*	
CYANOPHYTES	**13.19 (18.96)** *2.53 (0.98)*	**6.25 (7.98)** *3.25 (0.35)*	**23.61 (26.57)** *2.6 (0.25)*		**5.21 (8.84)** *4.33 (0.58)*	**10.19 (10.02)** *3.94 (0.14)*
TURF	**92.36 (6.61)** *1.21 (0.46)*	**93.75 (4.17)** *1.87 (0.21)*	**79.17 (15.59)** *2.18 (0.45)*	**94.44 (13.61)** *1.51 (0.34)*	**94.79 (4.31)** *2.31 (0.57)*	**97.22 (8.33)** *1.32 (0.43)*

ASSOCIATED BIOLOGICAL COMMUNITIES

Virtually all monitoring and assesement activities conducted in the PRIAs are accomplished by scientists from the USFWS and PIFSC-CRED, working in collaboration with the University of Hawaii's Joint Institute for Marine and Atmospheric Research (JIMAR). Their protocols involve various methods and are similar to methods used in many other jurisdictions across the Pacific.

FISH

Quantitative assessment and monitoring of shallow reef fish assemblages were conducted around the U.S. Pacific Islands as an integral part of PIFSC-CRED's mission to improve the scientific understanding of these fish resources. Fish are the primary sustainable living resource on Pacific coral reefs, and survey results contribute to the scientific basis essential for sound management. Related objectives include: creating a baseline to measure MPA effectiveness; monitoring size-frequency assemblages; assessing the status of target, indicator or keystone species; assessing fish community response to possible ecosystem impacts (e.g., overfishing, habitat damage, sedimentation, prey size changes); assessing species composition and diversity by area; and assessing effectiveness of temporal monitoring of managed areas.

Field surveys were conducted in 2000, 2001, 2002, and 2004 in the U.S. Line (Jarvis, Palmyra Atoll, Kingman Reef) and Phoenix (Baker, Howland) Islands, and in 2004 at Johnston Atoll (Figure 12.8). Fish data from 2000 were largely qualitative with the primary focus on site selection. An initial species inventory was a prerequisite for comprehensive assessment of reef fish assemblages in each area. Subsequent biennial monitoring surveys are planned for each geographic sub-region to document temporal variability in reef fish assemblages. Habitat types surveyed included mainly outer reef slopes around most islands, but also included lagoon patch reefs, bays, backreefs, and shallow oceanic banks where present.

Inventories and assessments of shallow reef fishes have now been completed by the PIFSC-CRED at all U.S. Pacific Islands (except Wake Island and Farallon de Mendinilla [CNMI] which are restricted areas), and monitoring has begun. Ongoing analysis of this growing database will enable species-specific numerical and biomass densities to be calculated, fish assemblage structure to be described at various spatial and temporal scales, and statistical correlations to be determined. Further analysis of PIFSC-CRED's oceanographic and biological data will aid in understanding patterns of fish distribution and abundance as well as ecosystem associations.

Methods

Several complementary, non-invasive underwater surveys were used to enumerate the diverse components of diurnally active shallow-water reef fish assemblages. Survey types included: 1) REA to document simple species presence at a station or reef/bank; 2) Belt transects to quantify relatively small-bodied and abundant fishes; 3) Stationary point counts (SPC) to quantify relatively larger (>25 cm total length [TL]) and more mobile fish species; 4) Towed-diver/video surveys (TDVS) to quantify relatively large-bodied (>50 cm TL), wide-ranging fishes over a broad-spatial scale, in conjunction with towed-diver/habitat video; and 5) Sound scattering layer echo-sounds (SSL) to identify patterns of migration in pelagic communities using sonar. Each method was replicated at sites within and/or among the various habitat types present around each island, atoll, or reef. Fish length-class was estimated for all quantified fish to provide an estimate of numerical size structure and biomass densities by taxa.

REA Protocol

A pair of diver-observers conducted an arbitrary swim at each site, recording fish presence and identifying them to the lowest recognizable taxon. This method was typically used at deeper, time-limited sites or where the current was too strong to conduct transects. The REA protocol was also used following completion of a belt-transect or SPC, dive time permitting. The REA data complement the other visual protocols to assemble more complete reef-and archipelago-specific fish species inventories at each island, atoll, or reef.

Belt Transect Protocol

A pair of scuba diver-observers conducted parallel swims along three 25 m long transect lines, recording size-class specific counts of all fishes encountered (using TL) and identifying them to the lowest possible taxon, within visually estimated belt-transects: 4 m wide for fishes ≥20 cm TL (100 m^2 area) on the initial swim-out, and 2 m wide for fishes <20 cm TL (50 m^2 area) on the subsequent swim back. Transects lines were typically set at depths of 10-15 m. Reef ledges and holes were visually searched. Stations were completed on all sides of the island/atoll/reef, weather and sea conditions permitting.

SPC Protocol

One SPC diver-observer conducted surveys in conjunction with, but at least 10 m away from, the two belt-transect divers. All fishes ≥25 cm TL that entered a 20 m diameter cylinder (area about 314 m^2) during a 5-minute period were counted and identified to the lowest possible taxon. Individuals or groups were estimated to the nearest 5 cm TL size-class bin. Four replicate, 5-minute surveys were conducted at each station. Care was taken to avoid overcounting large transient or schooling species.

TDVS Protocol

A pair of divers were towed about 60 m behind a small boat about 1 m above the bottom, at a speed of about 1.5 knots across about 2 km of coral reef habitat (during a 50-minute survey), generally at a constant isobath around the island. One diver recorded all fish ≥50 cm TL within a 10 m wide swath. The other diver quantified benthic habitat composition by type and macroinvertebrate densities. Fish were identified to lowest possible taxon and recorded in 25-50 cm TL size-class bins. Both towboards were equipped with digital cameras (video for fish and still for habitat) and temperature/depth/time recorders for more detailed future analysis. The towboat concurrently logged a GPS track position every 5 seconds. The fish diver performed a 360° scan during the first minute (plus another scan at the end of the tow), recording all large fish within visible range, and then completed 10 5-minute survey segments. Laboratory analyses of the digital videos recorded during towed-diver fish surveys are ongoing.

Results and Discussion

Preliminary results from the US Line and Phoenix Islands are presented here as full analysis of the data from these assessments is ongoing. The major effort by the PIFSC-CRED during its first few years focused primarily on field assessments.

U.S. Line and Phoenix Islands

Results of the PIFSC-CRED assessments found that numerical densities of reef fishes were high at these islands. Small fish (particularly planktivores such as *Pseudanthias*, *Lepidozygus* and *Luzonichthys*) were quite abundant at Howland, Baker, and Jarvis Islands, particularly along the west side where upwellings occurred; fewer reef fishes occurred at Palmyra and Kingman. Distributional differences between islands were also discovered for these species (e.g., basslets). Densities of large fish (e.g., sharks, jacks, grouper, snapper, parrotfish) were higher in the U.S. Line Islands than in the U.S. Phoenix Islands or NWHI (Figure 12.18). Certain species of groupers, snappers and emperors occurred only at the southern or northern islands of the U.S. Line Islands.

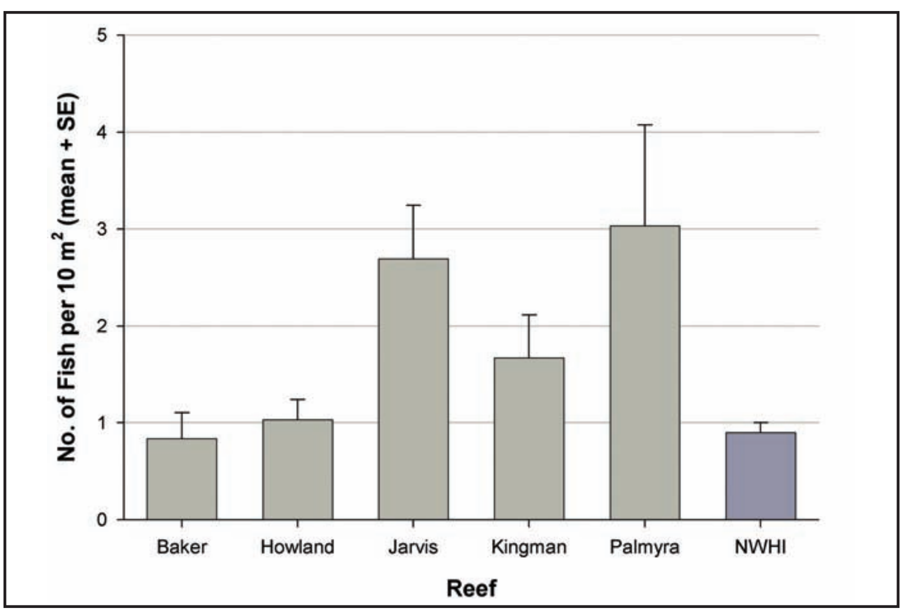


Figure 12.18. Density of large fish (>20 cm TL, all species pooled) in the U.S. Line and Phoenix Islands from belt-transects, compared to the NWHI in 2002. Source: PIFSC-CRED (R. Schroeder), unpublished data.

Biogeographic patterns indicate that the majority of these reef fishes are widespread Indo-Pacific species that occurred at all five islands. A total of 480 fish species was recorded in the U.S. Line and Phoenix Islands in 2002. Total number of species was highest at Palmyra (343), followed by Howland (302), Jarvis (252), Baker

(241), and Kingman (225). Many new records for species presence at these islands were found: over 96% at Kingman (where very few previous surveys were conducted), 78% at Baker, 72% at Jarvis, 60% at Howland, and 35% at Palmyra (where most earlier sampling focused). Inter-island differences in species patterns were also found. These islands include a significant component of south-central Pacific endemic species not found at other U.S. reefs. The U.S. Line and Phoenix Islands appear to be at the junction of two biogeographic areas, one centered in French Polynesia and a larger one centered in Micronesia. This is exemplified by the contribution of the PIFSC-CRED data to a recent revision of the surgeonfish genus *Ctenochaetus*, which demonstrated that the U.S. Phoenix Islands are the only area of co-occurrence for a western-central Pacific species and an otherwise French Polynesian species. A few fish specimens were collected (by permit) in 2002 and 2004 from each of these islands for genetic study to further clarify taxonomic relationships and to help understand dispersal patterns. A collaborative study with ecological geneticists at the University of California-Santa Cruz evaluated species differentiation in one group of Indo-Pacific fishes (the three-spot damselfish, *Dascyllus trimaculatus,* species complex) that includes the recently described gold-finned domino, *Dascyllus auripinnis,* found in the U.S. Line and Phoenix Islands. The distribution of mtDNA genotypes within the group was consistent with geographic separation but incongruent with external characteristics that define some of the nominal species, indicating that more work on the systematics of this group and likely many other central Pacific fishes is needed. The occurrence of south-central Pacific Ocean species in the U.S. Line and Phoenix Islands is unique among U.S. coral reef ecosystems and adds to the exceptional conservation value of these five islands.

Preliminary analysis of the towed-diver fish data for the U.S. Line and Phoenix Islands focused on trends within four families of carnivorous fish. Jacks (Carangidae), snappers (Lutjanidae), sharks (Carcharhinidae, Sphyrnidae), and grouper (Serranidae) were recorded in substantially higher numerical densities in the U.S. Line and Phoenix Islands than in American Samoa or in most other U.S. Pacific Islands surveyed by the PIFSC-CRED. This phenomenon of consistently high densities of top carnivores may be a result of the remoteness of the islands and oceanic conditions conducive to enhanced productivity. Within the U.S. Line and Phoenix Islands, jacks and snappers were recorded in the

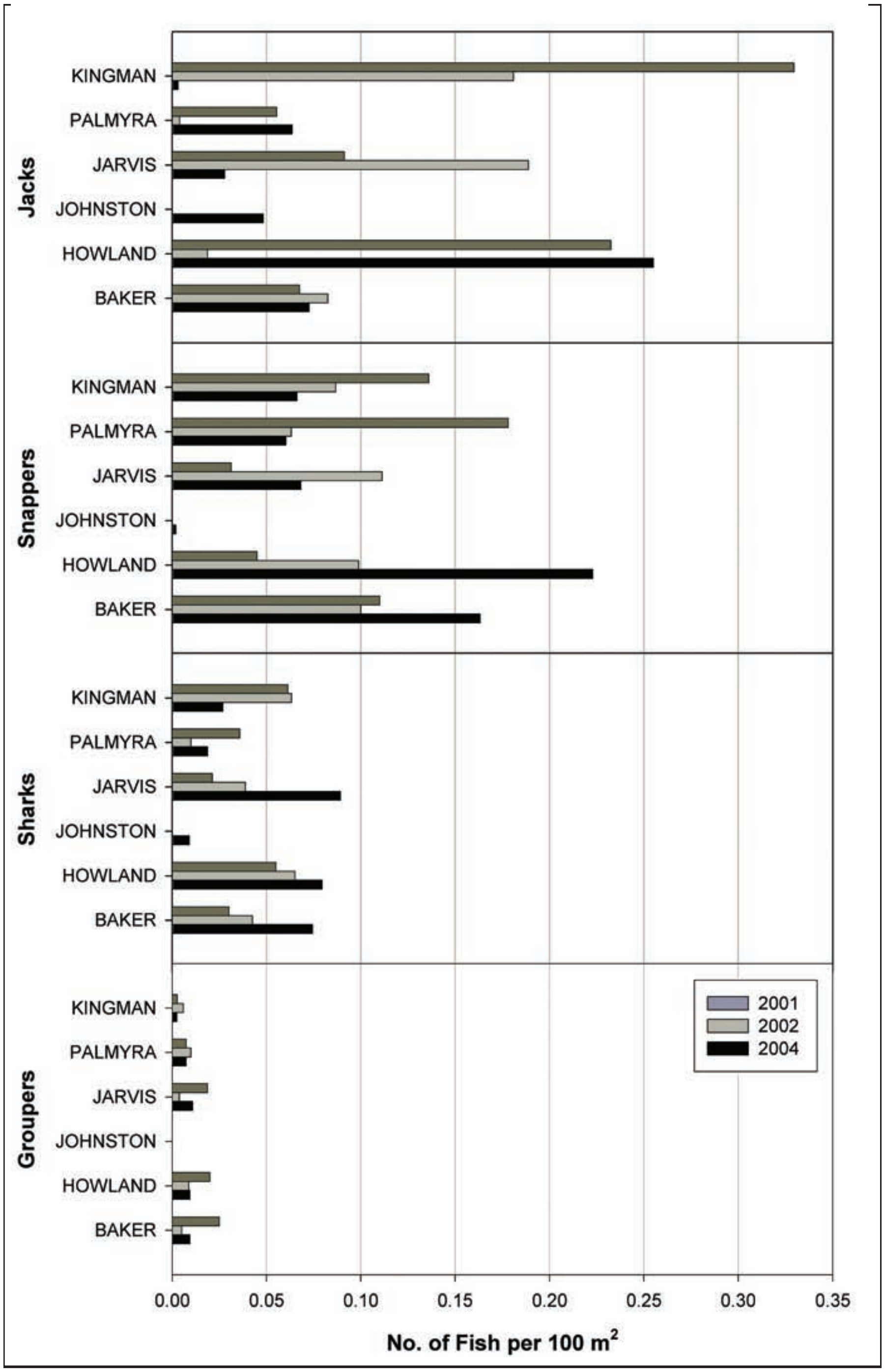


Figure 12.19. Density of common large fish (>50 cm TL, all species pooled) by family from towed-diver surveys conducted in the U.S. Line and Phoenix Islands (2001, 2002, 2004) and Johnston Atoll (2004 only). Source: PIFSC-CRED (S. Holzwarth), unpublished data.

greatest densities, followed by sharks and then groupers (Figure 12.19). When the data were grouped by island, it was evident that the abundance of large predators fluctuated considerably between years and sites (Figure 12.20). In general, large fish densities appeared to increase at Howland and Baker from 2002 to 2004, while decreasing at Kingman and, to a lesser degree, Palmyra (for three of the four families).

Howland and Baker Islands (U.S. Phoenix Islands)

Baker Island is characterized by a subsurface eastward flowing EUC that lies beneath the westward surface flowing SEC. This causes an upwelling of cooler, nutrient- and plankton-rich waters along the west side of the island, which contributes to enhanced ecosystem productivity. In 2002, the density of planktivorous fishes was higher along the west side (Figure 12.21).

Fish were resurveyed at Howland and Baker Islands from January 21-24, 2004. Observations from 11 belt-transects and SPCs (five at Howland and six at Baker) yielded the following preliminary results: 164 and 166 fish species were documented at Howland and Baker, respectively, compared to 126 and 127 species seen in 2002. Species richness averaged 118 and 117 species (median among stations) at the respective islands.

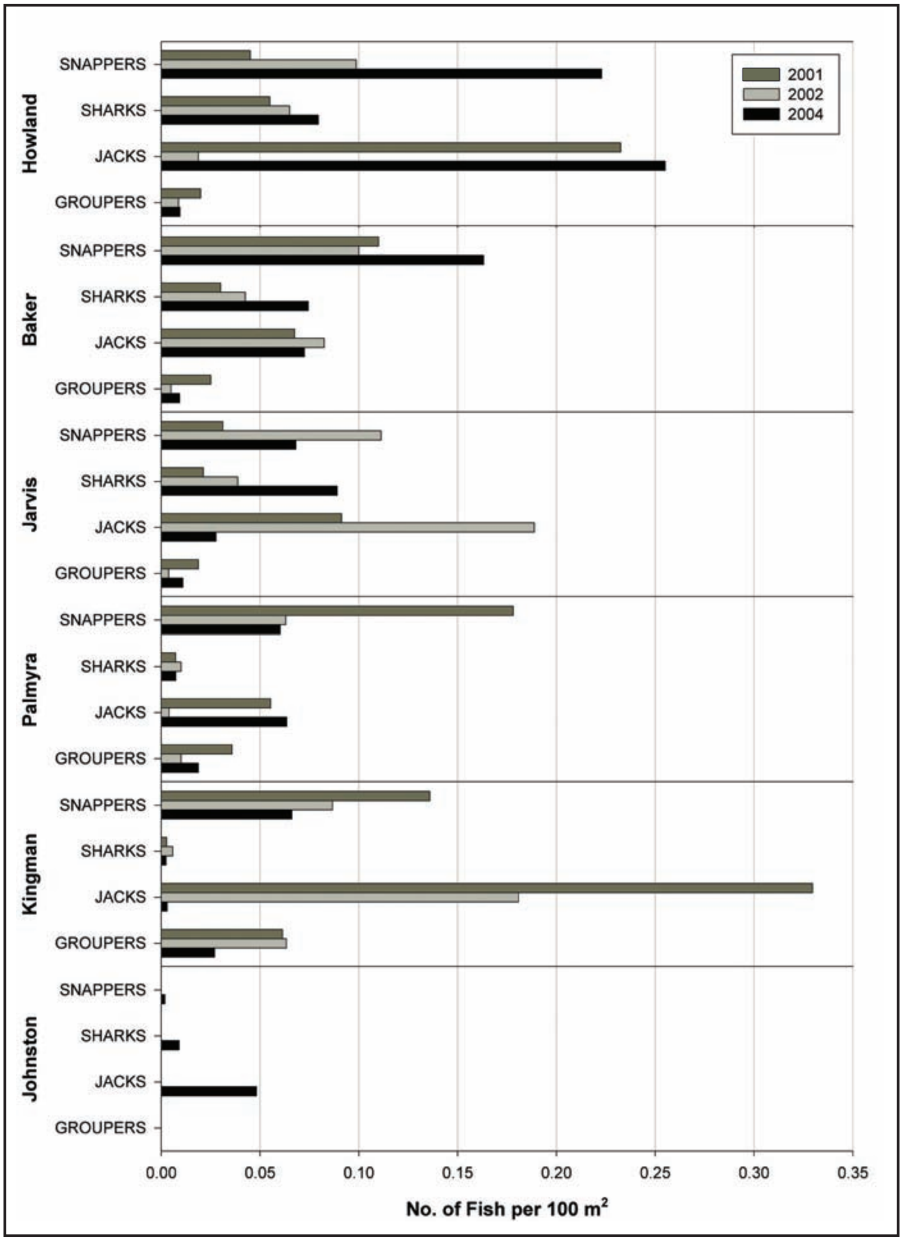


Figure 12.20. Density of common large fish (>50 cm TL, all species pooled) by family from towed-diver surveys conducted in the U.S. Line and Phoenix Islands (2001, 2002, 2004) and Johnston Atoll (2004 only). Source: PIFSC-CRED (S. Holzwarth), unpublished data.

Together with observations from other dive teams (e.g., towboard fish team), a grand total of about 210 fish species were recorded at Howland and Baker. Both numerical and biomass densities of resident reef fish species remained high (as observed on the 2001 and 2002 surveys). A trophically diverse fish fauna, representative of healthy coral reef ecosystems, contributed to the high biomass. The body size distributions of fishes spanned a broad range of sizes, further indicative of a healthy fish assemblage. Three species of small-bodied (<10 cm TL) zooplanktivores were numerically dominant, including two species of anthiine basslets (*Pseudanthias bartlettorum* and *Luzonichthys whitleyi)*, and the basslet-like damselfish, *Lepidozygus tapeinosoma*. Major contributors to biomass included numerous medium-sized (10-20 cm TL) benthic fishes (both herbivorous surgeonfishes and parrotfishes as well as benthivorous carnivores) and diverse, large-bodied (generally 25-60 cm TL) piscivores. In terms of biomass, the mid-water piscivore community near the reef was dominated by twinspot snapper (*Lutjanus bohar*), grey reef sharks (*Carcharhinus amblyrhynchos*), reef whitetip sharks (*Triaenodon obesus*), and several carangids (primarily the black jack [*Caranx lugubris*], rainbow runner [*Elegatis bipinnulatus*], and bluefin trevally [*C. melampygus*]). A half dozen species of grouper (primarily the peacock grouper [*Cephalopholis argus*], blacktip grouper [*Epinephelus fasciatus*], coral hind [*C. miniata*], flagtail grouper [*C. urodeta*], and slenderspine grouper [*Gracilla albomarginata]*), also contributed to fish biomass near reefs.

The density of groupers at both Howland and Baker Islands appeared substantially higher than at sites in American Samoa and CNMI, particularly where substantial fishing occurs (e.g., Tutuila, Guam, Saipan). In 2002, two- to four-fold differences were found between Howland and Baker Islands in terms of mean densities of epinepheline groupers and pygmy angelfishes.

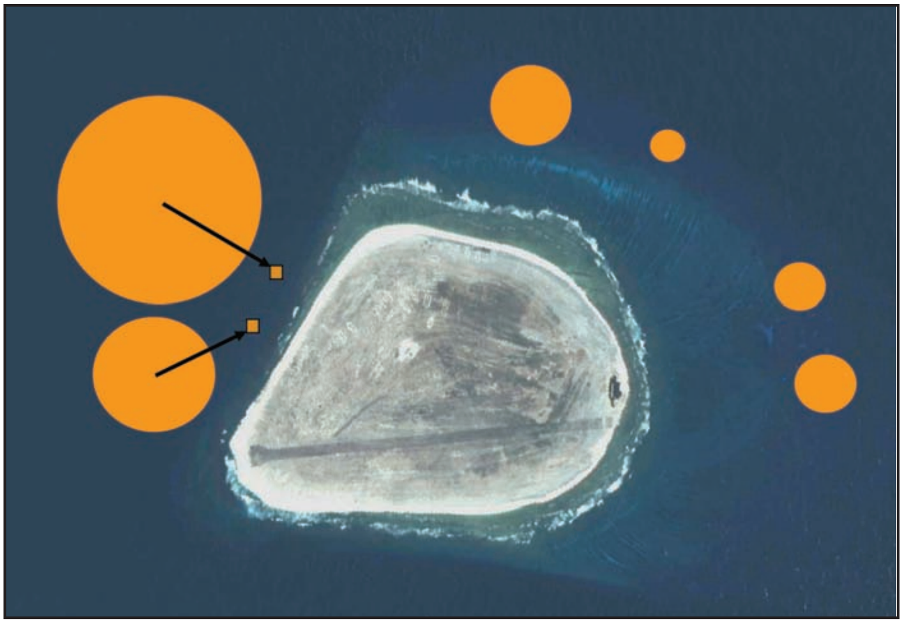


Figure 12.21. Relative distribution of planktivorous fishes from belt-transect surveys around Baker Island (2002), indicating higher densities along the western upwelling side (size of circle proportional to density of planktivores at that station; mean 8-161 fish/100 m^2). Source: PIFSC-CRED (R. Schroeder), unpublished data.

Quantitative surveys of large fish were completed by towed-divers in 2001, 2002, and 2004 at the U.S. Phoenix Islands. Snapper and shark numerical densities appeared to increase in 2004 at Howland and Baker Islands, while decreasing at most of the U.S. Line Islands. This could reflect differences in illegal fishing pressure (e.g., undocumented shark fining), or simply natural population fluctuations. The majority of sharks observed were gray reef sharks (*Carcharhinus amblyrhynchos*), but there were also galapagos sharks (*C. galapagensis*), blacktip and whitetip reef sharks (*C. melanopterus* and *Triaenodon obesus*), and hammerhead sharks (Family *Sphyrnidae*). Twinspot snapper (*Lutjanus bohar*) were very abundant at both islands. Bigeye jacks (*Caranx sexfasciatus*) were found in large schools at Howland, and black jacks (*C. lugubris*) were very common at both islands. In 2004, the towed-diver fish team saw one large humphead wrasse (*Chelinus undulatus*) at Howland and three in deep water at Baker, while none were encountered by the fish REA team. Overall, large fish remained abundant at the U.S. Phoenix Islands (Figures 12.19 and 12.20).

Jarvis Island (U.S. Line Islands)

Fish were surveyed at Jarvis Island from March 26-27, 2004. Preliminary observations from six belt-transects and six SPCs, all re-surveys of sites established by the PIFSC-CRED in February of 2001 or 2002, indicated that stock abundances appeared relatively unchanged from the high levels recorded in previous years, including a significant apex predator presence. The total number of coral reef fish species documented at Jarvis by PIFSC-RED was 148 in 2002 and 171 (from 34 families) in 2004. Planktivores remained abundant, especially along the west side; in 2004 they were also found to be abundant on the southeast reef terrace in 2004. Jarvis, like Howland and Baker, is in line with the EUC, resulting in enhanced upwelling and productivity on the west side of the island. The density of large fish remained high at all sites. Sharks, mostly gray reef (*Carcharinus amblyrhynchos*) and white tips (*Triaenodon obesus*), were common (typically >10 individuals from 130-180 cm TL per site), but seemed to be slightly less common along the west side than in earlier years. Groupers were very abundant at all sites surveyed in 2004. The most common species were flagtail grouper (*Cephalopholis urodeta*), coral hind (*C. miniata*), and peacock grouper (*C. argus*). Lyretail grouper (*Variola louti*) were also somewhat common and quite large (>50 cm TL). Jacks were common at all sites, including the black jack (*Caranx lugubris*) and the bluefin trevally (*C. melampygus*). Snappers were rare at Jarvis, except for the twinspot snapper (*Lutjanus bohar*); some individuals were >70 cm TL. Only six species of parrotfish were observed; most common were the bridled parrotfish (*Scarus frenatus*), redlip parrot (*S. rubroviolaceus*), and Pacific steephead parrot (*Chlororus microrhinos*), some of which exceeded 60 cm TL. Density of surgeonfishes was relatively low and primarily represented by whitecheek surgeonfish (*Acanthurus nigricans*) and spotted bristletooth (*Ctenochaetus marginatus*).

Towed-diver fish data from Jarvis Island suggest that densities of jacks were lower in 2004 compared to previous years, groupers and snappers were of similar range, and sharks were higher (Figure 12.19). Sharks were represented by gray reefs (*Carcharhinus amblyrhnchos*), blacktips (*C. melanopterus*), and whitetips (*Triaenodon obesus*). In addition, a school of 15 large (400-500 cm TL) great hammerhead sharks (*Sphyrna mokarran*) were encountered in deep water on the edge of the southeast terrace. A relatively high number of manta rays and a single whale shark (*Rhincodon typus*) were also seen in this area of the reef. Turtles were also abundant, with over 60 recorded during tow surveys in 2004. With the exception of jacks, large fish remained abundant at Jarvis in 2004.

Palmyra Atoll (U.S. Line Islands)
Fish were surveyed around Palmyra Atoll from March 29 to April 1, 2004. No surveys were conducted in the heavily dredged, sediment-laden lagoon. Preliminary observations from 10 belt-transects and 10 SPCs, all re-surveys of sites established by PIFSC-CRED in February of 2001 or 2002, indicate that stock abundances appeared relatively unchanged from the high levels recorded in previous years. The total number of coral reef fish species documented at Palmyra by PIFSC-CRED was 193 in 2002 and 209 (from 34 families) in 2004. Large fish were common but not as abundant as at Jarvis. Sharks (mostly blacktip, followed by gray reef and white tip) were small (130-160 cm TL), and occasionally seen, but seemed to be slightly less common than two years earlier. About 16 species of grouper were seen at Palmyra, with most common being the peacock grouper (*Cephalopholis argus*; 15-35 cm TL) which were present at every site. The flagtail grouper (*C. urodeta*) and the camouflage grouper (*Epinephelus polyphekadion*) were somewhat less common. Jacks were common at all sites, including large giant trevally (*Caranx ignobilis*; about 100 cm TL), bluefin trevally (*C. melampygus*), and black jacks (*C. lugubris*). Snappers were very common at Palmyra, with the twinspot snapper (*Lutjanus bohar*), humpback snapper (*L. gibbus*), smalltooth jobfish (*Aphareus furca*), and onespot snapper (*L. monostigma*) observed at every survey site. Most twinspot snapper ranged from 30-40 cm TL, smaller than those seen at Jarvis Island. Humpback snappers were observed in loose aggregations of up to 50 individuals.

Preliminary results from towed-diver fish surveys indicated differences in mean counts (numerical density) between fish families and years (Figure 12.20). Snappers were most abundant in 2001. Densities of jacks were least abundant in 2002. Shark abundance was fairly consistent between years, although a predominance of juvenile gray reef sharks (85% were less than 150 cm TL) may be indicative of fishing pressure. Most reef whitetip and blacktip sharks appeared to be mature size. Pooled grouper species at Palmyra varied in number among the three surveyed years. Most of the grouper >50 cm TL recorded were lyretail grouper (*Variola louti*), but relatively large individuals of the genera *Epinephalus* and *Cephalopholis* were also counted.

Kingman Reef (U.S. Line Islands)
Fish were surveyed at Kingman Reef from April 2-4, 2004. Preliminary observations from nine belt-transects and nine SPCs, all re-surveys of sites established by PIFSC-CRED in February of 2001 or 2002, indicate that stock abundances appeared relatively unchanged from the high levels recorded in previous years. However, overall fish density for both small and large fish appeared to be lower than in previous years, with the possible exception of fish assemblages along the outer reef slopes. The total number of coral reef fish species documented at Kingman was 165 in 2002 and 187 (from 35 families) in 2004. Sharks were less abundant and smaller at Kingman than at either Jarvis or Palmyra. An average of only one or two sharks was seen at most sites (none at some sites), compared to approximately 12 sharks observed on a typical dive in 2002. The same three shark species–reef whitetip (most common), blacktip, and grey reef–were most abundant. Groupers were not as abundant at Kingman compared to Palmyra or Jarvis. The peacock grouper (*C. argus*) was most common, observed at every survey site. Also relatively common were the flagtail grouper (*Cephalopholis urodeta*) and the camouflage grouper (*Epinephelus polyphekadion*). Six species of jacks were observed at Kingman but were generally less abundant than at Palmyra or Jarvis. Most common were bluefin trevally (*Caranx melampygus*) and black jacks (*C. lugubris*). The twinspot snapper (*Lutjanus bohar*), observed at every survey site, was the only common large snapper at Kingman, although most were smaller than those observed at Palmyra or Jarvis. Humpback snapper (*L. gibbus*) and smalltooth jobfish (*Aphareus furca*) were present in lesser numbers. No maori wrasse (*Cheilinus undulatus*) or bumphead parrotfish (*Bolbometopon muricatum*) were observed by any dive team, consistent with previous years. Like Palmyra and Jarvis, Kingman is a NWR and levels of historical or recent fishing are unknown. There are, however, occasional unconfirmed

reports of fishing, especially at Kingman and Palmyra. The lower densities of sharks and large fish found in 2004, compared to earlier survey years, may suggest possible recent poaching activity. The USFWS may need to increase its enforcement presence at Kingman.

Preliminary results of the 2004 towed-diver fish surveys suggest that snapper, shark, jack and grouper densities all declined at Kingman, compared to previous years (Figure 12.20). No large schools of bigeye jacks (*Caranx sexfasciatus*) were seen, as in previous years, and black jacks (*Caranx lugubris*) were mostly smaller than 50 cm TL. Gray reef sharks were rare in 2004, however reef whitetip density increased. Parrotfish, especially steephead parrots (*Chlorurus microrhinos*), were more abundant in 2004 than in past years. Milkfish (*Chanos chanos*) were also more common in 2004. The large fish data from towed-diver surveys suggest a shift or disturbance may have taken place at Kingman Reef between 2002 and 2004. The PIFSC-CRED biennial monitoring surveys planned for the U.S. Line Islands will document long-term (e.g., annual to decadal) trends in large fish densities and, together with comprehensive PIFSC-CRED data on the coral reef ecosystem, should help reveal causative factors.

Johnston Atoll (U.S. Line Islands)

Fish were surveyed at Johnston Atoll for the first time by the PIFSC-CRED from January 12-16, 2004. Preliminary observations from belt-transects and SPCs at each of 12 stations indicate that reef fish diversity was low; many abundant Hawaiian species, including endemics, were either absent or rare, and several widely distributed Indo-Pacific species (abundant in Hawaii, the closest neighbor islands) were conspicuously absent (e.g., bigeye emperor, *Monotaxis grandoculis*; bluespine unicornfish, *Naso unicornis*). Overall, numerical densities of reef resident species appeared low, possibly due to the general scarcity of juvenile fishes. Standing biomass also appeared relatively low, mostly due to few large-bodied species. Carangids like the bluefin trevally (*Caranx melampygus*) were infrequently observed and often small in size; no giant trevally (*C. ignobilis*) were encountered. Grey reef sharks (*Carcharhinus amblyrhynchos*) appeared to be in robust body condition but uncommonly observed. The observed scarcity of both jacks and reef sharks likely reflects the location of survey sites within lagoons. Due to a large northwest storm swell, surveys were restricted to within the atoll (11 were conducted in the lagoon and one on the backreef). Conclusions are therefore limited because of the near or total lack of data for backreef and forereef habitats, respectively. It is very possible that the dearth of juvenile life-stages, including older young-of-year-sized fish, is a reflection of the infrequent, low-intensity recruitments that occur at a very isolated atoll inhabited by substantively self-seeding reef fish populations.

At Johnston Atoll, towed-divers completed 26 surveys during the initial baseline assessment in 2004. During the survey period there was a large northwest swell that complicated the surveying the exposed fore-reef and generated sub-optimal survey conditions with decreased visibility. Although the large swell hampered diving operations in general, the tow team was able to tow over a variety of habitats throughout the atoll, covering areas that were inaccessible to the other dive teams. Fish assemblages at Johnston are more similar to Hawaii than to the U.S. Line and Phoenix Islands. Johnston had almost no shallow-water large groupers or large snappers (Figure 12.20). Jack and shark densities appeared low at Johnston compared to other islands, due in part to the difficult survey conditions encountered there in 2004. The shallow backreef and submerged terrace, areas with fewer large fish, received comparatively more of the survey time than the forereef, because of safety considerations. The tow team was able to dive on the forereef, but not extensively, and this is where most jacks and sharks were seen. Solitary large jacks were mostly bluefin trevally (*Caranx melampygus*) and a school of about 200 bigeye jacks (*C. sexfasciatus*) were recorded. In addition to a number of small to medium-sized sharks, several very large Galapagos sharks (*Carcharhinus galapagensis*) and gray reefs (*C. amblyrhychos*) were seen, as well as a 2.5 m tiger shark (*Galeocerdo cuvier*).

SSL Protocol

Methods

SSLs are comprised of pelagic communities of small fish, shrimp, and squid that occur in waters deeper than 300 m during the day and rise into the photic zone at night. SSLs are common in pelagic waters and along coastlines, where they form the mesopelagic boundary community. In Hawaii, boundary community SSLs are thought to play an important role in the coastal ecosystem as a major link between zooplankton and higher trophic levels. The observed horizontal migration towards shore at night of the Hawaiian community also suggests SSLs may play a significant role in the coral reef ecosystem through input of biomass and nutrient cycling. Little is known about the character of boundary community SSLs associated with islands outside of the main Hawaiian Archipelago. To improve our understanding of these communities, island-associated SSLs were investigated using ship-based echo-sounders during a PIFSC-CRED cruise to Jarvis Island, Palmyra Atoll, and Kingman Reef in 2004.

Results and Discussion

Jarvis Island

Echo-sounder surveys were conducted along the southern and western shores of Jarvis Island during afternoon and night/morning hours on March 26 and 27, 2004. Survey lines were run approximately 400-600 m from shore in waters 300-600 m deep. Each line was conducted at approximately 00:00, 02:30, 05:00, and 14:00 hours.

The surveys revealed a clear diurnal trend in the occurrence of a layer of surface-associated biomass. At night, the layer is generally concentrated in the top 130 m, just above the thermocline and centered on the chlorophyll maximum observed during CTD casts (Figure 12.22). The layer's nighttime density was more or less constant along both transect lines. During the day, the layer was absent from the southern transect, but was very dense towards the northern end of the western transect. Because trawling for samples was not feasible during this cruise, the biological composition of the layer is presently unknown.

Palmyra Atoll

Echo-sounder surveys were conducted along six transect lines around Palmyra Atoll between March 30 and April 1, 2004. Transect line lengths ranged from 4 to 9 km. Two lines were run along the edge and on the southwestern bank of the atoll, one along the southern shore, one along the edge of the southeastern bank, one along the northeastern edge of the bank, and one along the northern shore. All but the northern and northeastern transects were run multiple times during the same and/or successive nights, as well as during the day.

The data revealed that a dense SSL exists around the entire perimeter of the atoll at night. This community resides primarily along the atoll's steep slopes at a depth 120-180 m and is centered on the thermocline (Figure 12.23). A secondary, less dense layer of organisms occurs above the thermocline in patches. Opportunistic observations made during transits perpendicular to the atoll's edges indicate that both layers extend well offshore (4-6 km) along the southwestern side of the atoll, but that they are restricted to less than 2

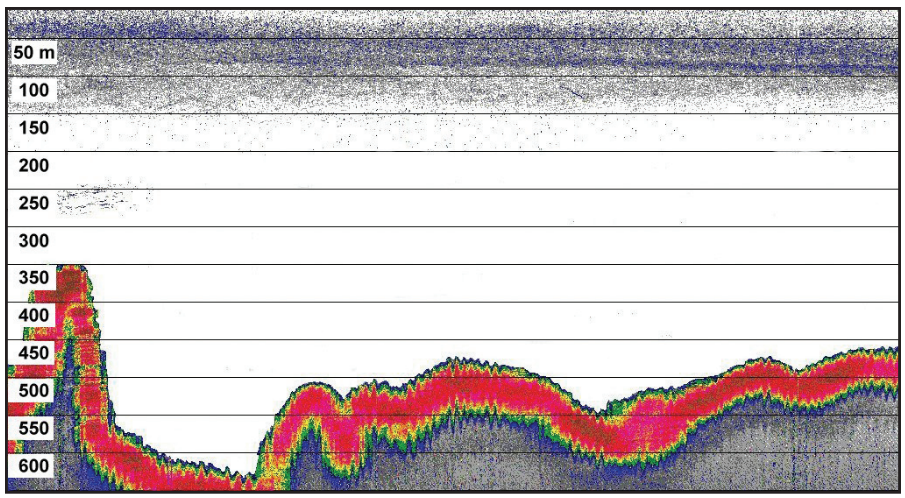


Figure 12.22. Echogram of the SSL at Jarvis Island. Depth is plotted on the y-axis, horizontal distance on the x-axis (2.6 km). Red regions represent the bottom. Source: M. Lammers, unpublished data.

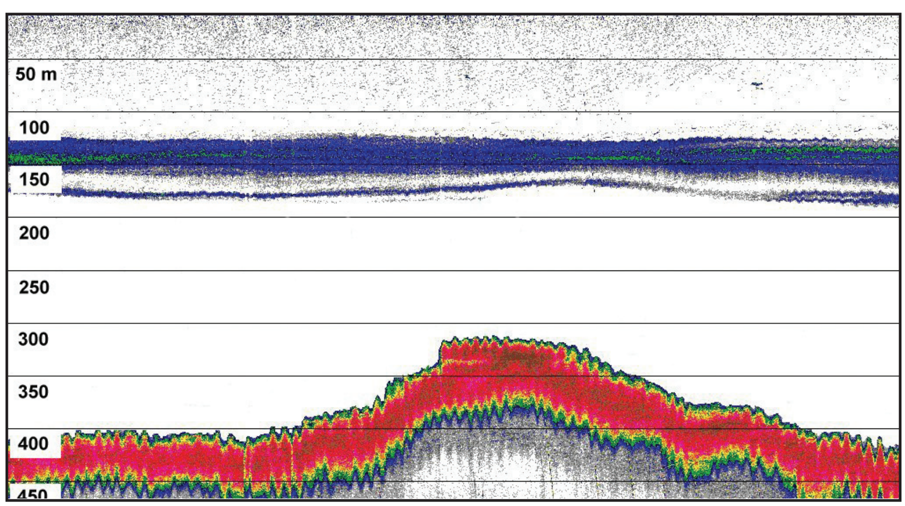


Figure 12.23. Echogram of the SSL at Palmyra Atoll. Depth is plotted on the y-axis, horizontal distance on the x-axis (2.6 km). Red regions represent the bottom. Source: M. Lammers, unpublished data.

km offshore along the other sides. A tentative explanation for this observation is that the southwestern side is enriched by nutrients flowing out of the lagoon. The main channel into the lagoon lies on the southwest corner and the prevailing tradewinds blow from the northeast, probably creating a net movement of water towards the southwest. Coincidentally, several observations of melon headed whales (*Peponocephala electra*) were made along this side of the atoll. This species is known to feed primarily on squid.

Kingman Reef
Echo-sounder surveys were conducted along four transect lines along the southern and eastern sides of the atoll between April 2-4, 2004. Two transect lines were run parallel to the atoll's slopes and two were perpendicular. The two parallel transects were conducted at 18:00, 21:00, 0:00, and once towards the middle of the day. The perpendicular transects were run at 19:00 and at 01:00. Echo-sounder data were also collected opportunistically on one occasion while transiting along the southwestern corner of the atoll.

An assessment of the data collected indicates that a SSL is conspicuously missing along most parts of the eastern and southern sides of the atoll. Both night and daytime transects revealed only dispersed patches of mid-water organisms. These patches were very localized and ranged in depth between 80 m and 130 m. The most prominent patch was observed along the southwestern corner of the atoll. This again coincided with the primary channel into and out of the atoll, similiar to that seen at Palmyra.

The echo-sounder data collected at the three sites reveal that each location is quite distinct in the density and distribution of the mid-water biomass occurring there. Jarvis and Palmyra appear to be much more productive than Kingman. Furthermore, Palmyra supports a dense, thermocline-associated community that was not observed at either Jarvis or Kingman.

It is interesting to note that three locations are quite distinct oceanographically and ecologically. Jarvis Island is the top of a steep pinnacle rising from the ocean floor. It is located almost at the equator and is fed by upwelling from the EUC and is also a major seabird colony. Nutrient inputs from these two sources probably contribute to the mid-water productivity observed there. Palmyra, on the other hand, is a forested network of islets that also supports a significant seabird population. Nitrogenous and organic outflows from the terrestrial ecosystem are likely a contributing factor behind the productivity observed there, particularly along the southwestern side where the lagoon's waters flow out. Finally, Kingman Reef is influenced by neither the EUC nor any terrestrial-based ecosystem. A minimal or reduced influx of nutrients at Kingman may explain the lack of a well-defined SSL there.

MARINE MAMMALS
Very little is presently known about the marine mammal populations in the U.S. PRIAs. Although no systematic marine mammal surveys have ever been conducted in these areas, recent visits during the PIFSC-CRED operations revealed that all sites visited do have cetacean populations associated with local island or atoll ecosystems. Of the odontocetes encountered, bottlenose dolphins (*Tursiops truncatus*) were by far the most common species sighted. Populations of 50 to 100 or more animals occur at Johnston, Howland, Baker, Jarvis, Palmyra and Kingman. Repeated sightings made during consecutive days suggest that these populations are resident. Palmyra also supports a population of melon-headed whales (*Peponocephala electra*). These were seen on successive days over a three-day period and were consistently located near the southwest side of the atoll. Anecdotal accounts from USFWS staff familiar with Palmyra (J. Maragos, pers. obs.) report having seen both *T. truncatus* and *P. electra* on past visits. Similarly, USFWS staff familiar with Jarvis Island (M. Rauzon, pers. comm.) report having seen *T. truncatus* and sperm whales (*Physeter macrocephalus*) there previously.

Although not directly observed, beaked whales may also be present at some PRIA sites. A skeleton tentatively identified as Cuvier's beaked whale (*Ziphius cavirostris*) was found at Kingman Reef. In addition, the oceanographic and bathymetric conditions (upwelling, deep waters) found at Jarvis are characteristic of habitat known to be exploited by beaked whales.

Mysticetes were reported only for one location visited by the PIFSC-CRED cruises. Humpback whales (*Megaptera novaeagliae*) were observed at Johnston Atoll. This finding is rather significant as there are no modern records of this endangered species there. According to observer accounts, all social roles typically found on winter mating grounds are present at Johnston, including mothers and calves with male escorts, competitive groups, and singers. It is speculative, but Johnston Atoll may represent a relatively newly established or re-established mating ground of the north Pacific humpback whale population.

The role that marine mammals play in the ecosystems of PRIA sites is presently not well understood. The high metabolic needs characteristic of mammals suggest that their role is probably not trivial. Recent modeling work on the impacts of great whales (including sperm whales) on global primary productivity has revealed that up to 62% of the ocean's primary production may have gone to sustaining whales during pre-whaling times (D. Croll, unpublished data). Although similar estimates are not presently available for smaller cetaceans, this does suggest that a more detailed assessment of the composition and abundance of marine mammals in the PRIAs is warranted.

MARINE INVERTEBRATES OTHER THAN CORALS

Historically, biodiversity assessments and monitoring programs for coral reefs have focused on cnidarians and fish, so less information is available for other invertebrates. However, the sponge, mollusk, echinoderm, crustacean, annelid, bryozoan, and tunicate fauna associated with coral reefs are also integral components to the overall biodiversity.

Most data collection efforts in the PRIAs have focused on fish, ciguatera, algae, and corals, but some information on non-coral invertebrates is available from baseline faunal surveys conducted in the mid-1960s (Brock et al., 1966; Amerson and Shelton, 1976). A presentation of the species richness of non-coral invertebrates for the PRIAs will be a compilation of studies conducted since the early 1900s and collections held at the Bishop Museum. The information reported here will only provide data for porifera, hydroids (Cnidaria; Order Hydroida), anemones (Cnidaria; Order Actiniaria), selected mollusks, and echinoderms. To date, the data for all invertebrate groups are preliminary but these particular species have the most complete species richness data. Only species recorded from coral reef and associated shoreline areas will be included in the species richness data provided in this section in Table 12.7.

Table 12.7. Species richness data for selected non-coral invertebrates. Sources: Godwin, 2004, 2002; Coles et al., 2000; Brock, 1979; Amerson and Shelton, 1976; Brock et al., 1966; Kay, unpublished data.

PHYLUM PORIFERA	20
PHYLUM CNIDARIA	
Order Hydroida	5
Order Actiniaria	9
PHYLUM MOLLUSCA	
Class Gastropoda	247
Class Bivalvia	47
PHYLUM ECHINODERMATA	67

The PRIAs possess marine invertebrate diversity and richness contained in habitats with a broad spectrum of anthropogenic influence. Locations such as Kingman Reef in the northern U.S. Line Islands represent locations with very little anthropogenic influence, while the coral reef habitats at Johnston Atoll are heavily impacted by alterations. Despite this vast difference, each of the PRIAs provides a refuge for marine invertebrate communities that recruit from a variety of source locations. For example, the giant clams *Tridacna maxima* and *Tridacna squamosa* can be found commonly in most of the PRIAs, with Kingman Reef possessing the most abundant communities. These clams have been heavily depleted in other parts of their range and the PRIAs represent a refuge for these species, if existing management and protection remains in place there.

Overall Conditions and Summary of Analytical Results

NOAA, USFWS, Bishop Museum, and other scientists and volunteers have now completed species inventories (including many new records) and assessments and initiated monitoring of reef fishes and corals using several complementary underwater survey techniques at most of the PRIAs: the U.S. Line and Phoenix Islands, Johnston Atoll, and Rose Atoll. Based on the inventories, assessments, and monitoring thus far, several summary statements can be made:

- Based on the fish assemblage composition surveyed from 2000-2004, coral reef ecosystems of the PRIAs appear to remain quite healthy and productive.
- Levels of unauthorized fishing around the U.S. Line and Phoenix Islands are unknown, but believed to be negligible to light. Overall, reef fish assemblages at these islands appear to be basically healthy, with large apex predators common.
- There is presently no known harvesting for the coral and live reef fish/species trades in these islands.
- Substantial COTS predation on corals has been observed at Kingman and Palmyra but appears low elsewhere in the PRIAs.
- High densities of small planktivorous fishes found along the west side of the equatorial islands (Jarvis, Baker, Howland) were associated with upwellings caused by impingement of the EUC.
- Coral larvae transported in ECC from the western Pacific may be responsible for the substantially higher levels of coral species diversity at Palmyra and Kingman.
- Surveys conducted at Kingman in 2004 suggest an apparent decline in large fish densities (e.g., gray reef sharks, jacks, groupers) from earlier years.
- Abandoned WWII material, military construction, occupation, and ship groundings continue to be sources of stress, alien species, and perhaps coral disease to resident reef ecosystems.
- Although uninhabited atolls and islands serve as important minimally-disturbed refuges, they are also vulnerable to unauthorized fishing and collecting due to the lack of on-site surveillance and enforcement.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

The USFWS and NOAA will continue to collaborate on research expeditions to the 10 NWRs with coral reefs that are co-managed in the U.S. Line Islands, U.S. Phoenix Islands, Guam, American Samoa, and Hawaii. The USFWS and NOAA will continue to monitor fish and wildlife resources, assess impacts of residual anthropogenic stress to these ecosystems, and work with partners to restore ecosystems. As part of a new initiative, the USFWS will prepare and coordinate the development of comprehensive conservation plans for all of its NWRs beginning in 2004. The USFWS will work with partners to improve surveillance and enforcement and discourage unauthorized access and poaching of fish and wildlife. All but two of the NWRs in the PRIAs will continue to be managed as no-take MPAs, and catch-and-release fishing at the remaining two NWRs will be adjusted accordingly to protect resident fish and seabird stocks. The USFWS will vigorously defend all of its refuges against commercial fishing, destructive fishing, and unauthorized fishing.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

Cooperative biennial surveys should continue at these remote islands to: 1) improve the scientific understanding of these fish and wildlife resources as a basis for sound management; 2) monitor spatial and temporal changes in fish and wildlife assemblages in response to natural and anthropogenic forces; 3) help elucidate associations between fish (the primary resource of interest) and other components of the coral reef ecosystem; and 4) assist the USFWS and other resource managers to improve the scientific basis for protecting fish and wildlife within NWRs and other MPAs.

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The State of Coral Reef Ecosystems of the Marshall Islands

Silvia Pinca[1], Maria Beger[2], Dean Jacobson[1], Terry Keju[3]

INTRODUCTION AND SETTING

The reefs of the Marshall Islands are among the most pristine in the Indo-Pacific, having suffered minimal damage from bleaching, destructive fishing techniques, and sedimentation. However, signs of unsustainable resource exploitation are apparent, including the earlier extirpation of the largest giant clams, and the ongoing reduction of reef shark, grouper, and Napoleon wrasse populations. In addition, localized outbreaks of crown-of-thorns starfish (COTS) and coral disease, principally on the capital atoll of Majuro, are ongoing. Another concern is the growing, unregulated exploitation of reef fish for the local markets.

The Republic of the Marshall Islands (RMI) encompasses approximately 1,225 individual islands and islets with 29 atolls and five solitary low coral islands (Figure 13.1). Land makes up less than 0.01% of the area of the Marshall Islands, with a total dry land area of approximately 181.3 km^2. Most of the country is open ocean with a seafloor that reaches 4.6 km deep. Including the Exclusive Economic Zone (EEZ; shoreline to 200 miles offshore), the RMI covers 1,942,000 km^2 of ocean within the larger Micronesian region. Furthermore, there are 11,670 km^2 of semi-enclosed water within the lagoons of the atolls.

Scattered throughout the country are nearly one hundred isolated submerged volcanic seamounts. Seamounts with flattened tops, or guyots, are thought to have formed millions of years ago but were unable to keep pace with subsidence or persist as islands or atolls.

The average elevation of the Marshall Islands is about 2 m above sea level. Humidity is around 80% with considerable salt spray. The air temperature averages 27.8ºC with an annual range of 24-32ºC. Rainfall tends to be seasonal, ranging from 4 m a year in the south to as little as 0.6 m a year in the north. In extremely dry years, there may be no precipitation on some atolls. Tropical storms (typhoons) are relatively rare, but can be devastating when they occur.

The atolls vary in size from Kwajalein, the world's largest atoll with 16.4 km^2 of dry land and a lagoon of 2,174 km^2, to Bikar with 0.5 km^2 of land and 37.4 km^2 of lagoon, and Namdrik with 2.7 km^2 of land and 8.4 km^2 of lagoon. Individual islands range from tiny sand-spits and vegetated islets that are inundated during storms and extreme high tides to much larger islands such as Kaben Island at Maloelap Atoll, and Wotho Island, the main island at Wotho Atoll, both of which are over 8 km^2. Lagoons within the atolls typically have at least one deep-pass access; however, some, such as Namdrik Atoll, have no natural passes.

The atolls and islands of the Marshalls formed when fringing reefs began to establish and grow around emergent volcanoes. The ancient volcanic peaks then gradually sank and shrank, while fringing reefs continued to grow, eventually becoming coral atolls after the volcanoes disappeared entirely beneath the sea. The five solitary islands of the RMI were formed in much the same way, but the peaks were small enough that no interior lagoon developed.

For the most part, the atolls of the Marshalls are not circular, nor do they have uniform islets. They are much larger than those in the Indian Ocean and are surrounded by more numerous islets. The islets are more prevalent on the windward side and encircle a deep lagoon. The lagoons of RMI atolls also differ from others in that they are typically deeper (to about 60 m) and have greater circulation.

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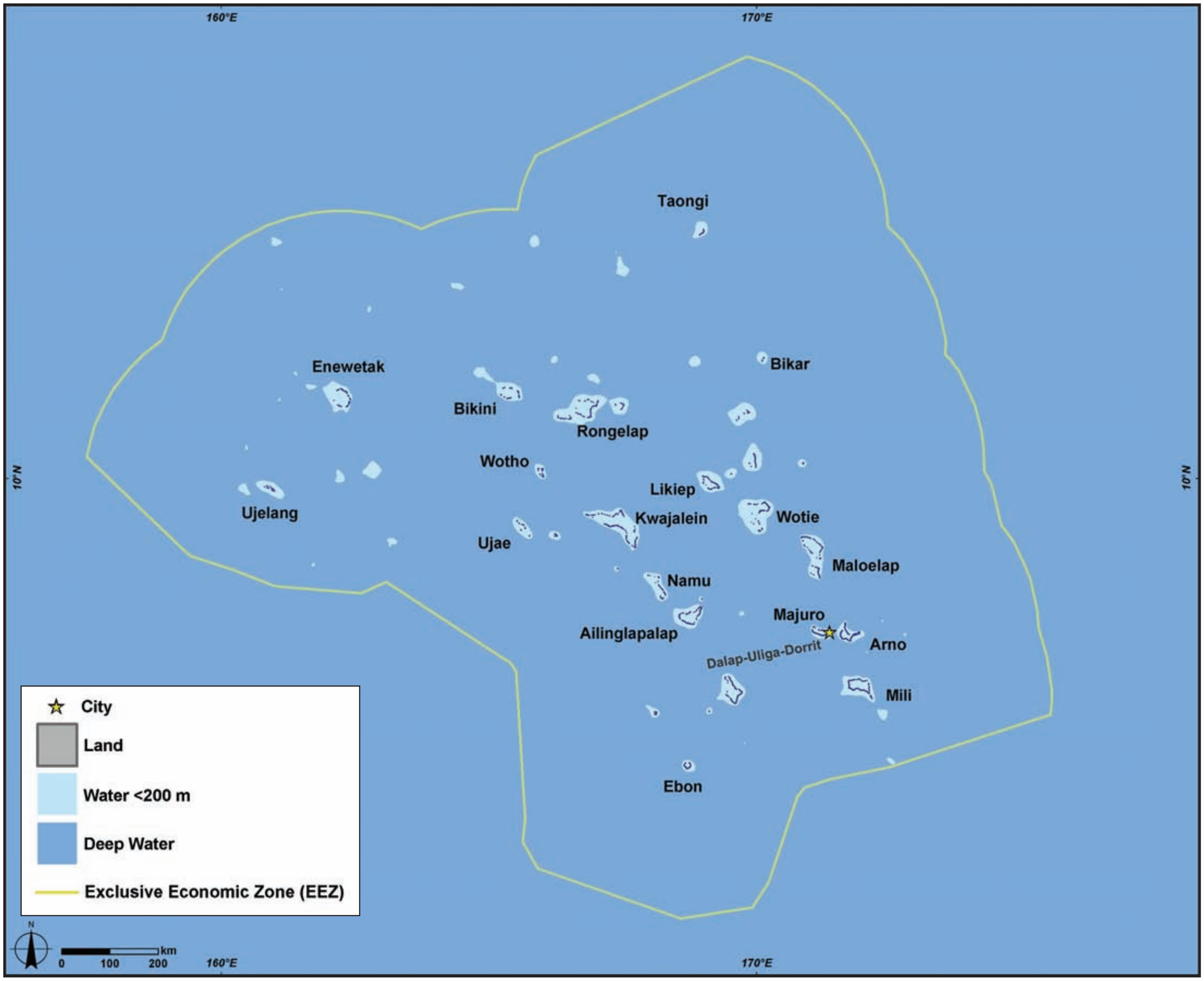

Figure 13.1. Locator map for the Marshall Islands. Map: A. Shapiro.

The islets are extremely young geologically and likely formed when sea level dropped about 2 m to its present level around 4,000 years ago, with more recent land creation resulting from the action of large waves which cast large reef blocks, coral rubble, and sand on top of shallow reefs. Vegetation, birds, crabs, and other animals then colonized the emergent islands, and eventually the Micronesian ancestors of the present day Marshall Islanders arrived on sailing canoes. In contrast, the atoll reefs are 50 million years old or more, and up to 1.5 km thick atop their volcanic foundation.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

Low lying coral reef islands, such as the Marshalls, are at great risk from climate change, particularly from sea level rise, which could result in total submergence. It was suggested during an inter-governmental meeting that such countries could be considered for United Nations Environmental Programme protection as 'endangered species' (South Pacific Regional Environmental Programme, 1989).

It has been projected that air temperatures in the Marshall Islands will continue to rise on all atolls, with the highest increases in the northern areas (Crisostoma, 2000). This could decrease total rainfall, causing severe droughts while also impacting freshwater supplies. A slight change in temperature would increase both the intensity and frequency of storm events, which have a greater impact on low-lying islands.

The average sea temperature around the Marshall Islands is about 29°C, near the upper limit for coral survival of about 31°C. An increase of just 1°C could trigger massive coral bleaching. Some of the very shallow flat reefs on the lagoon side of Majuro Atoll bleached during a time of particularly elevated temperatures and calm conditions, coinciding with the period of spring tide; this occurred during the new moons of Sept-Nov 2002 and resulted in high reef flat mortality. Similar anecdotal observations for the same time period (in 2002) came from local inhabitants in Jaluit Atoll. Considerable bleaching, restricted to certain species of *Acropora,* was later seen on Jaluit, both in 2003 and 2004. However, local residents did not recall any other similar reef flat events in the RMI. No sign of coral bleaching was recorded during recent surveys of several atolls (Pinca, 2001; Beger and Pinca, 2003a; Pinca et al., 2004a,b), but reef flat bleaching was recorded in February 2005.

Diseases

Coral disease is visible on some reefs of the Marshall Islands (Figure 13.2), most notably a rapidly spreading "white" syndrome affecting Acropora spp. (see below). Two rare diseases also occur: a single Favid colony showing signs of red band disease was located on Arno, and some *Platygira sinensis* colonies have slowly progressing lesions bordered by a bright green algal margin. Coralline lethal orange disease, or CLOD, which is caused by an orange bacterium fatal to coralline algae, is common along the southern and eastern shores of Majuro.

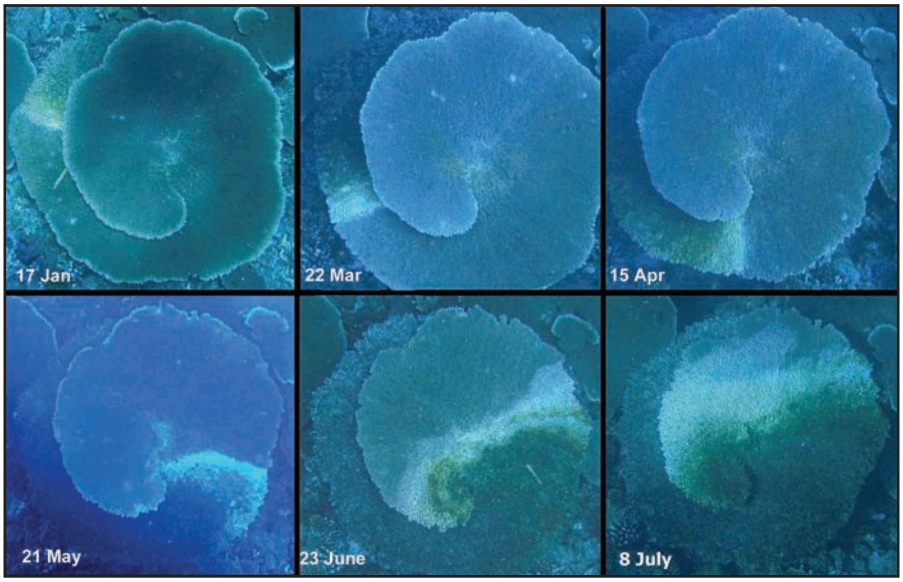

Figure 13.2. The rapid progression of a coral disease on a table coral in the Marshall Islands. Photo: D. Jacobson.

The white syndrome affecting table corals (*Acropora* spp.) is ubiquitous, particularly on the leeward shore of Majuro; this is a region with high human population density and where a shallow outfall bathes the reef shelf with untreated sewage. This disease is typically found on *A. cytherea*, *A. clathrata* and similar species; small digitate or caespitose species as well as branching colonies are not affected. Disease signs usually progress steadily at a rate of 2 cm per day. This disease can kill a 2 m colony in 10 months, as a narrow white band sweeping radially along the colony edge like the hand of a clock. Disease mortality on Majuro has been quantified at a leeward ocean site near the airport over a 12-month period. Based on surface area, 16% annual mortality occurs, in contrast to approximately 20% of annual growth. Mortality is density-dependent; in a local patch of particularly dense *A. cytherea* tables, mortality exceeded 30% over a 7 month interval as the disease spread to neighboring colonies. 2003-2004 mortality was much higher than in the few previous years, suggesting this disease outbreak had a recent inception (i.e., the year 2000). A disease "hot spot" is located far to the west at Laura, which experienced at least 50% mortality. Microbiological characterization of pathogens is ongoing (B. Willis, pers. comm.) and involves at least one virulent bacterium and a large histophagous ciliate whose aggregations appear as macroscopic yet minute spots within corallites. This disease is rare on outer atolls: barely detectable on Jaluit, and uncommon on the western shore of Arno, nearest to Majuro. It is also absent on the pristine northern shore of Majuro. Identical disease signs have been sighted on Pohnpei and Kosrae as well. Disease vectors are unknown, and new infections appear in every season and month.

Tropical Storms

Although major typhoons are not common in the Marshall Islands (Figure 13.3), they can be devastating when they hit. In 1991, Typhoon Zelda hit the southern atolls. It was quickly followed in early 1992 by Typhoon Axel, which scoured the south-facing reefs of Majuro, covering the land, including the airport, with coral debris and rubble. Shortly thereafter, Typhoon Gaye ravaged much of the northern atolls, including Wotho. In late 1997, Paka changed from a tropical storm to a typhoon while in the Marshalls and caused considerable damage to Ailinglaplap (N. Vander Velde, pers. comm.).

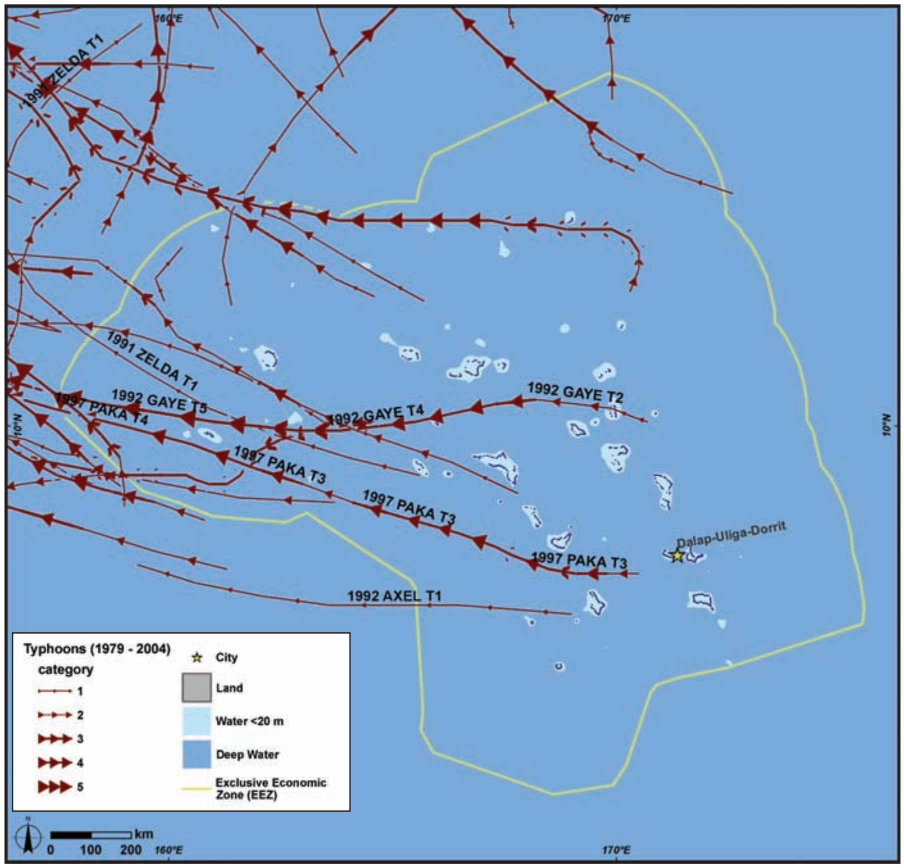

Figure 13.3. The path and intensity of typhoons passing near the Marshall Islands from 1979-2004. Many Pacific typhoons are not named or the names are not recorded in the typhoon database. Map: A Shapiro. Data: Unisys, http://weather.unisys.com/hurricane.

Coastal Development and Runoff

The human population has increased significantly in the Marshall Islands over the past century (Figure 13.4), doubling in size between 1973 and 1999 (RMI Embassy, http://rmiembassyus.org/statistics/statistics.html, Accessed 01/31/05). Although little data on the extent or impact of coastal development exists, population density on the heavily populated islands of Kili and Majuro in 1999 was 2,150 and 6,314 people per mi^2 respectively (1999 Census of Population, RMI).

In Majuro and other outer atolls, such as Likiep, eutrophication has been observed near human settlements.

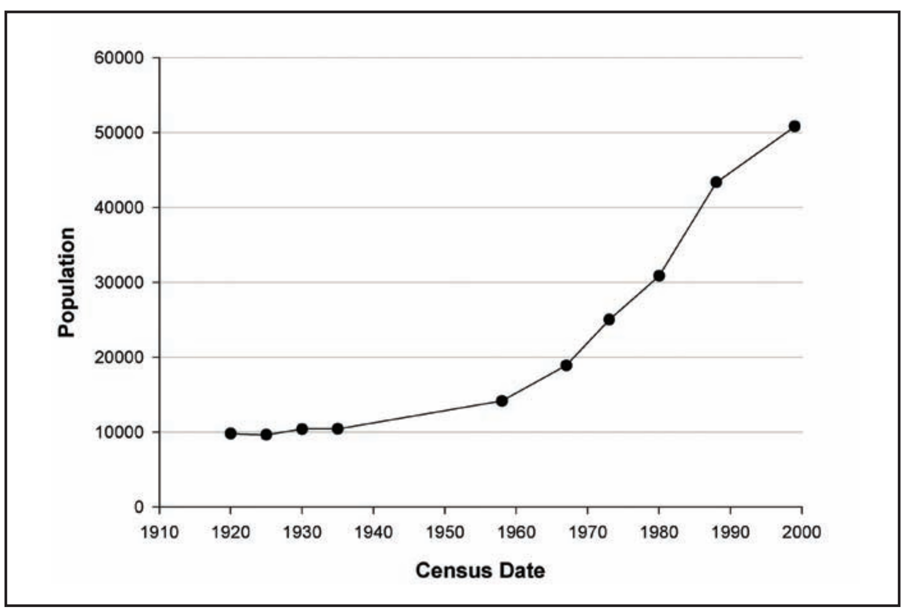

Figure 13.4. The population in the Marshall Islands doubled between 1973 and 1999. Source: RMI Embassy, http://rmiembassyus.org/statistics/statistics.html, Accessed 01/31/05.

Coastal Pollution

Little information on this threat is available, but obvious biotic affects appear down-current from the sewage outfall on Majuro. Table corals are unusually fragile, and the substrate is dominated by a slimy black encrusting algae, a eukaryotic red form. The more typical *Halimeda* spp. of algae are entirely absent. Such a biotic shift will reduce coral recruitment. Within the lagoon, a correlation between a eutrophic algae, *Dictyota* spp., and the most populated regions of Majuro is apparent. A particular *Zooanthus* spp. is also restricted to this eastern lagoon region where eutrophication is apparent.

Tourism and Recreation

The number of visitors to the Marshall Islands has fluctuated in the past two decades, but is generally fairly modest. The highest number of visitors to Majuro occurred in 1996, when arrivals totaled 7,563 persons; in 2003, there were 7,195 visitors (Marshall Islands Visitors Authority, http://www.spc.int/prism/country/mh/stats/toutism/travelers.htm, Accessed 01/31/05). Despite the low numbers of visitors, visitor expenditures did contribute an estimated $4 million to the Marshall Islands' economy in 2000 (U.N. Economic and Social Commission for Asia and the Pacific database, http://unescap.org/stat/data/apif/index.asp, Accessed 01/31/05) when 5,246 people visited.

Fishing

Subsistence and artisanal fishing play an important role in the Marshall Islands, especially in the outer atolls, where they provide the local population with a major source of animal protein. According to RMI Embassy statistics, nearly 3,400 households were engaged in subsistence fishing in 1999 (RMI Embassy, http://rmiembassyus.org/statistics/pdf/demographics/SubActbyAtoll99.pdf, Accessed 01/31/05). In most places, fishing was the most common subsistence activity, with more households participating in fishing than other subsistence activities such as growing food, producing copra, breeding livestock, or making handicrafts.

In addition to the subsistence harvest, a major commercial fishery exists in the RMI, and sale of fishing rights in the EEZ generates between $1-3 million per year. The Marshall Islands Marine Resources Authority (MIMRA) maintains statistics on total annual catch and method of catch, which are shown in Figure 13.5 (http://www.spc.int/prism/country/mh/stats/economic/fish_catch.htm, Accessed 01/31/05). However, most of the commercial fishing activity is focused on offshore tuna stocks and is not likely to impact reef ecosystems. MIMRA also operates the National Fisheries and Nautical Training Center, which educates approximately 75 Marshallese students per year, providing skills that prepare them to work in commercial fisheries enterprises.

Little information was available to characterize the threat to reef ecosystems from fishing. However, some industrial fishing impacts were noted in Rongelap in the form of longlines that were found entangled on corals at four outer reef sites at the leeward site of the atoll. Long-line shark fishing activities were occurring in RMI at the time, but were permitted only 5 miles off the coast. The lines may have been evidence of illegal shark fishing on the reefs, as longline shark fishing is no longer allowed nearshore.

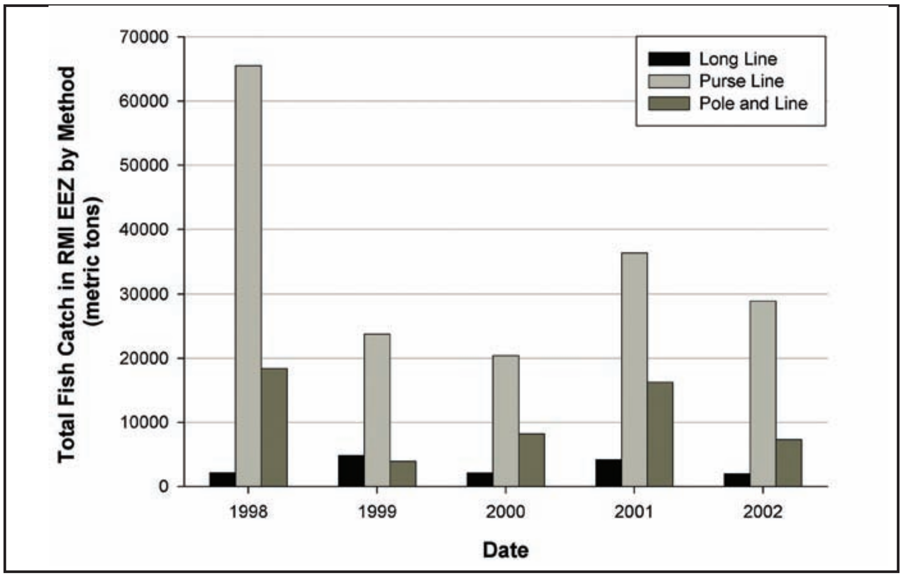

Figure 13.5. Total annual catch and method of capture in the Marshall Islands' commercial fishery, which targets offshore tuna stocks. Data on reef species and subsistence catch were not available. Source: MIMRA database.

Trade in Coral and Live Reef Species

Harvesting live rock and other coral reef products can have serious implications for reef communities. In the Marshall Islands, many species are exported for the aquarium trade (Figure 13.6), and seashells are frequently used in handicrafts, but little quantitative information on the amount of material removed from the reefs is available. However, a clam and live coral farm and a pearl farm are exporting sustainably-produced organisms for the aquarium market.

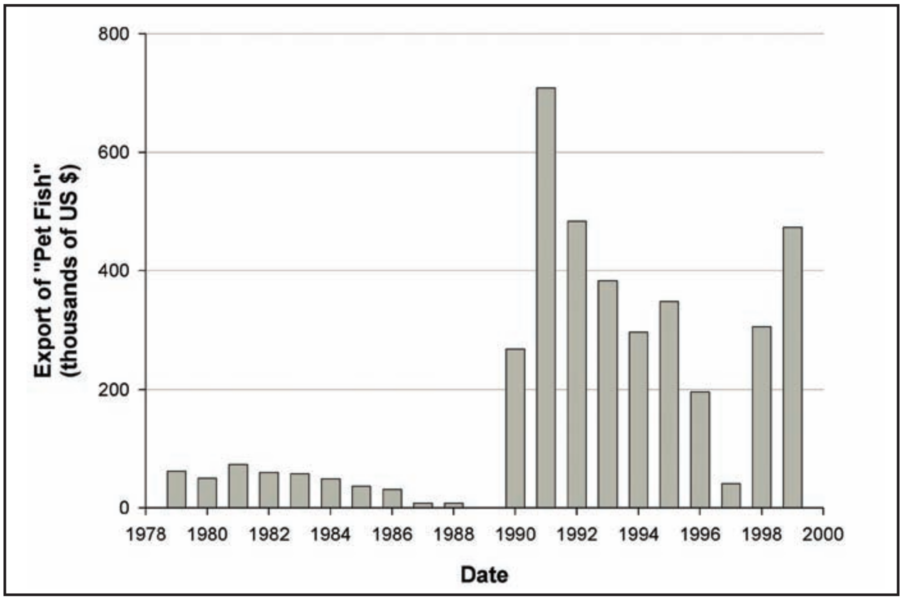

Figure 13.6. The value of 'pet fish' exported for the aquarium trade from 1979-2000. Source: RMI Division of Statistics; MIMRA database.

Ships, Boats, and Groundings

No information on this threat is available.

Marine Debris

Plastic, glass and metal trash and fishing and packaging debris are found along both lagoon and ocean shores on Majuro. Human-produced debris is found on outer atolls as well, but the amount produced by human settlement is much higher at the capital atoll and around its city. The most common pieces of debris produced by the city are plastic diapers, plastic bags, glass bottles and metal cans that accumulate on the bottom of the lagoon around town or remain trapped in coral branches.

Aquatic Invasive Species

Invasive and non-native species are a subtle, but potentially more permanent threat, especially on land. Many terrestrial invasive species have been documented and some of these, such as ironwood (*Casuarina equisetifolia*), can impact coastal areas by out-competing the native vegetation that protects the shoreline. Fouling marine invertebrates have been introduced, especially in ports where they probably arrived on ship hulls. Non-native algae and fishes have been documented, but the full impact of their presence has not been studied. Indications are that invasive species have a high potential to damage coral reefs (NBTRMI, 2000; N. Vander Velde, pers. comm.).

Security Training Activities

The most destructive series of anthropogenic events involving RMI islands, atolls, and lagoons occurred half a century ago. On March 1, 1954, a thermonuclear test bomb, code-named "Bravo," was detonated on Bikini Atoll. Within seconds, a mile-wide 15-megaton blast vaporized entire islands and created a huge crater in the reef. Fish, corals, and other marine and terrestrial animals were destroyed when millions of tons of water and debris were thrown high into the air and then fell back to the lagoon (Simon, 1997; Walker et al., 1997; Robison and Noshkin, 1999; Niederthal, 2001). This test was part of a series of thermonuclear and hydrogen bomb tests that were conducted from 1946–1958 on Bikini and nearby Enewetak Atolls. Winds spread the airborne radiation to nearby atolls, including inhabited Rongelap and Utrik and uninhabited Rongerik and Ailinginae.

Unfortunately, the complete picture of nuclear testing on the Marshalls' biodiversity is neither simple, nor necessarily what it seems to casual observers. For example, Delgado (1999) observed in his book Ghost Fleet that there was "no tangible evidence of the testing" on Bikini. Maragos (pers. comm.) counters, stating that "the 2 km wide and 50 m deep crater in the reef at the Bravo test site is certainly evidence of lasting impacts along with the islands that were evaporated by the Bravo blast." Although a half-century has passed, the full extent of the impact on the biota from radioactive materials introduced during the nuclear testing program is unknown (NBTRMI, 2000). Analysis to compare fish diversity data between two surveys in 1984 and 2002 produced no clear results because of the ambiguous nature of the old data (Beger et al., 2003). As Kenchington and Salvat (1988) stated, "radioactive wastes may have long-term and largely unpredictable effects upon the genetic nature of the biological community." Risks from the consumption of large amounts of locally grown food are still acknowledged to exist, even though returning residents are again eating the crabs.

Offshore Oil and Gas Exploration
Oil and gas exploration activities are not known to occur.

Other
Evidence of damage from COTS, *Acanthaster planci*, is apparent on the reefs of the Marshall Islands (Figure 13.7), with densities along the south western lagoon shore of Majuro exceeding 1000 per km^2. *Acropora* species (tabulate and branching) have been decimated (over 90% mortality) in 2004 and 2005. Currently (Spring 2005) slow-growing massive species, particularly *Porites lobata*, *Pavona duerdeni*, and *Lobophyllia* sp., as well as *Pocillopora eydouxi*, are being killed in an area previously targeted by starfish eradication dives. The only unaffected species is *Porites rus*, which is clearly increasing its dominance. Smaller reef flat *Acropora* spp. are also unaffected. Following a wave of *Acropora* mortality, dead coral surfaces have become colonized by a thick carpet of *Dictyota* algae, even in regions previously dominated by *Halimeda* and lacking *Dictyota*. Another COTS 'hot spot' at Majuro Atoll is in Calelin Pass near Irooj Island. Feeding scars on *Porites* colonies are also evident in the far eastern lagoon, near Rita. Along the southern ocean fringing reef, COTS are abundant only in the far western district of Laura.

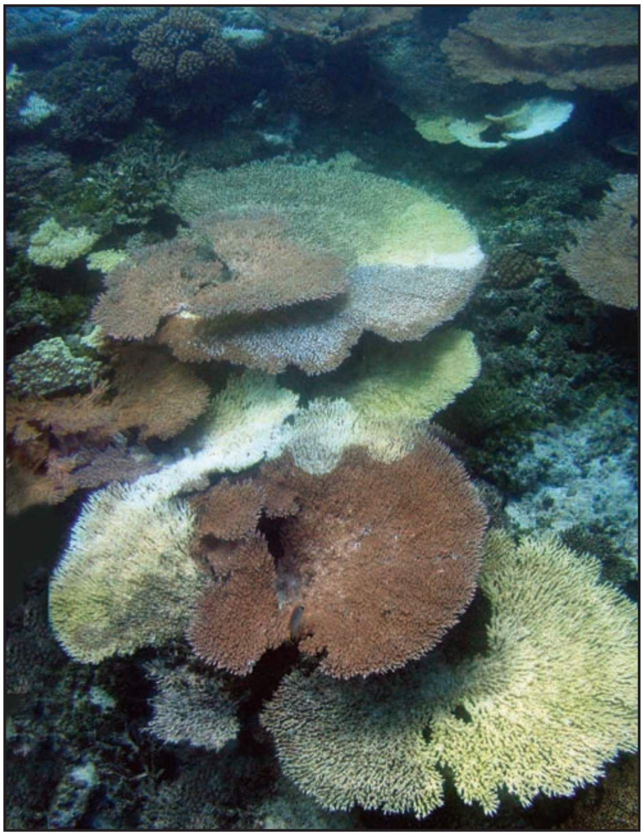

Figure 13.7. Crown-of-thorns starfish, *Acanthaster planci*, damage *Acropora* corals in Majuro lagoon, a region where *Acropora* mortality is over 70%. Photo: D. Jacobson.

This COTS outbreak may be the first to occur since a major eradication effort in 1970. A major outbreak also occurred 15-20 years ago on Enewetak atoll. Even now, *Acropora* is entirely absent on the ocean side of the inhabited Enewetak island, although luxuriant stands of *Acropora* survive in a small refugium in a reef flat quarry pool on the north end of the island.

Another predator of coral, the corallivorous gastropod, *Drupella* spp., is locally common (especially near the densely populated district of Delap) and can cause large feeding scars on *Acropora* spp. Several dozen snails can be found hiding during the day under the base of a single colony.

CORAL REEF ECOSYSTEMS—DATA GATHERING ACTIVITIES AND RESOURCE CONDITION

In addition to the outer island surveys on Rongelap, Bikini, Ailininae, Mili, Arno, Namu and Likiep scientists at the College of the Marshall Islands (CMI) have been paying close attention to local ecosystem indicators in the capital atoll of Majuro (i.e., bleaching, coral and coralline algal disease, COTS outbreaks, and pollution-associated changes in macroalgae). Permanently-marked transects are being installed in transitional sites to photographically monitor long-term changes. One of these sites has been extensively photo-mapped (over a 15 x 130 m area) to closely monitor the incidence of coral disease. In addition, a project involving manta tows over several km of leeward shore on Majuro is planned to map the distribution and abundance of schooling food fish species (i.e., rabbitfish, parrotfish, and surgeonfish).

WATER QUALITY

Coastal construction of ports, docks, airfields, causeways, and roads has affected water quality in the RMI, most notably in the capital atoll, Majuro. Development projects often require sources of fill material and expansion of land areas that lead to dredging and filling of adjacent reef areas (Maragos, 1993). While underway, construction along the shoreline introduces sediments, increases turbidity, and can change the circulation patterns in lagoons.

BENTHIC HABITATS

Pioneering studies on coral reefs in the Marshall Islands encompassed several atolls before 1955 (Tracey et al., 1948; Hiatt, 1950; Ladd et al., 1950; Wells, 1951 and 1954; Emery et al., 1954). A two-volume report on the natural and biological resources of Enewetak Atoll is perhaps the most comprehensive treatment of any of the Marshall Islands (Devaney et al., 1987). In 1988, Maragos coordinated coastal resource inventories and atlases of Arno, Kwajalein, and Majuro Atolls. There were additional marine biodiversity surveys of the northern RMI islands and atolls involving marine biologists and cultural specialists (Titgen et al., 1988; Thomas et al., 1988; AAA Engineering and Drafting and University of Hawaii Sea Grant Program, 1989; AAA Engineering and Drafting et al., 1989; Manoa Mapworks, 1989; Maragos, 1994.

In 2001, Pinca led a systematic survey of coral reef resources at Likiep Atoll with community support through the CMI and MIMRA (Pinca, 2001). Similar surveys followed at Rongelap and Bikini in the summer of 2002 (Pinca et al., 2002) and at Milli, Rongelap, and Ailininae Atolls in the summer of 2003 (Beger and Pinca, 2003a,b; Pinca et al., 2004a,b). Surveys of Majuro and Namu Atolls occurred in November 2004 (S. Pinca, pers. obs.).

During these systematic surveys, four transects parallel to the shoreline were laid at four different depths (5, 10, 15, and 20 m) and divers on each transect recorded data on percentage cover of substrate type, coral life-forms and target species of corals, seaweed groups, abundance and size of target fish species, and abundance of commercial invertebrates. In addition, the 15 m transect was replicated three times to give an indication of the variability at this depth. Sites were selected on both the ocean and lagoon side of atolls, including pinnacles and patch reefs. Biodiversity of fish and corals were recorded during 60-minute vertical swims from 30 m to the surface. In 2001 in Likiep, and in 2004 in Arno, manta tows were also used to assess broad changes in the benthic communities of coral reefs.

The results of these assessments confirm that coral cover is generally high in the Marshall Islands (Figure 13.8), with peak areas at the leeward ocean sides of the atolls. High values of hard coral cover vary between 57 and 68% (calculated as an average across sites in all four depth categories). Local coral cover at a single site reached as high as 79% of total substrate cover in Rongelap. Although coral cover was generally lower at lagoonal sites, a very high concentration of rare branching *Acropora* species were found in these environments. The lowest coral cover was generally recorded on the leeward lagoon side. However, many patch reefs and pinnacles with high coral cover and diversity are present inside the lagoons. The most common coral species or species groups are *Porites lobata-australiensis*, *Isopora palifera/cuneata*, and *Porites rus*. *Acropora* spp. were predominantly found inside the lagoon, as branching and tabulate growth forms, while non-*Acropora* encrusting, foliose, and *Millepora* spp. were more common at the oceanic sites. At some sites, blue corals (*Heliopora coerulea*) represented more than 20% of total coral cover (e.g., on the west side of Likiep Atoll). On the windward ocean side, where the mechanical energy of the wave action is much stronger than on the leeward side, the most abundant corals were the encrusting forms and *Millepora* spp. (fire coral). Fire coral was growing here in smaller colonies and was predominantly an encrusting form, compared to the fire coral on the leeward side, which grew in a branching and taller form.

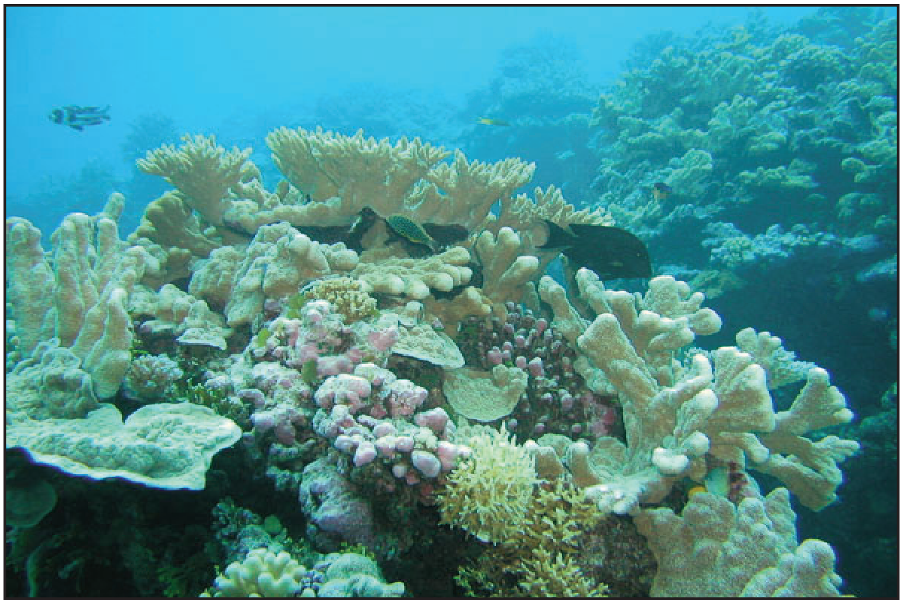

Figure 13.8. The upper forereef at Rongelap Atoll is an area of high coral cover and diversity in the Marshall Islands. Photo: S. Pinca.

Range extensions (when a species is found that had not been previously recorded at RMI) for several species of corals and fish were established during the 2002 and 2003 expeditions. A new species of coral (*Acropora rongelapensis*) was described in 2003 from Rongelap (Richards and Wallace, 2004).

Soft corals were rare in most atolls in the RMI. However, in Mili, *Sarcophyton* spp. and *Lobophyton* spp. were relatively abundant, as were gorgonians of the genus *Melithea*.

Fleshy seaweeds (especially *Microdyction* spp. and *Halimeda* spp.) and coralline algae were abundant and coexisted with healthy hard corals. Seaweed cover was higher at the west ocean and south ocean sites in Mili and east, south, and north ocean sites in Rongelap. Coralline algae dominated west ocean sites in Likiep. Two hundred and twenty-two species of macroalgae, three species of seagrass, and five species of mangroves have been identified in the Marshall Islands.

In 2001, a total of 18 sites around the six islands of Likiep Atoll were sampled by Pinca (2001). The general ecological health of coral reefs in Likiep Atoll was very good, although there are sharp differences among the six islands surveyed. The islands differ both ecologically (associations of different species of organisms, both corals and fish), as well as in the degree of integrity (status of corals, quantity and structure of fish populations). Some inhabited islands show initial signs of eutrophication by the presence of blue-green algae on the lagoon sand bottom in front of the villages. Also, a live-fish fishing enterprise that catches groupers and other reef fish was present in fall 2001, although its impacts have not been quantified.

ASSOCIATED BIOLOGICAL COMMUNITIES

In 2002 and 2003, a total of 45 sites in Rongelap Atoll were surveyed (Pinca et al., 2002; Beger and Pinca, 2003a; Pinca et al., 2004b), including sites at pinnacles and patch reefs inside the lagoon, as well as ocean and pass sites. A very high diversity and richness of fauna exist in Rongelap atoll, with particularly abundant and large fish, abundant megafauna such as sea turtles, rays, and sharks, as well as large and abundant giant clams. This atoll has been uninhabited for the past 50 years due to the evacuation of local people following radioactive fallout from the nuclear tests at Bikini Atoll. Coastal managers and marine biologists analyzed the results from the 2003 surveys and recommended specific sites to be preserved for their pristine health and high biodiversity.

A total of 20 sites were surveyed at Mili Atoll during a two-week period in 2003 (Pinca et al., 2004a), including nine sites on the ocean side of the atoll, two pass sites, and nine lagoon and pinnacle sites. The team worked directly with local landowners and government officials to propose that a few islands be dedicated as a marine sanctuary in the northeast corner of the atoll. The reefs were found in mostly pristine condition, with a large number of fish, coral, soft corals, and algae present. Sharks were not very abundant, and local anecdotal evidence suggested that illegal shark fishing by foreign large-scale fishing operations was to blame (Figure 13.9). Beaked whales, spinner dolphins, sharks, and large-size fish were found in the area proposed for a marine sanctuary. The proposed sanctuary area includes a variety of important habitats, such as ocean walls, passes, pinnacles, and lagoonal reef habitats.

Figure 13.9. Fins harvested from hundreds of sharks lay drying in the sun. While fishing for sharks is not illegal for Marshallese fishers, illegal shark fishing is suspected in some areas of the Marshall Islands, such as at Mili Atoll. Photo: S. Pinca.

The highest abundance of fish was found at the northern and southern ocean sides of the atolls of Likiep and Mili, and at the southeast lagoon, pass and slope areas of Rongelap (Pinca, 2001; Beger and Pinca, 2003a; Pinca et al., 2004a,b). Surgeonfish, snapper, wrasse, fusilier, parrotfish, and grouper are the most abundant food fish families. Seven of the 860 species of reef fishes recorded in the Marshall Islands are endemic. A total of 373 fish species were recorded at Mili Atoll in 2003. The richest areas were the central pinnacles in the southern lagoon and the ocean area that is being considered for designation as a marine protected area (MPA). The number of fish species at each site varied from 95 to 162 with an average of 124 fishes. Rongelap Atoll had a total of 397 species with the richest area being the tip of Jabwan at Rongelap Island, on the main pass, where the highest fish species numbers were counted both in 2002 (179 species) and in 2003 (205 species). The number of fish species counted at each site during a single visit varied from 91 to 205. On average, sites harbored 124 species of fish.

Passes generally support more species of fishes, since they combine aspects of outer and lagoonal habitats. Sheltered sites in the lagoon support lower fish abundances, but they harbor many unusual species. Humphead wrasses (*Cheilinus undulatus*) were observed in the eastern part of Rongelap Atoll, where they were found at the edge of the drop-off and on lagoon pinnacles near and in passes. They were slightly less abundant in Likiep, and least abundant in Mili Atoll.

The after-effects of some of the 67 nuclear tests in the northern Marshalls between 1946-1958 on fish have also been studied. Noshkin and Robison (1997) summarized the results from all available data on the radionuclide concentrations in flesh samples of reef and pelagic fish collected from Bikini and Enewetak Atolls between 1964 and 1995. Although they found that 239 + 240Pu (plutonium) and 241Am (americium) had not significantly accumulated in the muscle tissue of any species of fish, a variety of other radionuclides had accumulated in all species of fish (Noshkin et al., 1986). Over the years, many of those radionuclides have diminished by radioactive decay and natural processes (Noshkin and Robison, 1997). The authors report that fish collected in the 1980s and 1990s show only low concentrations of a few remaining long-lived radionuclides. By the 1990s, 207Bi (bismuth) remained below detection limits in muscle tissue of all reef fish except goatfish. Levels of 137Cs (cesium) diminished to detection limits in mullet and goatfish at many islands, and 60Co (cobalt) was undetected or at low concentrations.

Giant clams (*Tridacna* spp.) are significantly more abundant at leeward ocean sites. Four species of giant clams were recorded for Mili, where the highest total number is found at the south pass. Five species were recorded in Rongelap, where the highest numbers were represented by *Tridacna maxima* at the west pass.

Similarly, all five species of giant clam were recorded at pinnacles inside the lagoon. Sea urchins are most abundant at the windward ocean sites and relatively in low abundance elsewhere. Sea cucumbers are present in very high numbers on the lagoon side of the East Likiep Atoll.

RMI atolls support substantial populations of megafauna such as green sea turtles, whales, rays, and sharks. A high number of sharks are often observed around RMI atolls, on the reef flat and slope, and inside and outside the lagoon. Every dive is accompanied by either gray reef sharks (*Carcharhinus amblyrhynchos*), the most abundant species overall, or white tip sharks (*Triaenodon obesus*), and silvertip sharks (*Carcharhinus albimarginatus*) in deeper waters. Nurse sharks (*Nebrius ferrugineus*) appear to be rare and were only seen at three sites in Rongelap Atoll. A tiger shark was also observed by the main pass of this atoll, in shallow water. A few black tip sharks (*Carcharhinus melanopterus*) are also encountered, especially in shallow waters. Zebra sharks (*Stegastoma varium*) were seen in Rongelap and Namu atoll.

Manta rays (*Manta birostris*) were spotted in Rongelap, including at patch reef sites inside the lagoon; and eagle rays (*Aetobatus narinari*) are frequent in Majuro, as well as in all outer atolls visited.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

The primary agencies involved in protecting coral reef ecosystems are MIMRA and RMI Environmental Protection Authority (RMI-EPA). In 2000, the National Biodiversity Strategy and Action Plan (NBSAP, http://www.biodiv.org/doc/world/mh/mh-nbsap-01-en.pdf, Accessed 01/25/05) and the National Biodiversity Report (NBTRMI, 2000) were approved by the Cabinet. Both address the need for conservation and management of natural resources. The NBSAP recommends strengthening the concept of 'mo', a traditional system of taboo identifying certain areas as 'pantries' that could be harvested only periodically. The NBSAP also addressed the need for sustainable fishing practices and retention of local knowledge.

The Marine Science Program at the CMI (MSP-CMI) is studying the status of marine resources to help each atoll population manage its resources and plan fishing and other activities in a sustainable manner, with the specific purpose of conserving particularly rich or threatened zones (Pinca, 2003a). The MSP-CMI collaborates with MIMRA, RMI-EPA, Marshall Islands Visitor Authority, and Ministry of Internal Affairs to design community-based fishery management plans (Pinca, 2003b). During the past outer atoll surveys, MSP-CMI, together with the Natural Resources Assessment Surveys (NRAS, http://www.nras-conservation.org, Accessed 3/15/05) team, combined local marine survey expertise with international scientific expertise to conduct underwater surveys assessing reef health and fishing impacts.

The need to protect Marshallese marine resources stems from both a precautionary effort to conserve pristine reefs and a direct demand from local fishers who report a decline in target species for both commercial and local use. Lower abundance of clams, fish, lobsters, and cowry shells have been reported by local populations from the outer atolls. Marine reserves and other management measures are still in their infancy, but several atolls (Jaluit, Arno, Likiep, Mili, and Rongelap) are spearheading this effort. Selection of conservation sites and practices is based on biodiversity and conservation theories. Ecological observations like the ones collected by NRAS indicate where healthy and productive ecosystems are, where conservation is more urgent and more efficient for repopulation of scarce species, and where the recruitment of important species takes place, since it is important to protect both nursery and spawning areas. To help identifying source and sink areas of propagules, a study that models the water circulation at Rongelap Atoll is underway (Peterson et al., in review). The processes for MPA designation involve consulting with the community, identifying their expectations and preferences, and incorporating the results of research conducted by local and foreign scientists. Conservation will hopefully also help protect fishing grounds from illegal fishing operations. With outstanding diversity and coral cover, Likiep, Rongelap, and Mili Atolls provide refuge for a suite of marine organisms. Because of the difficulty of enforcing fishing regulations in remote locations, these atolls and other atolls such as Ailinginae, Bikini, and Jaluit are likely to experience illegal fishing.

Proposed MPA sites near Likiep include Jeltonet (east of the atoll), Liklal (north), and Lukonor (west) on the ocean side. In Mili, the northeast area around Reiher's Pass was proposed as a sanctuary by the community. In order to conserve the high biodiversity of this area, a reserve network in Mili Atoll has also been discussed. In Rongelap, Jabwan Point is recommended for sanctuary designation.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

In general, the reefs of the Marshall Islands are in good condition. While the two atolls used for the nuclear testing program have experienced unique stresses, the reefs of the RMI as a whole have escaped the extensive damage seen in other parts of the world. Reefs surveyed at various locations in 2001, 2002, and 2003 were found to be in a very healthy condition, with a large number of fish, healthy corals, and algae. One could argue that because no humans inhabit atolls affected directly or indirectly by nuclear testing, the reefs at these atolls have recovered to support seemingly natural equilibrium populations that largely remain unexploited to date. Abundant megafauna such as sea turtles, whales, rays, and Napoleon wrasses were also recorded.

Training for local personnel to manage and monitor the reef areas is essential to the success of any community-based solution to conservation and sustainable development. Training and capacity building activities for local people are being undertaken at CMI, and conservation and management workshops are planned for the future. Local inhabitants are demonstrating interest in becoming park rangers and are requesting specific training. A certificate program in marine resource management, which includes reef ecology and monitoring techniques, was offered by RMI in 2004 and will be replicated in 2005.

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The State of Coral Reef Ecosystems of the Federated States of Micronesia

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INTRODUCTION AND SETTING

From east to west, the Freely Associated States include the Republic of the Marshall Islands (RMI), the Federated States of Micronesia (FSM), and the Republic of Palau. The FSM and Palau are known as the Caroline Islands, which span 2,500 km and are among the longest island chains in the world. All of these Micronesian islands were formerly a part of the Trust Territory of the Pacific Islands administered by the United States after World War II (WWII). All three countries achieved independence within the past 25 years but retain close economic and strategic ties to the U.S. (Hezel, 1995). Although the process was initiated as early as 1979, the Compact of Free Association between the U.S. and the RMI and FSM did not go into effect until 1986; the Compact of Free Association between the U.S. and the Republic of Guam was effective in 1995.

The FSM is comprised of four states, from east to west; Kosrae, Pohnpei, Chuuk, and Yap (Figure 14.1). Each island or group has its own language, customs, local government, and traditional system for managing marine resources. The FSM has both high islands and atolls, and islanders have a strong dependence on coral reefs and marine resources, both economically and culturally. The islands support three basic reef formations: fringing reefs, barrier reefs, and atolls, which correspond to the stage of reef development at each island.

Kosrae is a single volcanic island with a land mass of 109 km^2 and a maximum elevation of 629 m. It is among the least developed of the U.S. Territories and Freely Associated States, with approximately 7,700 people residing there. Kosrae is surrounded by a fringing reef and has a single harbor. In areas where the reef flat is wide, there are a number of large solution holes, some of which support extensive coral development. The reef is narrow along the east and south coasts, but wide enough along the west and north coasts to nearly be considered a barrier reef. The island is surrounded by coastal mangrove forest and extensive fringing reefs. Kosrae's reefs and mangroves are considered some of the healthiest in Micronesia and support a small but growing diving and ecotourism industry (currently about 1000 visitors per year). However, recent coastal development and land use patterns have resulted in coastal erosion and degradation of the coastal mangrove ecosystem, placing the health of Kosrae's reefs at risk.

The volcanic island of Pohnpei, the site of the FSM capital, is the largest island in the FSM (345 km^2) and along with eight smaller island and atolls, makes up the state of Pohnpei. Pohnpei Island has a well-developed barrier reef and associated lagoon.

Chuuk State (formerly known as Truk) is made up of 15 inhabited islands and atolls, and is famous for the Japanese wrecks that were sunk in the lagoon during WWII. Chuuk Lagoon is the largest atoll in the FSM and serves as the population and political center of Chuuk State.

Yap State has a main island with a land area of approximately 100 km^2, and includes an additional 15 islands and atolls. The lifestyle of Yap islanders is among the most traditional in the FSM, with a highly sophisticated marine tenure and marine resource management system.

1 Yap Marine Resource Management Division
2 Conservation Society of Pohnpei
3 Kosrae Fisheries Department
4 Chuuk Department of Marine Resources

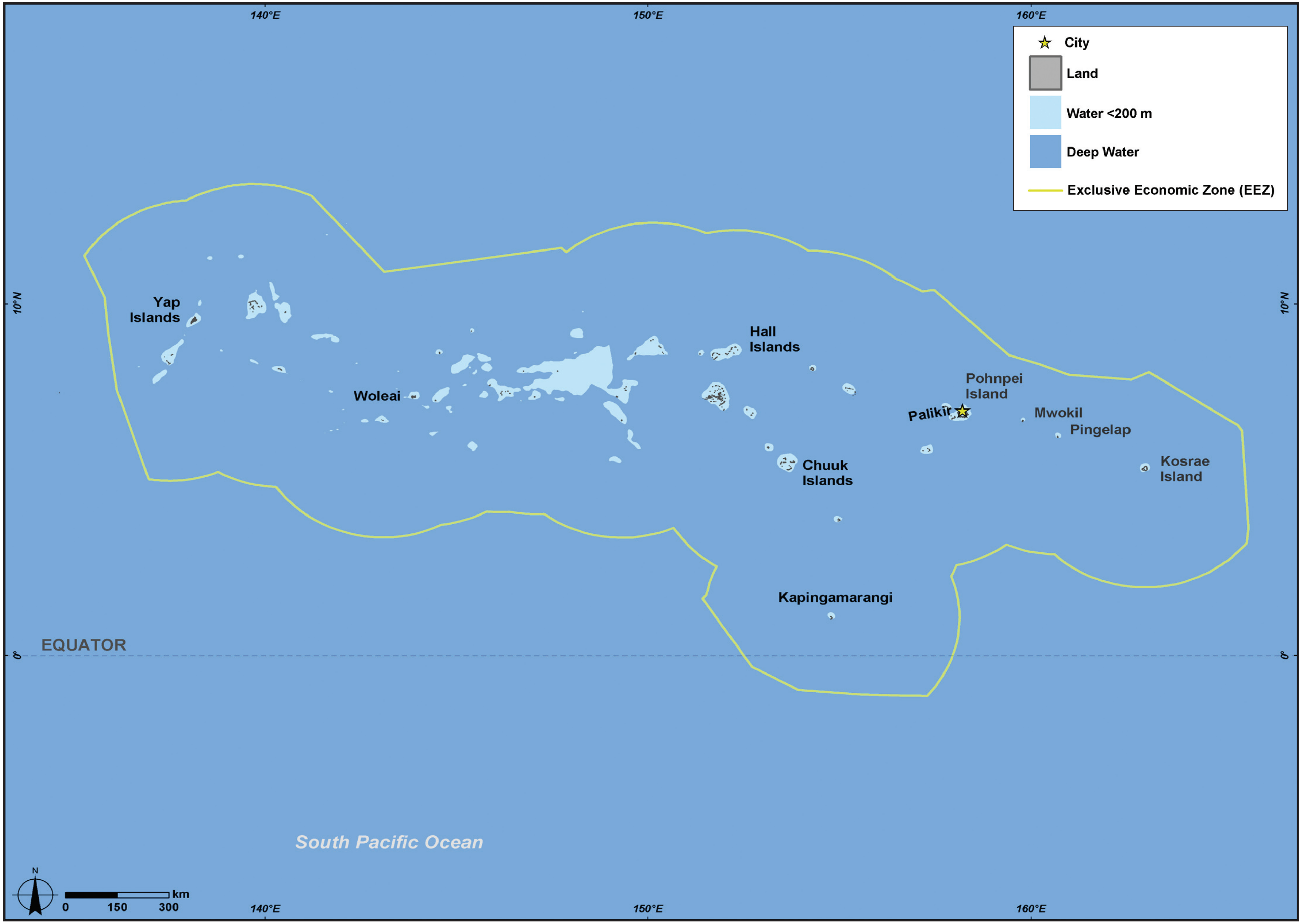

Figure 14.1. Locator map for the Federated States of Micronesia. Map: A. Shapiro.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

There have been a few cases of localized bleaching in some areas around Pohnpei's lagoon but these have been associated with unusually heavy rain events.

Diseases

No information on this threat is available.

Tropical Storms

Tropical storms frequently pass through or near the FSM (Figure 14.2). In 1990, a destructive typhoon passed over remote reefs in Pohnpei State (Holthus et al., 1993). Large waves at Minto Reef caused massive coral heads to be transported from the lagoon to the reef flat, killing a variety of associated wildlife. In early 2004, another large destructive typhoon passed by Chuuk and Yap, causing structural damage to reef areas.

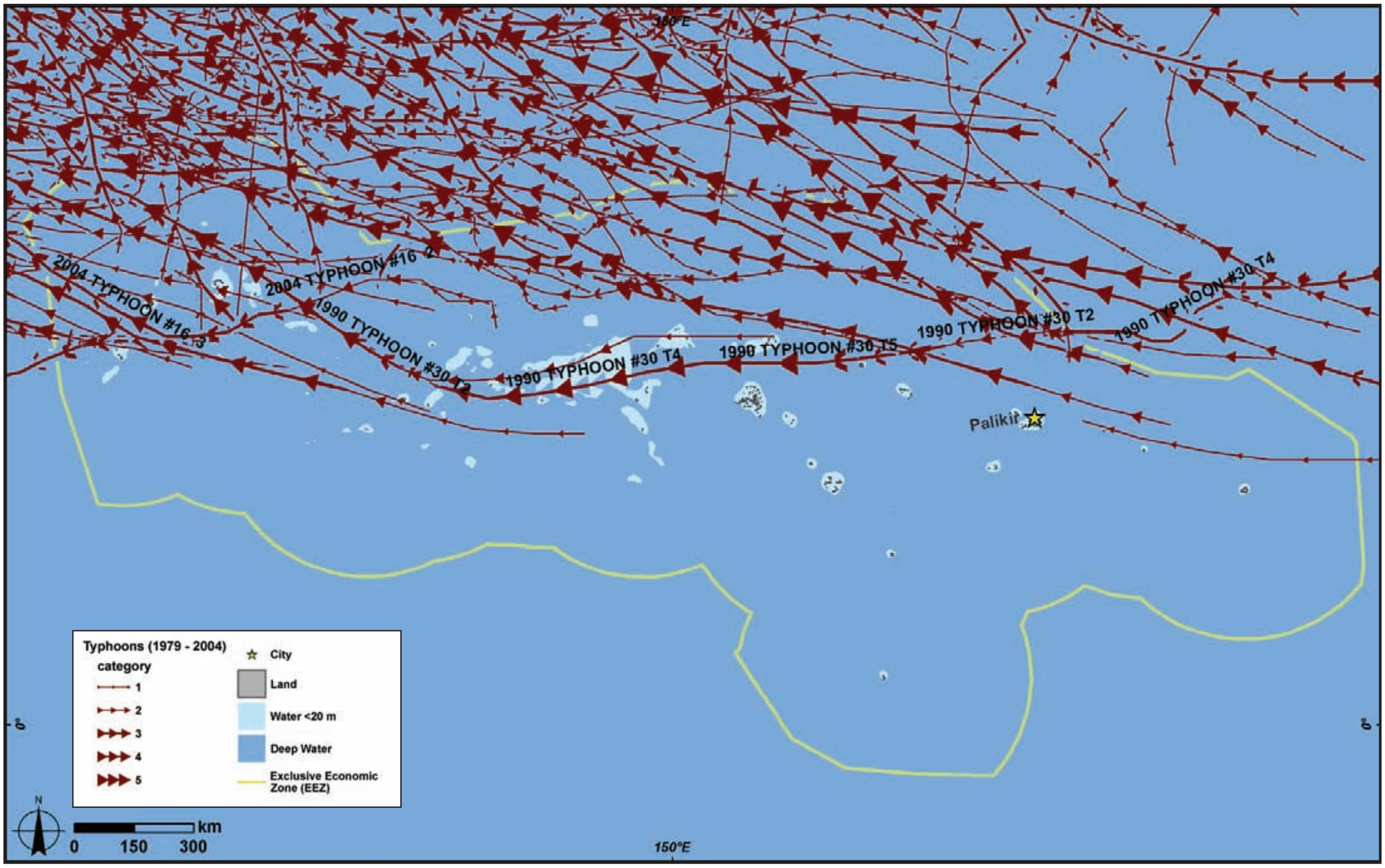

Figure 14.2. The path and intensity of typhoons passing near the FSM from 1979-2004. Many Pacific typhoons are not named or the names are not recorded in the typhoon database. Map: A Shapiro. Data: Unisys, http://weather.unisys.com/hurricane.

The population of the FSM has increased in the past several decades (Figure 14.3), with 50% of the population residing in Chuuk State (FSM Division of Statistics, 2002). By 2000, the average population density reached 395 persons per mi^2 in 2000 (FSM Division of Statistics, 2002). However, since the signing of the Compact of Free Association with the U.S. in 1986, the effect of the population increase has been mitigated by emigration of Micronesians to pursue education and employment opportunities in U.S. states and territories. Guam, Hawaii, and the Commonwealth of the Northern Mariana Islands (CNMI), and are the primary destinations for Micronesians who leave to live and work abroad.

Reefs in Kosrae have been impacted by coastal development, and one of the most noteworthy projects was the construction of the airport on the reef flat at Okat. Sedimentation, caused by dredging and road construction projects, has resulted in the destruction of reefs in Okat and Lelu (M. Tupper, pers. comm.). A new road is being constructed to connect the villages of Utwe and Walung on the south coast, and this will likely lead to increased soil erosion and sedimentation in the Utwe-Walung Marine Park. A large solution hole in Lelu, named "the Blue Hole", is a popular snorkel and dive site, but has been impacted by the construction of a causeway across the lagoon to Lelu village. The Blue Hole now suffers from high turbidity and macroalgal overgrowth (M. Tupper, pers. comm.).

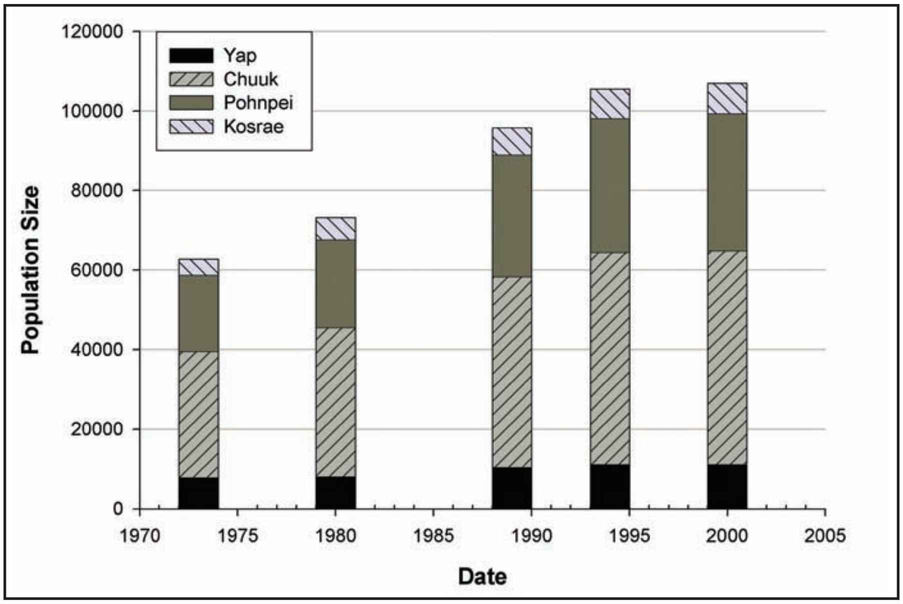

Figure 14.3. Human population growth in the FSM, 1973-2000. Slightly more than half of the population resides in the islands of Chuuk State. Source: FSM Division of Statistics, 2004.

Coastal Pollution

Increased population is a concern for the future of some islands as they come to terms with the need for associated infrastructure, including sewage treatment plants and waste disposal facilities.

Tourism and Recreation

Tourism and recreation have increased in the FSM, with a peak in visitor arrivals of 20,501 in 2000 (FSM Division of Statistics, 2004). According to the FSM Division of Statistics, total international visitors to FSM in 2003 was 18,168 people. Approximately 72% of visitors were citizens of the U.S. (41%) or Japan (31%).

The FSM Visitors Board maintains an informative and attractive website (FSM Visitors Board, http://www.visit-fsm.org, Accessed 1/31/05) to help guide potential visitors to the country and has established Visitors Bureau offices in each state. Overseas tourism offices are co-located with Embassy or Consul offices in Guam, Honolulu, Tokyo, Fiji, and Washington, D.C.

Each of the four states in the FSM have deep draft harbors and modern jet airfields served by Continental Airlines, a major U.S. carrier. A range of accomodations, from simple traditional huts to fancy hotels and luxury resorts, can be found in each state with online booking often available. In addition, three live aboard dive vessels are offering cruises in Chuuk in 2005. Diving is one of the most popular activities for visitors who are drawn to the abundant marine life in the FSM and the numerous planes and ships that were sunk, especially in Chuuk Lagoon, during WWII.

Fishing

Commercial fishing in the FSM is focused primarily on the offshore tuna and billfish stocks, which contribute $14-24 million to the national government annually from the sale of fishing rights to foreign vessels (FSM Division of Statistics, 2004). In addition, the value of exports of marine products in 2002 was over $9 million, which represents a decrease of about 25% over the export value in the previous two years. Only a fraction of this total value is represented by reef fish (1.2% or less) and other inshore species (Figure 14.4); the majority of reef-associated products exported for sale originate in Chuuk (Figure 14.5). The commercial fishing industry employed between 280 and 340 people per year between 1999 and 2002 (FSM Division of Statistics, 2004).

Reef fish species are primarily exploited for subsistence purposes, but little information exists to characterize subsistence or artisinal catch by species or method of capture. The FSM Division of Statistics reports that of total GDP, approximately one-third can be attributed to subsistence activities such as fishing, agriculture, and copra production (FSM Division of Statistics, 2004), so it is likely that the harvest of reef-associated organisms is substantial. There have been numerous anecdotal reports of destructive fishing practices in the past, but little published information is available.

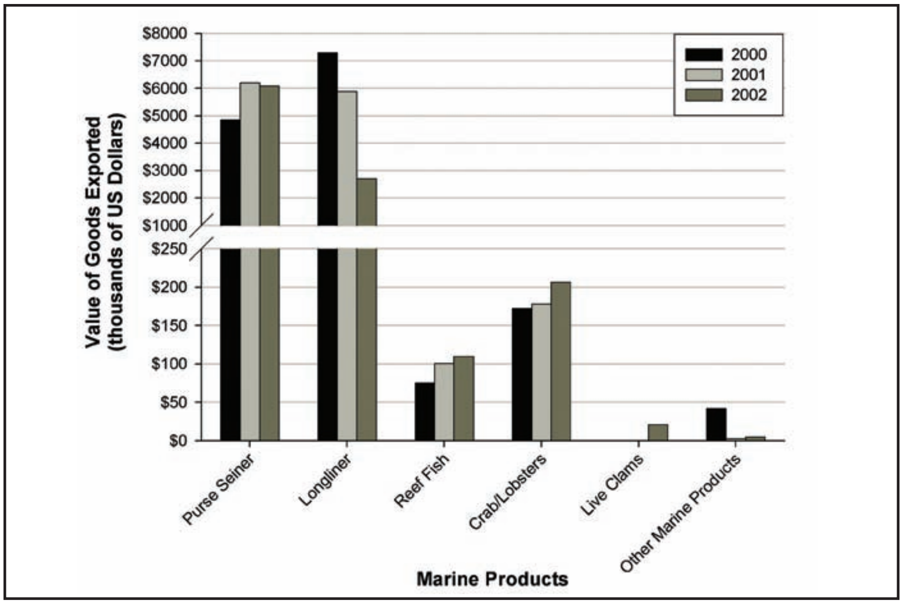

Figure 14.4. Fisheries resources contribute siignificantly to FSM exports, though only a small fraction are from reef fish. Source: FSM Division of Statistics, 2004.

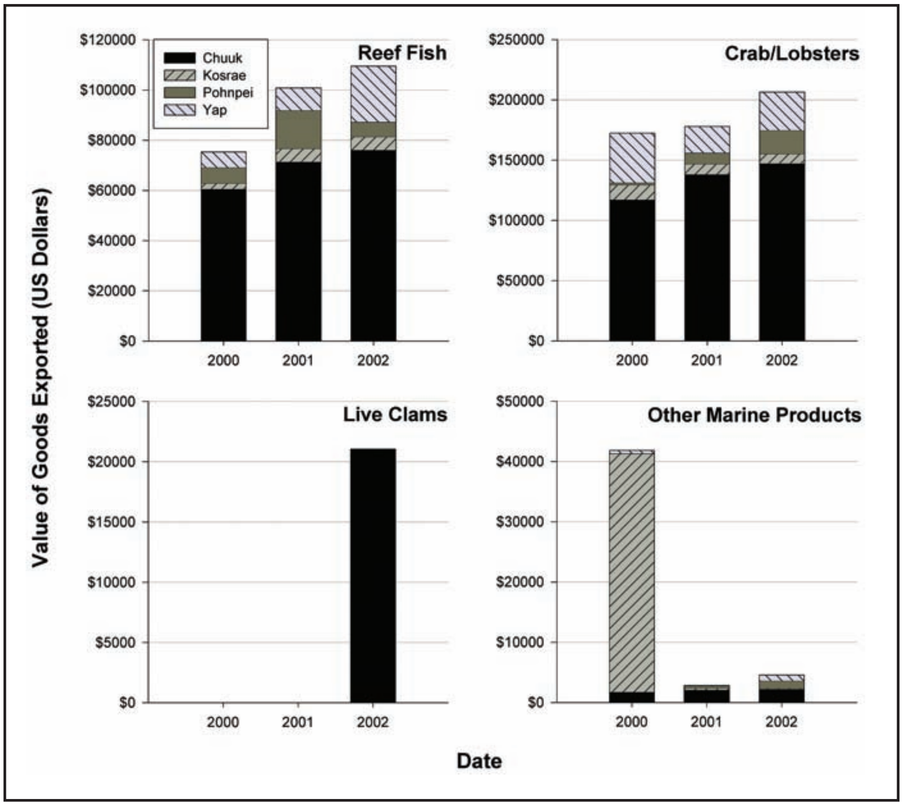

Figure 14.5. The majority of exports of reef fish and other reef-associated species originates in Chuuk. Source: FSM Division of Statistics, 2004.

Trade in Coral and Live Reef Species

No information on this threat is available.

Ships, Boats, and Groundings

Ship groundings have been a problem for both the high islands and atolls in the FSM. Foreign long-line vessels have been abandoned on numerous FSM reefs, and virtually no funds are available to clean up associated oil spills or remove the ships. Large shipping vessels have also run aground, most recently in Satawal, Yap and on the island of Pohnpei. Maragos and Fagolimul (1996) reported extensive direct (13,000 m^2) and indirect (300,000 m^2) impacts of the 1994 grounding and subsequent removal of a large freighter from a reef at Satawal Island, Yap. Sediments generated by the erosion at the reef site migrated to other reef areas more than a kilometer away, smothering corals, burying reef flats, creating new beaches on the island, and damaging reef life in a fish reserve. The people of Satawal reached an out-of-court settlement with the ship owners for more than $2 million (J.E. Maragos, pers. comm.).

Marine Debris
No information on this threat is available.

Aquatic Invasive Species
No information on this threat is available.

Security Training Activities
No information on this threat is available.

Offshore Oil and Gas Exploration
No information on this threat is available.

CORAL REEF ECOSYSTEMS—DATA GATHERING ACTIVITIES AND RESOURCE CONDITION

The Government of the FSM has two regulatory agencies that manage coral reef ecosystems. Each state has a Marine Resources Management office and an Environmental Protection Agency (EPA) office. Cooperation among regional institutions, formalized under the Marine Resources Pacific Consortium and funded by the U.S. Department of the Interior, is intended to increase the local and regional capacity for assessment and monitoring. In addition, the College of Micronesia-FSM has faculty and staff trained in marine resource assessment and monitoring. Non-governmental organizations (NGOs)active in the FSM, such as The Nature Conservancy, offer technical and financial assistance for reef-related programs. The Conservation Society of Pohnpei (CSP) is playing a large role in spearheading the development of a statewide coral reef monitoring program and promoting public awareness programs. CSP also assists local communities in designating and monitoring local marine protected areas. The Peace Corps has a presence in the FSM, and some of its volunteers have been involved in monitoring programs.

WATER QUALITY

Kosrae is a steep volcanic island with high annual rainfall. Erosion and sedimentation are problems wherever land clearing and road construction activities occur. Turbidity is quite high in Okat, Utwe Bay, and Lelu Harbor, particularly in the vicinity of streams and river mouths. Dredging in Okat also periodically increases turbidity in the area. However, pollutants such as pesticides and fertilizers do not appear to have a large impact.

Students from Xavier High School in Chuuk, in conjunction with the Chuuk State EPA, surveyed the water quality of Chuuk Lagoon from 1998-2000. Water quality testing included measurements of water clarity, temperature, turbidity, salinity, pH, dissolved oxygen, and coliform bacteria counts. Although the water quality data collected in Chuuk Lagoon was not available for inclusion in this reporting effort, more information about the students' monitoring efforts can be found at: http://www.xaviermicronesia.org (Accessed 02/02/05).

BENTHIC HABITATS

Coral reef biodiversity and complexity is high within the reefs of the FSM and this diversity decreases in scale from west to east away from the center of marine diversity in Southeast Asia. It is estimated that the FSM has more than 300 species of corals (200 in Yap, 300 in Chuuk, 200 in Pohnpei, and 150 in Kosrae). A total of 143 species of algae were reported from Yap. In Pohnpei, the most recent report documented 74 species of algae. FSM has 14 documented species of mangroves.

Marine Resource Monitoring in Kosrae

In Kosrae, the status of the reefs is monitored annually by the Kosrae Conservation and Safety Organization (KCSO), a local NGO, to detect changes in benthic cover and fish abundance.

Methods

Reef Check methods and protocols are used by the government agencies in Kosrae to carry out monitoring. Details on the Reef Check methods can be found at: http://www.reefcheck.org.

Results and Discussion

Kosrae's coral reefs are generally in good to excellent condition, but some reefs have been impacted by coastal development. Unregulated mangrove clearing over the past two decades has resulted in shoreline erosion all along the coast and has caused sedimentation to occur on the adjacent reef flats and seagrass beds. Data has been collected annually from five permanent monitoring sites around the island for the past three years (Figure 14.6). Surveys conducted within and adjacent to the Utwe-Walung Marine Park indicated healthy coral cover, ranging from 80% at Hiroshi Point to 50% at the mouth of Utwe Bay. In contrast, live coral cover around the airport at Okat was less than 10% (M. Tupper, pers. comm.).

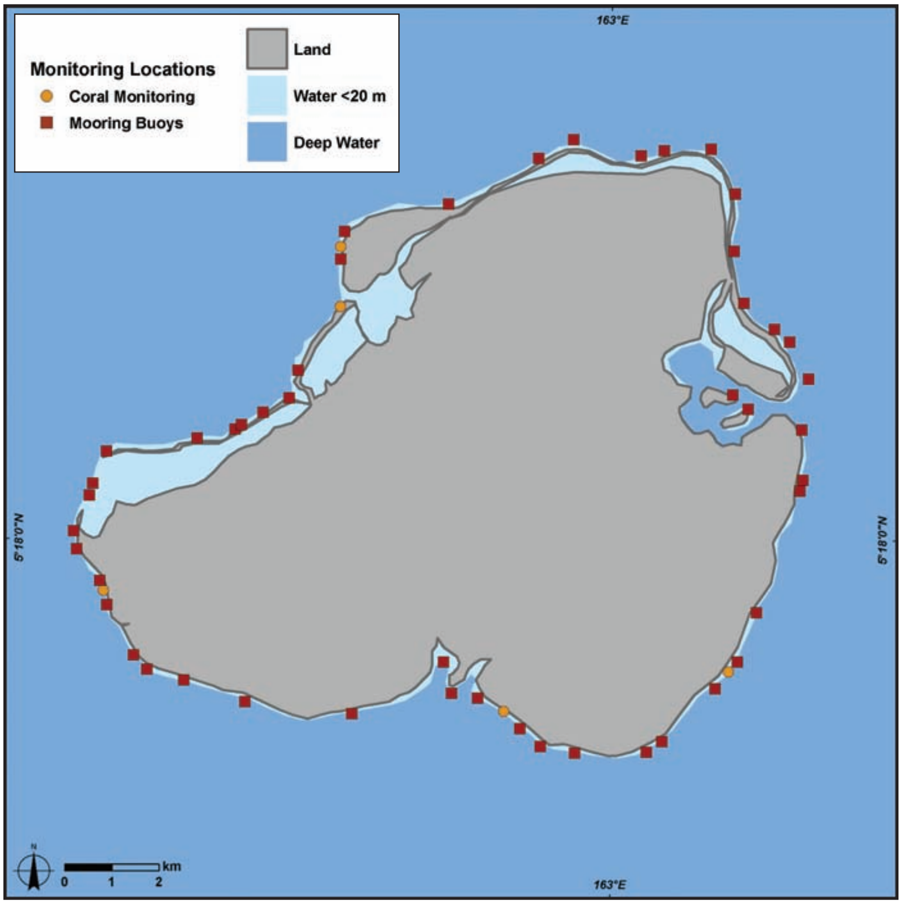

Figure 14.6. Locator map of monitoring sites and mooring buoys around Kosrae. Map: A. Shapiro. Data: Palau International Coral Reef Center, unpublished data.

Data on hard coral cover were collected at five monitoring sites around Kosrae by University of Guam scientist, Laurie Raymundo, and are presented in Figure 4.7. From left to right, the bars correspond to sites near Malem Reef Shelf, Hiroshi

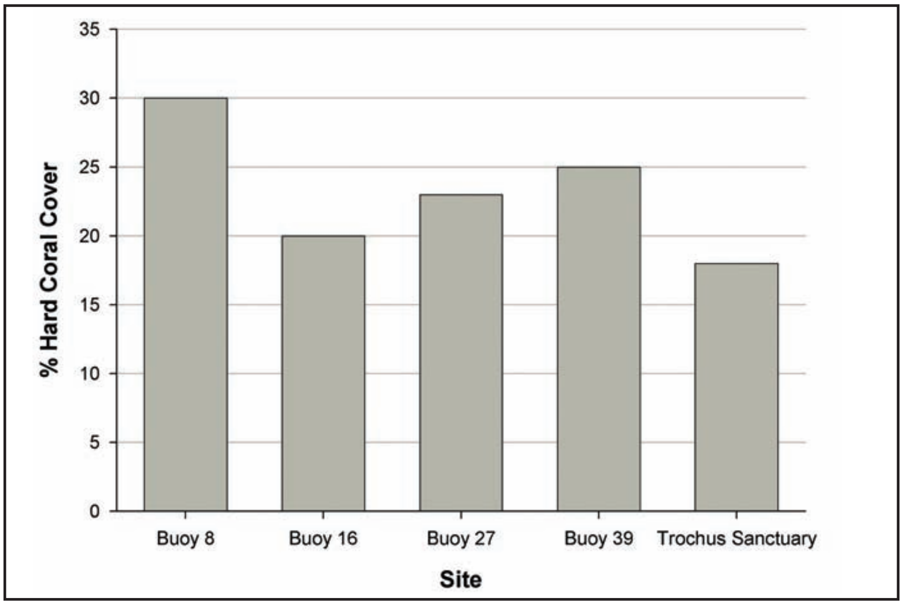

Figure 14.7. Percent cover of hard coral at Kosrae monitoring sites in 2002 at 10 m depth. Source: L. Raymundo, unpublished data.

Point, Walung Drop-off, Shark Island, and the Trochus Sanctuary, which is located near the airport on the north-west coast.

Conservation Society of Pohnpei (CSP) Marine Resource Monitoring

The CSP has been conducting monitoring activities in Pohnpei since 2001. This program monitors has several ecosystem components: 1) grouper spawning aggregations; 2) MPA effectiveness; and 3) changes in benthic communities over time.

Methods

The Australian Institute of Marine Science (AIMS) line-intercept method was used to record benthic communities at monitoring sites. At four of the MPA sites (Figure 14.8), 50 m belt-transects were used to assess fish and invertebrate abundance. The monitoring of the large grouper aggregations occurs during the peak spawning seasons during the first half of the year. They are monitored from 10 m to 30 m depths over several days each month in the spawning season.

Results and Discussion

The reefs around the island of Pohnpei vary in condition. Surveys performed adjacent to Sokehs Channel after a ship grounding found the average coral cover above 20%, and limited surveys around the main island show coral cover ranging from 10% to more than 80% at selected monitoring sites (Figure 14.9). Due to high annual rainfall and steep volcanic topography, erosion and sedimentation rates can be high. Upland clearing of forested areas to grow sakau (kava) has resulted in landslides and other impacts to coastal villages and resources.

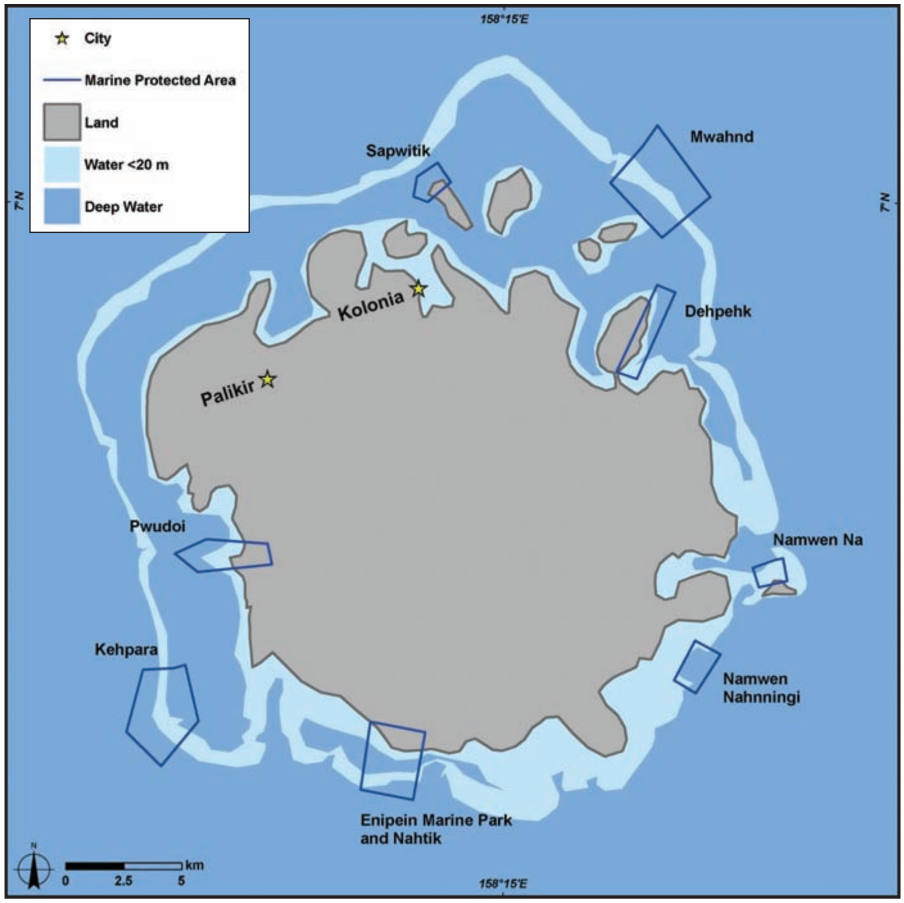

Figure 14.8. Several MPAs have been established in coastal areas of Pohnpei. Map: A. Shapiro. Source: Conservation Society of Pohnpei, unpublished map.

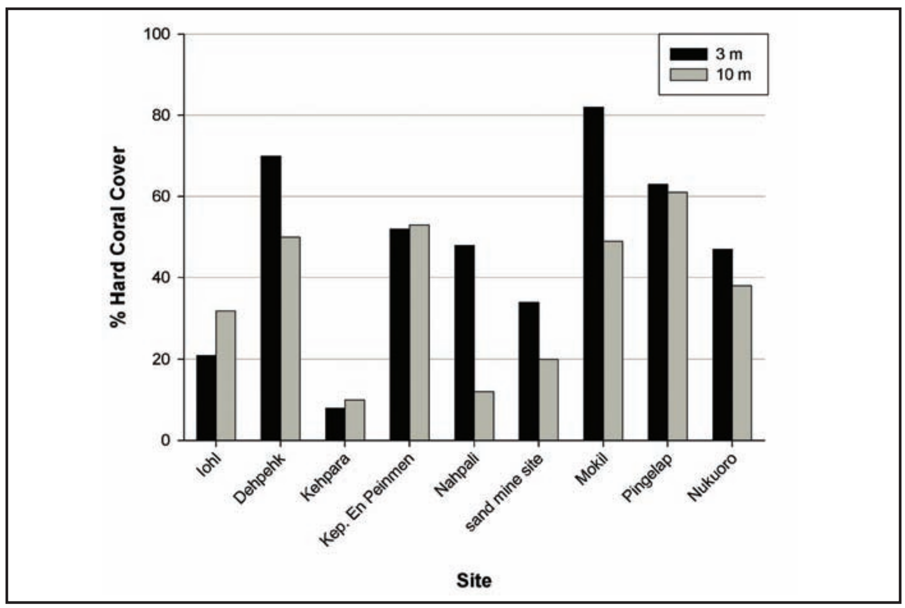

Figure 14.9. Limited surveys conducted at 3 m and 10 m sites around Pohnpei found hard coral cover percentages ranging from about 10% to 80%. Source: Conservation Society of Pohnpei, unpublished data.

Chuuk

The coral cover in Chuuk is indicative of generally high water quality, although overfishing has been observed as a result of foreign commercial activities. Destructive fishing practices, including the use of explosives taken from the wrecks, have caused localized damage in certain areas. Surveys conducted in 1998 at two sites showed that hard coral cover averaged around 25% on inshore reefs. Typhoon events in 2002 and 2003 caused structural damage to large sections of coral reefs, particularly in the lagoons.

Yap

Surveys of 18 sites around the island of Yap conducted in 1995 and repeated 16 months later found mean coral cover at 28.8% and 28.7% respectively (Richmond, 1997), even though a typhoon hit the island between surveys. Crustose coralline algae was also abundant on the reefs. Typhoon Sudal hit Yap in April 2004 causing widespread damage on the island as well as on the adjacent reefs. The potential damage to coral reefs in Yap has not yet been quantified.

FSM is increasing coral reef ecosystem monitoring efforts, focusing on coral cover, commercially important fish abundance, and the occurrence of reef fish spawning aggregations. The capacity to monitor coral reefs has improved since the 2002 status report (Turgeon et al., 2002). Since that time, all state marine resource agencies have received training in monitoring reef fish spawning aggregations and efforts are currently underway to identify and monitor any existing large aggregations of commercially important reef fish species. Kosrae State is continuing its annual coral reef monitoring program examining benthic cover and fish populations. In Pohnpei State, governmental and private environmental organizations have collaborated to develop a statewide coral reef monitoring program focusing on four permanent sites.

ASSOCIATED BIOLOGICAL COMMUNITIES

Recent surveys were undertaken by the Kosrae Fisheries Department to assess stocks of bumphead parrotfish, humphead wrasse, and groupers. Bumphead parrotfish, in particular, were once very important to Kosraean fisheries, but have since declined. The results of this survey were very disturbing. Not one commercially valuable grouper of any species was seen in 75 dives (M. Tupper, pers. comm.). This includes the squaretail coral grouper (*Plectropomus areolatus)* and camouflage grouper (*Epinephelus polyphekadion*). These species are known to form spawning aggregations at Kosrae, but much deeper than elsewhere in Micronesia (i.e., 100-120 m as opposed to 40 m in Pohnpei or 10-15 m in Palau). However, no catches of these species were recorded in the Kosrae reef fishery this year. The survey also recorded only three bumphead parrotfish and seven humphead wrasse in 75 dives. When interviewed, fishers suggested that Taiwanese and Hong Kong long-liners have been fishing the shelf edge illegally at night and have removed most of the groupers, humphead wrasse, and bumphead parrotfish. Unfortunately, fisheries officers could not confirm or deny this. Healthy spawning aggregations of snappers, surgeonfishes, and rabbitfishes are still known to occur at Kosrae.

Over 1,000 species of fish and over 1,200 species of mollusks are thought to be found in the FSM. 873 of the 1,125 marine fish species recorded for the FSM are reef-associated (FishBase, 2002). Overall catch and export data are limited, but some market information suggests the scale of the fisheries operation may be substantial. While commercial export has the greatest impact on FSM fisheries, overfishing by foreign vessels has also been documented. Yap and Kosrae have recently limited the export of reef organisms except for personal and family use, such as shipping coolers of fish to relatives on Guam and in the CNMI. Chuuk had the largest commercial export. Commercial export of fish and crab from Pohnpei occurred until a recent cholera outbreak caused it to shut down. Destructive fishing practices, including the use of explosives taken from the wrecks, have caused localized damage. Better quantitative assessments of fisheries resources within the FSM are needed.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Over the past several years, Kosrae has begun to develop a MPA program that involves co-management of coastal resources between local communities and state resource management agencies. Non-governmental organizations active in Kosrae include the Peace Corps and KCSO.

Kosrae has an extensive system of 54 mooring buoys around the island (Figure 14.6) designed to minimize anchor damage to corals at popular dive sites. Currently, Kosrae has four MPAs that are managed by government agencies and/or local communities. These are the Utwe-Walung Marine Park and three Areas of Special Concern: the Tukasungai (*Trochus niloticus*) Sanctuary (commonly referred to as the "Trochus Sanctuary"), the Giant Clam (*Tridacna* spp.) Sanctuary, and the Okat-Yela Mangrove Reserve. The Utwe-Walung Marine Park was created in 1996 to protect extensive mangrove and coral reef ecosystems along the undeveloped southern shore of Kosrae. The Marine Park is a community-based project managed by a Board of Directors that includes the park manager, private landowners, and directors and senior technical staff of several resource management agencies including the Kosrae Island Resource Management Program and Department of Land, Agriculture, and Fisheries-Division of Marine Resources. The Board is responsible for developing and revising the marine park management strategy, and plans to use the results of the community-based project to revise and improve the strategy. The stated objectives of the Marine Park are: to maintain and manage an area with ecologically valuable, undisturbed, and highly scenic features; to provide a variety of benefits, from the protection of natural habitat to enhancing the tourism and recreational appeal of Kosrae; and to provide opportunities for public education and scientific research.

Limited traditional and subsistence harvesting activities are permitted within the Marine Park. The Trochus and Giant Clam Sanctuaries are legislated under Kosrae State Code and managed by government agencies. The objective of the sanctuaries is to protect species of *Trochus* and *Tridacna* from overfishing, in addition to preventing logging and coastal development along the sanctuary shorelines. Unfortunately, Kosrae's MPAs are not strictly enforced, and surveys of reef fish and invertebrate biomass within and adjacent to protected areas show no difference in biomass of commercial species (Figure 14.10).

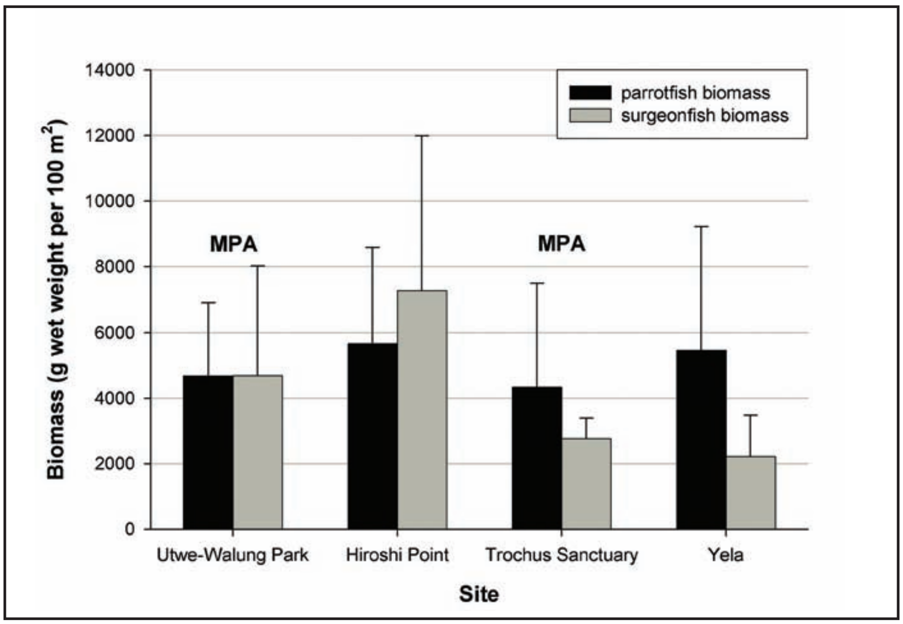

Figure 14.10. Biomass of commercially valuable parrotfish and surgeonfish in MPAs and adjacent fished areas in Kosrae, FSM. Source: M. Tupper, unpublished data.

Chiefs and other traditional leaders usually control protection of specific areas. In Yap, the villages own the reefs and have authority over resource use. A number of the islands have areas set aside for reef protection and limited resource extraction, but currently the FSM lacks the enforcement capacity to protect the MPAs (A. Edward, pers. comm.).

OVERALL CONCLUSIONS AND RECOMMENDATIONS

A number of conservation programs are in place for Kosrae's reefs. Mapping of coastal reefs and reef resources is ongoing. Unfortunately, the Kosraean government does not possess extensive finances, manpower, or technical expertise. Thus, it is important that both institutional and community capacity be strengthened and integrated to ensure sound management of Kosrae's coastal resources.

The coral reefs of Kosrae are in relatively good condition, but the effects of land use practices and reef fishing are cause for concern. The greatest need for Kosrae is an integrated watershed management program that will address both terrestrial (pollution and habitat destruction) and marine (overfishing) issues. In order to meet this need, more funding and support for resource management agencies are necessary.

Reef fisheries on some islands have been overexploited. Damaging blast fishery practices have been documented in Chuuk Lagoon as late as 1994 (J.E. Maragos, pers. comm.).

Improved coordination of management activities among the states is recommended. Educational programs involving the community need to be expanded. Ship groundings need to be addressed at the state and national level, possibly requiring vessels to post bonds to cover any damage to the reefs. Additional support for the resource agencies is necessary if they are to meet their mandates.

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The State of Coral Reef Ecosystems of the Commonwealth of the Northern Mariana Islands

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INTRODUCTION AND SETTING

The 290 km long Mariana Islands Archipelago encompasses 14 islands of the U.S. Commonwealth of the Northern Mariana Islands (CNMI), the U.S. Territory of Guam, and numerous offshore banks (Figure 15.1). From a geological perspective, the islands can be divided into two groups: a southern and a northern island arc region. Although the islands of the older southern arc, which includes Rota, Tinian, Saipan, and Farallon de Mendinilla (FDM), are volcanic in origin, they are nearly all covered with uplifted limestone derived from coral reefs. The West Mariana Ridge (WMR) is a series of seamounts, lying 145 to 170 km west of and parallel to the main island chains. Some of these mounts rise to within 13 m of the surface. The WMR is intermediate in age, as it is being younger than the southern island arc and older than the northern island arc. The southern arc islands have the oldest and most developed reefs in the CNMI, which are predominantly located along the western (leeward) sides. The majority of the CNMI's residents live on Rota, Tinian, and Saipan, the capital.

Southern Mariana Islands

Rota is 117 km southwest of Saipan and 76 km north of Guam, is the southernmost island in the Mariana Island Chain (Figures 15.1 and 15.2). It has a land area of 85.5 km^2 and is approximately 17 km long and 5 km wide. The principal communities are Sinapalo and SongSong. As Rota was neither developed extensively by the Japanese nor invaded during World War II (WWII), it still has much of its native vegetation. However, the island is becoming more of a tourist destination and development is increasing, which may impact the existing fringing reefs. Fringing reef surrounds the island and modern reef development is most significant on the northwest coast, west of Teteto Beach, and in the Sasanhaya Bay on the southwest coast. Continuous reef is found inside Sasanhaya Bay and an area along the western shore. Erosion along the Talakaya cliffline on the southern coast is causing sedimentation problems on adjacent reefs.

Aguijan (Goat Island) is an uplifted limestone island with a land area of 7.3 km^2 (Figure 15.1). It is presently uninhabited, although it was populated during WWII. The island is now under the management of the Tinian Municipal Council. The neighboring islet, Naftan Rock, was used as a bombing target prior to the U.S. Navy's use of FDM and unexploded ordnance remains in the surrounding waters. The island is now home to nesting seabirds. The reefs just off the northwest coast are the largest and most developed.

Tinian, with a land area of 102 km^2, lies 4.4 km south of Saipan, across the Saipan Channel (Figures 15.1 and 15.2). The principal community is San Jose. Nearly two-thirds of Tinian is leased to the U.S. Military. Tinian's coral reefs are more developed on the western side, most notably in the vicinity of the Tinian Harbor, an area likely to be negatively affected by future development.

Saipan, the largest of the Northern Mariana Islands, has a land area of 122 km^2 and is approximately 20 km long and 9 km wide (Figures 15.1 and 15.2). The island consists of a volcanic core enveloped by younger coral reef-derived limestone formations. The island has the most diverse types of coral reefs and associated habitats in the Commonwealth. A fringing and barrier reef system protects the majority of the beaches along the western and coastal plains. The western side of the island is the most populated and the coral reefs along these areas are negatively affected by human activity. Continuing sediment and nutrient pollution combined with sporadic stressors such as outbreaks of crown-of–thorns starfish (COTS) (*Acanthaster planci*) and temperature-induced bleaching affect many of Saipan's western and southeastern reefs. Furthermore, coral habitat on two large

1 Pacific Marine Resource Institute, Inc.
2 CNMI, Division of Environmental Quality
3 NOAA Fisheries, Pacific Islands Fisheries Science Center
4 CNMI, Division of Fish and Wildlife
5 University of Hawaii, Joint Institute for Marine and Atmospheric Research
6 NOAA Fisheries, Pacific Islands Regional Office

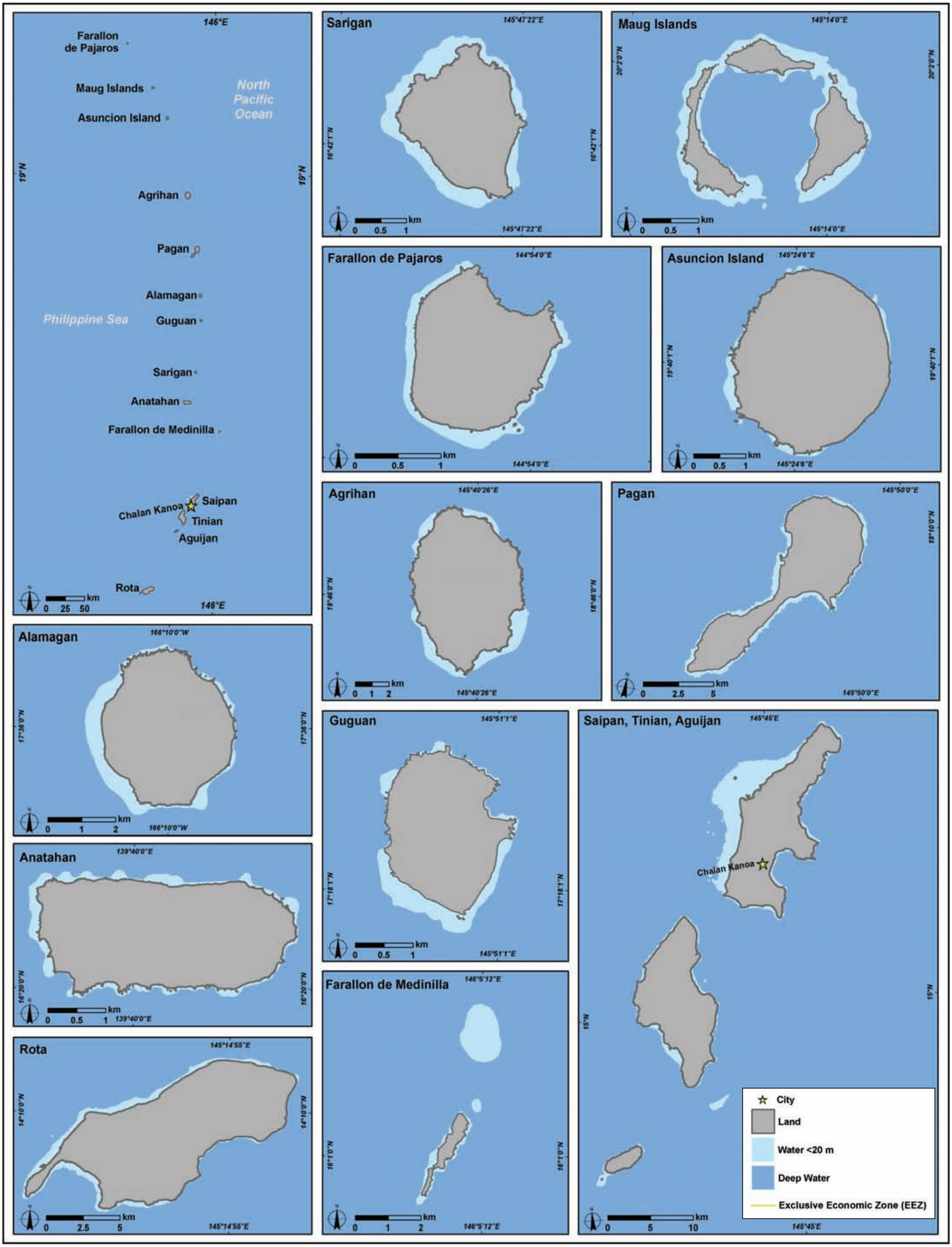

Figure 15.1. Locations in the CNMI mentioned in this chapter. Top left panel shows the spatial distribution of islands and banks in the chain; additional panels provide a closer view of the individual islands and banks. Map: A. Shapiro.

offshore banks (18 km x 22 km) in water depths between 30 m and 60 m on the western side of Saipan are negatively affected by the anchorage of commercial and naval vessels.

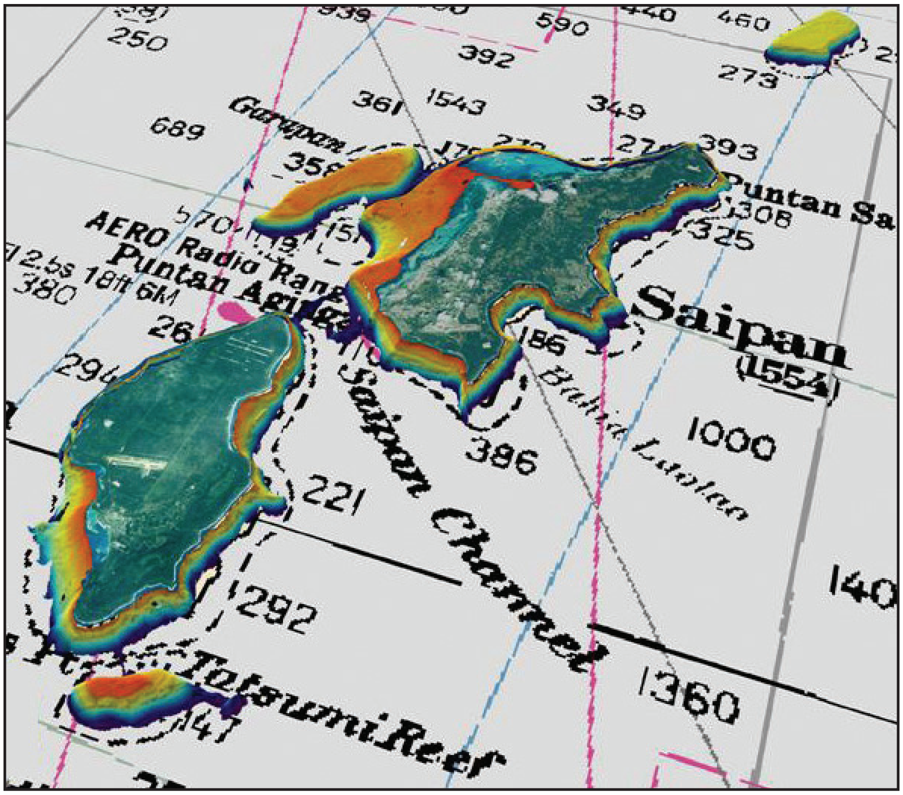

Figure 15.2. Detailed bathymetric map of Saipan, Tinian and Rota in the CNMI. Source: PIFSC-CRED, unpublished data.

FDM is a steep-sided, raised limestone island with a land area of 0.8 km^2 (Figure 15.1). The island supports one of the largest breeding colonies of Masked Boobies (*Sula dactylatra*) in the western Pacific along with several other species of seabirds. The island is surrounded by a fringing reef. Deeper habitat consists of pavement dotted with various sized boulders, some spur and groove formation, and sandy flats. A submerged platform reef with high coral cover exists off the center island lee. Shoal reefs, with a minimum depth of 6 m, occur approximately 1-2 km north of the northern tip of FDM. These reefs consist of complex channels and ridges with a biotic structure similar to that of the windward side of the island.

FDM is presently leased to the U.S. Military as a bombing range. A significant amount of controversy has arisen, especially in the past 10 years, with regard to the U.S. Navy's use of this island. The effects of bombing are causing accelerated erosion of the landmass.

A variety of fish species that have become uncommon around the populated islands of Saipan and Tinian are more abundant around FDM. Over 350 species of fish have been identified. In addition, survey teams have observed numerous sea turtles (including green and hawksbill) and numerous pods of whitebelly spinner dolphins. In addition, terrestrial wildlife surveys following military live-fire exercises have observed species of whale including Brydes, Sperm, and Humpback whales in the vicinity of FDM.

Northern Mariana Islands

Anatahan is a small volcanic island (32.4 km^2; Figures 15.1 and 15.4). Prior to this island's eruption on May 6, 2003, feral goats were creating severe erosion problems and the resulting sediment runoff was impacting the nearshore environment. A feral animal control program was started by the U.S. Fish and Wildlife Service (USFWS) and the Northern Island Mayor's Office, with financial support from the U.S. Navy. Ash fallout from the 2003 eruption caused extensive damage to nearshore reef habitats, especially on the northern side (Figure 15.3). Although all surveyed locations during the 2003 National Oceanic and Atmospheric Administration (NOAA) Marianas Research and Monitoring Program (MARAMP) cruise contained a layer of ash covering the substrate (Figure 15.3), portions of the south shore and southeastern corner had only a veneer layer. Anatahan provides a unique opportunity to observe recovery and development of reef communities over the next several decades.

Sarigan is an uninhabited volcanic cone with a land area of 4.9 km^2 (Figures 15.1 and 15.4). Sarigan has experienced no terrestrial impacts since the removal of feral animals, although fishery resources continue to be harvested. Since the elimination of feral animals on this island (1997-1998), the vegetation has dramatically recovered, presumably reducing sediment runoff. According to the NOAA MARAMP towed-diver surveys, continuous reef areas along the east and south shores contained roughly 50% live coral cover. The MARAMP dive at Sarigan revealed a layer of sediment that had been deposited from the 2003 Anatahan eruption.

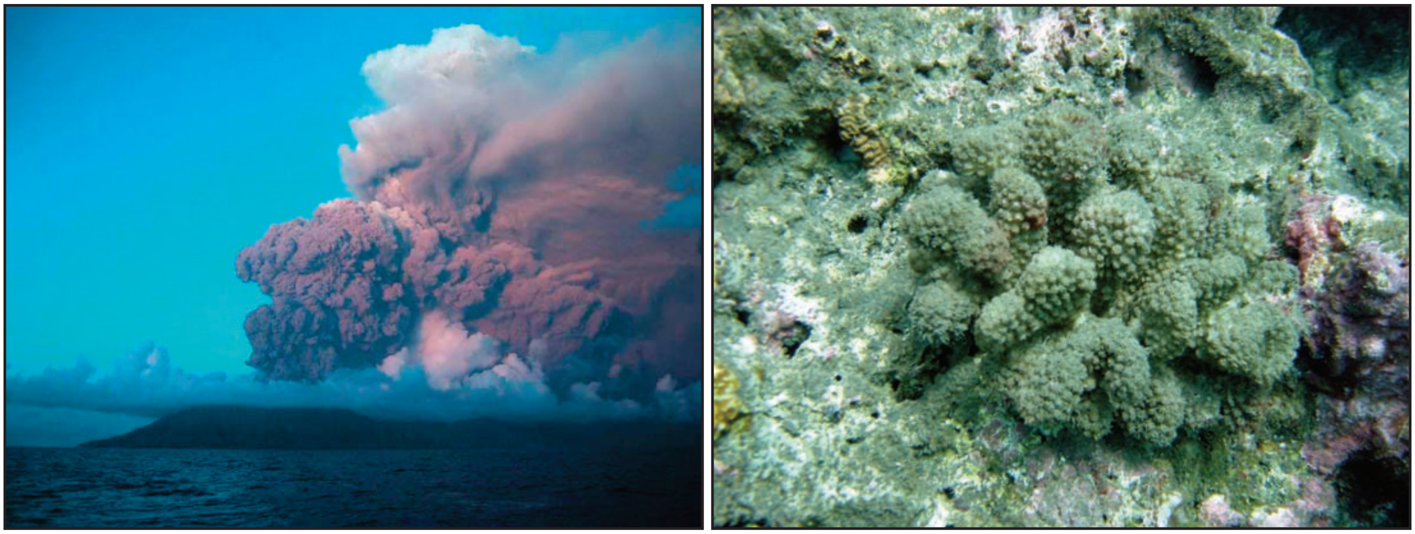

Figure 15.3. Left panel shows Anatahan Volcano eruption, May 11, 2003. Photo: CNMI Emergency Management Office. Right panel shows an ash covered habitat at Anatahan. Photo: S. Holzwarth.

Guguan has a land area of 4.1 km^2 (Figure 15.1) and is an active volcano with two cones, one of which is dormant. It is protected from development by the CNMI Constitution as it has been declared a wildlife conservation area, with large seabird colonies of Sooty Terns (*Sterna fuscata*), Gray-backed Terns (*S. lunata*), Brown Noddies (*Anous stolidus*), Black Noddies (*A. minutus*), and Red-footed Boobies (*Sula sula*). The reef communities observed around most of Guguan are as well developed as any seen in the northern islands, except for Maug. Unlike the exposed southeast shores of other northern islands, Guguan's southeast shore has developed reef communities.

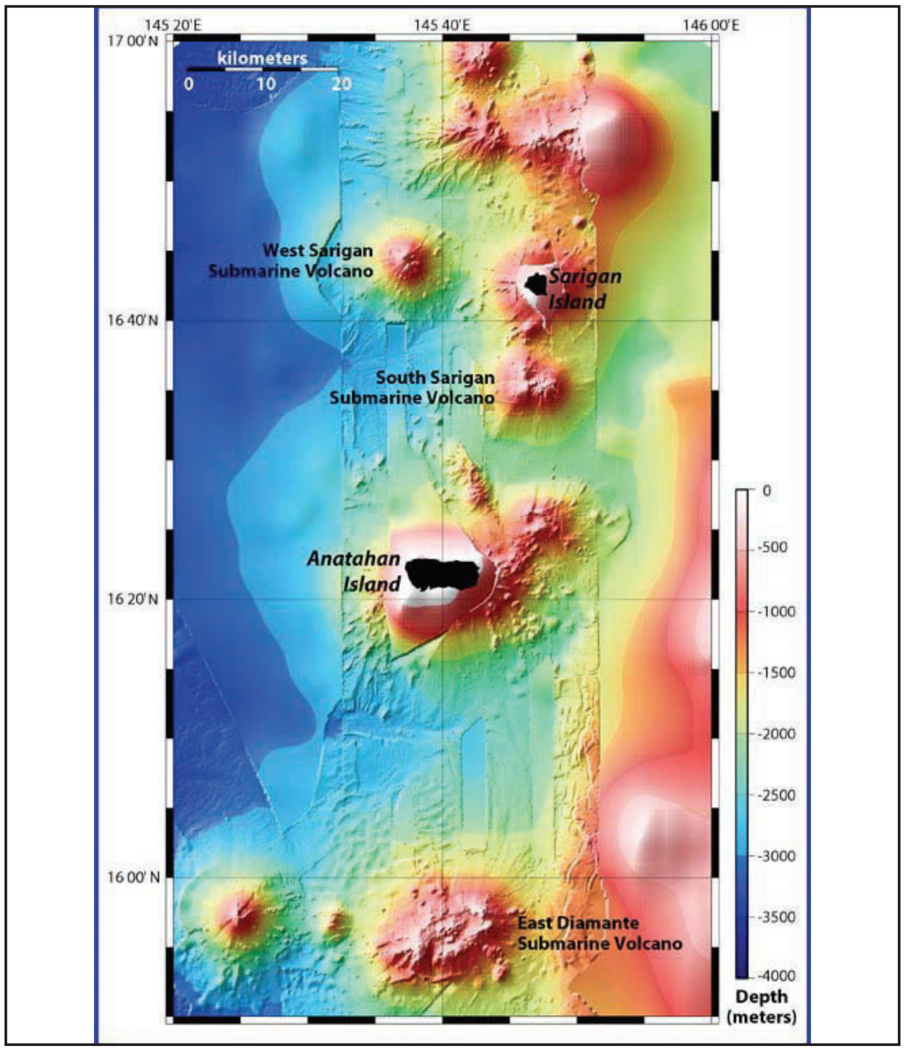

Figure 15.4. Map showing the volcanic islands of Sarigan and Anatahan. Zealandia Bank is also shown approximately 20 km north of Sarigan Island. The bathymetry data are a combination of satellite bathymetry overlaid with EM300 multibeam bathymetry, collected aboard the R/V *Thomas G. Thompson* in 2003 and 2004. Source: R. Embley and NOAA Ocean Exploration.

Alamagan, with a land area of 11.2 km^2, is an active volcano (Figure 15.1). Feral pigs, goats, and cattle are causing extensive damage to terrestrial ecosystems (T. de Cruz, pers. obs.). These terrestrial effects are likely linked to the marine environment through runoff and sedimentation. The reef communities at Alamagan are noticeably less developed than those observed at Guguan Island, which lies only 26 km to the south.

Pagan has a land area of 48.2 km^2 (Figure 15.1) and a volcanically active northern portion that is connected to a dormant southern portion by a narrow isthmus. A major eruption in 1981 caused the evacuation of residents and the ashfall negatively affected reefs (Eldredge and Kropp, 1985). Continuing erosion of unconsolidated ash is having unknown effects on the near shore environment. Large numbers of feral pigs and cattle are present. Cattle have been observed walking on the eastern fringing reef flats (T. de Cruz, pers. obs.). Fish surveys conducted by the CNMI Division of Fish and Wildlife (DFW) in the late 1990s found the nearshore fish resources to be in good condition.

Agrihan is a dormant volcanic cone, with a land area of 47.4 km^2 (Figure 15.1). The impact of feral goats and pigs is most evident on the eastern side of the island where resulting sedimentation and runoff is thought to have a significant effect on the marine environment. This is presently the only northern island that supports a permanent population, which currently stands at seven people.

Ascuncion Island is an active volcanic cone and has a land area of 7.3 km^2, which is protected from development by the CNMI Constitution, as it has been declared a wildlife conservation area (Figure 15.1). It is home to nesting colonies of Sooty and Gray-backed Terns (*Sterna fuscata* and *S. lunata*, respectively).

Maug consists of three small islands (Higashi, Kita, and Nishi), with a total land area of 2.1 km^2 (Figure 15.1) surrounding a flooded caldera that is considered to be a dormant volcano (Figure 15.5). The presence of countless seabirds on the three pinnacles that form the island of Maug provides a steady source of nutrients and organic matter into the caldera waters (Embley, 2004).

Maug is uninhabited and is protected from development by the CNMI Constitution. It has been declared a wildlife conservation area. Fisheries resources are currently harvested, although there has been some interest within the CNMI government to extend conservation to the coastal areas. Results from the 2003 and 2004 NOAA surveys (MARAMP and Ring of Fire) show that Maug, with 73 species recorded, is the most coral-rich island in the northern islands.

Farallon de Pajaros (*Uracas*) is an active volcano, with a land area of 2.1 km^2 (Figures 15.1 and 15.5). A major eruption and lava flow in 1943 affected coastal habitats. Very steep, sloping, boulder habitats surround Uracas, but provide little suitable habitat for corals. The reef is most developed on the southwest (leeward) side. Uracas was found to have the highest density of large predatory fish in the northern islands based on the MARAMP surveys.

Uracas is protected from development by the CNMI Constitution and has been declared a wildlife conservation area. Although Farallon de Pajaros translates to "the Island of Birds," only those Terns and Noddies that can nest on bare lava have established colonies. Seabird colonies were last surveyed in 1992.

Figure 15.5. NOAA Ship *Oscar Elton Sette* at Uracas Island during the MARAMP cruise in 2003. Photo: R. Schroeder.

Offshore Banks and Reefs

Tatsumi Reef

Tatsumi Reef is a steep-sided, flat-topped submerged bank approximately 2 km southeast of southern Tinian Island and is oriented in a northeast to southwest alignment. It is approximately 5.5 km long by 2 km wide, with a small secondary peak about 1.5 km to the west-southwest (Figure 15.6). The shallowest point on Tatsumi is approximately 6 m. In 2003, Tatsumi was surveyed using multibeam sonar and the R/V *Acoustic Habitat Investigator* (*AHI*; Figure 15.6). Two towed-diver surveys during the NOAA MARAMP cruise showed

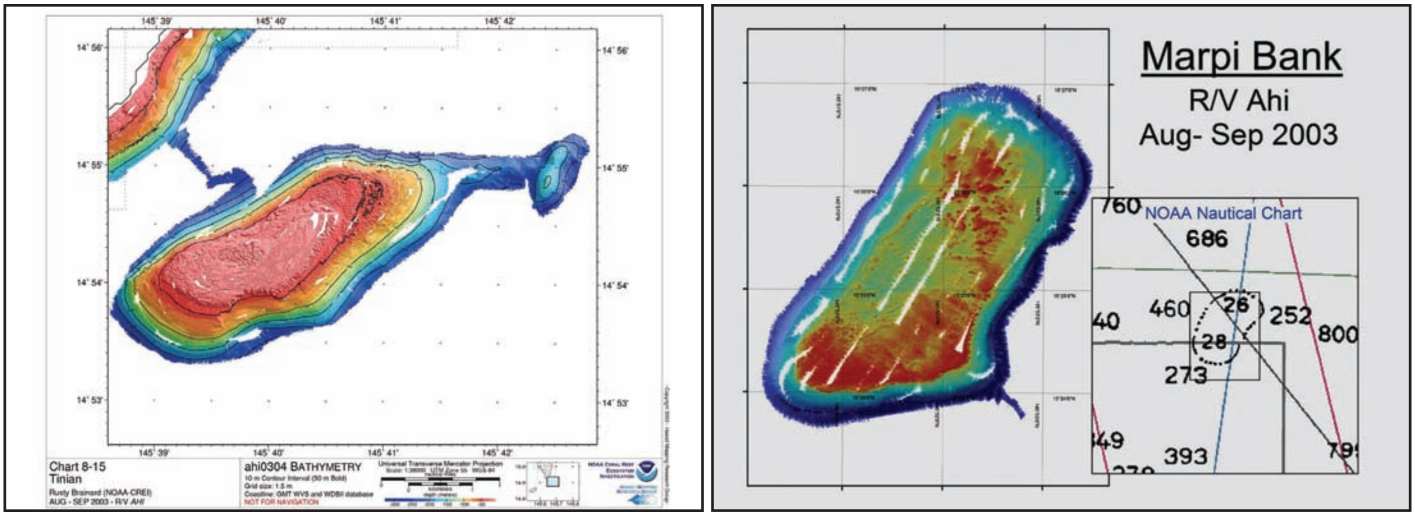

Figure 15.6. Multibeam bathymetric map of Tatsumi Reef, (~2 km southeast of southern Tinian Island; left panel) and Marpi Bank (~28 km north of Saipan; right panel). These field maps were created during the 2003 MARAMP surveys using R/V AHI. Source: PIFSC-CRED, unpublished data.

carbonate pavement to be the dominant habitat with low to moderate coral cover. Tatsumi is a popular fishing location, easily accessible from Tinian.

Esmeralda Bank

Esmeralda Bank is located approximately 37 km west of Tinian. There are two shallow banks plotted near Esmeralda Bank and NOAA's Nautical Chart 81004 shows four soundings less than 80 m in depth. One of these is a kidney-shaped area labeled "Active Sulphur Boil (1945)" with a depth of 30 fathoms (55 m) indicated on the chart. This bank does not exist, while the other bank and Esmeralda Bank are smaller than indicated on the chart. A multibeam survey of Esmeralda Bank was carried out during the NOAA Ring of Fire cruise in April 2004 (NOAA, 2003, 2004). Esmeralda Bank appears to have experienced recent volcanic activity and shows signs of current hydrothermal circulation (Embley, 2004).

Marpi Bank

Marpi Bank is a steep-sided, flat-topped submerged bank approximately 28 km north of Saipan. It is approximately 9 km long by 4 km wide and is oriented in a northeast to southwest alignment similar to Tatsumi Reef; the shallowest point shown on NOAA's Nautical Chart 81067 is 26 fathoms (53 m). Marpi Bank is also a popular fishing location. In 2003, Marpi Bank was surveyed using multibeam sonar and the R/V *AHI* (Figure 15.6).

Arakane Bank

Arakane Bank is located approximately 325 km west-northwest of Saipan. On NOAA's Nautical Chart 81004, it is identified by a single sounding of 5 fm (9 m). It is smaller than indicated on the chart and its true center is approximately 1 km southeast of the center of the charted bank. It was mapped in September 2003 using single-beam sonar and an underwater video camera (Figure 15.7) during the NOAA MARAMP cruise. Encrusting and fleshy algae, hard and soft corals, and sand were seen on hard substrate ridges.

Pathfinder Bank

Pathfinder Bank is located approximately 275 km west of Anatahan in the West Mariana Arc. Pathfinder Bank is 3 km southeast of its plotted position on NOAA's Nautical Chart 81004 and includes areas shallower than 10 m, rather than the 8 fathoms (15 m) shown on the chart. It was mapped in September 2003 using single-beam sonar and an underwater video camera during the NOAA MARAMP cruise (Figure 15.7). Hard and soft corals were found on ridges of carbonate pavement, separated by channels containing rubble.

Zealandia Bank

Zealandia Bank is located approximately 20 km north of Sarigan Island (Figure 15.4). This flat-topped bank with two pinnacles is surrounded by vertical walls. Rhodoliths, calcareous nodular bodies produced by algal accretion, and *Halimeda* algae beds were seen by video camera at depths of 115 m.

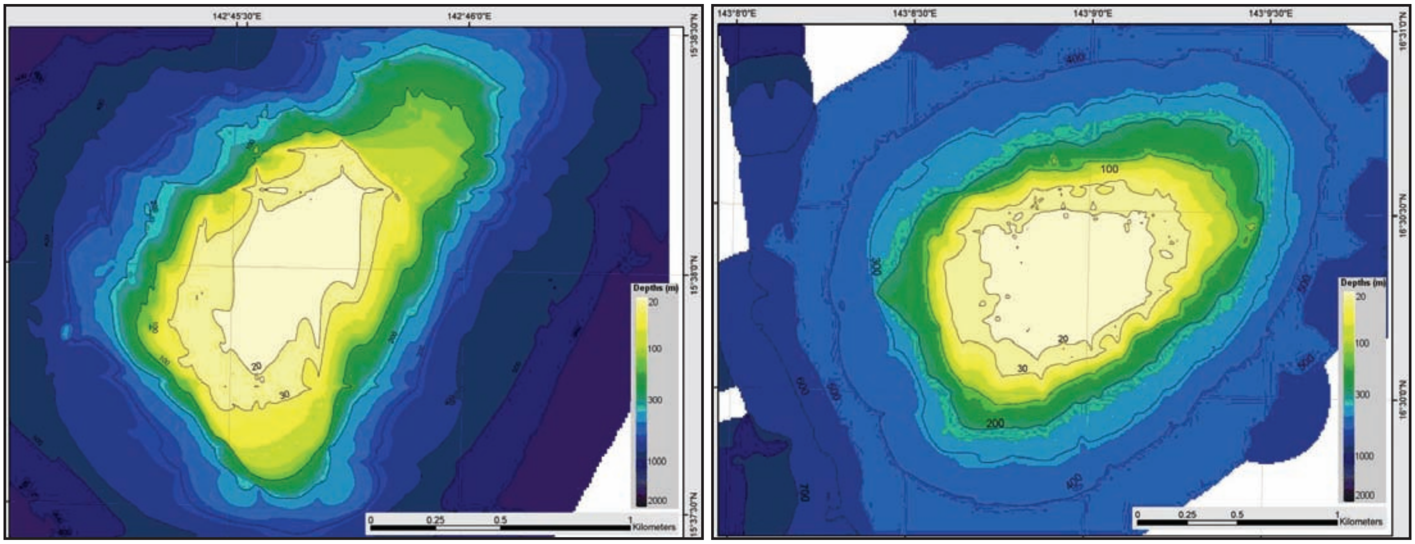

Figure 15.7. Bathymetric maps of Arakane Bank (left) and Pathfinder Bank (right) were made from single-beam soundings taken aboard the NOAA ship *Oscar Elton Sette* in September 2003. Source: PIFSC-CRED, unpublished data.

Supply Reef

Supply Reef is located approximately 18.5 km northwest of Maug Island and identified as two 5 fathom (9 m) soundings on NOAA's Nautical Chart 81004. Brief surveys were conducted from the NOAA ship *Oscar Elton Sette* in 2003. Hard and soft corals and rock were seen at this volcanic pinnacle during a video camera tow.

Stingray Shoals

Stingray Shoals is located approximately 275 km west of Uracas in the West Mariana Ridge. Stingray Shoals is a steep-sided pinnacle that has well-developed continuous reef on the small summit (~300 m x 500 m). Evidence of fishing activity is present, including anchors and long-line gear on the reef.

Socioeconomic Context

Population levels (Figure 15.8), habitation patterns, and the related impacts on reefs have varied tremendously over time. There is evidence of at least temporary settlement on all of the southern Mariana Islands, from Guam to FDM (Fritz, 1986).

In the 17th century, the entire population of the Mariana Islands was removed to Guam and Rota during the Spanish domination of the archipelago. It was not until the end of the 19th and beginning of the 20th century that the foundations of the modern communities in the CNMI returned from Guam and Rota (Spoehr, 2000).

Although some of the islands north of Saipan have held small permanent and seasonal communities, most permanent residents were evacuated in 1981 after the eruption of Pagan. A volcanic eruption also resulted in the evacuation of a small community on Anatahan in 2003. A community of seven individuals remains on Agrihan.

As the population of the CNMI continues to grow and diversify, its effects on adjacent reefs become more pronounced and complex. Fishing appears to have been at subsistence levels until at least the 1950s (Spoehr, 2000). More recently,

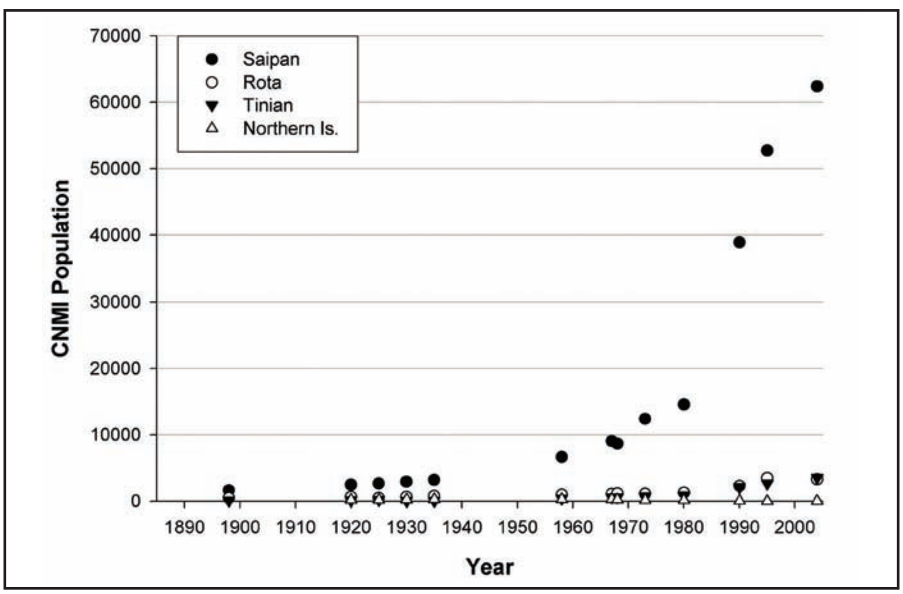

Figure 15.8. Yearly population growth in the CNMI from 1989-2004. Gaps indicate that no data was available. Source: various sources, compiled by J. Starmer.

fishing has grown in importance as a commercial venture with numerous permanent and roadside vendors evident around Saipan.

Tourism experienced a period of explosive growth in the late 1980s. The majority of tourism-related development has occurred along the western Saipan Lagoon. The importance of coral reefs as both a scenic backdrop and a focal point for recreational activities has grown along with the tourism industry. There is a clear recognition of the importance of the marine environment for tourism. However, negative effects have occurred in the adjacent marine ecosystems. Understanding the problems faced by CNMI's coral reefs is the first step in effective management.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

Coral bleaching has been noted in the CNMI several times since 1994. However, there has been no quantitative assessment of these events. In 1994, bleached corals were observed in water depths of 16 m at Akino Reef, at the eastern end of the western barrier reef in Saipan, and to a lesser extent in 1995 and 1997 at Unai Bapot in Lau Lau Bay, Saipan and at the site of a vessel grounding in Pagan (Tomokane, 1997). Over the summer of 2001, most shallow water areas (<3 m) on Saipan, Rota, and Tinian appeared to have been affected by bleaching as deep as 18 m. Many encrusting *Montipora* and staghorn *Acropora* corals died as a result. For instance, an *Acropora*-dominated backreef habitat in the Saipan Lagoon exhibited 50-72% mortality (CNMI Inter-Agency Marine Monitoring Team, unpublished data).

The 2003 MARAMP cruise reported 30-50% of relatively mild coral bleaching at the islands north of Pagan and < 30% at some of the more southern islands. The highest percentage of bleached coral was observed at the two northernmost sites surveyed, Uracas Island and Stingray Shoals. Two reefs on Maug and Ascuncion were exceptions to this trend, with no bleaching observed.

Diseases

With the exception of coralline lethal orange disease (CLOD), coral reef diseases are not well documented on CNMI reefs. Recent research by scientists from the University of Mississippi indicates that other diseases are prevalent, but further work is required to understand their ecological significance (D. Gochfeld, pers. comm.).

CLOD is common on most of the southern islands' reefs, but remains at low levels. Another possible disease of coralline algae (Littler and Littler, 2003), which forms concentric circles on live algae, has been recorded by the CNMI Inter-Agency Marine Monitoring Team (MMT) on Saipan and Tinian. The cause of the circular pattern is unknown.

Black-band disease is known from sight records from Tinian, in front of Taga Beach, and from Saipan, just south of Garapan's Lighthouse Channel. Coral tumors have been recorded in a number of species including *Isopora palifera, Acropora robusta, Montipora elschneri, Acropora digitifera, Porites lobata,* and *Astreopora myriophthalma.*

Tropical Storms

Typhoons are a routine part of the annual seasonal cycles in the CNMI (Figure 15.9). These storms can affect coral reefs even when they do not pass directly over an island. Increased swells can cause coral damage through direct wave impact and by shifting loose objects (e.g., coral, debris, grounded vessels) around the reef. The precipitation associated with typhoons also tends to increase sedimentation and nutrient inputs from polluted runoff.

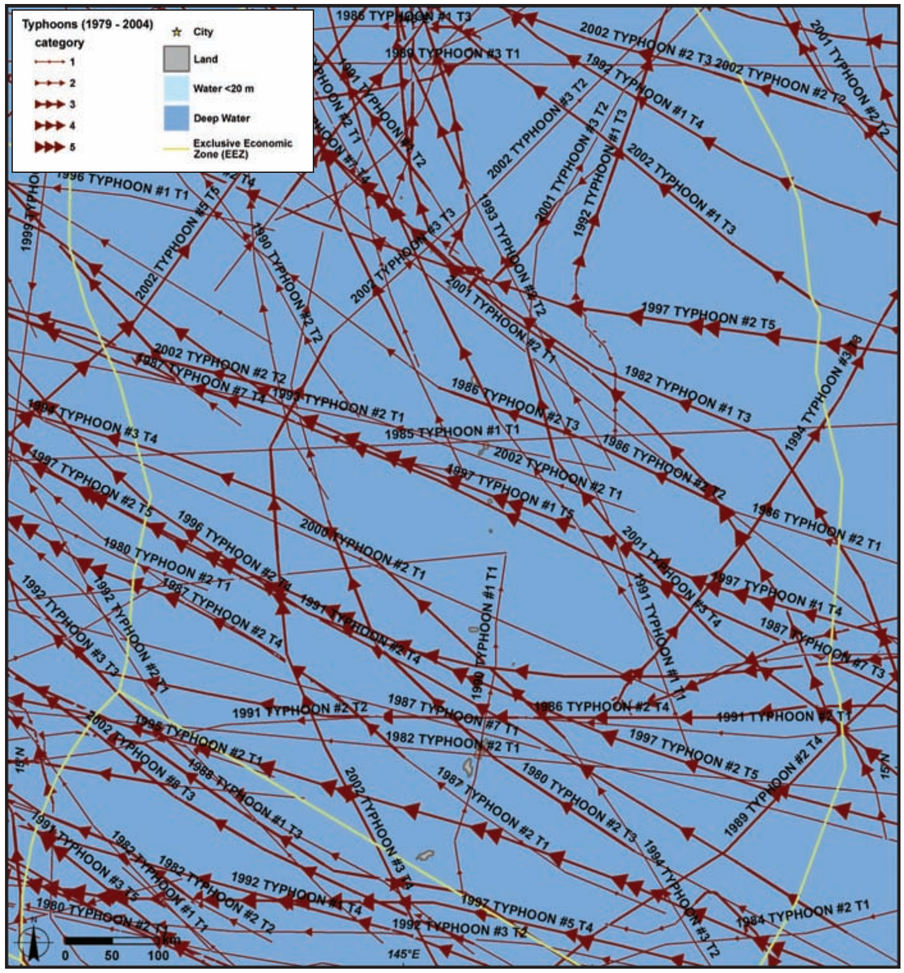

Figure 15.9. The path and intensity of typhoons passing near the CNMI from 1979-2004. Many Pacific typhoons are not named or the names are not recorded in the typhoon database. Map: A Shapiro. Data: UNISYS, http://weather.unisys.com/hurricane.

Coastal Development and Runoff

The boom in rapid urban development in the late 1980s and early 1990s has led to overburdened and failing waste management systems, increased negative effects from sedimentation, and added fishing pressures.

Coastal Pollution

As a whole, CNMI's marine waters meet the high water quality standards designated by the CNMI Division of Environmental Quality (DEQ). The majority of CNMI's marine waters are designated "Class AA" which reflects the highest water quality. Five areas in the CNMI have been designated "Class A" to allow for industrial activities (Table 15.1).

Table 15.1. Class A waters in the CNMI. Source: Houk, 2004.

WATER BODY	REASON FOR CLASS A DESIGNATION
Puerto Rico Industrial, Saipan	Commercial port and municipal waste outfall
Agingan Point, Saipan	Municipal waste outfall
East Harbor, Rota	Commercial port
West Harbor, Rota	Commercial port
San Jose Harbor, Tinian	Commercial port

Nonpoint Source Pollution

The beach warnings posted by the DEQ are, perhaps, one of the most constant reminders of the direct effects of human actions on marine water quality through nonpoint source pollution. In recent years, most microbiological violations occurred in areas with heavy stormwater runoff. Many of these sites were within the highly developed Garapan district, where drainage issues are in the process of being addressed. Other frequent violations occur within Saipan's marinas or in waters surrounding docks.

CNMI's three major inhabited islands have unpaved secondary roads that funnel soil and sediment into nearshore waters during periods of heavy rain, thereby increasing turbidity of nearshore waters. There have been several reports of sedimentation events associated with major construction projects (e.g., the Nikko Hotel, Lau Lau Bay Resort, and Bird Island Road) that were deleterious to nearshore corals. Treatment of secondary roads with crushed limestone without addressing drainage problems created chronic sedimentation problems along Lau Lau Bay and Obyan Beach. On several of the northern islands, deforestation and overgrazing has led to increased nearshore sedimentation. Deforestation from illegal burning has also created an area of eroding badlands on the southern coast of Rota.

Aerial photographs of FDM indicated that the island was eroding at an unprecedented rate. No quantitative studies have been conducted to determine whether bombing has resulted in increased sediment runoff from the island. However, reports of persistent areas of low visibility on the windward side of the island are not reported elsewhere in the CNMI.

Point Source Pollution

Only two sewage outfalls (Agingan and Sadog Tasi, Saipan) exist in the CNMI. Both sewage treatment plants are operated by the Commonwealth Utilities Corporation (CUC) and are designed to provide secondary treatment for an average daily flow of 3 and 4.8 million gallons per day, respectively. The Sadog Tasi's treated effluent is discharged through a marine outfall, approximately 365 m offshore into the Class A receiving waters off Tanapag Harbor, Saipan Lagood at a depth of 15 m. The Agingan plant's treated effluent is discharged at the surf line through an intertidal outfall into the Class A receiving waters of Tinian Channel. Individual National Pollutant Discharge Elimination System permits are issued to each plant. Both plants are presently in violation of local water quality standards (WQS). The U.S. Environmental Protection Agency (EPA) has been working with the CUC to address this. While progress is being made, there is no set deadline for these plants to come into compliance.

Reverse osmosis units used by hotels and other tourist-related facilities to improve the quality of the public water supply are discharged into the lagoon in several locations. These discharges contain nitrate and phosphate at up to 100 times above DEQ's accepted limits. The EPA issued Administrative Orders to all CNMI dischargers in 2002, resulting in the decision to allow discharges into injection wells. Injection wells have been installed at four of the reverse osmosis facilities, and plans were underway for the remaining facilities to be in compliance before the end of 2004. Once accomplished, all reverse osmosis discharges to Commonwealth waters will cease.

Tourism and Recreation

The Coastal Resources Management Office (CRM) regulates commercial marine sports through its permitting process. Scuba diving, personal watercraft (jet skis), banana boats, parasailing, submarine tours, and other motorized marine sports activities must receive permits from CRM (Table 15.2). The CRM has further designated jet-ski exclusion zones near hotels, shallow reefs and seagrass areas.

Table 15.2. Number of marine sports activity permits issued by CRM in 2003. CRM has implemented a zoning plan and permitting program for several recreational and tourism activities. Source: CNMI, CRM.

PERMITTED ACTIVITY	SAIPAN	ROTA	TINIAN	TOTAL
Jet ski	12	0	2	**14**
Banana Boat	17	0	2	**19**
Parasailing	10	0	1	**11**
Sea/Aqua Walker	4	0	0	**4**
Scuba	27	1	2	**29**
Snorkel Tours	2	0	0	**2**
Misc. Marine Sports	10	0	0	**10**

Fishing

Coral reef fisheries are difficult to manage, as these fisheries are typically multi-species and harvested by a wide variety of gear types. In the CNMI, conventional controls on catch are hard to justify socially while gear restrictions and size limits are virtually impossible to administer. Human pressures on coral reef fisheries combined with developmental perturbations have been detrimental to reef habitats and subsequently to reef fish resources. In short, management of coral reef fisheries in the CNMI has not provided protection against the overexploitation of reef fish resources and degradation of marine habitat by human-induced activities.

The DFW Fisheries Data Section collects commercial landings data through a voluntary vendor invoice system. These data list the pounds sold and the corresponding value, with reef fish typically lumped together under the general heading of "Reef Fish." A confounding factor with this system is that many reef-associated species, such as Lethrinids and Serranids are grouped under "Assorted Bottomfish," and Lutjanids are grouped with "Assorted Reef Fish." The commercial landings of reef fish have been fairly constant over time, averaging about 143,400 lbs, (65,000 kg) although catch per unit effort (CPUE) has steadily decreased from a peak in 1994 (Figure 15.10).

In general, CNMI fisheries are in good condition, although local depletion was determined to exist in the southern islands, especially on the lee aspect of Saipan. Surveys conducted by the University of Guam in 1979 and in collaboration with DFW in 1996 revealed that considerable changes had occurred for some major food fish groups in Saipan Lagoon (Amesbury et al., 1979; Duenas and Associates, Inc., 1997; Figure 15.11).

Additionally, the DFW conducted a sampling program of the reef fish scuba-spear fishery from 1993 to 1996. Data from these surveys resulted in two DFW technical reports (Graham, 1994; Trianni, 1998b) that indicated local depletion for some species of commercially important reef fish. Comparitive analyses of parrotfish landings from a scuba-spear fishery in the northern islands with a scuba-spear fishery in the southern islands revealed a decrease in the percentage of terminal phase males both spatially and temporally (Trianni, 1998b; Table 15.3). Reef fish scuba-spear CPUE was noted to have declined between 1993 and 1996.

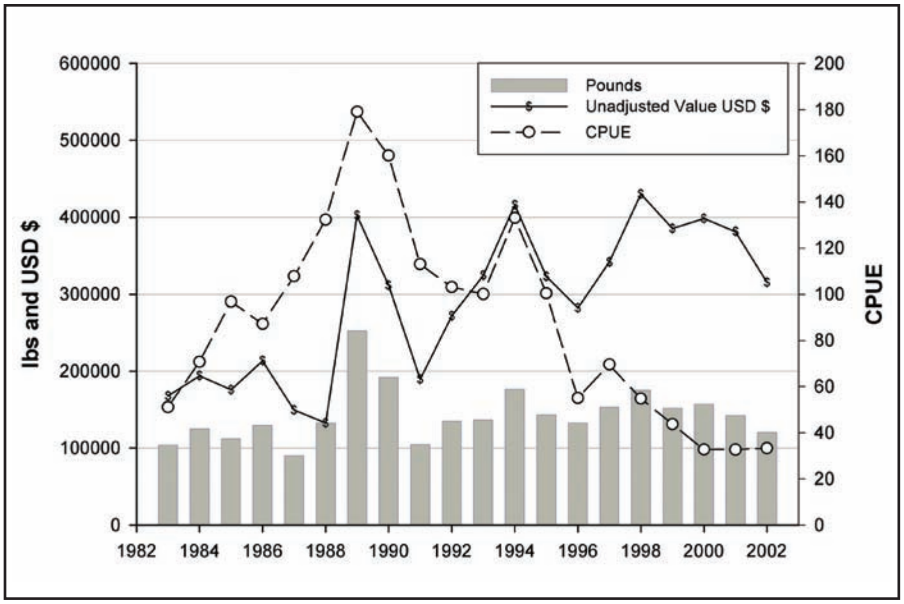

Figure 15.10. Reef fish CPUE, commercial landings and value in USD as estimated from the voluntary invoice system. Source: CNMI DFW, unpublished data.

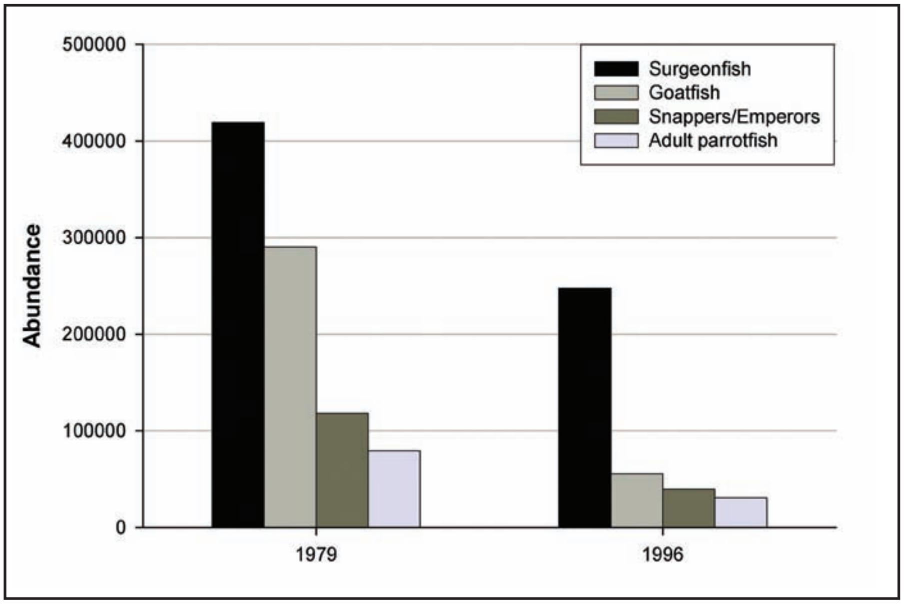

Figure 15.11. Changes in estimated abundance of some commercial reef fish between 1979 and 1996 surveys in Saipan Lagoon. Source: CNMI DFW, unpublished data.

Table 15.3. Percentages of terminal phase parrotfish from the Northern Islands and Southern Islands for two sampling periods. ND = no data. Source: CNMI DFW, unpublished data.

PERIOD/ DATES	NORTHERN ISLANDS	SOUTHERN ISLANDS	SAIPAN	TINIAN
Period 1 (1993-1994)	78	52	48	53
Period 2 (1995-1996)	ND	66	61	68

Over the past several years, the DFW noticed a major increase in the numbers of imported reef fish into the CNMI (Figure 15.12). As a result of these findings, the CNMI Department of Lands and Natural Resources (DLNR) and DFW initiated regulatory changes that restricted the use of gill, drag, and surround-nets, and scuba and hookah spear fishing in the CNMI. Reef fish abundance will be monitored closely over the next several years for signs of recovery in areas where localized depletion was observed.

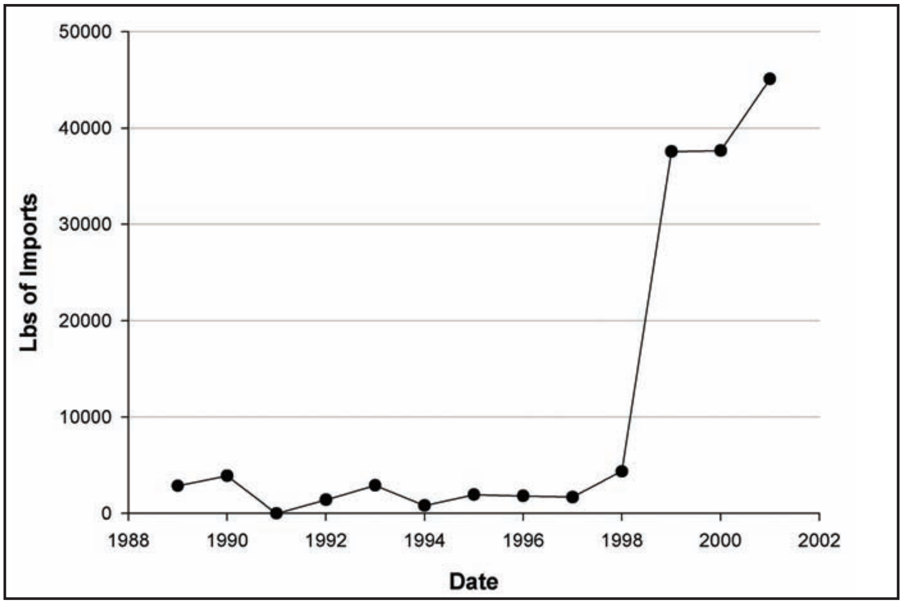

Figure 15.12. Reef fish imports into the CNMI between 1989–2001. Source: CNMI DFW, unpublished data.

DFW regulation prohibits the use of explosives, chemicals, poisons, and electronic shocking devices. The extent of such illegal practices is unclear. There exists no evidence that explosives or electronic shocking devices are currently used for harvesting fish. The use of rotenone, a poison extracted from a plant (*Derris* spp.) has been reported by DFW conservation officers, although the use of other poisons or chemicals has not been verified.

Invertebrate fisheries

A historical fishery for sea cucumbers targeting *Actinopyga mauritiana,* with incidental captures of the black teatfish, *Holothuria whitmaei*, was active from 1995-1996 on Rota and Saipan (Trianni, 2002). The fishery was closed in 1997 due to declining catch. In 1998, a 10-year moratorium was placed on the harvest of sea cucumbers in the CNMI, creating the largest no-take zone for these invertebrates in the world.

The introduced topshell *Tectus niloticus* has been placed in a harvest moratorium since 1981. Although this moratorium is continual, the DLNR Secretary can lift the moratorium and declare an open season following consultation with the DFW Director. This was done in 1996 and a two-month open season ensued (Trianni, 2002). In addition to the state of moratorium, two protected areas for *Tectus* were also established in 1981 - one at Tank Beach on the windward side of Saipan, and the other along a one-mile section of the barrier reef at Saipan Lagoon.

Trade in Coral and Live Reef Species

DFW regulation prohibits the export of live fish for consumption and restricts the export of live fish for the aquarium trade. The collection of reef fish for commercial and personal display is also regulated by the DFW. The number of commercial or personal display permits has been low since 1996, never exceeding five per year. The DFW issues a limited number of permits for the production of slaked lime (locally known as *afuk*) from dead coral for cultural purposes. Lime is traditionally chewed with betel nut (*Arecia* sp.). Much of the lime for this purpose is now being imported from Yap, Federated States of Micronesia, or the Republic of Palau. The number of permits granted from 1996-2004 has ranged from none to four per year.

Ships, Boats and Groundings

Anchoring

Anchor damage is noticeable at some popular fishing and dive sites in the Mariana Islands. At present, there are no restrictions on recreational anchoring outside of marine protected areas (MPAs). Concern over anchoring effects prompted the installation of moorings at most commercial dive sites around Saipan, Tinian, and Rota. The Northern Marianas Dive Operators Association (NMDOA) reports that the installation of these moorings has resulted in noticeable improvement in the corals at these sites and the organization has continued to independently maintain the moorings. U.S. Coral Reef Initiative funds have allowed the purchase of additional mooring maintenance and installation materials. New moorings were installed on Rota thanks to the local efforts of Dive Rota and will be installed with the assistance of NMDOA at sites on Saipan and Tinian in the coming year.

The anchoring of large commercial vessels on the extensive shallow (25-40 m) reef platform to the west of Saipan has been impacting reef coral habitat since the mid-1990s. DFW has obtained some data on vessel anchorage behavior. The number of days at anchor from December 1999 to March 2001 ranged from 3-42. For the same period, the number of pre-positioned vessels at anchorage at any one time ranged from 1-5, with the effective range being 2-4.

DFW Anchoring Study

The DFW Fisheries Research Section undertook dive surveys in May and June 2002 to obtain preliminary data on fish and benthic habitat in high use anchorage zones and control sites (Table 15.4). The sample sizes were relatively small at each site, given the average survey depth of 30 m and the restricted available bottom time.

Table 15.4. Differences in ecological parameters at commercial anchorage and control sites off the west coast of Saipan. Source: CNMI DFW, unpublished data.

	ANCHORAGE (n=6)	CONTROL (n=2)
Fish Density	2.3	2.4
Density Range	0.6 - 4.8	1.1 - 4.5
# Species Range	14 - 29	16 - 31
% Live Coral Cover	9.2	6.3
% Algal Cover	40	35.6
% Abiotic Benthos	50.2	56.6

Methods

Fish stationary point counts (SPCs) involved the identification of all species within 5 m circular areas. Benthic sampling (n=30; n=20), involved documenting 16 random points inside a 0.5 m^2 quadrat.

Results and Discussion

Results from the preliminary fish surveys indicated very little difference between the sites, although the sample size was small. Terminal phase parrotfish, however, were more abundant at control sites (mean of 5.5/5 m diameter) than at anchorage sites (mean of 0.7/5 m diameter). Large snapper and wrasse, as well as schools of fusiliers and unicornfish were observed in the vicinity of a control site.

Benthic surveys indicated a greater percentage of live coral cover and lesser percentage of abiotic benthos at control sites. The overall results of the preliminary survey showed lower fish abundance and diversity as well as lower coral cover. It is noteworthy that recreational fishing activity occurs in this general area.

During the August and September 2003 MARAMP cruise, the R/V *AHI*, used a combination of multibeam echosounder and side-scan sonar to survey the pre-positioned vessel anchorage near Saipan Lagoon. The NOAA ship *Oscar Elton Sette* conducted some underwater video and photographic observations in the anchorage zone during the same period using a tethered optical assessment device (TOAD). In November 2004, NOAA Fisheries, DFW, and DEQ conducted an extensive TOAD survey of the pre-positioned anchorage zone. Following this survey and development of the resulting products, the U.S. Navy plans to expand the number of pre-positioned vessels in the anchorage area.

Abandoned and Grounded Vessels

Nineteen vessels, ranging in size from commercial steamers to canoes, are recorded to have been lost in the CNMI between 1600 and 1940 (Carrell, 1991). Between 1940 and 1946, numerous vessels are recorded to have been sunk in the vicinity of the Mariana Islands (e.g., 38 around Saipan), but only 15 of them appear to have sunk or grounded in nearshore waters (Carrell, 1991). Wreckage of tanks, landing craft, airplanes, and pontoons from WWII are also visible on coral reefs. These craft are considered an important part of the historical record and are unlikely to be removed.

In the past two decades, more than 20 commercial vessels have grounded in the CNMI. The majority of these groundings were typhoon-related and two were the result of operator error. Some of these vessels have since been removed, but nearly half remain in the water. Although these vessels were reportedly cleaned of fuel and oil, they still pose a threat to coral reef habitat as they break apart and their parts are moved across reefs during storms.

Salvage operations of various kinds have also resulted in further disturbance to the marine environment. Salvage operations on Spanish galleons in the CNMI, including the *Nuestra Señora de la Concepción* on Saipan and the *Santa Margarita* on Rota, have caused negative impacts to coral reef environments during the excavation activities.

In addition, small vessels cause damage to the marine environment. One area of seagrass habitat in the Saipan Lagoon was recently discovered by the MMT to contain a mosaic of propeller scars.

CRM intends to coordinate the development of a CNMI Vessel Grounding Action Plan that will guide the CNMI in closing communication gaps, creating or revising laws and regulations, strengthening enforcement, developing preventative measures, and addressing funding and resources limitations. NOAA has provided technical assistance and nominal monetary assistance for grounded vessel inventory and removal.

Marine Debris

While some marine debris washes in from offshore and is deposited on beaches, most of the Southern Mariana Islands have cliffs and limited reef development along the windward (eastern) shores. This limits the opportunity for oceanic marine debris to end up on reefs. A greater problem is debris originating from local, land-based activities. Both the DEQ and CRM have active anti-litter education programs. In addition, the DEQ and several civic groups sponsor monthly beach cleanups. Annual reef cleanups have also been sponsored by local resource management agencies. As a result, marine debris does not generally accumulate on or near local reefs and is considered a minor concern in the CNMI.

Aquatic Invasive Species

Mollusks

The only successful intentional introduction of a marine species in the CNMI has been that of *Tectus niloticus* (locally known as *aliling tulumpo*). *T. niloticus* was introduced as a commercial venture by the Japanese in 1938. Its harvest was essentially unregulated after WWII, prior to the formation of the CNMI. A continual moratorium is presently in effect, although the DLNR Secretary can lift it when the resource is deemed exploitable. Two no-take reserves are established: one at Tank Beach, and the other along the western barrier reef of Saipan Lagoon, called the "Lighthouse Reserve." As an industry, harvests of *Tectus* shells were limited by availability of suitable habitat (Adams et al., 1994). The effects of its introduction on other marine organisms are not known.

The giant clam species, *Tridacna derasa*, was imported from the Micronesian Mariculture Demonstration Center (MMDC) in Palau and released in Saipan in 1988. In 1991, 2,000 *Tridacna derasa* and 2,000 *T. gigas*, as well as some *Hippopus hippopus* and *Tridacna squamosa*, from MMDC were placed in cages in Saipan Lagoon as part of a regional growth study. These introductions failed to produce desired economic benefits and the growth study was hampered by poaching. In 2001, several species of *Hippopus* were found in Saipan Lagoon during surveys by the MMT, although it appears unlikely that the few surviving individuals comprised a reproductively viable population. Currently, there are plans to commence with another aquaculture venture in the CNMI using the same four giant clam species from the renamed Palau Mariculture Demonstration Center. This project is expected to commence in early 2005.

Fish
Red tilapia (*Oreochromis mossambica*) was intentionally introduced to brackish lakes on Saipan, Pagan, Tinian, and Anatahan between 1955 and 1957. It is currently cultivated at the Northern Marianas College (NMC) Aquaculture Center, and is also provided by the NMC as an outreach product for use in private ponds. This species is currently being kept in open-system pools next to the Saipan Lagoon in fully marine water. There is a distinct possibility that these animals could enter the Saipan Lagoon and become established.

Ballast Water
The potential for the introduction of invasive species through the discharge of ballast water exists in the CNMI, but the threat has not been evaluated. As the CNMI is primarily a destination rather than a source of goods, most vessels are more likely to take in rather than discharge ballast. Commonwealth Ports Authority regulations prohibit discharge of ballast water within the commercial port areas.

Security Training Activities

FDM
In 1998, the U.S. Navy completed an environmental impact statement (EIS) as required by Section 102(2)(C) of the National Environmental Policy Act of 1969 (P.L. 91-190). As a result of that process, it was determined that an annual marine survey must be conducted for a three-year period from 1999 through 2001. Subsequently, the Navy decided to continue annual surveys as long as FDM was being used for training activities. The DFW requested that the U.S. Navy continue to fund surveys even after cessation of training activities. The yearly reports stemming from these surveys indicated that damage to the nearshore coral reef environment was minimal. However, it appears that use of live explosives has resulted in accelerated erosion at FDM.

The FDM area serves as prime fishing grounds for large and small vessels from Saipan. The distance from FDM to Saipan (roughly 80 km) makes it relatively inaccessible to boaters except during favorable seas. In addition, the U.S. Navy claims a three-mile exclusion zone around FDM, which is extended to 10 miles during live-fire military training activities, thus further limiting annual fishing effort.

Tinian
During WWII, the island was almost entirely a military base. Waste disposal in the northern part of the island has resulted in several formerly-used defense sites that are awaiting cleanup. Leaching of materials into groundwater is a concern. Debris from both WWII invasions and later dumping activities remains embedded in the reef along the west coast of Tinian.

The U.S. Navy presently leases approximately two-thirds of the northern portion of Tinian for training exercises and maneuvers. Results of qualitative surveys reveal very little damage to the reef structure from these activities. In general, recent military activities on Tinian have been conducted with a high level of sensitivity to the potential impact on the environment. However, because of the large number of personnel and equipment involved in some of the Navy's exercises, the CNMI should continue to monitor these activities.

Offshore Oil and Gas Exploration
Offshore oil and gas exploration are currently not an issue of concern in the CNMI.

Other

COTS
Outbreaks of COTS (*Acanthaster planci)* have occurred in the late 1960s, 1984, and 1990s. Control programs during the 1969-1970 period removed nearly 14,000 of the animals from Rota, Saipan, and Tinian (Tsuda, 1971). An outbreak also occurred at Putan Taipingot, Rota in 1995 (M. Michael, pers. comm.). Presently, the starfish has been noted in low numbers on most surveyed reefs in Aguiguan, Rota, Saipan, and Tinian. Three areas with apparently persistent and dense populations have been identified by the MMT: the eastern side of Puntan

Naftan (near Boy Scout Beach), Lau Lau Bay Site 2 on Saipan, and Unai Babui on the eastern side of Tinian. At Boy Scout Beach, *A. planci* does not appear to have a significant effect on coral cover (Figure 15.13), but may be the causal agent for changes in coral community structure (Figure 15.13).

During the 2003 NOAA MARAMP cruise, towed-divers observed few COTS in the northern islands (Table 15.5). *A. planci* were more prevalent in the southern island arc. Towed-divers recorded 2.2 COTS per km at Tatsumi Reef, 4.2 COTS per km at Saipan, 1.8 COTS per km at Tinian, 6.4 COTS per km at Aguijan, and 10.5 COTS per km at Rota(Figure 15.14).

Volcanic Eruptions

Volcanic eruptions have been sporadic (Table 15.6), but appear to have great influence on the coral communities on some of the geologically active northern islands (Eldredge and Kropp, 1985). Monitoring the recovery of reefs affected by the 2003 eruption of Anatahan will allow an improved understanding of the abilities of coral reefs to recover from these events and the role that volcanic disturbance has played in shaping the reef ecosystems in the northern islands.

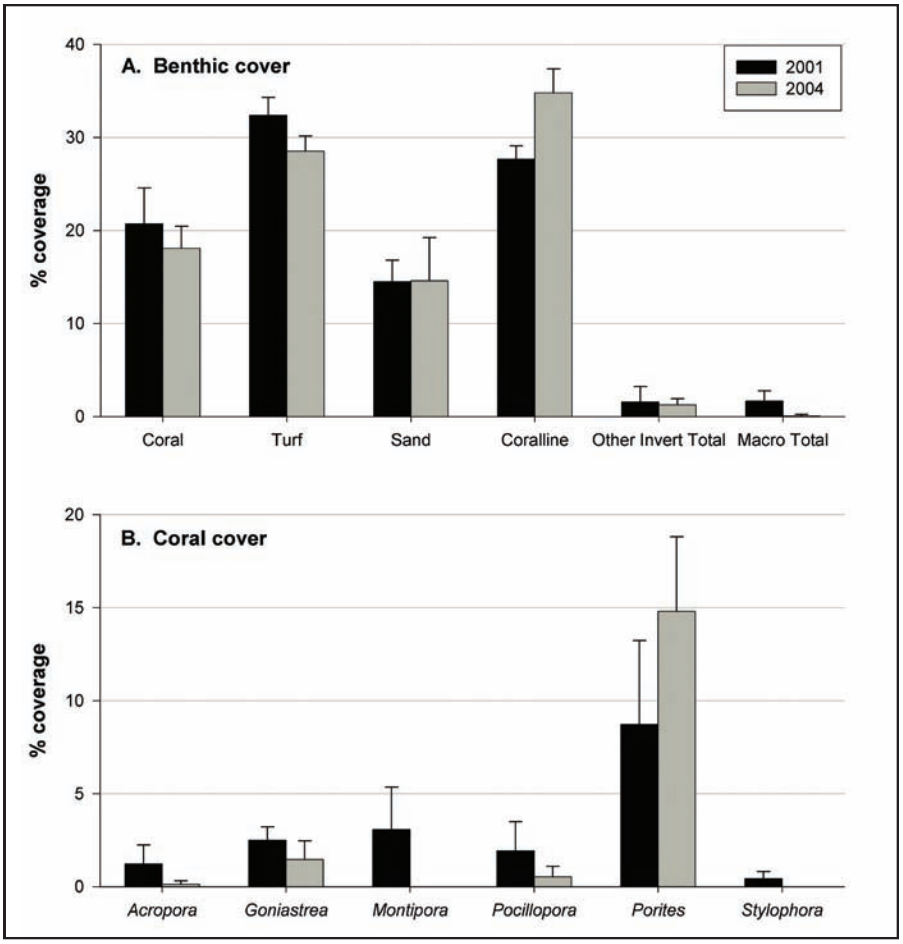

Figure 15.13. Change in benthic cover (A) and coral cover (B) at Boy Scout Beach between 2001 and 2004. Source: CNMI MMT (P. Houk), unpublished data.

Table 15.5. The number and density of COTS recorded during MARAMP 2003 towed-diver surveys. Source: PIFSC-CRED (M. Timmers), unpublished data.

REGION	COTS	TOW LENGTH (KM)	COTS/KM
Northern Islands	18	201.14	0.09
Southern Islands	421	62.88	6.7
TOTAL	**439**	**264.02**	**6.79**

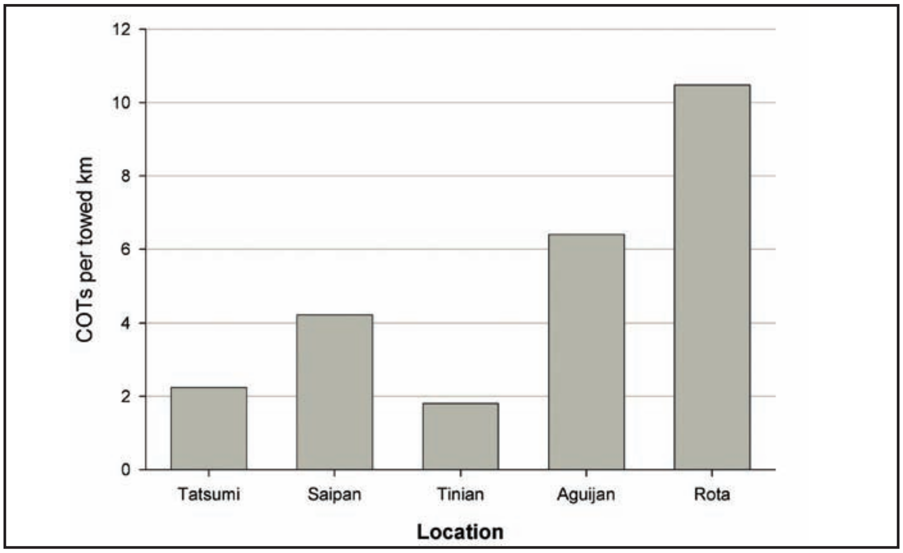

Figure 15.14. Crown-of-thorns densities from towed diver surveys. Source: PIFSC-CRED, (M. Timmers), unpublished data.

Table 15.6. Records of volcano eruptions in the CNMI. * denotes uncertainy of volcano eruption date. Source: Adapted from Siggurdsson et al., 2000.

NAME	TYPE	ELEVATION (m)	ERUPTION DATES
Farallon de Pajaros (Uracas)	Stratovolcano	360	1967, 1952-53, 1951, 1947, 1943, 1941, 1939, 1936, 1934, 1932, 1928, 1925, 1912, 1900-01*, 1874-76*, 1864-76*, 1864
Supply Reef	Submarine Volcano	-8	1989, 1985*, 1969
Ascuncion	Stratovolcano	857	1924*, 1906, 1775*, 1690*
Agrigan	Stratovolcano	965	1917
Pagan	Stratovolcanoes	570	1998, 1998*, 1987, 1993, 1992, 1981-85, 1929-30*, 1925, 1923, 1917, 1909, 1873*, 1864, 1825, 1669
Alamagan	Stratovolcano	744	1887*, 1864*
Guguan	Stratovolcano	287	1883
Anatahan	Stratovolcano	788	2005, 2004
Ruby	Submarine Volcano	-230	1996, 1995
Esmerelda Bank	Submarine Volcano	-43	1987*, 1982*, 1975*, 1970*, 1964*, 1944*

Unexploded Ordnance

The CNMI was a major battlefield during WWII, and war debris and unexploded ordnance is still common in the near shore waters. A moderate, but locally concentrated amount of ordnance has been noted by the MMT south of Agingan Point and the southern end of Lau Lau Bay. Unexploded ordnance was also recorded near Aguijan using towed-diver surveys during the NOAA MARAMP cruise (Figure 15.15). The effects of chemical leaching of ordnance materials, including explosive chemicals and structural metals (e.g., copper, lead, tin, etc.), upon marine life have not been evaluated.

Figure 15.15. Unexploded ordinance observed during NOAA MARAMP towed-diver survey. Photo: S. Holzwarth.

Modern use of explosives for blast fishing occurred until recently (Johannes, 1979). Education regarding long-term environmental effects and enforcement efforts appear to have been effective. Blast fishing is not considered a concern in the CNMI at present, though the practice is difficult to detect near less inhabited parts of the CNMI. In 1996, through the CNMI Governor, the Director of the CNMI Emergency Management Office requested that the U.S. Navy detonate depth charges on a WWII subchaser wreck at the popular Coral Gardens dive site in the Sasanhaya Bay Fish Reserve (SBFR) as it was felt that the charges posed a hazard to recreational divers and fishermen (Worthington and Michael, 1996). The force of the detonation caused significant damage to the SBFR, the oldest of CNMI's MPAs. The blast killed numerous fish, decimated coral, and killed an endangered hawksbill turtle (Trianni, 1998a).

In addition, considerable secondary damage was caused by an extensive sediment plume that resulting from the blast, which blanketed a large area including in and around the Coral Gardens site. Two typhoons subsequently caused further damage, which expanded the impacted area to approximately 29,000 m^2. Estimates based on a value of \$2,833/m^2 resulted in a total economic impact of \$82 million (Richmond and Romano, 1997).

CORAL REEF ECOSYSTEM—DATA GATHERING EFFORTS AND RESOURCE CONDITION

Three main programs within the CNMI currently collect marine monitoring data. The DEQ monitors nearshore marine water quality for bacterial contaminants and a range of standard physical water quality parameters. The DFW Fisheries Research Section monitors fish and benthic parameters in marine preserves. The MMT, which includes staff from DEQ, DFW, and the CRM, monitors fish, invertebrates, and benthic parameters cooperatively at sites around the southern four islands of the CNMI.

In addition, NOAA has been actively involved in geological and ecosystem-based research around the CNMI. NOAA's Office of Ocean Exploration funded two geological cruises in 2003 and 2004 aboard the R/V *Thomas J. Thompson* to study active volcanism and hydrothermal activity in the Marianas Archipelago. These cruises provided invaluable baseline bathymetric data. Results from these cruises can be accessed on-line (NOAA's Office of Ocean Exploration, http://oceanexplorer.noaa.gov/explorations, Accessed 01/07/05).

NOAA's Coral Reef Conservation Program and Pacific Island Fisheries Science Center (PIFSC) funded the first MARAMP cruise on the NOAA ship *Oscar Elton Sette* in 2003. Extensive baseline studies of coral, fish, algae, oceanography, benthic habitats, and bathymetry were conducted from Uracas to Guam. These cruises are planned to continue biennially.

DEQ Activities

The DEQ Surveillance Laboratory was established to provide monitoring data required by the Federal Safe Drinking Water Act (P.L. 93-523) and other environmental programs. The data generated by the laboratory are used to evaluate the quality of drinking water and recreational waters in the Commonwealth. The DEQ has been testing water quality at a number of sites adjacent to the high population centers on Saipan since 1980. More recently, water quality testing has been extended to Tinian and Rota. DEQ posts warnings at local beaches when water quality parameters exceed the acceptable limits for public health.

DFW Activities

The DFW Fisheries Research Section established a Marine Sanctuaries Program (MSP) in 1998 and has been surveying MPAs in the CNMI since 1999. The primary goal of the survey is to monitor annual trends in reef fish abundance and diversity. Secondary goals include monitoring changes in benthic habitat composition, macroinvertebrate abundance, and habitat heterogeneity.

MMT Activities

The MMT - consisting of staff from the DEQ, CRM, and DFW - has also included participation from NMC staff. The MMT was initially established in 1997 to help the CNMI understand the current condition of its coral reefs and coral reef resources. DEQ prepared the first *State of the Reef Reports* for Rota and Saipan (Houk, 2000 and 2001, respectively). These reports documented baseline conditions and will be used for future assessments and regional management recommendations. It is the goal of the MMT to carry out this long-term monitoring program to continually assess our reefs as the CNMI grows. Monitoring locations for the MMT are shown in Figure 15.16.

The DEQ plays a major role in the MMT through its Marine Monitoring Program, Nonpoint Source Pollution Program, and Surveillance Laboratory. Since the previous report on water quality required by Section 305(b) of the Federal Clean Water Act, the DEQ and MMT have initiated two large-scale biocriteria monitoring programs. Both of these are very different from EPA-funded biocriteria monitoring programs in the U.S. mainland. Tropical marine systems are much more dynamic and harbor very different organisms. Biocriteria programs set forth in the U.S. mainland fail to provide useful techniques for the CNMI. One monitoring effort is the Saipan Lagoon Monitoring Program (DEQ and CRM), and the other is the CNMI Nearshore Reef Monitoring Program (DEQ, CRM, and DFW). The goal of these programs is to gather continuous data from marine systems that are affected by water quality concerns (e.g., watershed drainages, sewage pump failures and outfalls, and other sources of point and nonpoint source pollution).

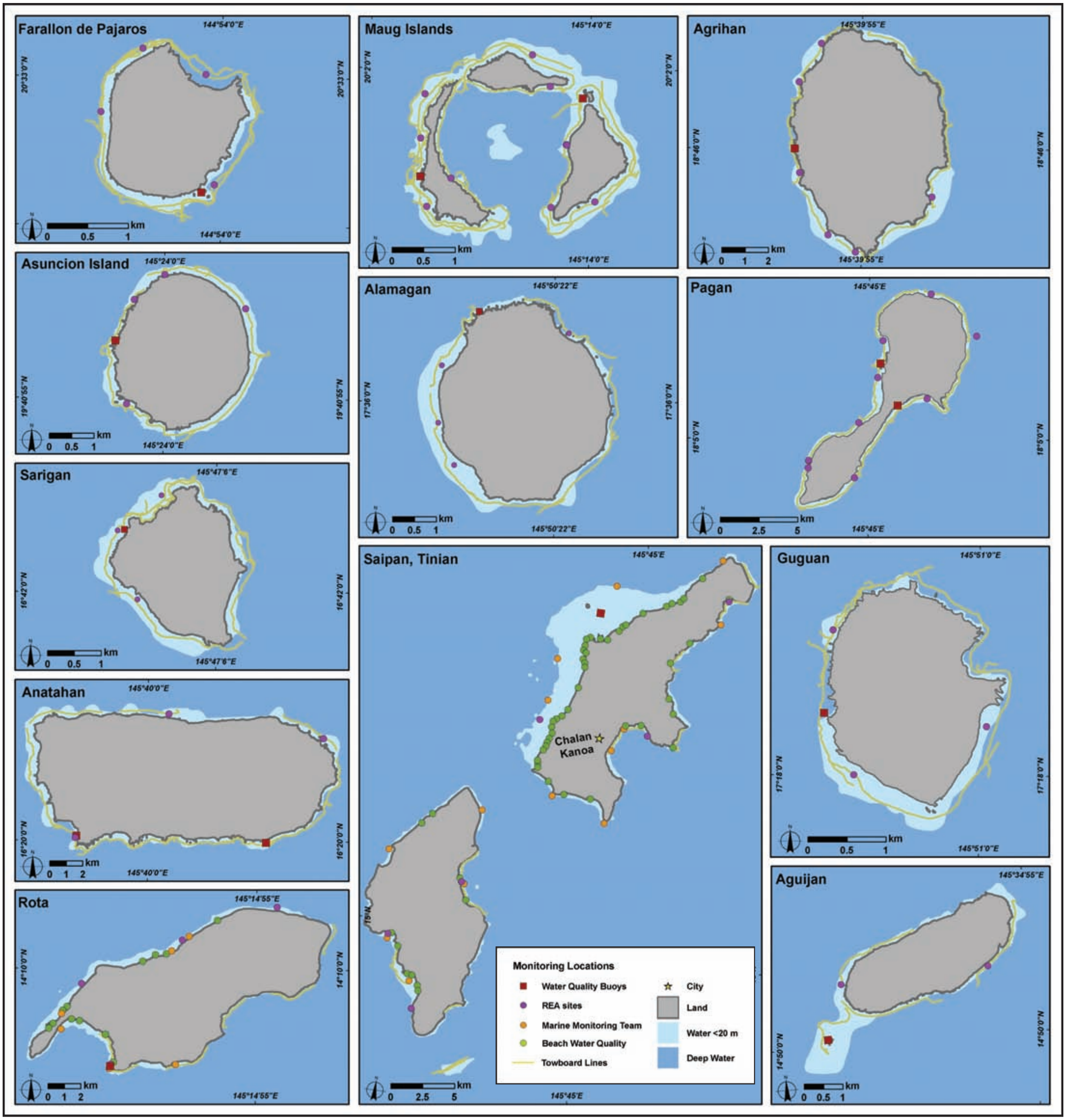

Figure 15.16. Monitoring site locations in the CNMI. Map: A. Shapiro.

Irregular sources of information about the marine environment are site surveys conducted to satisfy local or regional requirements, such as EISs. These surveys provide snapshots of CNMI reefs and can be very informative, but are usually limited to a single reef area. For example, two sites in Lau Lau Bay were surveyed in 1991 and recently re-surveyed in 2001 by the MMT (Houk, 2001). Turf algae was the single most abundant component of benthic cover (47% and 52%). Coral cover represented 28% and 42% on these two reefs. The second site showed a long-term decrease in mean coral diameter and relative frequencies of large branching corals, attributed to the 1983 COTS outbreak. Between 1991 and 2001, the abundance of macroinvertebrates, such as sea urchins and sea cucumbers, decreased at both sites (Houk, 2001).

NOAA MARAMP Cruise

The MARAMP research cruise aboard the NOAA ship *Oscar Elton Sette* from August 22 to September 29, 2003 was led by the PIFSC-Coral Reef Ecosystem Division (CRED) in collaboration with scientists and resource managers from the DFW, DEQ, CRM, Guam Division of Aquatic and Wildlife Resources, NOAA Ocean Service (NOS)-National Geodetic Survey, University of Guam Marine Laboratory, University of Hawaii's Joint Institute for Marine and Atmospheric Research and Hawaii Mapping Research Group, University of Florida, and National Park Service. Other key collaborators assisting and supporting the cruise included NOS' Special Projects Office, NOAA's Center for Coastal Monitoring and Assessment-Biogeography Team (CCMA-BT), NOAA Satellites and Information's Office of Applied Research, NOAA Research-Atlantic Oceanographic and Meteorological Laboratory, Western Pacific Regional Fishery Management Council, USFWS, Bishop Museum, Guam Fisherman's Cooperative, and R/V *Oscar Elton Sette* crew and officers. The cruise was designed to provide an archipelago-wide baseline assessment of the living marine resources, including fish, coral, other invertebrates, and algae, in the context of their benthic and oceanographic habitats. It was the most comprehensive, multi-disciplinary study ever conducted of the coral reef ecosystems in the Marianas Archipelago.

During the cruise, rapid ecological assessments (REAs), benthic habitat mapping, and oceanographic research were conducted at 14 islands (Guam, Rota, Aguijan, Tinian, Saipan, Anatahan, Sarigan, Guguan, Alamagan, Pagan, Agrihan, Asuncion, Maug, and Uracas) and at many oceanic reefs and banks (Santa Rosa Reef, Galvez Bank, 11 Mile Bank, Esmeralda Bank, Tatsumi Reef, Marpi Reef, Arakane Reef, Pathfinder Bank, Zealandia Bank, Supply Reef, Stingray Shoals, and an unknown bank southeast of Uracas Island). During 29 days of operations in CNMI waters, specialized teams of scientists performed 76 REAs of reef fishes, coral, other invertebrates, and algae; 138 towed diver habitat and fish surveys covering about 265 km of habitat; 76 towed diver turtle and fish surveys covering an estimated 178 km of habitat; 45 bioacoustic surveys of biomass in the water column; 338 oceanographic station visits (using conductivity, temperature, and depth instruments [CTDs]); ocean current profiles along over 664 km of transects; 100 TOAD deployments; 106 single-beam and bottom classification surveys; and high resolution multibeam acoustic mapping of 244.2 km^2 of benthic habitats using the R/V *AHI*. Many of these locations are shown in Figure 15.16. In addition, an array of surface and subsurface oceanographic moorings were deployed as part of NOAA's Coral Reef Watch Program to monitor ocean conditions influencing reef health and to provide resource managers and researchers with coral bleaching and other alerts using the Coral Reef Early Warning System (CREWS).

The MARAMP cruise has provided researchers with a tremendous baseline data set about each of the principal components of these complex coral reef ecosystems. The simultaneous information about the status and diversity of the marine resources along the entire Marianas Archipelago, including their spatial and habitat distributions, provides an opportunity for researchers and resource managers to better understand how these complex ecosystems function. This baseline data set will be used to evaluate temporal changes of these ecosystems as the MARAMP evolves to biennial monitoring cruises. By monitoring the spatial and temporal variability of the marine resources and oceanographic conditions, local and national resource managers will be better equipped to make and apply ecosystem-based management principles to conserve and protect these coral reef ecosystems.

WATER QUALITY

Standard water quality parameters are regularly monitored in nearshore marine waters on Saipan, Tinian, and Rota by the DEQ Surveillance Laboratory. Full information on methods and results are available in the CNMI Integrated 305(b) and 303(d) Water Quality Assessment Report (Houk, 2004; online at: http://www.deq.gov.mp/305b%202004%20Final.pdf, Accessed 01/06/05).

The collaborative efforts of NOAA MARAMP cruises promise to expand the quantity and variety of oceanographic data being collected in the future. PIFSC-CRED deploys oceanographic monitoring systems throughout the archipelago. Information on ocean currents, water temperatures, salinity, and turbidity were collected during the 2003 NOAA MARAMP cruise and will be collected biennially during future cruises.

DEQ Beach Water Quality Monitoring Program

Methods

The DEQ Surveillance Laboratory was established by the CNMI to provide monitoring data required by the Safe Drinking Water Act, and other environmental programs. Salinity (‰), dissolved oxygen (% DO), temperature (°C), pH, turbidity (NTU), orthophosphate (PO_4), nitrates (NO_3), and *Enterococci* spp. bacteria (cfu/100ml) are monitored weekly at 84 fixed sites around Saipan, Rota, and Tinian. The data collected by this program comprise the longest consistently-collected set of marine water quality data available for the CNMI.

Development of the CNMI WQS was largely based upon the review of WQS from other tropical islands (Houk, 2004). Due to the potential important influence of water quality on coral reef ecosystems and the lack of existing data, stringent WQS for nutrients were adopted for the CNMI. DEQ recently initiated the collection of nutrient data. It has not yet been determined whether the nutrient concentrations recorded are due to anthropogenic sources. At all islands, PO_4 levels exceeded WQS more than 50% of the time, with the exception of Managaha Island, which has no major sources of terrestrial input (Houk, 2004).

The goal of the DEQ's Surface Water Quality Monitoring Program is to assess CNMI's waterbodies for compliance with recreational uses and aquatic life uses. EPA guidance material was used to classify each waterbody as 1) non-supportive, 2) partially supportive, or 3) fully supportive for use (Table 15.7).

Table 15.7. Criteria for waterbody classification. Source: Houk, 2004.

DEGREE OF AQUATIC LIFE USE SUPPORT	CRITERIA
Fully Supporting	For any one pollutant, WQS was exceeded in ≤10% of measurements
Partially Supporting	For any one pollutant, WQS was exceeded in 11-25% of measurements
Not Supporting	For any one pollutant, WQS was exceeded in >25% of measurements

Results and Discussion

Recreational use classifications were based upon elevated counts of *Enterococcus* bacteria. Saipan Island has the largest number of waterbodies that were classified as non-supportive for recreational use. Rota, Tinian, and Managaha Islands each had only one non-supportive waterbody. For Saipan Island, regression analysis was used to examine the relationship between rainfall and *Enterococcus* bacteria counts. Rainfall explained a significant amount ($p<0.05$) of the variance in bacteria levels at the majority of non-supportive waterbodies (Table 15.8).

Observations have shown that storm events quickly inundate many of the sewage lift stations around Saipan, and the overflow enters the marine environment through drainages, leading to elevated bacteria levels at many beach locations. Other known causes of excessive bacterial contamination include urban runoff from the heavily populated Garapan district. Only one site among the remaining islands - a site adjacent to the relatively highly populated village of Song Song, Rota - was classified as non-supportive (Houk, 2004). PO_4 levels exceeded the WQS at all waterbodies on Saipan, Rota, and Tinian Islands (Houk, 2004). This suggests that the water quality criterion (0.025 mg/L) is not appropriate for the CNMI, and that the WQS should be updated in the next review cycle to account for this. The only exception to this finding was for Managaha, which is a small (~0.5 km^2) island situated away from terrestrial input.

DO measurements followed similar trends as for microbiological data (Houk, 2004). Most non-supportive sites are associated with drainage regions on Saipan especially areas where observations show frequent sewage lift station overflow or heavy urban runoff. DO readings are influenced by wave activity, and waterbodies protected from rough oceanographic conditions naturally have lower levels. As a result, all monitoring locations in the Saipan Lagoon consistently had DO readings below the water quality criterion. This also suggests that during the next WQS review the DO criterion should also be evaluated.

Table 15.8. Summary of DEQ beach monitoring locations for which data were available for regression analysis of rainfall (Y) on *Enterococcus* levels (X). Waterbody ranking of 1= non-supportive, 2= partially supportive, and 3= fully supportive based on WQS for recreational and aquatic life uses. Regression analysis results are presented as p-values at a significance level of * p <0.05, ** p <0.01, ***p <0.001. Source: adapted from Houk, 2004.

DEQ BEACH IDENTIFIER	BEACH NAME	NUMBER OF SAMPLES IN 2003 *(Enterococcus)*	PERCENT VIOLATIONS *(Enterococcus)*	WATERBODY RANKING	SAMPLES SIZE FOR HISTORICAL REGRESSION	P VALUE FOR REGRESSION ANALYSIS
WB 1	Wing Beach	52	11.54	2	84	0.619
WB 2	PauPau Beach	52	19.23	2	84	0.63
WB 3	Nikko Hotel	52	23.08	2	84	0.617
WB 4	San Roque School	52	50	1	84	0.179
WB 5	Plumeria Hotel	52	23.08	2	84	< .01 **
WB 6	Aqua Resort Hotel	52	19.23	2	84	< .01 **
WB 7	Tanapag Meeting Hall	48	54.17	1	84	< .001 ***
WB 8	Central Repair Shop	39	61.54	1	84	< .001 ***
WB 9	Sea Plane Ramp	46	17.39	2	84	< .05 *
WB 10	DPW Channel Bridge	46	93.48	1	84	0.068
WB 11.1	N. Puerto Rico Dump	6	33.33	1	57	0.805
WB 11.2	S. Puerto Rico Dump	36	47.22	1	9	0.069
WB 12	Smiling Cove Marina	46	36.96	1	62	< .001 ***
WB 12.1	American Memorial Park	45	44.44	1	45	< .001 ***
WB 13	Outer Cove Marina	46	17.39	2	74	0.622
WB 14	Micro Beach	52	15.38	2	74	< .001 ***
WB 15	Hyatt Hotel	52	21.15	2	84	0.115
WB 16	Dai-Ichi Hotel	52	34.62	1	84	0.074
WB 17	Drainage #1	46	71.74	1	57	< .01 **
WB 18	Samoan Housing area	52	38.46	1	76	< .001 ***
WB 19	Hafa-Adai Hotel	52	51.92	1	76	< .001 ***
WB 20	Drainage #2	41	51.22	1	44	0.212
WB 21	Garapan Fishing Dock	46	82.61	1	75	< .001 ***
WB 22	Garapan Beach	52	55.77	1	62	< .001 ***
WB 23	Drainage #3	46	54.35	1	59	< .001 ***
WB 24	Chalan Laulau Beach	52	11.54	2	66	< .01 **
WB 25	San Jose Beach	52	13.46	2	78	0.885
WB 26	Civic Center Beach	52	19.23	2	76	0.845
WB 27	Diamond Hotel	52	17.31	2	84	0.616
WB 28	Grand Hotel	52	9.62	3	86	0.195
WB 29	Community School Beach	52	19.23	2	71	0.251
WB 30	Sugar Dock	46	69.57	1	76	0.937
WB 31	CK District #2 Drainage	46	36.96	1	68	< .001 ***
WB 32	CK District #4 Lally Beach	52	15.38	2	80	< .001 ***
WB 33	Chalan Piao Beach	52	15.38	2	80	< .001 ***
WB 34	Hopwood School Beach	48	29.17	1	46	0.121
WB 35	San Antonio Beach	52	5.77	3	73	< .001 ***
WB 36	Pacific Islands Club (PIC)	52	23.08	2	81	< .001 ***
WB 37	San Antonio Lift Station	46	52.17	1	50	< .001 ***

CRM Marine Temperature Monitoring
A shallow-water bleaching event in 2001 prompted the CRM to reinstate its Temperature Monitoring Pogram, which began and ceased operation in 1999.

Methods
Continuous data on temperature were recorded using data loggers installed at 6 m depths at the Lau Lau #2, Outside Grand, and Sasanhaya MMT reef monitoring sites. In addition, a recorder was placed at a 1 m depth in the Saipan Lagoon just north of the Outside Grand site.

Results and Discussion
Temperature data collected for this project, such as those presented in Figure 15.17, will assist managers in understanding the causes of differential bleaching phenomena among the lagoon and reef sites in the southern Mariana Islands.

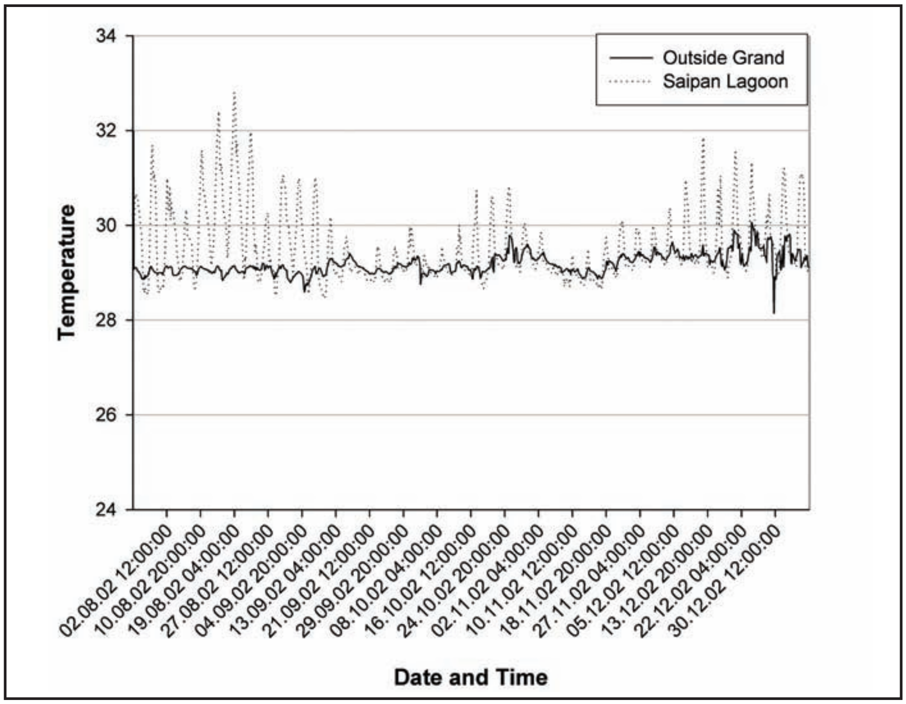

Figure 15.17. Hourly water temperature data within the Saipan Lagoon (1 m) and the adjacent fore reef (6 m) over five months, illustrating the differences in temperature changes. Source: CNMI CRM, unpublished data.

NOAA MARAMP, Study of Water Quality and Oceanographic Conditions

The volcanic island arc/subduction zone topography and associated extremely steep slopes of the Marianas Archipelago greatly modify the oceanography of the nearshore waters of the islands. Localized upwelling and the associated nutrient enrichment of surface waters, nutrient enrichment and seawater chemistry changes due to volcanic seeps and vents, freshwater inputs, and anthropogenic impacts all have poorly understood effects on the nearshore ecosystems. The effects of seasonal and climatic changes on the islands' marine ecosystems, as well as changes due to episodic events such as typhoons and volcanic eruptions, are also poorly understood. In order to better understand the linkages between oceanography and ecology, NOAA's PIFSC-CRED is taking a two-pronged approach: 1) intensive assessment of oceanographic conditions and ecological assessments at each island and 2) establishment of long-term oceanographic monitoring. Intensive oceanographic assessments at each island are accomplished by continuous recording of water temperatures as a function of depth during all towing operations, shallow-water CTDs (e.g., turbidity and chlorophyll measurements) at regular intervals around the islands, and deep water CTDs and acoustic doppler current profiler (ADCP) transects. During the 2003 MARAMP cruise, 40 deep-water (500 m) CTD casts and 271 shallow-water (30 m) CTD casts were deployed along with four surface velocity profile (SVP) drifters, one CREWS buoy, 11 subsurface temperature recorders (STRs), two SST buoys, and two wave and tide recorders (WTRs; Figure 15.16).

Methods

Long-term oceanographic monitoring is accomplished by deploying a variety of both internally recording and near-real-time telemetered instrument platforms and oceanic drifters. These instruments include CREWS buoys, SST buoys, WTR buoys, ocean data platforms (ODPs), STRs, and satellite drifters. Telemetered data is being recorded and analyzed by PIFSC-CRED, but the WTR, ODP, and STR data will only be available after recovery of the instruments during the MARAMP cruise scheduled for 2005.

Results and Discussion

A number of generalizations can be made about the oceanographic conditions of the Marianas Archipelago from preliminary analysis of 2003 MARAMP cruise data. All measured SSTs were 0.5-0.8°C degrees warmer than NOAA's Pathfinder SST monthly climatology data for the region. Relatively strong cross-island chain currents exist, and they accelerated at the northern and southern tips of the islands, presumably due to tides. Oxygen concentrations appear to increase at deeper depths towards the northern end of the chain. Several areas of hydrothermal seeps have been noted. CTD measurements of these areas at Maug have shown temperature increases of up to 3°C from surrounding waters, as well as large salinity and other (e.g., transmissometry) anomalies. Large plumes of extremely turbid water were noted at Anatahan. These plumes may be associated with hydrothermal vents, or with volcanic ash runoff from Anatahan's recent eruption. Transmissometry values within these plumes are several orders of magnitude greater than other locations surveyed. Depending on their number and distribution, these features may contribute significantly to local circulation, nutrient loading, and, particularly in the case of Anatahan, are likely to have deleterious effects, such as increased sedimentation and runoff, on reef ecosystems.

BENTHIC HABITATS

DEQ Lagoon and Coral Reef Biocriteria Monitoring Programs

Methods

The CNMI's biocriteria monitoring programs assess marine community shifts in response to nutrient loads, sediment loads, temperature, turbidity, and other water quality parameters (Rogers, 1990; Telesnicki and Goldberg, 1995). The CNMI uses weekly water quality data combined with other benthic community data to evaluate waterbodies. Biocriteria monitoring occurs at the Saipan Lagoon and at various nearshore coral reefs. Information on methods and results is available in the CNMI Integrated 305(b) and 303(d) Water Quality Assessment Report (DEQ, http://www.deq.gov.mp/305b%202004%20Final.pdf, Accessed 01/12/05).

Ecological surveys were completed to evaluate each waterbody's ability to support aquatic life in comparison to a control site. Based on EPA guidance each site was given an aquatic life use support (ALUS) classification of: 1) non-supportive, 2) partially supportive, or 3) fully supportive. All waterbodies assessed are adjacent to areas with development on land, and have experienced anthropogenic pollution. As a result, there is no ideal reference or control site. Biocriteria monitoring programs, however, were designed to sample sites along a disturbance gradient. A degree of measure was established for each variable based upon relative site comparisons (mean and standard deviations) (Table 15.9).

Table 15.9. A description of how relative measures were used to assign appropriate Aquatic Life Use Support designations. Source: Houk, 2004.

BIOLOGICAL COMMUNITY MEASURE	AQUATIC LIFE USE SUPPORT DESIGNATION
Less than one standard deviation below the mean	Not Supporting
Not different from the mean	Partially Supporting
Greater than one standard deviation above the mean	Fully Supporting

Results and Discussion

There were three regions in the Saipan Lagoon identified as non-supportive for aquatic life use. The largest is in the vicinity of Garapan, with high levels of bacteria and nutrients, and low DO associated with urban runoff. As a result, macroalgae (*Caulerpa* spp.) dominates benthic communities. Another large, non-supportive waterbody in the lagoon is adjacent to Beach Road, at the southern end of Garapan. These waters receive large inputs of stormwater during rainfall events due to adjacent topography, and are also associated with relatively high bacteria and nutrient levels. The last small, non-supportive waterbody is located adjacent to Chalan Kanoa village, presumably due to frequent sewage lift station failures. Water quality results agree with benthic data showing high bacteria and nutrient levels.

Twenty coral reef monitoring locations were used for waterbody evaluation (Table 15.10). Only sites with appropriate reef development can be used to evaluate water quality, since at other locations, environmental factors such as exposure, reef slope, and prior geological development have a larger influence on the benthic community than water quality.

Of the 20 locations surveyed, one was non-supportive, five were fully supportive, and the remaining 14 were partially supportive of aquatic life use (Table 15.10). Rankings were calculated using two measures: the benthic community and the coral community. The final ALUS ranking is based upon EPA guidance stating if any one measure of the community is non-supportive, it is classified as such, and both must be fully supportive for such a classification. The suggested explanation for most sites resulting in a partially supportive classification is the larger distances that impaired waters would have to travel to reach the reef monitoring locations compared with the lagoon monitoring locations.

Fully supportive reefs are present only in relatively unpopulated watersheds or barrier reef locations not heavily influenced by stormwater runoff. In general, the results of REAs based upon relative measures are less desirable than data analysis from long-term studies and monitoring programs, which better elucidate small changes with greater statistical power. However, the present evaluation serves to fill an important role for regulatory agencies.

Table 15.10. Results from the CNMI coral reef biocriteria monitoring program for aquatic life use support (ALUS): a ranking of 1= non-supportive, 2= partially supportive, and 3= fully supportive. The final ALUS ranking is based on EPA guidance material where if any one measure of the community is non-supportive, it is classified as such, and both must be fully supportive for such classification. Source: Adapted from Houk, 2004.

SITE NAME	CORAL COMMUNITY DATA							BENTHIC COMMUNITY DATA		ALUS
	Coral Community Evenness (Margalef s D Statistic)	Rank	Coral Species Richness	Rank	Average Coral Geometric Diameter	Rank	Coral Community Ranking	Ratio of Benthic Substrate Health	Benthic Community Ranking	
Aguijan - 2	10.6	3	82	3	9.1	3	3	1.28	3	Fully
Akino	7.3	2	53	2	7.4	2	2	0.93	2	Partially
Barcinas Bay	4.6	1	45	2	8.7	3	2	0.3	1	Partially
Boy Scout	9.7	2	74	2	5.8	2	2	0.81	2	Partially
Coral Gardens	4.4	1	42	1	5.2	2	1	0.75	2	Partially
Coral Ocean Point	8.8	2	72	2	9.2	3	2	0.68	2	Partially
Iota N	4.6	1	21	1	6.5	2	1	0.84	2	Partially
Iota S	5.7	1	28	1	4.6	1	1	0.39	1	Non
Lau Lau Bay #1	8.9	2	50	2	7.3	2	2	0.29	1	Partially
Lau Lau Bay #2	6.6	2	59	2	5	2	2	0.77	2	Partially
Obyan	11.7	3	76	3	8	2	3	0.97	2	Fully
Outside Garapan	8	2	66	2	5.3	2	2	0.17	1	Partially
Outside Grand	8.4	2	79	3	8.8	3	3	1.18	3	Fully
Outside Managaha	8.5	2	77	3	6.1	2	2	1.32	3	Fully
Rota - 6	6.9	2	61	2	3.9	2	2	no data	no data	Partially
Rota - 5	7.3	2	69	2	5.4	2	2	no data	no data	Partially
Saipan - 1	9.2	2	47	2	8.7	3	2	0.84	2	Partially
Tinian - 1	11.4	3	65	2	6	2	2	no data	no data	Partially
West Harbor	8.5	2	49	2	4.5	1	2	0.32	1	Partially
Wing Beach	7.7	2	73	2	6	2	2	1.41	3	Fully
Average	**7.9**		**59.4**		**6.6**			**0.78**		
Standard Deviation	**2**		**16.7**		**1.7**			**0.37**		

MMT Nearshore Coral Reef Monitoring Program

Methods

This program complements to the DEQ Biocriteria Monitoring Program discussed above. In many cases, sites and methods show close overlap. However, the primary goal of this data collection program is to understand the ecological condition of coral reefs in regions that are associated with potential water quality disturbances (e.g., runoff, sewage outfalls, urban development) as well as reference sites with low anthropogenic influence. Three to five 50-m transects were used based on standard coral reef survey techniques. Methods are described in detail in Houk (2000, 2001).

Results and Discussion

The majority of MMT survey sites showed no significant differences within sites over the two to four years of monitoring (Figure 15.18). When combined with available historical data, however, differences become much more obvious.

Lau Lau Bay was the location of some of the oldest scientifically valid coral reef surveys using methods comparable to those of current MMT survey protocols (PBEC, 1984; Randall, 1991). It thus serves as an exemplar for the utility of monitoring to understand long-term trends in ecological trajectories. Unlike most other MMT sites, variation in yearly surveys at Lau Lau #1 (southeastern Lau Lau Bay) and Lau Lau #2 (northeastern

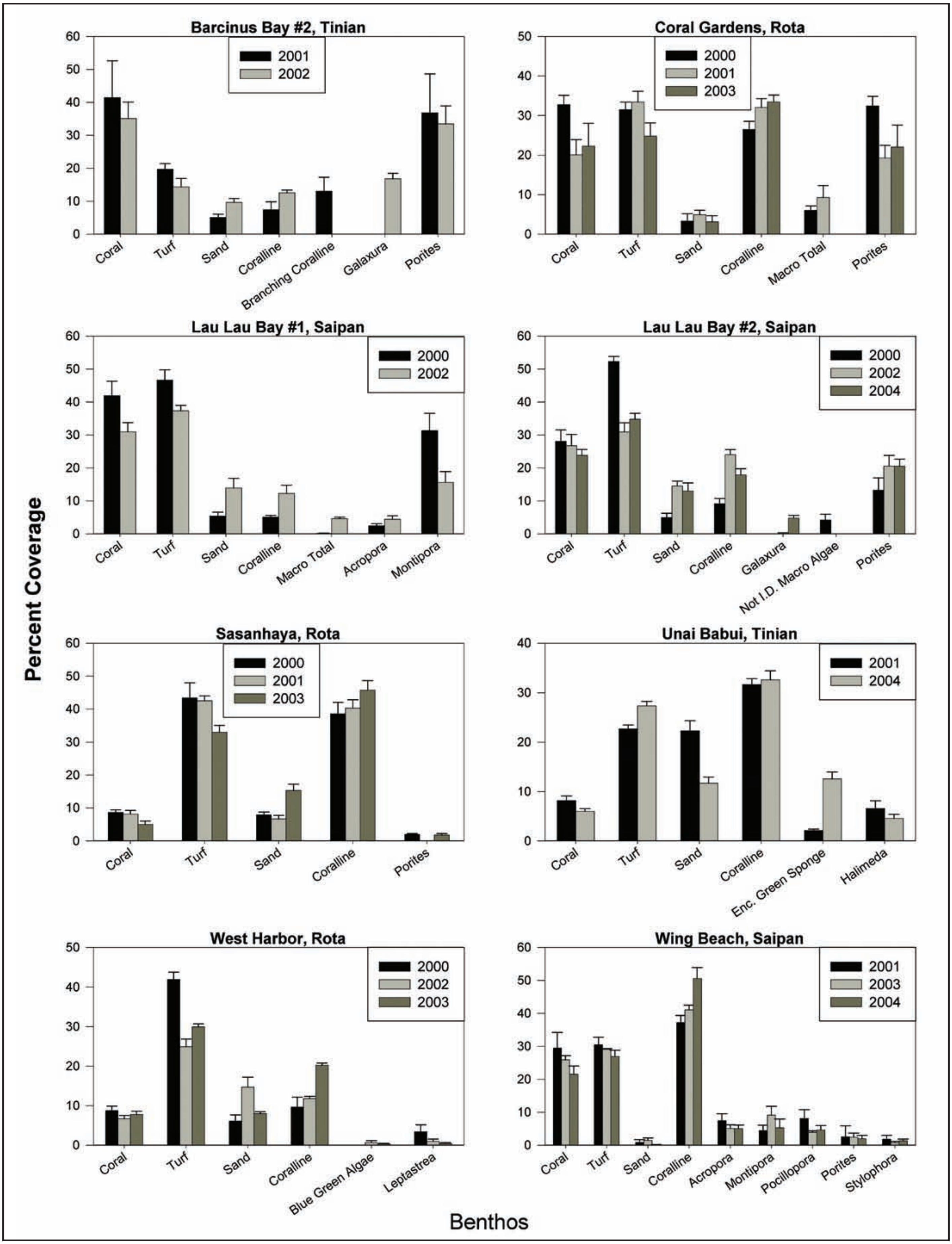

Figure 15.18. Percent cover of the benthos recorded between 2000 and 2004 at selected long-term monitoring sites on Tinian, Rota, and Saipan. Source: CNMI MMT (P. Houk), unpublished data.

Lau Lau Bay recreational dive site) was clearly present. However, after four years of surveys, it is still not apparent if the data are depicting clear trends in population trajectories for coral taxa. In comparison to decadal changes, year-to-year changes from 2000-2004 at either site are minimal (Figure 15.19). The implications of these results are that continued negative effects from sedimentation, *Acanthaster planci* predation, bleaching, recreational use, and storm damage have significantly changed the composition of the coral community at Lau Lau Bay. Information on community change allows regulatory agencies to more effectively target ecological baseline conditions for restoring such environments.

While recent surveys have not detected major changes in community composition, comparison of community evenness between 1991 and 2003-2004 provides additional information. Evenness is a measure of how equitably coral cover is distributed among taxa sampled within a transect. The decrease in evenness over this time period is the result of an increased dominance of disturbance-resistant taxa such as *Porites* spp. (Figure 15.20).

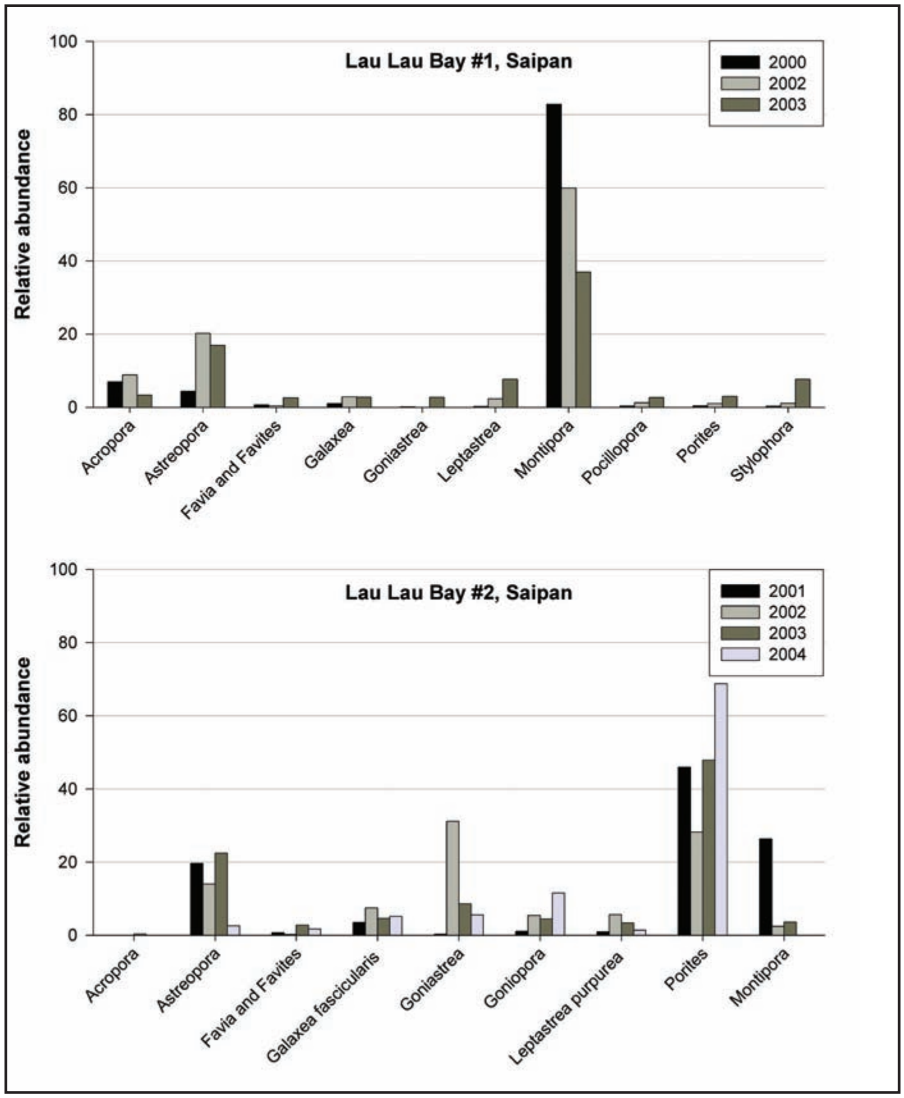

Figure 15.19. Changes in relative abundance of corals over a four year period at two long term monitoring sites in Lau Lau Bay, Saipan. Source: CNMI MMT (P. Houk), unpublished data.

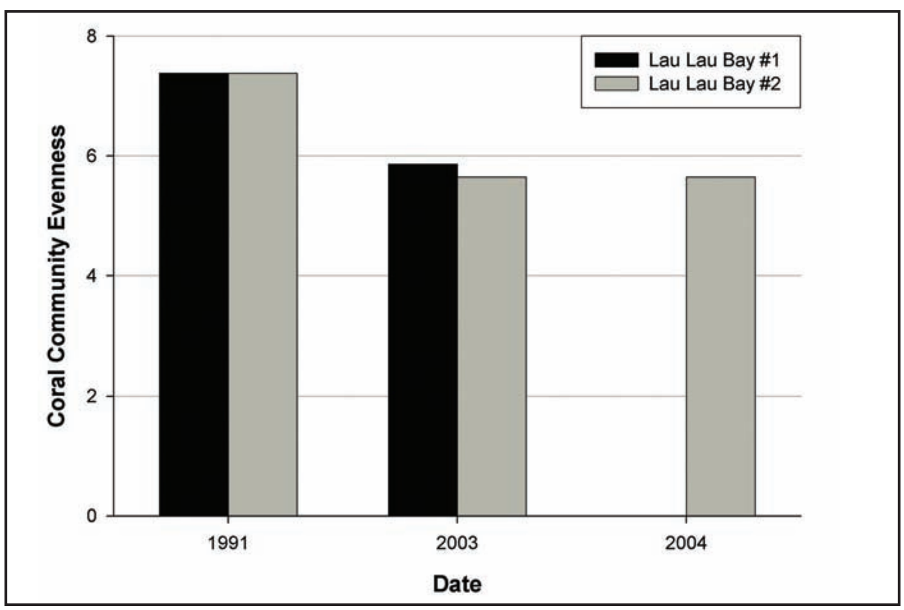

Figure 15.20. Change in community evenness at two long-term monitoring sites. Source: CNMI MMT (P. Houk), unpublished data.

NOAA MARAMP Coral Community Structure Study

Methods

Coral abundance, distribution, condition, biodiversity, and population structure in the CNMI were surveyed at 53 sites during the 2003 MARAMP cruise. Several techniques were used: towed-diver video surveys each averaging about 2 km in length; REAs each covering between 1000-5000 m^2 and consisting of a quadrat-based coral community survey; direct observations for species diversity, coral disease, and bleaching; and video benthic surveys at three 50-m transects.

Results and Discussion

A moderately high prevalence (30-50%) of mild coral bleaching was found at the islands north of Pagan, while a lower prevalence was found at more southerly islands. The highest percentages of coral bleaching were observed at the two northernmost sites surveyed, Uracas Island and Stingray Shoals. Coral species diversity was greatest in the southern islands and lowest in the northern islands. The coral cover of oceanic banks varied along the extent of the archipelago. Stingray Shoals in the north had high coral cover. Arakane, Pathfinder, and Santa Rosa Banks primarily exhibited spur and groove and carbonate formations. Species diversity of corals, algae, and fishes was generally low at the oceanic banks due to limited habitat diversity.

NOAA MARAMP Algae Community Structure Study

Methods

Algal surveys using photoquadrats, field observations, and specimen collection were conducted along the same transect lines used for fish surveys (Vroom, in review).

Results and Discussion

Over 45 genera, representing up to 198 species, were recorded. Macroalgae, with the exception of algal turf, contained 60% of the total number of algal species known for the Marianas Archipelago (198 out of 332; Vroom, in review). Large standard deviations of prevalence for most genera indicated that algal composition differed substantially among individual islands.

BENTHIC HABITAT MAPPING

NOAA CCMA-BT Benthic Habitat Atlas

Methods

NOAA's CCMA-BT initiated a nearshore benthic habitat mapping program for Guam, American Samoa, and the CNMI in 2003. IKONOS satellite imagery was purchased from Space Imaging, Inc. for all three jurisdictions, and used to delineate habitat polygons in a geographic information system (GIS). Habitat polygons were defined and described according to a hierarchical habitat classification system consisting of 18 distinct biological cover types and 14 distinct geomorphological structure types.

Results and Discussion

The project was completed in 2004 and resulted in maps of 158.5 km^2 of nearshore habitat in the CNMI. A series of 96 maps are currently being distributed as a print atlas, on a CD-ROM, and are available on-line (CCMA-BT, http://biogeo.nos.noaa.gov/products/us_pac_terr/, Accessed 01/12/05). The benthic habitat maps are depicted in Figure 15.21.

CNMI DEQ and CRM Mapping of the Saipan Lagoon

Detailed habitat maps for the Saipan Lagoon have been developed through a collaborative project between the DEQ and CRM. Cross-lagoon transects were used to delineate habitats, which were validated using video transect data. Habitats were mapped in a GIS using orthorectified aerial photography. GIS-based spatial analysis of maps using IKONOS imagery is also being tested. As this method is refined, prior habitat maps are being revised for consistency. Preliminary results of this project are currently available (CNMI DEQ, http://www.deq.gov.mp/mmt/lagoon.htm, Accessed 01/10/05).

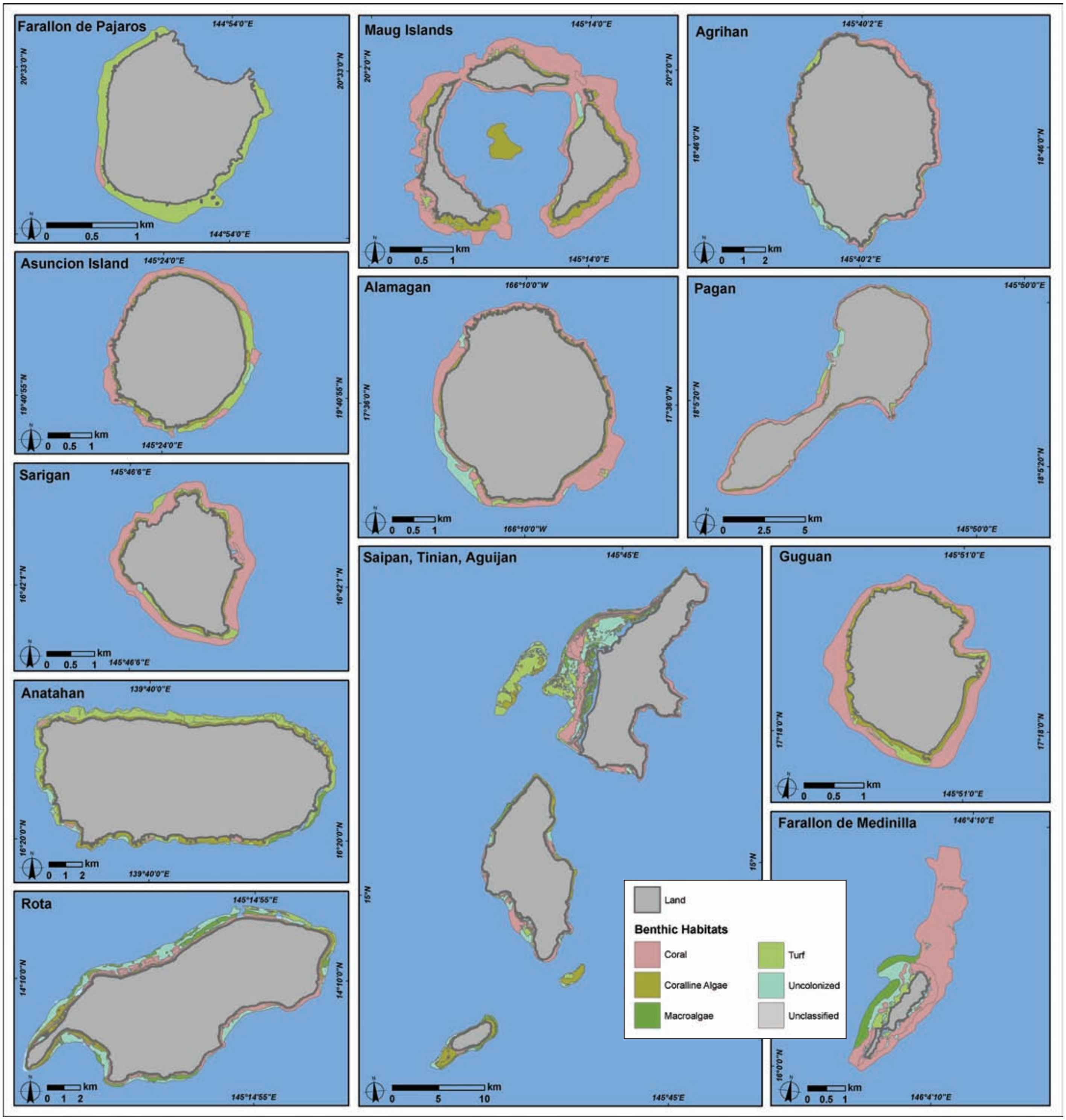

Figure 15.21. Nearshore benthic habitat maps were developed in 2004 by CCMA-BT based on visual interpretation of IKONOS satellite imagery. For more info, see: http://biogeo.nos.noaa.gov. Map: A. Shapiro.

NOAA MARAMP Benthic Habitat and Multibeam Mapping

During the 2003 MARAMP cruise, PIFSC-CRED scientists conducted numerous benthic habitat mapping activities including multibeam bathymetric surveys, drop video camera surveys, Quester-Tangent bottom classification surveys, and diver surveys in water depths to 30 m. All but the last method are discussed below.

Multibeam Mapping Methods

The R/V *AHI*, a new PIFSC-CRED vessel, was deployed in the southern islands of the CNMI and Guam in August and September 2003. The 8 m launch was equipped with a RESON multibeam echosounder and a POS/MV motion sensor, and produced high resolution depth and backscatter data across a 150 degree swath of the seafloor. These data have been used to develop many of the high resolution bathymetric maps and images shown in the 'Introduction' section of this chapter; approximately 120 km were surveyed in southern CNMI. With tremendous support from the DFW, including use of the DFW research vessel, high quality surveys were completed in water depths ranging from 20 m to greater than 250 m in almost all areas visited. Backscatter imagery from the multibeam data is being processed and will be combined with other data to create benthic habitat maps.

Results and Discussion

Multibeam data collected by the R/V *AHI* were used to prepare gridded bathymetric maps and images of Rota, Tatsumi Reef, Tinian, Saipan, and Marpi Bank. Bathymetric data processing has been completed, and the 5-m resolution grids with comprehensive metadata are available on-line (PIFSC-CRED, http://pifsc.noaa.gov/cred/hmapping/datadownload.html#mariana Accessed: 01/10/05). All gridded data sets are also being submitted to the NOAA Coral Reef Information System, and multibeam data will be submitted to the NOAA's National Geophysical Data Center for general distribution when all processing has been completed. Processed backscatter imagery, seafloor texture, and video from the towboard and TOAD vehicle surveys will be integrated in a geographic information system GIS to further characterize benthic habitats.

Integration of multibeam data and other information from the NOAA Ring of Fire cruises with data from the 2003 MARAMP cruise is underway and is scheduled to be complete before the MARAMP cruise in fall 2005. This collaborative work will synthesize deep and shallow bathymetric data into a coherent ecosystem-wide view of the Marianas Archipelago. PIFSC-CRED scientists are also working closely with scientists from CCMA-BT and Analytical Labs of Hawaii (ALH) to integrate shallow-water benthic habitat information derived from visually interpreted IKONOS imagery with the extensive multibeam and video data collected during MARAMP cruises.

As a top priority, PIFSC-CRED scientists are working to synthesize data collected at the Saipan anchorage site near Saipan Lagoon for use by CNMI resource managers as well as and commercial and military users of the anchorage. Bathymetric data processing is complete; backscatter imagery processing, seafloor texture analysis, and analyses of 10 existing video tapes are underway. Scientists from PIFSC-CRED and ALH returned to Saipan in fall 2004 to collect hundreds of additional video clips that will be used to refine the benthic habitat maps in this and other important anchorage areas and to develop a method to integrate and cross-reference the map products being developed independently by PIFSC-CRED, CCMA-BT, and ALH scientists. It is important that analyses of potential impacts to the anchorage areas be completed and evaluated prior to increasing either the size of the designated anchorage or the number of vessels permitted to use the area.

TOAD Optical Data and Quester Tangent Corp. Bottom Classification

The TOAD is an undersea tethered vehicle that is deployed from the R/V *Oscar Elton Sette* during night operations in depths ranging from 20 m to 140 m. Still images and video footage collected via the TOAD are used to ground-truth data and produce benthic habitat maps. Ninety-five TOAD deployments have resulted in 69 photographs, 93 video segments, and 109 Quest Tangent Corp. (QTC) files. Analyses of the video data are underway by the PIFSC-CRED.

Bioacoustics Surveys

During the 2003 MARAMP expedition, a 38-kHz Simrad echosounder was used to record water column scattering data for bioacoustics surveys. Sound scattering layers (SSLs) are vertically migrating communities of small fish, shrimp, and squid that occur in waters deeper than 300 m during the day and rise into the photic zone at night. The observed horizontal migration of the Hawaiian community towards shore at night also suggests SSLs may play a significant role in the coral reef ecosystem through input of biomass and nutrient cycling.

These bioacoustic surveys indicate that the SSL off Rota Island is present during both daylight and nighttime hours at depths between approximately 50 m and 100 m. Aside from Maug Island, which features a persistent SSL inside the crater, all of the islands surveyed in the CNMI presented an active mesopelagic community which exhibited diurnal migration.

ASSOCIATED BIOLOGICAL COMMUNITIES

FISH

DFW Marine Sanctuaries Program

Methods

The DFW MSP conducts annual surveys to assess reef fish abundance within designated marine sanctuaries. Using a habitat-based stratified sampling method, data are collected along 25 m by 4 m transects located haphazardly within habitat types. Methods are described in detail in DFW technical reports (Trianni, 1999a,b).

Results and Discussion

Abundance results for select foodfish groups from the Managaha Marine Conservation Area (MMCA) are presented in Figure 15.22. These data indicate a general decline in abundance for most of the depicted fish groups from 2000-2002. The one exception is for Labridae which shows a spike in 2001, a trend that was also observed in other parts of the CNMI for some groupers. Although the MMCA was enacted into law in 2000, enforcement of regulations did not commence until 2002. Enforcement benefited significantly from the use of U.S. Coral Reef Initiative Management Grant funds, and has been successful in the past two years. Therefore, the first three years of the survey are viewed as preliminary results.

Data collected from 2000-2002 from the SBFR in Rota are depicted for a range of abundant select reef fish groups in Figure 15.22. The abundance estimates for the SBFR show mostly insignificant variability among all three years for the groups depicted. The most notable exceptions are decreases in the Lethrinidae and Nasinae, and increases in the Labridae (Figure 15.22) and terminal phase Scaridae (Figure 15.23).

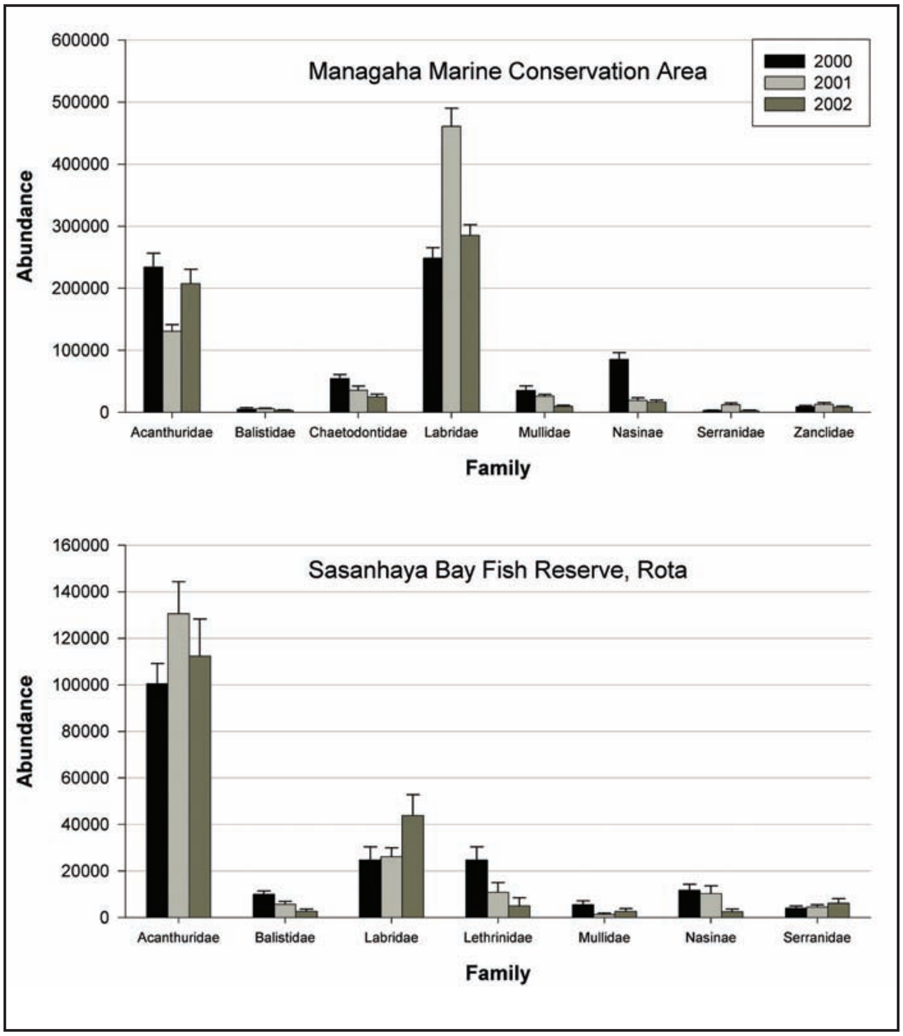

Figure 15.22. Abundance estimates from the MMCA (upper panel) and SBFR (lower panel) for various reef fish families. Source: Trianni, in prep.

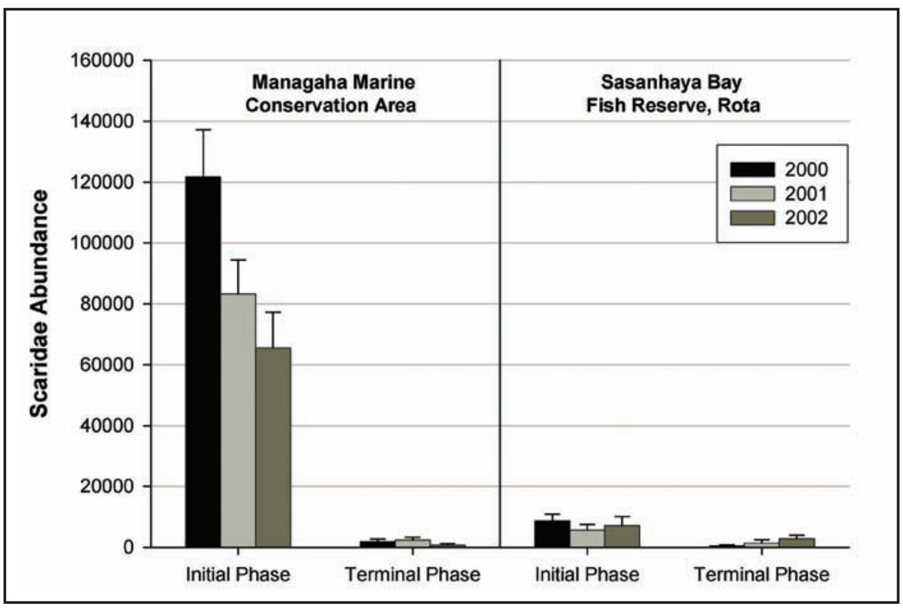

Figure 15.23. Abundance of initial and terminal phase Scaridae in the MMCA and SBFR, 2000-2002. Source: Trianni, in prep.

NOAA MARAMP

Methods

REAs, belt transects (BLTs), SPCs, and towed-diver/video surveys (TDVSs) were used to census diurnally active shallow-water reef fish assemblages. Each method was replicated at sites within or among the various habitat types. Fish length-class was estimated for all fish to provide an estimate of numerical size structure and biomass densities by taxa.

Results and Discussion

Preliminary results from the CNMI are presented here because full analysis of the data from these assessments is ongoing.

In general, all three methods (BLT, SPC, and TDVS) recorded the highest densities of large fish (all taxa pooled) at the northernmost islands (Asuncion, Maug, and Uracas) and banks (Stingray Shoals and Supply Reef; Figure 15.24). High to moderate densities occurred throughout the central part of the chain (to Sarigan). Densities of the largest jacks (Figure 15.25) and groupers (Figure 15.25) were highest at the northern end of the archipelago, as observed by TDVSs. Moderate densities occurred through the central part of the chain, a pattern supported when smaller fish were measured using the SPC (>25 cm total lenght [TL]) and BLT (>20 cm TL) methods. The largest (i.e.,>50 cm TL) snappers occurred at the northernmost islands, with high to moderate densities south to Anatahan (Figure 15.26). The largest surgeonfish occurred at Stingray Shoals in the far northwest, with moderate densities extending from the northern islands to the central part of the chain (Figure 15.26). Other target families (e.g., parrotfish, wrasses, and emperors) also exhibited the same trends found in surgeonfish. However, there were some exceptions, such as shark which occurred in low densities in the north. Overall, the 2003 PIFSC-CRED fish surveys found that common fishery target species in the Marianas Archipelago were most abundant in the northern islands, although less abundant than about a decade ago, particularly around the southern populated islands. However, these results, together with REAs surveys, found highest fish diversity at the southern islands (especially for emperors, wrasses, squirrelfish, and parrotfish), moderate fish diversity at the western banks, and lowest fish diversity at the northern islands.

High densities of recently recruited young juveniles were present for a number of species at many of the northern reefs, with very high densities of the red-toothed triggerfish (*Odonus niger*) at Rota. In contrast, fish at Anatahan were nearly absent along some transect lines due to the major volcanic eruption of this island only four months earlier. Visibility was very poor (average 1-2 m) around much of the island due to suspended ash in the water column, which also buried much of the reef.

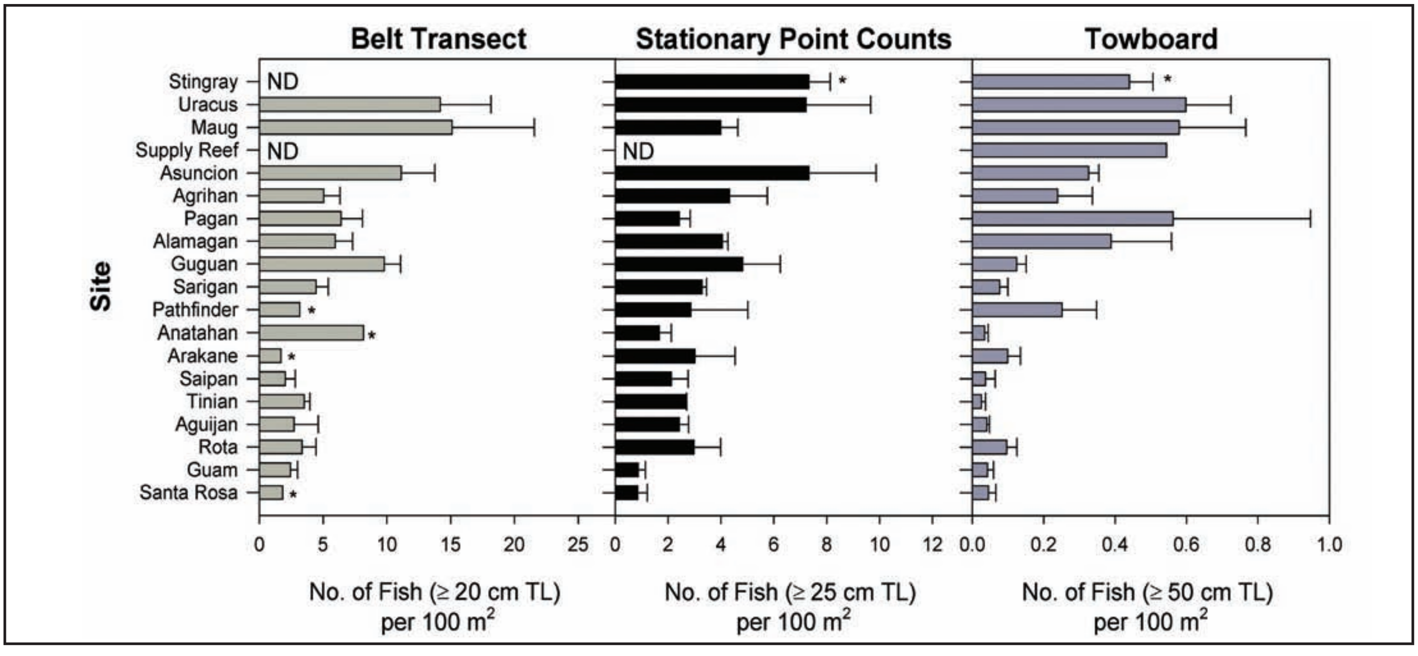

Figure 15.24. All three fish survey methods used during the NOAA MARAMP cruise documented a high abundance of large fish (all taxa pooled) at the northern islands and banks in the Marianas Archipelago. Source: PIFSC-CRED (R. Schroeder), unpublished data.

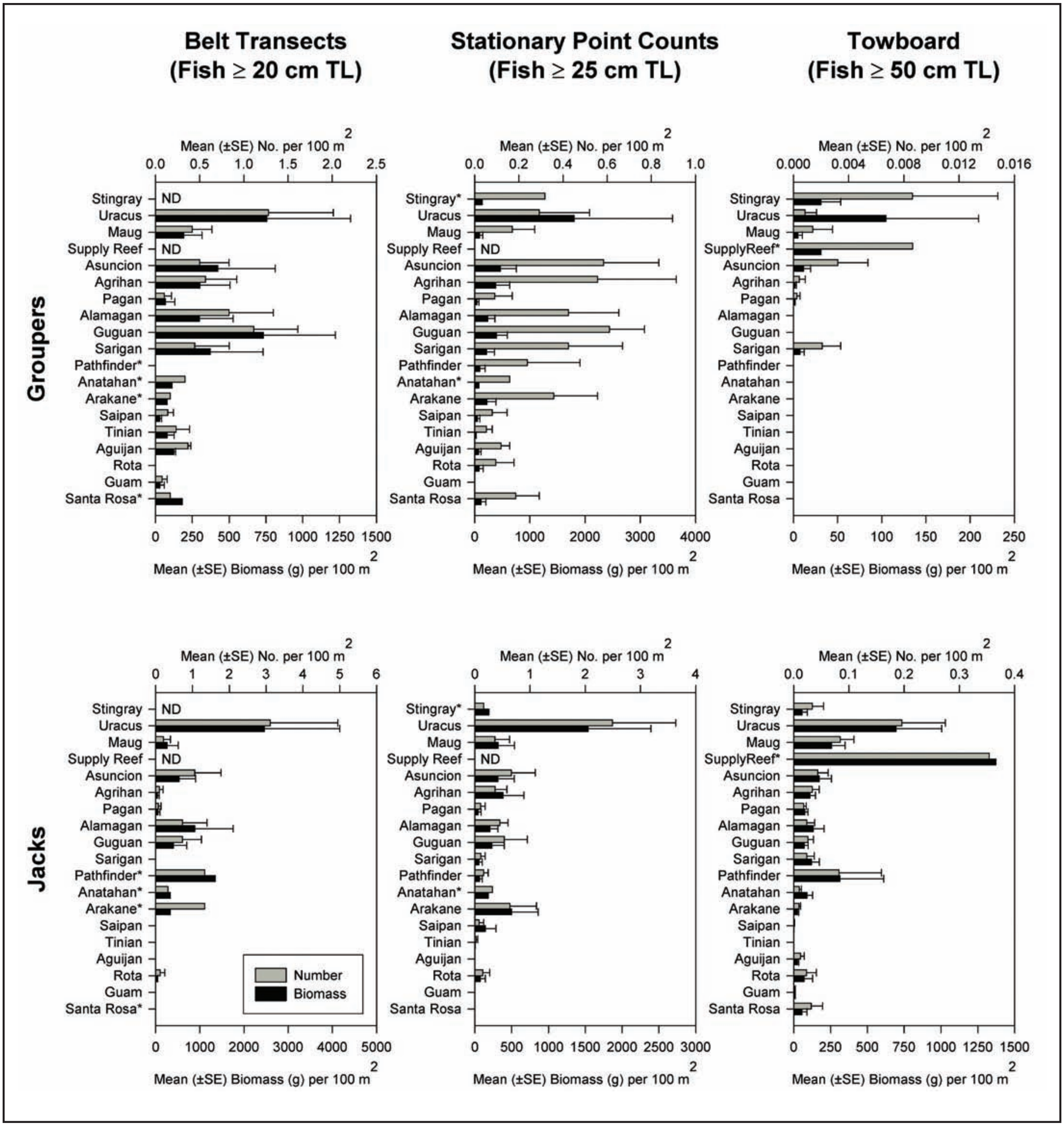

Figure 15.25. Number and biomass of Jacks and Groupers observed in the CNMI by sampling method. Source: PIFSC-CRED (R. Schroeder), unpublished data.

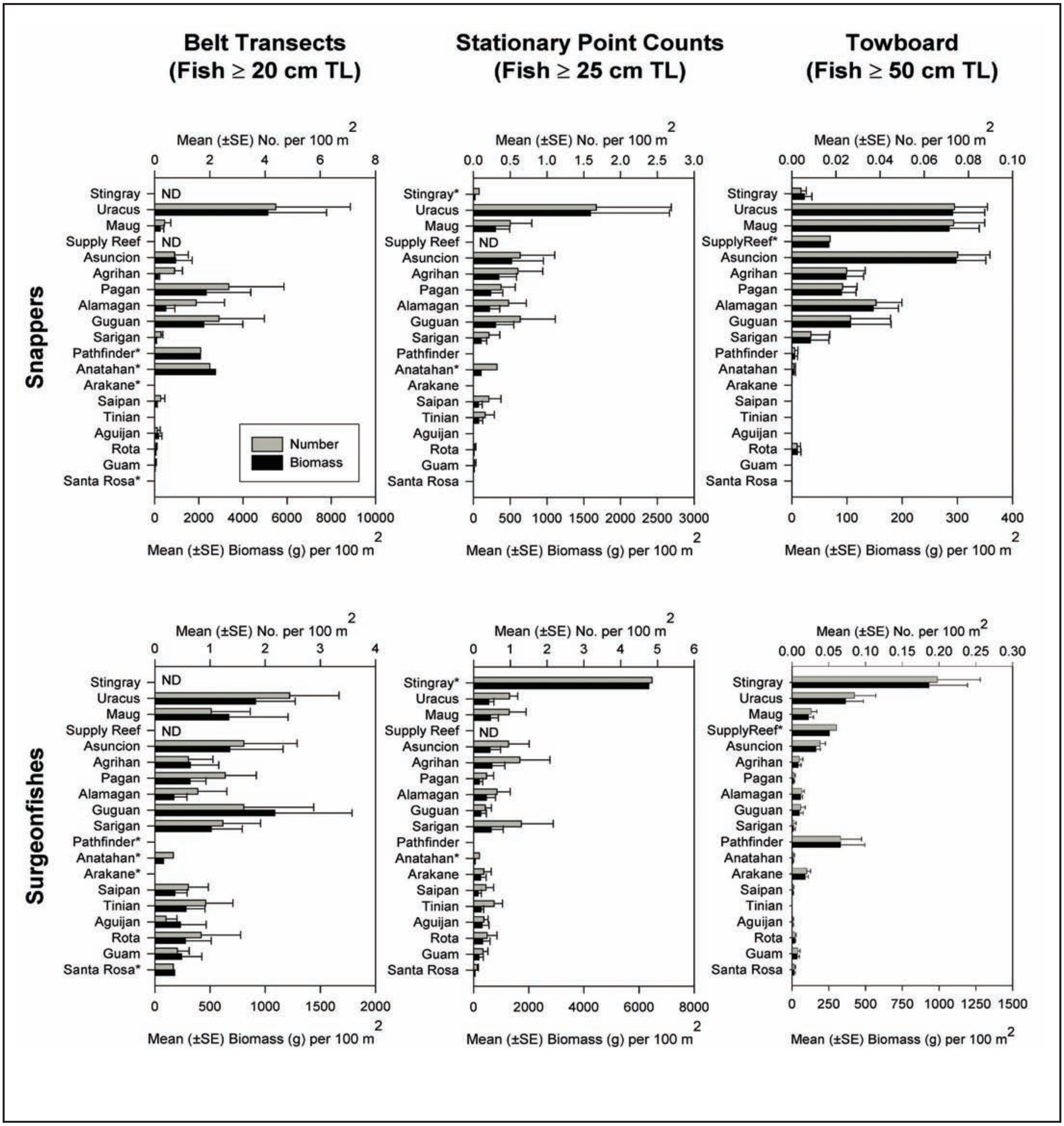

Figure 15.26. Number and biomass of Snappers and Surgeonfish observed in the CNMI by sampling method. Source: PIFSC-CRED (R. Schroeder), unpublished data.

INVERTEBRATES

NOAA MARAMP Invertebrate Surveys

Methods

Surveys focusing on marine invertebrates other than corals were performed in conjunction with surveys of coral and macroalgae, collectively termed the benthic survey. Two types of data on the benthic macroinvertebrate fauna of the CNMI were obtained: 1) quantitative data on the abundance of conspicuous species using BLTs and 2) qualitative information on the occurrence of other invertebrate species at each site.

Results and Discussion

The dominant invertebrate groups observed throughout the CNMI were sponges and echinoids. All sites had a diverse assemblage of encrusting and boring species of sponges. *Terpios hoshinota*, a coral killing sponge, was observed in Guguan and Uracas. The most common echinoid throughout the northern Mariana Islands was the small black-spined sea urchin, *Echinostrephus aciculatus*, with densities of up to 2-3/m^2. The most abundant sea star observed was the fissiparous *Linckia multifora*, with high densities that reached up to 0.75/m^2. The coral-predatory COTS, *acanthaster planci*, was present in Agrihan, Pagan, Anatahan, Saipan, and Rota but was not observed at densities more than 0.06/m^2.

The dominant genera of alcyoniid soft corals were *Sarcophyton, Lobophytum, Sinularia,* and *Cladiella*; soft corals were present at all of the islands and shoals, except in Uracas, where soft corals were almost completely absent. Among the mollusks, the giant clam *Tridacna maxima* was present at all CNMI islands and was especially abundant in Guguan and Maug Islands. The maximum density recorded was along the interior slope of the eastern end of the northern island, where densities reached 0.5-1/m^2.

MMT Nearshore Coral Reef Monitoring Program

Methods

This program was previously described in this chapter and the data presented here are based on replicate 50 m by 2 m transects. Methods are described in detail in Houk (2000, 2001).

Results and Discussion

Variables measured at the majority of MMT monitoring sites showed no significant within-site differences in invertebrate abundances during the two to four years of monitoring. Several sites showed significant variation in sea urchin abundance (Figure 15.27). Despite the magnitude of these changes, they are not consistent among or within sites. These data are being further analyzed to examine relationships with other parameters monitored by the MMT. It is more likely that an understanding of this variation will depend on the collection of additional, long-term data to clarify the nature of the population dynamics for these animals.

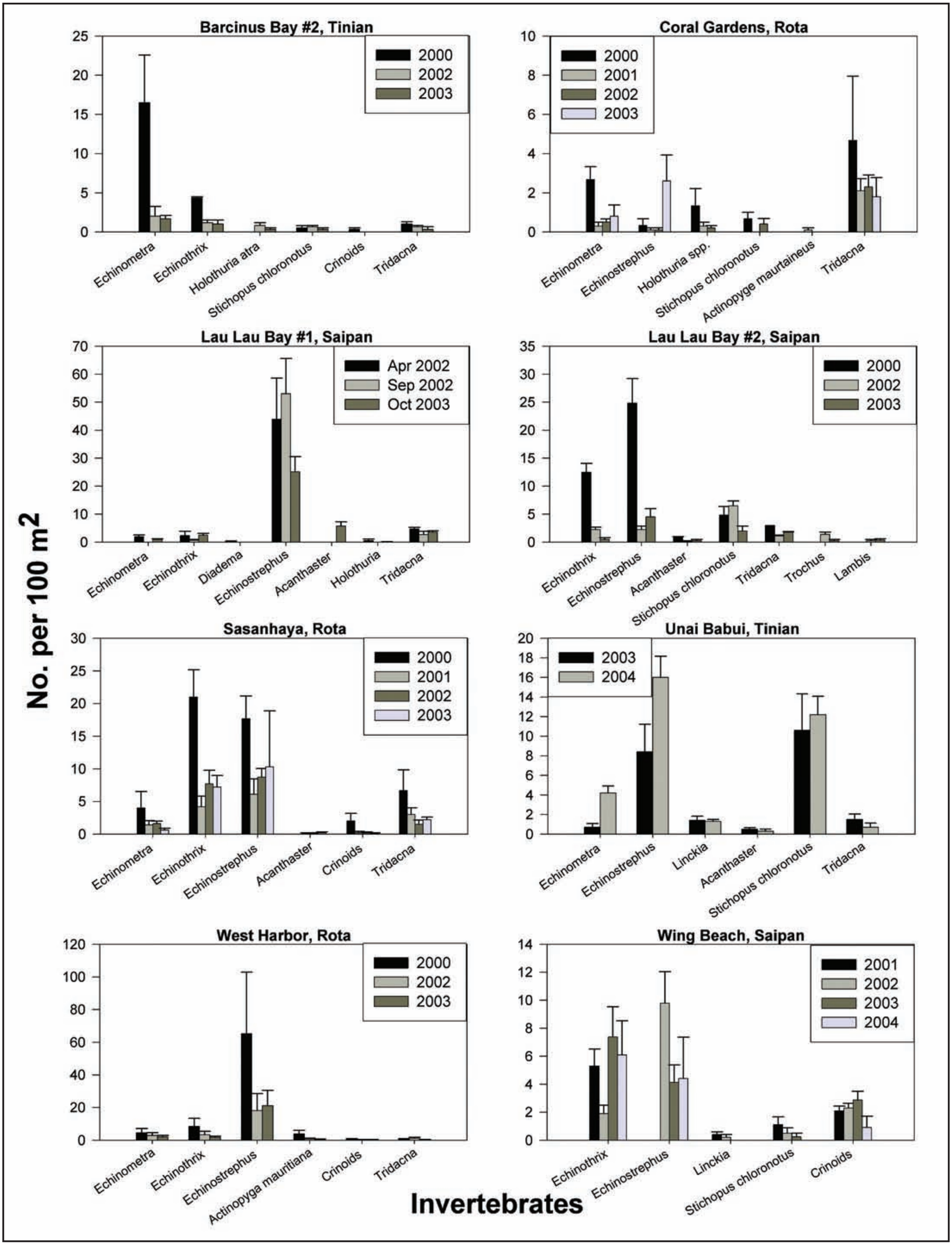

Figure 15.27. Invertebrate abundance at selected long-term monitoring sites at Tinian, Rota, and Saipan. Source: CNMI MMT (P. Houk), unpublished data.

TURTLES

Methods

Sea turtles have been surveyed in the nearshore waters of CNMI southern arc islands (Kolinski et al., 2001, 2004). During the 2003 MARAMP cruise, methods were modified for use in the northern arc islands (Kolinski et al., in prep.) and at isolated bank and reef systems (Kolinski et al., in press). A combination of towed-diver, dive, and surface surveys were employed to assess turtle presence.

Results and Discussion

Resident Turtles

Previous surveys suggest roughly 1,000 to 2,000 mainly immature green turtles (*Chelonia mydas*) reside in CNMI southern arc waters (Kolinski et al., 2004; Figure 15.28). Hawksbill turtles (*Eretmochelys imbricata*) have been infrequently sighted in these waters, and transitory visits by leatherbacks (*Dermochelys coriacea*) and olive ridleys (*Lepidochelys olivacea*) are known. Extensive examination of seven shallow-water (≤ 40 m) isolated reef systems within the Marianas Archipelago identified only two immature and one juvenile/adult green turtles, suggesting that these habitats support minimal numbers of this species, perhaps for transitory periods of time (Kolinski et al., in press). Data analysis of turtle observations from northern arc waters is in progress. For the nine surveyed islands (Figure 15.28), 166 green, four hawksbill, and three unidentified turtle observations were made. A projected upper boundary for the resident green turtle population size throughout the CNMI portion of the Marianas Archipelago is not likely to exceed 2,700 turtles (Kolinski et al., in prep). Hawksbill numbers likely do not exceed 50 individuals.

Nesting

Small numbers of green turtles are known to nest on the southern arc islands of the CNMI (Wiles et al., 1989, 1990; Pultz et al., 1999; McCoy, 1997; Kolinski et al., 2001; Ilo and Manglona, 2001). There are no reports of turtles nesting at northern arc island locations. Available northern arc beach substrate is limited and consists mainly of black volcanic sands and ash, although beaches at Maug and Pagan also include calcareous sands (Kolinski, pers. obs.).

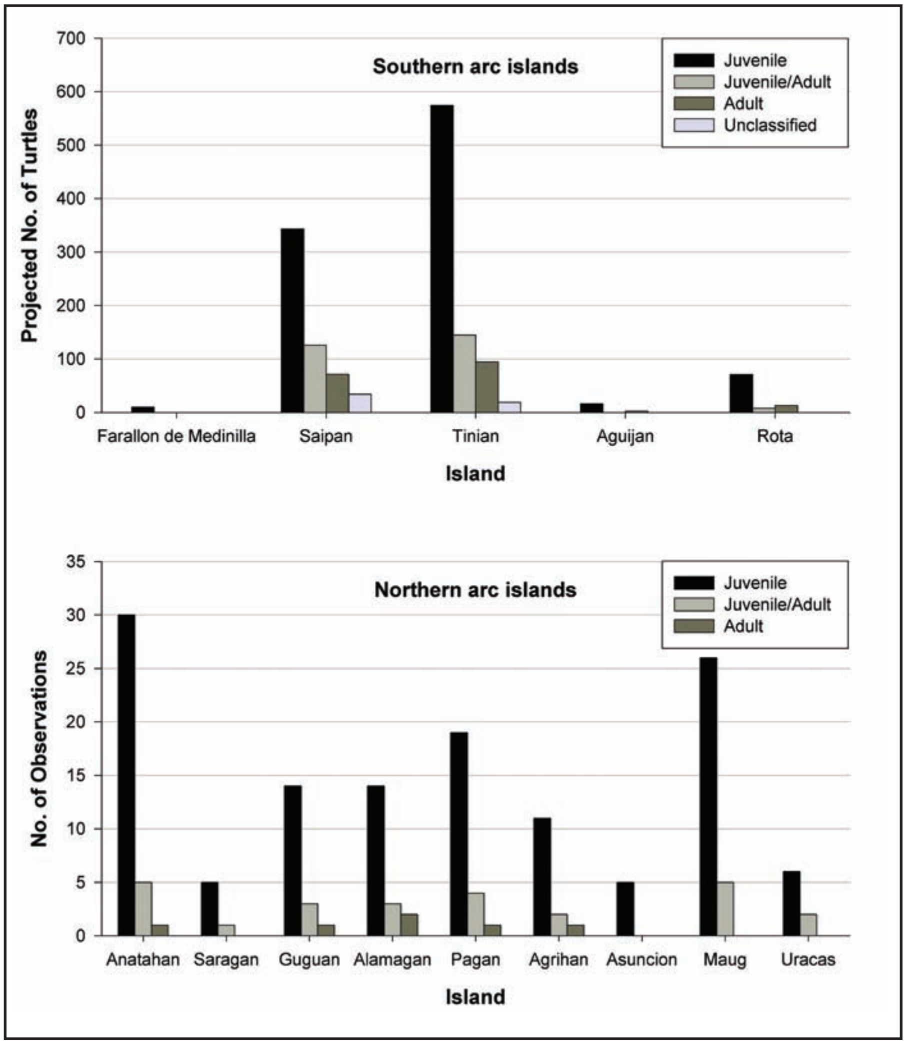

Figure 15.28. Upper panel shows projected population structures of *Chelonia mydas* at surveyed CNMI southern-arc islands. Source: Kolinski et al., 2004. Lower panel shows the numbers of observations of *Chelonia mydas* at surveyed CNMI northern-arc islands. Source: Kolinski et al., in prep.

Overall Condition and Summary of Analytical Results

Coral reef ecosystems in the CNMI are, on the whole, reasonably healthy. However, it must be recognized that coral reef ecosystems in the CNMI cannot be realistically treated as a single entity since the geology, oceanography, ecological history, and human activities vary widely across the 14 islands and associated reef shoals and banks. Biological diversity, across coral reef taxa, is variable among islands and isolated reefs, with limited data indicating that offshore banks and reefs support lower diversity, probably due to lower habitat diversity.

Anthropogenic effects, such as nonpoint source pollution and fishing pressure, have clearly affected areas in proximity to the populated southern islands. While these stressors are actively being managed by local government agencies, some solutions, such as the replacement of sewer infrastructure, exceed locally available funding. From a fisheries perspective, the northern islands and more distant banks and reefs appear to be in better condition than those closer to population centers.

Environmental stressors such as volcanic ashfall, elevated SST, and *Acanthaster* predation have clearly had localized negative effects on coral reefs in the Marianas. Anthropogenic stressors also create an additive, if not synergistic, increase in coral reef degradation. It is imperative to support and expand monitoring programs that provide information to managers which helps them address both natural and anthropogenic sources of coral reef degradation.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Saipan Lagoon and Tinian Marine Management Areas

Activities within the Saipan Lagoon fall under the general jurisdiction of several CNMI government agencies. The CRM has designated the lagoon as part of an Area of Particular Concern and is involved in protecting the lagoon's environment by preventing and reducing user conflicts. One of CRM's primary activities in the lagoon is the regulation of commercial marine sports. The Commonwealth Ports Authority further regulates the Tanapag Harbor and Harbor Channel. Management of these areas also falls under the jurisdiction of DFW, DEQ, and Marianas Public Lands Authority.

Marine Protected Areas

Current opinion supports the need for permanent spatial and temporal reef fish sanctuaries in the hope that they will act as insurance against fishery "collapse." Setting aside MPA to serve as spawning stock areas and to ensure habitat integrity, not only for coral reef fish but for food organisms as well, may be the most effective management tool available to maintain levels of spawning stock biomass necessary to replenish or sustain coral reef fisheries.

In 1985, the concept of the establishment of marine parks in the CNMI was explored when the CRM studied whether to propose marine parks on the populated southern islands of Saipan, Tinian, and Rota to promote and enhance tourism (PBEC, 1985). More recently, concern over declining catch rates around Saipan, Tinian, and Rota raised concern over management protocols for coral reef fisheries (Trianni, 1998b).

In 1998, the DFW MSP commenced a project with funding from the Sportfish Restoration Act (16 USC § 777-777k) administered by the USFWS. The goal of the project was to provide funding for the monitoring and assessment of coral reef fish in existing no-take MPAs (nMPAs) in the CNMI, as well as to conduct surveys of all CNMI islands for the designation of additional nMPAs. When the project commenced, the SBFR in Rota was the only nMPA in existence, as it was designated in 1994. Shortly after the DFW MSP project commenced, a bill was introduced to create the Tinian Marine Sanctuary (TMS; Tinian Island) and MMCA (Saipan Lagoon). Geographic placement of these nMPAs generally followed the suggestions of the 1985 CRM-funded study, although the "no-take" provisions were added. The MMCA was subsequently passed into law in August 2000, while the TMS has yet to be enacted. Law enforcement of the SBFR did not begin until late 2000, while MMCA rules and regulations are being developed. DFW enforcement activities have increased over the past two years with the increased funding provided by a Coral Reef Initiative Management Grant. The funds have provided for two boats, dive gear, dive training, and workshops and support two conservation officer positions. Monitoring of the MMCA has resulted in several arrests for illegal spearfishing and use of rotenone, a poison derived from the naturalized plant *Derris* sp. In addition to enforcement activities, DFW has initiated an education and outreach program to promote compliance with MPA and fisheries regulations.

Education and Outreach

Support for educational efforts is increasing with recognition that education has an important role in marine conservation. The DFW has a dedicated education specialist to visit schools and educate students about endangered species issues. MPA pamphlets were produced and distributed by DFW on Rota and Saipan, and these pamphlets are currently being updated and translated into Chammoro, Carolinian, Mandarin, Tagalog, Japanese, and Korean in an attempt to educate all CNMI population sectors about MPAs. In addition, the Saipan DLNR erected educational signs at entrances to the Bird and Forbidden Island MPAs.

The DEQ has a strong education program targeting nonpoint source pollution and coral reef water quality issues. DEQ's Nonpoint Source Program also coordinates with EPA, NOAA, and CRM to implement the requirements of EPA's Coastal NonPoint Source Pollution Control Program (pursuant to Section 6217 of the Coastal Zone Reauthorization Amendments of 1990). NOAA funding recently supported the short-term hiring of a coral reef education specialist to assist DEQ, DFW, and CRM to build the coral reef education components of their outreach programs.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

The recent expansion of coral reef assessment, mapping, and monitoring in the CNMI is, in part, driven by funding from the U.S. Coral Reef Initiative to provide important baseline data. Without a firm understanding of the actual condition and ecological trends on local coral reefs, CNMI managers are forced to follow precautionary measures, rather than base decisions on locally reliable data. While this is changing with the maturation of local monitoring and assessment programs and the initiation of the NOAA MARAMP, understanding of Mariana Island coral reefs is far from complete. Long-term monitoring of fisheries, water quality, and other ecological parameters will be necessary to support management efforts.

Through an extensive process of stakeholder meetings, the CNMI has developed local action strategies that identify those areas of greatest concern for the continued effective management of local coral reefs. These strategies provide a blueprint for how the CNMI hopes to address the identified areas of concern. Nonpoint source pollution, fishing pressure, and improvement of reef-related education and outreach were identified as the three areas of highest priority. While these areas have been the management focus even before the formation of the Commonwealth, the boom in development and concomitant population growth have outpaced the ability of local government to effectively manage them. The U.S. Coral Reef Initiative, through NOAA, EPA, USFWS, and other organizations, has provided tremendous support to build local capacity to effectively manage coral reef ecosystems.

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The State of Coral Reef Ecosystems of Guam

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INTRODUCTION AND SETTING

This report is an assessment of the status of coral reef ecosystems in Guam from 2002 to 2004. Data on coral reef ecosystems were synthesized from assessments and monitoring programs conducted by local and federal organizations. Included in the report are assessments of the environmental and anthropogenic stressors affecting coral reefs, information on data gathering activities and the condition of coral reef ecosystem resources, a description of current conservation management activities, and overall conclusions and recommendations to monitor and manage coral reef ecosystems better in the future.

Guam, a U.S. territory located at 13° 28´N, 144° 45´E, is the southernmost island in the Mariana Archipelago. It is the largest island in Micronesia, with a land mass of 560 km^2 and a maximum elevation of approximately 405 m (Figure 16.1). It is also the most heavily populated island in Micronesia, with a population of about 164,000 people (July 2003 estimate). The northern portion of the island is relatively flat and consists primarily of uplifted limestone. The island's principle source aquifer "floats" on denser sea water within the limestone plateau. It is recharged from rainfall percolating through surface soils (Guam Water Planning Committee, 1998). The average annual rainfall is 218 cm (NOAA National Weather Service, http://www.prh.noaa.gov/guam/normal.html, Accessed 4/17/04). The southern half of the island is primarily volcanic, with more topographic relief and large areas of highly erodible lateritic soils (SCS, 1988). This topography creates a number of watersheds throughout the southern areas which are drained by 96 rivers (Best and Davidson, 1981).

The island possesses fringing reefs, patch reefs, submerged reefs, offshore banks, and barrier reefs surrounding Cocos Lagoon in the south and part of Apra Harbor (Randall and Eldredge, 1976). However, only Apra Harbor has substantial lagoonal habitats deeper than 10 m (Paulay, 2003a). The reef margin varies in width, from tens of meters along some of the windward areas, to over 781 m in Pago Bay (Randall and Eldredge, 1976). The combined area of coral reef and lagoon is approximately 69 km^2 in nearshore waters between 0-3 nmi (5.5 km), and an additional 110 km^2 in U.S. waters greater than 3 nmi offshore (Hunter, 1995). Sea surface temperatures (SSTs) range from about 27-30°C, with higher temperatures measured on the reef flats and in portions of the lagoons (Paulay, 2003a). Although Guam's marine life is not as diverse as the neighboring islands to the south (Palau and the Federated States of Micronesia), it lies relatively close to the Indo-Pacific center of coral reef biodiversity (Veron, 2000). Table 16.1 includes the number of currently documented species for major coral reef taxa on Guam or in some cases for the Mariana Islands as a whole.

Guam's coral reefs are an important component of the island's tourism industry. The reefs and the protection that they provide make Guam a popular tourist destination for Asian travelers. According to the Guam Economic Development Authority, the tourism industry accounts for up to 60% of the government's annual revenues and provides more than 20,000 direct and indirect jobs. Guam's primary tourist market is Asia, with the majority (70-80%) of tourists arriving from Japan. As such, Guam's economy is tied to that of Asia, which has suffered a series of setbacks starting in the early 1990s involving the Asian economic crisis, a massive earthquake and several devastating typhoons, the terrorist attacks on September 11, 2001, the severe acute respiratory syndrome outbreak, and the war in Iraq that began in 2003. Despite these events, Guam still hosted nearly one million visitors in 2003 (GVB, 2004), and expects to host over one million in 2004 (GHRA, 2004).

Traditionally, coral reef fishery resources formed a substantial part of the local Chamorro community's diet and included finfish, invertebrates, and sea turtles (Amesbury and Hunter-Anderson, 2003). Today coral reef resources are both economically and culturally important. Although somewhat displaced from the diet by westernization and declining stocks, reef fish are still found at the fiesta table and at meals during the Catholic Lenten season. Many of the residents from other islands in Micronesia continue to include reef fish as a staple of their diet (Amesbury and Hunter-Anderson, 2003). Sea cucumbers, sea urchins, a variety of crustaceans,

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3 Guam Environmental Protection Agency, Government of Guam, Barrigada, Guam
4 Guam Coastal Management Program, Bureau of Statistics and Plans, Government of Guam, Hagatna, Guam
5 Bureau of Statistics and Plans, Government of Guam, Hagatna, Guam

Figure 16.1. Locator map for Guam. Map: A. Shapiro.

Table 16.1. A recent compendium of over 5,000 species of marine organisms documented in Guam. Source: various authors, *Micronesica* 35-36, 2003.

GROUP	NUMBER OF SPECIES	SOURCES
Seagrasses	3	*Lobban and Tsuda, 2003*
Benthic Macroalgae	237	*Lobban and Tsuda, 2003*
Sponges	110	*Kelly et al., 2003*
Foraminiferan	303	*Richardson and Clayshulte, 2003*
Platyhelminthes	59	*Newman et al., 2003*
Hydroids	42	*Kirkendale and Calder, 2003*
Polychaetes	104	*Bailey-Brock, 2003*
Non-scleractinian Corals	119	*Paulay et al., 2003b*
Scleractinian Coral	377 *	*Randall, 2003*
Hydrozoan Corals	26 *	*Randall, 2003*
Bivalves	339	*Paulay, 2003c*
Prosobranch Gastropods	895	*Smith, 2003*
Opistobranch Gastropods	467	*Carlson and Hoff, 2003*
Cephalopods	21	*Ward, 2003*
Cirripedia	24	*Paulay and Ross, 2003*
Crustaceans	663	*Ahyong and Erdmann, 2003; Paulay et al., 2003a; Castro, 2003; Tan and Ng, 2003; Kensley, 2003*
Echinodermata	196	*Paulay, 2003b; Starmer, 2003; Kirkendale and Messing, 2003*
Ascidians	117	*Lambert, 2003*
Sea Turtles	3	*Eldredge, 2003b*
Marine Mammals	13	*Eldredge, 2003b*
Shorefishes	1019 *	*Myers and Donaldson, 2003*
Total Species	**5137**	

* Number of species is for the entire Mariana Archipelago. The actual number for Guam may be lower.

molluscs, and marine algae are also eaten locally. In addition to the cash and subsistence value of edible fish and invertebrates, reef-related fisheries are culturally important as family and group fishing is a common activity in Guam's coastal waters.

Over 10% of Guam's coastline has been set aside in five marine preserves: Tumon Bay, Piti Bomb Holes, Sasa Bay, Achang Reef Flat, and Pati Point. The preserves were established in 1997 as a response to decreasing reef fish stocks, but were not fully enforced until 2001. Fishing activity is restricted in the preserves with limited cultural take permitted in three of the five areas. The preserves are complemented by the War in the Pacific National Historical Park, Ritidian National Wildlife Refuge, Guam Territorial Seashore Park, Orote Penisula Ecological Reserve Area (ERA), and Haputo ERA. While management practices are enforced in the five marine preserves, there is currently limited management and enforcement in the other areas.

The health of Guam's coral reefs varies considerably, depending on a variety of factors including geology, human population density, level of coastal development, level and types of uses of marine resources, oceanic circulation patterns, and frequency of natural disturbances, such as typhoons and earthquakes. Many of Guam's reefs have declined in health over the past 40 years. The average live coral cover on forereef slopes was approximately 50% in the 1960s (Randall, 1971), but dwindled to less than 25% live coral cover by the 1990s with only a few having over 50% live cover (Birkeland, 1997). In the past, however, Guam's reefs have recovered after drastic declines. For example, an outbreak of the crown-of-thorns starfish (COTS) in the early 1970s reduced coral cover in some areas from 50-60% to less than 1%. Twelve years later, greater than 60% live coral cover was recorded in these areas (Colgan, 1987). A more distressing indicator of the health of Guam's coral reefs is the marked decrease in rates of coral recruitment. In 1979, Birkeland et al. (1982) obtained 0.53 coral recruits per plexiglass fouling panel. The use of similar materials and experimental design in 1989 and 1992 resulted in just 0.004 and 0.009 coral recruits per plexiglass fouling plates, respectively (Birkeland, 1997).

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

Large-scale coral bleaching events and associated coral mortality are not common on Guam. Since the establishment of the University of Guam Marine Laboratory (UOGML) in 1970, there have been only two recorded large-scale bleaching events. In 1994, 68% of surveyed taxa bleached on Guam (Paulay and Benayahu, 1999). The event was characterized by considerable inter-species variation in bleaching response and little mortality, and did not appear to be associated with above-average SSTs. In 1996, about half of *Acropora* species showed moderate to heavy bleaching, similar to the response of *Acropora* species to the 1994 bleaching event (G. Paulay, pers. comm.). There was also little mortality, except for a localized die-off on Piti Reef Flat due to extreme tidal conditions (G. Davis, pers. comm.). A recent bleaching event in Pago Bay appears to be linked to freshwater influx from the record rainfall associated with Tropical Storm Tingting in June 2004 (P. Schupp, pers. comm.). Bonito and Richmond (submitted) reported that a UOGML scientist observed cases of coral bleaching on Guam every year for at least the past seven years, but again, they were not accompanied by mass mortality. However, as SSTs continue to rise, coral bleaching events may become more frequent and more deleterious on Guam.

Diseases

Although many common coral diseases have been identified on Guam's reefs, no systematic survey specifically addressing disease has been undertaken. In general, coral disease appears to be much more problematic in the Caribbean and Atlantic than in the Pacific Ocean to date.

Tropical Storms

In the last decade, Guam has been hit directly by four typhoons with sustained winds of greater than 150 miles per hour and suffered high waves and winds from large systems passing close to Guam (Figure 16.2; Guard et al., 2003). These systems have had a tremendous impact on the island. In 2002, Guam was hit with two tropical storms, Typhoon Chata'an and Super Typhoon Pongsona. At Typhoon Chata'an's closest approach, wind speeds of 100-120 mph were recorded. Six months later, Super Typhoon Pongsona passed directly over the island, with wind speeds reaching super typhoon strength at 150 mph (Guard et al., 2003). These types of storms cause considerable damage on land and also impacted the marine environment, especially Guam's coral reefs (Figure 16.3).

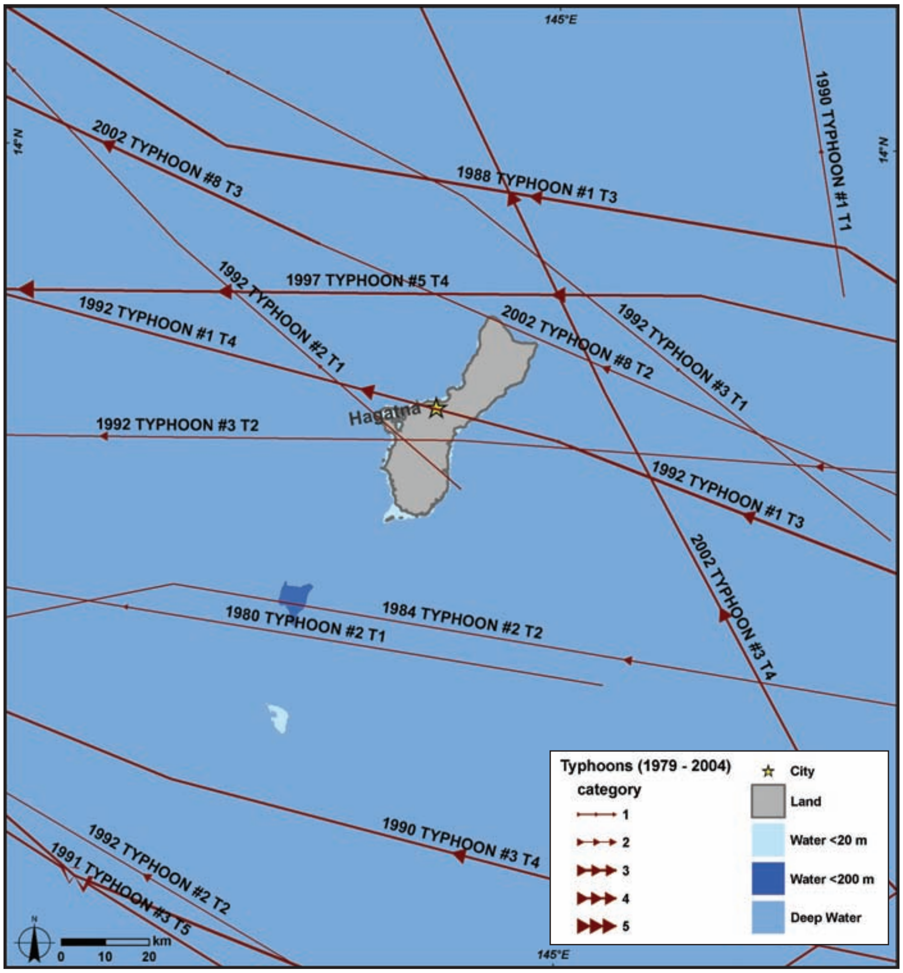


Figure 16.2. The path and intensity of typhoons passing near Guam from 1979-2004. Four major storms (sustained winds >150 mph) have hit Guam in the past 10 years. Many Pacific typhoons are not named or the names are not recorded in the typhoon database. Map: A Shapiro. Data: UNISYS, http://weather.unisys.com/hurricane.

According to Guam's Bureau of Statistics and Plans (2002), 175 sites were surveyed by damage assessment teams after Typhoon Chata'an. The surveyors identified problems with erosion, turbidity at river mouths, debris accumulation and debris staging sites. Of the sites identified as beach/shore, river, inland, reef, or infrastructure (bridge, drain, road, seawall), 76% showed signs of erosion. Beach and shore erosion were highest in the southern part of Guam with over 20 eroded sites identified.

Figure 16.3. In 1997, Super Typhoon Paka scattered debris across the island, including the reef flats. Photo: Guam Coastal Management Program.

The assessment teams identified many types of debris including a combination of metallic and household trash, natural wood, lumber, bamboo, coconut leaves, coconuts, dead animals, vegetation, tires, and rubber materials. The survey report indicated that the southern part of Guam had the highest concentration of medium to heavy debris from the 10 sites surveyed. A total of 69 pieces of debris were collected from ten sites. The Guam Diving Industry Association assisted with the water/ocean assessment portion of the study. Dive groups observed debris at six popular dive sites and reported that excess trash and debris were believed to be typhoon-related. The debris included cans, leaves, tree fronds, and pieces of plastics. The assessment after Super Typhoon Pongsona suggested that the debris from Typhoon Chata'an was moved off the reef and placed farther offshore by Super Typhoon Pongsona.

The effects of tropical storms are not limited to debris and erosion. Typhoon Chata'an caused waste oil to spill from a U.S. Navy storage waste oil barge into Apra Harbor in July 2002. In December 2002, Super Typhoon Pongsona caused three large fuel storage tanks to catch on fire and burn for six days at the Guam Commercial Port. This fire deposited a large amount of soot in the adjacent harbor. In addition, fire retardants applied to control this fire may have entered the adjacent marine environment.

Coastal Development and Runoff

The resident population of Guam increased 16.3% from 1990 (133,152) to 2000 (154,805) with an associated population density increase from 634.5 to 737.7 individuals/mi^2 (U.S. Census Bureau, 2003). This rate was lower than the population increases observed between 1980 and 1990 (25.6%) and between 1970 and 1980 (24.7%). The population growth rate in 1990 was 2.3 compared to 1.51 in 2000, and predictions estimate the growth rate to steadily decrease over the next 50 years. Nevertheless, the population is expected to reach 203,000 by 2020 and 242,000 by 2050 (U.S. Census Bureau International Programs Center Database, 2003).

Slow economic growth since 2001 has limited new development on Guam. During this time, development has primarily been residential or other small-scale construction. No major building construction projects (e.g., hotels, large office buildings) requiring review by Guam's Application Review Committee (ARC) were undertaken and no new applications for large development were submitted to the ARC in 2003 (DPW, 2004a). However, a small number of large developments that did not require review by the ARC (i.e., proposals that met all of the requirements set forth by Guam's existing rules and regulations) have been completed or are currently underway (DPW, 2004a).

In a recent report to the U.S. Congress on Guam's water quality (GEPA, 2003) the major causes of decline in water quality to marine bays were development (paving and creation of impervious surfaces), encroachment onto the shoreline without the use of pollution management measures, marine debris, mechanical beach sand raking, and construction without the use of management measures. Increased urban runoff associated with greater impervious surface cover and reduced vegetation cover is of particular concern for reefs fringing near the more densely populated and urbanized northern portion of Guam. Road construction has decreased considerably since the early 1990s and has remained relatively constant over the past six years. Three major road construction projects, totaling approximately 14 km of roadway, have been ongoing during the past two years and are expected to be completed in 2004 (DPW, 2004b). Two of the projects (Rt. 14 in Tumon and Rt. 4 in Yona) are located near the coastline and involve a total of 5 miles of heavily traveled roads. The required use of siltation fences has occurred at the Tumon site, but fences initially installed at the Yona site have not been properly maintained (T. Leberer, pers. comm.). The third project, involving the reconstruction of a section of Rt. 1 in Dededo, is farther from the coastline and is believed to be less of a threat to coral reef systems. In addition to these on-going projects, 17.4 km of highway have been constructed or repaired since 2000. This figure is approximately equal to the miles of road construction/repair that occurred between 1996 and 1999 (17.5 km) and much lower than occurring between 1992 and 1995 (42.25 km) (DPW, 2004b).

Sedimentation, resulting from construction projects and accelerated rates of upland erosion, is commonly considered one of the primary nonpoint source pollution threats to Guam's reefs. In southern Guam, sedimentation is exacerbated by steep slopes and underlying volcanic rock, which allow significant surface water flow and enhanced transport of sediments to coastal waters (Figure 16.4). For example, a road construction project along the southern shores of the island in the early 1990s resulted in the particularly heavy sedimentation of a 10 km section of fringing reef, killing much of the coral (R. Richmond, pers. comm.). A study conducted by the Natural Resources Conservation Service (NRCS; U.S. Department of Agriculture, 1995) examined four types of habitat within the Ugum Watershed in southern Guam. Using the Revised Universal Soil Loss Equation, the NRCS estimated that sediment yield at the mouth of the watershed totaled 5.5 tons per acre. According to the NRCS average estimates ravine forests eroded 12 tons per acre per year (t/a/yr), agricultural lands eroded 20 t/a/yr, savannah grasslands eroded 31 t/a/yr, and unvegetated badlands eroded 243 t/a/yr. Findings indicated that inappropriate road construction, off-road vehicle traffic, and wild land fires accelerated the erosion processes.

Figure 16.4. Sediment plumes due to upland erosion and heavy rainfall lead to serious problems for Guam's coral reef ecosystems. Photo: Guam Forestry and Soil Resources Division.

A recent study by Wolanski et al. (2003) suggested that land erosion in the La Sa Fua River catchment area caused significant sedimentation in Fouha Bay. This problem was exacerbated by the formation of muddy marine snow which has a much higher settling velocity than the unconsolidated clay particles in the river discharge. Wolanski et al. (2003) estimated that approximately 75% of the riverine sediments settle in the receiving bay and may smother juvenile corals. This sediment can become resuspended by storm swells a few times each year, causing high suspended sediment concentrations (1000 mgl/L) in the upper few meters of the bay.

Accelerated rates of upland erosion due to wildfires, clearing and grading forested land, recreational off-road vehicle use, and wild populations of introduced mammals continue to result in increased rates of sedimentation in southern Guam. Estimates suggest that between 1975 and 1999, Guam lost nearly a quarter of its tree cover, while increases in the acreage of badlands (bare soil with extremely high erosion rates) and other erosion-prone surface cover types have been observed (FSRD, 1999). The numerous fires set each year and the popular use of off-road vehicles are believed to be major contributors to the development and persistence of these erosion-prone surface cover types. According to the Guam Department of Agriculture's Forestry and Soil Resources Division (FSRD), an average of over 750 fires have been reported annually between 1979 and 2001, burning over 404 km^2 during this time period (Figure 16.5). Considering Guam's area is comprised of 560 km^2 and the amount of vegetated land is even less (Table 16.2), the impact of these fires is of great concern.

It is difficult to regulate the pollution in runoff and infiltration from the many small-scale agricultural activities on Guam. A study by Duenas and Associates (2003) stated that in 1998, only about 262 ha of land were under cultivation and the average farm size was 1.5 ha. Pig and poultry farms (commercial and non-commercial) censused prior to the severe typhoons of 2002 totaled 75 (averaging 30 pigs each) and 42 (with a total of 11,500 birds), respectively. The more significant use of fertilizers and pesticides on Guam's nine golf courses is carefully controlled through requiring GEPA approved turf management plans approved by Guam's Environmental Protection Agency (GEPA) and continuous monitoring through monitoring wells (Figure 16.6). Excluding the two military golf courses for which there are no available data the civilian courses cover over 567 ha (Duenas and Associates, 2003).

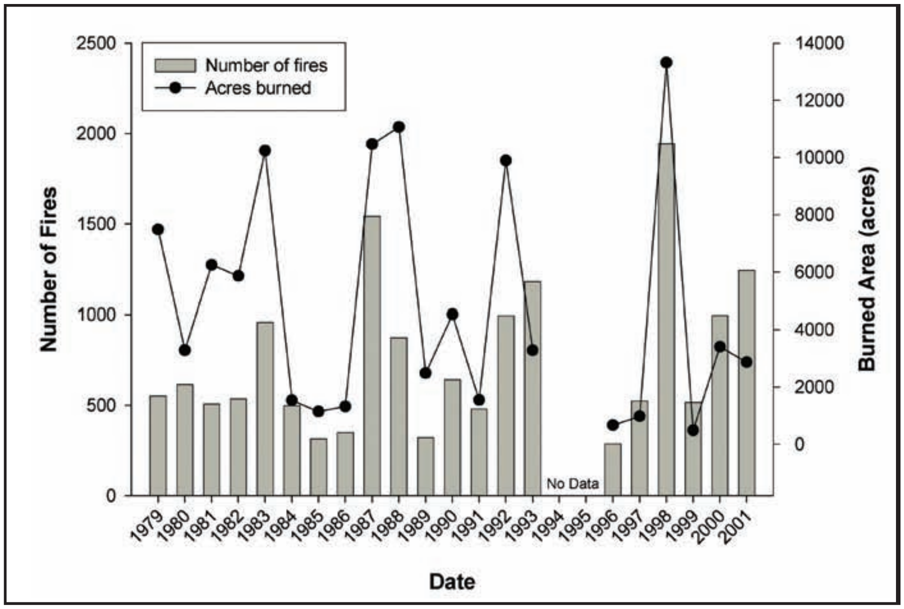


Figure 16.5. The frequency and acreage of wildfires in Guam from 1979-2001 (data unavailable for 1994-1995). Source: D. Limtiaco, unpublished data.

Table 16.2. The current land and water resources of Guam. Source: D. Limtiaco, unpublished data.

RESOURCE	TOTAL ACREAGE
Crop Land	14,227
Pasture Land	11,826
Range Land	21,454
Forest Land	51,058
Urban Areas	36,919
Freshwater	196
Total	**135,680**

Figure 16.6. Over 560 ha of land in Guam, such as this coastal area in Mangilao, have been converted to golf courses, and chemical run-off is a pressing concern. Source: Guam Division of Aquatic and Wildlife Resources.

Coastal Pollution

The primary pollutants to most waters, and specifically recreational beaches, are microbial organisms, petroleum hydrocarbons, and sediment. The GEPA administers the Water Quality Certification (Federal Clean Water Act Section 401) and National Pollutant Discharge Elimination System (NPDES) permits locally for the U.S. Environmental Protection Agency (EPA). Presently there are 19 active NPDES-permitted on Guam (Table 16.3.) The permitted discharges include treated wastewater from sewage treatment plants (STPs), thermal effluent from the Guam Power Authority power plants, and a number

Table 16.3. Guam EPA currently enforces nineteen NPDES permits on Guam. Facilities include wastewater treatment plants, power plants, and fuel facilities. Source: GEPA, 2003.

FACILITY	PERMITTEE	TYPE	VOLUME (millions of gallons/day)	RECEIVING WATER	MIXING ZONE
Northern District WWTP	Guam Waterworks Authority (GWA)	Municipal Wastewater	12	Philippine Sea	-
Tanguisson Steam Power Plant	Hawaiian Electric, Inc.	Cooling/ Low Volume Wastewater	97.92	Philippine Sea	-
Hagatna WWTP	GWA	Municipal Wastewater	12	Philippine Sea	-
Cabras Power Plant (Units 1-4)	Guam Power Authority (GPA)	Cooling Water	1) 173 2) 65.2	Piti Chanel	Yes
ESSO Eastern Cabras Terminal	ESSO Eastern, Inc. (Guam)	Stormwater	Varies	Apra Harbor	-
Mobil Cabras Terminal	Mobil Oil Guam, Inc.	Stormwater/ Tank Bottom Draws	Varies	Apra Harbor	-
Shell Cabras Island Docking Facility (F-1 Pier)	Shell Guam, Inc.	Stormwater/ Tank Bottom Draws	Varies	Apra Harbor	-
Unitek	Unitek	Stormwater	Varies	Piti Channel	-
Dry Dock	Guam Shipyard	Industrial Wastewater/ Balast	Varies	Inner Apra Harbor	-
GPA Piti Bulk Storage	GPA	Stormwater/Tank Bottom Draws	Varies	Piti Channel	-
Naval Station WWTP	Navy Public Works Center	Municipal Wastewater	4.3	Philippine Sea (Tipalao Bay)	Yes
Agat-Santa Rita WWTP	GWA	Municipal Wastewater	1.5	Philipine Sea (Tipalao Bay)	Yes
Umatac-Merizo WWTP	GWA	Municipal Wastewater	0.391	Toguan River & Philippine Sea	-
Leo Palace WWTP	Leo Palace Resort	Municipal Wastewater	0.100	Irrigation (Yona)	-
GIAA Parking Aprons	Guam International Airport Authority	Stormwater	Varies	Harmon Sink (Tamuning)	-
Continental Aprons	Continental Micronesia Airlines	Stormwater/Tank Bottom Draws	Varies	Harmon Sink (Tamuning)	-
Baza Gardens WWTP	GWA	Municipal Wastewater	0.600	Togcha River (Talofofo)	-
UOG Marine Lab.	University of Guam Marine Laboratory	Sea Water	0.216	Pacific Ocean	-
Shell Agat Terminal	Shell Guam, Inc.	Stormwater/Tank Bottom Draws	Varies	Big Guatali River (Piti)	-

of discharges that could contain minor amounts of oil and other toxic or biological materials. The guidelines for effluent limitations are based on Guam's water quality standards which underwent major revision in 2001 (GEPA, 2001). All permittees are routinely monitored by GEPA staff to verify compliance with applicable permit requirements and compliance schedules.

The 2003 NPDES monitoring reports indicate that shoreline monitoring stations at the Northern and Hagatna STPs did not register fecal coliform counts above the permit standard of 400 fecal coliform units/100 ml. Offshore monitoring stations for these STPs were not sampled. Water samples taken at the shoreline stations at the mouth of the Togcha River, downstream from the Baza Gardens STP, were within the orthophosphates and fecal coliform standards, but exceeded the nitrate-nitrogen standard of 0.10 mg/L half the time. Turbidity at these shoreline stations regularly exceeds water quality standards, but ambient turbidity measured upstream from the discharge likewise exceeded the current permit standards. Monitoring at the Umatac-Merizo (Toguan) STP showed orthophosphates and nitrate levels below standards, but turbidity was usually above the standard of 1.0 nephelometric turbidity unit (NTU). Turbidity levels were related to rainfall and of 27 recent samples, most registered turbidity less than 2.0 NTU; there were only four samples over 3.0 NTU - two at about 7 NTU, one at 13.6 NTU, and one at 14.2 NTU. It should be noted that when the five-year NPDES permits are renewed in 2006, the new 2001 Guam water quality standards will apply, but these permits are currently monitored according to standards in place when they were issued (GEPA, 2003).

Three of the island's outfall pipes discharge within 200 m of the shallow reef crest, in depths of 20-25 m and in areas where corals are found. These outfalls can be problematic as stormwater leaks into aging sewer lines. During heavy rain, this additional water forces the sewage treatment plants to divert wastewater directly into the ocean outfall pipes. In addition, during 2003 the effluent from the Hagatna STP was partly discharging into a shallow coral reef area due to a break in the outfall line caused by Super Typhoon Pongsona.

Nonpoint source pollutants in the north, such as nutrients from septic tank systems and agricultural or chemical pollutants from urban runoff and illegal dumping, infiltrate basal groundwater, and discharges in springs along the seashore and subtidally on the reefs. A two-year study of spring water discharges from the Northern Guam Aquifer into the marine preserve of Tumon Bay has recently been completed (PCR Environmental, 2002a, 2002b, 2002c). The springs discharge an estimated 64,350 m^3 per day. Chemicals detected in the discharges above GEPA water quality standards included perchloroetene (PCE), trichloroethene (TCE), aluminum, antimony, arsenic, magnesium, sulfate, oil and grease, total coliform bacteria and fecal coliform bacteria. The pesticides dieldrin, alpha-chlordane, and gamma chlordane were also detected in discharges. A recent dye study on water flows from Harmon Sink indicates that the stormwater was drained from the Guam International Airport and surrounding industrial areas, entered a karst formation sinkhole, and discharged through the aquifer to Tumon Bay and East Agana Bay coastal waters (Moran, 2002). Some of the flows reached East Agana Bay within four days of dye injection (traveling 360 to 645 m/day) and Tumon Bay within 17 days (80 to 175 m/day). A new dye study will determine the relation of stormwater discharges from Tiyan, south of Harmon Sink to East Agana Bay and Tumon Bay.

Recent studies of the heavy metals polychlorinated biphenyls (PCBs) and polyaromatic hydrocarbons (PAHs) in newly formed marine sediments and associated food chains in the four main harbor areas of Guam showed a moderate enrichment of contaminants in the harbors, especially Apra Harbor (Denton, et al., 1997; Denton et al., 1999). Sponges, soft corals, sea cucumbers, and fish from Apra Harbor were enriched with PCBs, while invertebrates showed concentrations of arsenic. Oysters showed copper and zinc contamination in Apra Harbor and Hagatna Boat Basin, but none of the fish or shellfish exceeded U.S. Food and Drug Administration food standards or guidance limits (GEPA, 2000b).

The U.S. Navy has been assessing and restoring 15 Comprehensive Environmental Response, Compensation, and Liability Act and Resource Conservation and Recovery Act sites, which could potentially impact coral reefs in Apra Harbor or Agat Bay. In 2001, it was determined that PCBs had entered the food chain offshore from the Orote Landfill site and off Gabgab Beach. The source of the PCBs has yet to be determined. However, PCBs as well as other chemicals are present in buried material at the landfill, which makes the site a potential source, even though it has been capped and contained by a restoration project costing over $15 million. Monitoring wells and other sampling techniques are being used to determine if the Orote Landfill was the source of the contamination. Seafood monitoring has detected PCBs in deep and shallow water reef fishes in the Philippine Sea off Orote Point and the public have been advised on the danger of consuming seafood from this area.

The public landfill located in the village of Ordot has been a source of leachate tentatively entering the Pago Bay reefs via the Lonfit/Pago Watershed. Baseline monitoring of the Pago Bay marine environment is planned by the Water and Environmental Research Institute of the UOG in 2005 to reflect changes related to the closing and capping of the landfill.

Tourism and Recreation

A total of 909,506 people visited Guam in 2003, representing a decrease of 14% from the number of visitors in 2002 (GVB, 2004). Based on visitor data collected from the first two months of 2004, visitor arrivals are expected to exceed one million (GHRA, 2004). According to the December 2003 Visitor's Arrival Statistical Report, 77% of the visitors came to the island for pleasure. A previous exit survey of Japanese visitors noted that the highest rated optional tourism categories were: parasailing, health spas, underwater observation, and jet-skiing (GVB, 2001). This suggests that marine resources are very important to Guam's tourism industry. There are a number of recreational activities that utilize or impact coral reefs, including snorkeling and scuba diving, charter fishing, and jet skiing.

Scuba diving and snorkeling are popular activities for tourists and residents. The Pacific Association of Dive Industry estimates that over 5,000 entry level certifications were issued in Guam last year (J. Bent, pers. comm.). This indicates that there are a large number of newly certified divers visiting Guam's reefs. One of the sites often visited by newly certified divers is the Piti Bomb Holes Marine Preserve. This has led to some negative impacts on the reefs in this area. Tsuda and Donaldson (2004) noted that snorkelers and scuba divers have caused considerable disturbances to the seagrass bed at this site. These disturbances include physical impacts, an increase in turbidity, and decreases in fish abundance and diversity. Other signs of impacts are broken pieces of coral and obviously worn or damaged coral heads (Figure 16.7). A number of other popular sites, including Gun Beach, Tumon Bay, and Ritidian, may also be impacted by reef walking activities.

Figure 16.7. Guam certifies a large number of new divers each year, and even more people try snorkeling in Guam's clear tropical waters. Unfortunately, these new divers and snorkelers often damage the environment by stepping on coral. Photo: D. Burdick.

Charter bottomfishing may also impact the coral reefs. According to an unpublished survey of fishing vessels by the Western Pacific Regional Fisheries Management Council (J. Calvo, unpublished data), there are approximately 10 locally-based charter fishing boats consistently operating in Guam. Most of these have little effect on the reefs as they target pelagic species. However, there are a few operations that offer bottomfishing targeting reef species on a regular, but infrequent basis. One operation offers bottomfishing charters on a daily basis out of the Agat Marina. Such charters normally work in depths of 18 to 110 m. There are an estimated 800 charter trips targeting the shallow water complex each year (Flores, 2003). In 2003, 2.1 metric tons of bottomfish were harvested, up from 1.3 metric tons in 2002, despite the decrease in the number of people participating in this sport (Flores, 2003).

Jet skiing is a popular tourist activity in Guam which may have several impacts on the reef due to jet ski use within the reef margin. These devices are loud, leak fuel, and may damage seagrass beds and corals, especially during low tides. Due to these impacts, jet ski use is limited to four locations within the reef margin: East Agana Bay, Apra Harbor, Cocos Lagoon, and Tumon Bay on a limited scale. A quantitative study on jet ski impacts is scheduled to begin in 2005 to determine the damage these watercraft may cause.

As a tourist destination, the stability and cleanliness of Guam's beaches is an important consideration. Although no known beach nourishment projects occurred in 2003, several of these projects occurred after Typhoon Yuri in 1992 in Cocos Island Resort, Tumon Bay, and Jeff's Pirates Cove in Ypan, Talofofo (G. Davis, pers. comm.). There are also ongoing mechanical beach cleaning operations in Tumon Bay and East Agana Bay.

Fishing

Guam's coral reef fisheries are economically and culturally important. The threat of overfishing is a serious concern that became more apparent in the 1980s. At that time, inshore fisheries data indicated that the number of hours spent fishing almost doubled, from 161,602 hours in 1984 to 300,861 hours in 1987, while the average catch per hour for reef fish declined (Sherwood, 1989). Data from recent creel surveys suggest that Guam's fisheries have not recovered from this decrease in the 1980s (Figure 16.8). In addition, *in situ* visual surveys have indicated that large reef fish are conspicuously absent from many of Guam's reefs (Figure 16.9; Paulay et al., 2001; Amesbury et al., 2001; R. Schroeder, in review).

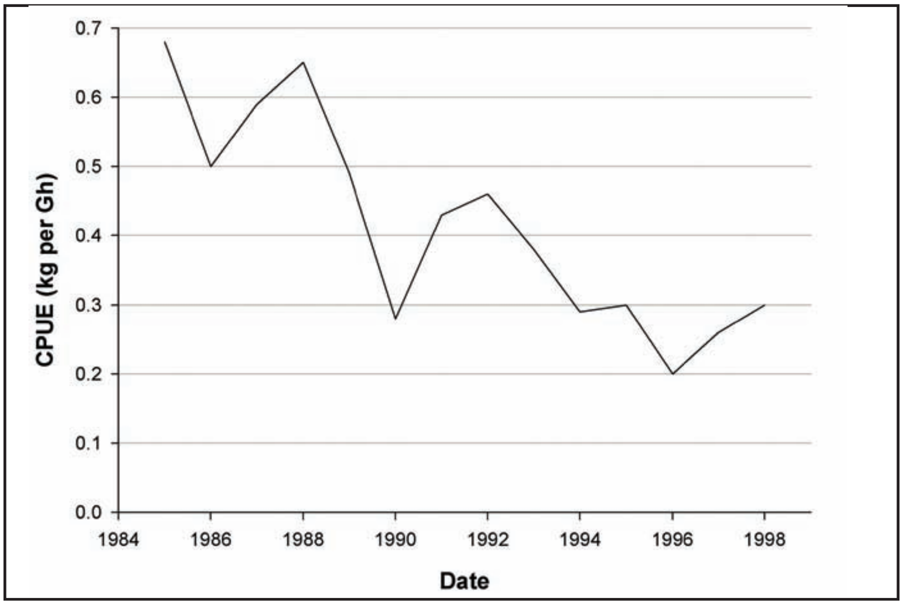


Figure 16.8. Catch per unit of effort (CPUE) declined sharply in the 1980s. Source: Guam Division of Aquatic and Wildlife Resources.

Marine Preserves

Guam established five marine preserves in 1997 to address this concern. The size of the preserves varies, but all preserves extend from 10 m above the mean high tide mark to the 600 ft (183 m) depth contour. The following activities are prohibited in all five marine preserves: dip netting, gill netting, drag netting, surround netting, spear fishing, the use of gaffs, shell collecting, gleaning, and removal of sand or rocks. Trolling may be conducted from the reef margin seaward, but only for pelagic fish. Bottomfishing may be conducted seaward of the 100 ft (30 m) contour in Tumon Bay Marine Preserve.

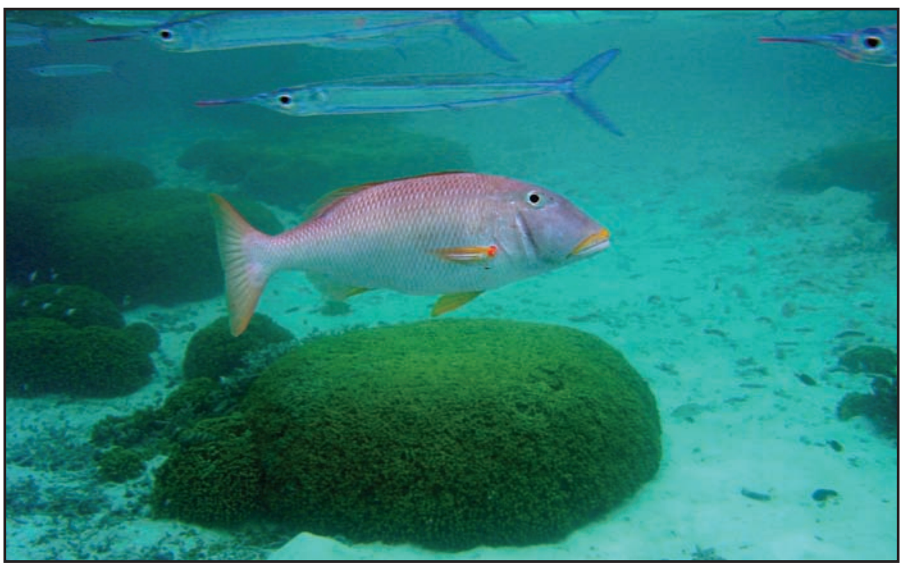


Figure 16.9. Large fish are rarely seen on Guam's coral reefs. This 55-cm yellowlip emperor (*Lethrinus xanthochilus*) has taken up residence in Tumon Bay Marine Preserve. Photo: D. Burdick.

Limited fishing is allowed in Tumon Bay, Pati Point, and Achang Reef Flat Marine Preserves. In Tumon Bay, hook-and-line fishing from shore and cast net (talaya) fishing from shore and along the reef margin are permitted for certain species. All other fishing methods are prohibited. From shore, catch is limited to rabbitfish (sesyon, mañahak), juvenile goatfish (ti'ao), juvenile jacks (i'e'), and convict tangs (kichu). All other fish must be released immediately. Cast net fishing along the reef margin is allowed for rabbitfish and convict tangs only. There are no species restrictions for fishing in Pati Point Marine Preserve, although fishing methods are limited to hook-and-line from shore. Limited cultural takes are permitted in Achang Reef Flat Marine Preserve for seasonal runs of juvenile rabbitfish (mañahak) and scads (atulai). No fishing is allowed in Piti Bomb Holes and Sasa Bay Marine Preserves.

Despite these laws, Guam Department of Agriculture conservation officers arrest over 40 people per year for fishing illegally in the marine preserves. Infractions range from buckets of sea cucumbers gleaned from the reef flat to large catches of parrotfish, surgeonfish, and other commercially important species taken from the forereef slope (DAWR, unpublished data). Despite these infractions, visual surveys suggest that the marine preserves are functioning as expected. Increases in fish density at Piti Bomb Holes and Achang Reef Flat

Marine Preserves of 113% and 115%, respectively, indicate that fish stocks are recovering in the preserves. Surveys at unprotected sites have shown decreases of 29% (Asan/Cocos) and 4% (Cocos/Pago) during the same period (Gutierrez, 2004).

Reef Fisheries

A number of fishing methods are used on Guam including traditional methods such as hook-and-line, talaya (cast nets), spearfishing, and surround nets (chenchulu), as well as more controversial methods such as the use of mono-filament "throw-away" gill-nets and nighttime scuba spearfishing. Fishing is a popular activity in Guam and is monitored by the Guam Division of Aquatic and Wildlife Resources (DAWR). Creel surveys have been conducted since the early 1970s, with expanded data available for the past two decades. Creel surveys provide valuable insight into fishing activities on Guam and allow the DAWR to estimate total harvest, total time spent fishing, and catch per unit effort (CPUE), which provides insight into the status of fish stocks. Creel surveys are divided into two categories, inshore fisheries and offshore fisheries. Inshore fisheries include shore-based fishing activities, usually involving nearshore casting, netting, and spearfishing. Offshore fisheries include boat-based fishing activities from small boats (3-15 m) such as trolling, bottomfishing, and boat-supported spearfishing (Flores, 2003).

Table 16.4 shows the estimated inshore and offshore coral reef fisheries harvest and CPUE for 2002 and 2003. Among the inshore methods, hook-and-line fishing resulted in the highest harvest for 2002, accounting for 33% of the total harvest. In 2003, snorkel spearing was ranked as the top method for 2003, with 41% of the overall harvest. Although the overall hook-and-line harvest is high, this method had the lowest CPUE of

Table 16.4. Estimated reef fish harvest and CPUE for all inshore and offshore methods from 2002-2003. Reef fish harvest exceeded 100 mt in 2002 and 2003. Inshore data excludes seasonal runs of juvenile siganids and bigeye scads. *CPUE measures for bottom and trolling methods were calculated based on total catch including pelagic and deepwater species. Sources: Gutierrez, 2003; Flores, 2003; DAWR, unpublished data.

	2002					2003				
	INSHORE		OFFSHORE		TOTAL	INSHORE		OFFSHORE		TOTAL
METHOD	Harvest (kg)	CPUE (kg/gr-hr)	Harvest (kg)	CPUE (kg/gr-hr)	Harvest (kg)	Harvest (kg)	CPUE (kg/gr-hr)	Harvest (kg)	CPUE (kg/gr-hr)	Harvest (kg)
Snorkel Spear	12,808	0.81	9,982	1.37	**22,790**	25,844	1.5	10,201	1.96	**36,045**
Hook and Line	20,714	0.1	-	-	**20,714**	20,449	0.12	-	-	**20,449**
Bottom	-	-	18,840	0.44*	**18,840**	-	-	30,087	0.69*	**30,087**
Gill Net	6,053	0.41	11,553	6.45	**17,606**	5,875	0.42	8,924	5.7	**14,799**
Scuba Spear	445	2	15,718	3.01	**16,163**	88	0.24	18,205	5.72	**18,293**
Cast Net	12,015	0.28	711	2.39	**12,726**	8,704	0.18	155	0.65	**8,859**
Surround Net	8,037	3.4	-	-	**8,037**	1,660	2.3	-	-	**1,660**
Trolling	-	-	2,136	1.55*	**2,136**	-	-	5,675	1.97*	**5,675**
Drag Net	1,643	3.3	-	-	**1,643**	-	-	-	-	**0**
Hooks and Gaffs	974	0.34	-	-	**974**	302	0.16	-	-	**302**
Jigging	-	-	757	1.1	**757**	-	-	905	1.1	**905**
Mix Spear	-	-	673	2.58	**673**	-	-	0	0	**0**
Spincasting	-	-	476	0.62	**476**	-	-	495	0.88	**495**
Atulai Jigging	-	-	227	0.99	**227**	-	-	802	0.99	**802**
Other Methods	431	0.14	-	-	**431**	712	0.16	-	-	**712**
Total	**63,120**	**0.21**	**61,073**	**1.34***	**124,193**	**63,634**	**0.24**	**75,449**	**1.67***	**139,083**

all inshore methods for both years. In 2002, surround net and drag net methods produced the highest CPUE of all methods with 3.4 kg/gear-hour (gr-hr) and 3.3 kg/gr-hr, respectively, despite a relatively low amount of effort (2,354 gear-hours and 501 gear-hours, respectively). In 2003, the CPUE for surround nets decreased by 32%. Harvest estimates for drag nets could not be determined for 2003, as no interviews for this method were conducted.

The total harvest of reef fish using offshore methods was similar to the inshore harvest for 2002, but exceeded the inshore harvest for 2003. The top three methods for 2002 harvesting over 75% of the total offshore reef fish catch, were bottomfishing, scuba spearfishing, and gill netting. In 2003, snorkel spearing took over the third spot, followed closely by gill netting. The top three methods for 2003 brought in 77% of the total offshore reef fish catch. Although bottomfishing had the highest harvest, this method had the lowest CPUE of all offshore coral reef fisheries for both 2002 and 2003. In 2002, gill netting produced the highest CPUE with 6.45kg/gr-hr, despite a relatively low amount of effort (1,790 gear-hours). This level decreased slightly in 2003 to a CPUE of 5.7 kg/gr-hr with a slight drop in effort (1,566 gear-hours). Scuba spearfishing produced the highest CPUE of all offshore methods in 2003 with a CPUE of 5.72 kg/gr-hr. This method was very effective, and produced approximately a quarter of the total offshore reef fish catch, while using a relatively low amount of effort (5,225 hours in 2002 and 5,205 hours in 2003).

The top 10 families harvested in 2002 and 2003 are shown in Table 16.5. Harvest composition varied from year to year; for example, Kyphosidae (rudderfish) accounted for 15% of the inshore catch for 2002, but was not a major component of the catch for 2003. Acanthuridae (surgeonfishes) were the most heavily fished inshore family in 2003, as 20% of the total inshore catch. Most of these families were targeted by hook-and-line, however, Kyphosidae were harvested primarily with cast nets. Offshore harvest was dominated by Lethrinidae (emperors) in both 2002 and 2003, with approximately 20% of the catch harvested primarily through bottomfishing. Other key target fish harvested primarily through bottomfishing techniques included Lutjanidae (snappers) and Serranidae (groupers). Acanthuridae, Scaridae (parrotfishes), and Labridae (wrasses) were often harvested using either Scuba spears or snorkel spears. It is interesting to note that scuba spears were used to capture nearly 70% of the scarid harvest. Also, of special concern is the harvest of humphead wrasse (*Cheilinus undulatus*). This valuable species, now listed on Appendix II of the Convention on International Trade in Endangered Species is targeted by fishers using scuba spearfishing methods with 789 kg harvested by this method in 2002 and 1826 kg in 2003. This species made up nearly 60% of the total offshore Labridae catch in 2002 and over 75% of the total offshore Labridae catch in 2003.

Table 16.5. Estimated harvest of top 10 families for inshore and offshore fisheries during 2002-2003. Inshore data excludes seasonal runs of juvenile siganids and bigeye scads. Sources: Gutierrez, 2003; Flores, 2003; DAWR unpublished data.

INSHORE				OFFSHORE			
2002		2003		2002		2003	
Family	Harvest (kg)	Family	Harvest (kg)	Family	Harvest (kg)	Family	Harvest (kg)
Kyphosidae (Rudderfishes)	9,465	**Acanthuridae** (Surgeonfishes)	12,691	**Lethrinidae** (Emperors)	13,598	**Lethrinidae** (Emperors)	11,632
Siganidae (Rabbitfishes)	8,773	**Carangidae** (Jacks)	9,699	**Acanthuridae** (Surgeonfishes)	9,329	**Serranidae** (Groupers)	10,737
Acanthuridae (Surgeonfishes)	7,786	**Siganidae** (Rabbitfishes)	5,640	**Scaridae** (Parrotfishes)	7,472	**Carangidae** (Jacks)	9,599
Carangidae (Jacks)	6,790	**Mullidae** (Goatfishes)	5,372	**Carangidae** (Jacks)	5,542	**Acanthuridae** (Surgeonfishes)	8,464
Lethrinidae (Emperors)	4,480	**Scaridae** (Parrotfishes)	4,302	**Serranidae** (Groupers)	2,983	**Scaridae** (Parrotfishes)	8,246
Mullidae (Goatfishes)	3,945	**Lethrinidae** (Emperors)	2,352	**Mullidae** (Goatfishes)	2,341	**Scombridae** (Mackerels)	3,431
Lutjanidae (Snappers)	2,712	**Diodontidae** (Porcupinefishes)	1,649	**Sphyraenidae** (Barracudas)	1,587	**Sphyraenidae** (Barracudas)	3,339
Serranidae (Groupers)	2,166	**Scombridae** (Mackerels)	1,307	**Lutjanidae** (Snappers)	1,509	**Lutjanidae** (Snappers)	3,087
Mugilidae (Mullets)	1,990	**Serranidae** (Groupers)	1,284	**Labridae** (Wrasses)	1,391	**Labridae** (Wrasses)	2,377
Belonidae (Needlefishes)	1,968	**Carcharhinidae** (Requiem Sharks)	1,258	**Siganidae** (Rabbitfishes)	1,389	**Carcharhinidae** (Requiem Sharks)	1,632

Invertebrates

The invertebrate harvest varied considerably during 2002 and 2003 for both inshore and offshore fisheries. The top five harvested invertebrate species for 2002 and 2003 are listed in Table 16.6. Inshore invertebrate harvest in 2003 increased 188% from the 2002 harvest. The increase in invertebrate harvest in 2003 correlates with a shift in method; snorkel spear gear-hours and CPUE increased by 11% and 85%, respectively. Although octopus comprised the majority of the top five invertebrate species harvested in 2002 and 2003, harvest of the spiny lobster (*Panulirus pencillatus)* increased 245% between 2002 and 2003. The offshore invertebrate harvest decreased from 2002 to 2003, with catches of the top shell (*Trochus niloticus)* and *Panulirus pencillatus* decreasing 40% and 14%, respectively, over this time period. The conch harvest also decreased over this time period, with over 1,400 kg of conch (*Lambis lambis* and *L. truncata*) harvested in 2002 and no catch recorded in 2003. However, the harvest of venus clams (Veneridae), reef crab (*Zosimus aeneus*), and octopus did increase during this period.

Table 16.6. Estimated harvest of top five invertebrate species during 2002-2003. Sources: Gutierrez, 2003; DAWR, unpublished data.

INSHORE				OFFSHORE			
2002		2003		2002		2003	
SPECIES	HARVEST (kg)	SPECIES	HARVEST (kg)	SPECIES	HARVEST (kg)	SPECIES	HARVEST (kg)
Octopus cyanea	1,052	*Octopus cyanea*	4,772	*Trochus niloticus*	1,525	*Trochus niloticus*	902
Panulirus penicillatus	572	*Octopus* other	3,105	*Lambis lambis*	1,224	*Veneridae*	635
Scylla serrata	508	*Panulirus penicillatus*	1,973	*Panulirus penicillatus*	289	*Panulirus penicillatus*	249
Octopus ornatus	383	*Carpilus maculatus*	145	*Lambis truncata*	218	*Zosimus aeneus*	235
Octopus other	359	*Octopus ornatus*	111	*Zosimus aeneus*	152	*Octopus cyanea*	219

Trade in Coral and Live Reef Species

Guam does not currently export coral or live reef species, but collection for local use does occur. Local pet shops collect approximately 250 ornamental fish per month for Guam's aquarium trade (B. Tibbatts, pers. comm.). In addition, two local aquaria collect approximately 450 local reef fish each month for display in their facilities (L. Goldman, pers. comm.). Guam's corals and live rock are protected by the island's Public Law 24-21. The UOGML is the only entity on the island permitted to harvest coral and live rock. UOGML's permit only allows harvesting in areas not designated as marine preserves and all surviving specimens must be returned to the area from which they were harvested. The UOGML collected 1,008 coral colonies in 2002 and 455 colonies in 2003 for research purposes. Harvested colonies included species of *Acropora, Alveopora, Favia, Goniastrea, Goniopora, Leptoria, Lobophyllia, Platygyra, Pocillopora, Porites,* and *Psammocora*. The colonies collected ranged in size from 2 cm x 2 cm to 40 cm x 20 cm (Amesbury, 2002, 2003; Smith, 2004).

Ships, Boats, and Groundings

Guam's Apra Harbor is the largest U.S. deepwater port in the Western Pacific and the busiest port in Micronesia. The harbor is shared by the Port Authority of Guam and the U.S. Navy. According to Guam's Port Authority (http://www.netpci.com/~pag4, Accessed 8/26/04), the port handled approximately two million tons of cargo and serviced over 2000 vessels in 2002. These vessels are primarily fishing vessels, as well as fuel ships, container ships, tender ships, barges, and cruise ships. The U.S. Naval installation is home to a number of naval vessels including submarines, a submarine tender ship, and two U.S. Coast Guard cutters, and is visited by numerous other vessels including aircraft carriers. The harbor also contains reefs with some of the highest coral cover on the island. Some reef areas have been dredged in the past and other areas (including patch reefs) may be dredged in the future as their growth impedes ship traffic and naval operations. The coral reefs can be damaged not only by such ship traffic and naval operation, but also by anchors, groundings, and illegal vessel discharges.

Commercial ships are not the only concern. According to the boating law administrator in the Guam Police Department's Special Programs Division, there are an estimated 3,000 recreational vessels and an estimated 5,000 commercial vessels under 20 m on Guam. Anchor damage from these ships is a concern due to the lack of operational mooring buoys around the island.

Ship groundings are inevitable due to the frequency of typhoon's affecting Guam. At this time, over 130 vessels are listed in the National Oceanic and Atmospheric Administration's (NOAA) Abandoned Vessel Inventory database for Guam (http://response.restoration.noaa.gov/dac/vessels/vess_main.html, Accessed 4/17/04). During a recent NOAA study, nine of the 31 vessels surveyed (29%) were located on coral reef, hardbottom, or lagoonal fauna (Helton et al., 2004). As these vessels deteriorate or are moved by storms, they may impact the surrounding habitat. Because of limited funding for the removal of these vessels, most of them will remain a threat to the reefs. Navigational buoys also pose a problem as storm swells can drag them onto the reefs, thereby damaging coral and other reef habitat. Such an incidence of this occurred in August 2004 when the storm surge from Typhoon Chaba displaced the navigational buoys outside of Agat Marina (KUAM TV, http://66.129.67.220/news/11022.aspx, Accessed 9/28/2004).

Marine Debris

Marine debris continues to impact Guam's reefs. According to the Guam Coastal Management Program (GCMP), the 2003 International Coastal Cleanup resulted in the collection of 924 bags of debris that weighed 19,640 kg from Guam's beaches and reefs, an increase from 3,252 kg of debris collected in 2002. Additionally, the Micronesian Divers Association, and Guam Marine Awareness Foundation remove 5-10 bags of debris from local reefs each month (M. Barnett, pers. comm.).

Beverage containers are the most common items collected, but other items include appliances, batteries, car parts, and abandoned fishing gear. Over 100 nets were collected during the 2003 cleanup event, along with fishing line, crab and fish traps, buoys, and lures. The DAWR reported that 35 additional nets were removed from coastal waters in 2002-2003. Typhoons are an additional source of debris and can blow objects as large as roofs onto the reefs. Although two powerful typhoons hit Guam in 2002, the debris from these storms appeared to be limited to smaller items such as beverage containers and palm fronds. In contrast, over 14 tons of debris, including tin roofing, auto parts, and dumpsters, were deposited on the reef in 1997 by Super Typhoon Paka (GCMP, 1998).

Aquatic Invasive Species

Although Guam has spent considerable time and resources studying terrestrial invasive species, such as the brown treesnake, little work has been done on invasive marine species (Paulay et al., 2002). Paulay et al. (2002) attempted the first systematic survey of nonindigenous marine species in three study sites on Guam: Apra Harbor, Orote Penisula ERA, and Haputo ERA. They found a total of 85 nonindigenous species on Guam, recognizing that many taxa have yet to be surveyed. Forty-one of those 85 species were catagorized as introduced and 44 as cryptogenic. They found the majority of these species to be sessile (76%) and surmise that they primarily arrived via vessel hulls into Apra Harbor. While further study is warranted, these nonindigenous marine species do not appear to be negatively impacting native species yet. Paulay et al. (2002) found that, although nonindigenous species were abundant on artificial substrates, they were relatively rare on natural reef bottoms.

Security Training Activities

The U.S. Department of Defense regularly carries out military training on Guam, often involving Navy and Marine exercises that impact coastal waters and adjacent reefs (U.S. Department of the Navy, 1998) Although attempts are made to minimize impacts by locating operations away from living corals, the explosions related to marine mine detection and demolition and the stress from landing craft have killed a limited amount of fish and invertebrates, and could threaten marine mammals and endangered sea turtles (DAWR, unpublished incident reports).

Offshore Oil and Gas Exploration

There are currently no oil or gas prospects identified near Guam.

Other

Guam continues to be affected by the COTS (*Acanthaster planci)*. While Guam has not had any large outbreaks of *A. planci*, aggregations of about 500 individuals have been documented (Randall, 1973). Bonito (2002) suggests that the feeding behavior of these aggregations may modify the coral community composition on Guam, as they prefer to feed on *Acropora, Montipora,* and *Pocillopora* species. The coral community at Tanguisson Reef was documented in 1981 and again in 2001; comparison of the data suggests that preferential feeding on these species may have created a shift in the reef community towards *Porites, Favia*, and other non-preferred species.

CORAL REEF ECOSYSTEM MONITORING EFFORTS AND RESOURCE CONDITION

A number of monitoring, research, and assessment activities are conducted on Guam. These include monitoring programs for communities associated with coral reefs, assessment of benthic habitat, and water quality. Table 16.7 describes all recent or ongoing studies related to Guam's coral reefs. Some of these studies are ongoing, while others have just started producing quantitative data. The studies with sufficient data will be discussed further in the next section.

Table 16.7. Summary information for Guam's coral reef monitoring, research, and assessment activities.

ACTIVITY	AGENCY	NO. OF YEARS	FUNDING	OBJECTIVE	DATA COLLECTION	FIT IN LARGER EFFORT
Marine Preserve Monitoring	DAWR	2	NOAA Coral Reef Monitoring Grant, Sportfish Restoration	Assess the effectiveness of Guam's Marine Preserves on Food Fish populations. Visual transects and interval counts are used to assess fish species. Some benthic baseline data has been collected but full-scale benthic monitoring is scheduled to start in 2004.	Every 1-2 years	Provides assessment of fisheries
	Univ. of Guam	2		Assess the effectiveness of Guam's Marine Preserves by looking at focal species abundance, population structure, and recruitment in preserves and adjacent control sites.		
Sedimentation	National Park Service	<1	Dept. of the Interior	Assess the level of sedimentation occurring in the watershed included in the War of the Pacific National Park. Data collected includes total sediment, % organic, % carbonate, sediment size, water temperature, and light penetration. Benthic transect and coral recruitment should be added in near future. Goal of the project is to assess the impacts of wildland fire on sedimentation.	Monthly	Provides sedimentation data and effect on reefs
Erosion	National Park Service	<1	Dept. of the Interior	Land based monitoring of erosion rates in burned vs. non-burned areas. In addition erosion flumes are being used to assess possible badland mitigation techniques.	Weekly	Addresses the land based issues affecting reefs.
	Univ. of Guam	1	EPA, NOAA	Monitoring sediment input in Fouha Bay to create a model of sediment flow and document corresponding changes in coral communities.	Weekly	Provides Water Quality Data affecting corals and marine life
Water Quality	Guam EPA	>20	U.S. EPA	GEPA 305b, Water Quality Report to Congress	Biennially	Provides Water Quality Data affecting corals and marine life
				EMAP, Recreational Water Quality,	Weekly	
			NOAA/US EPA	Denton et al. 1997, 1999, PCR Environmental, 2002 reports,	One time	
			Permittee	Monitoring wells, golf courses and restoration sites	Quarterly	
Benthic Habitat	NOAA Pacific Islands Fisheries Science Center-CRED	<1	NOAA; Dept. of the Interior	Document baseline conditions of the health of coral, algae, and invertebrates, refine species inventory lists, monitor resources over time to quantify possible natural or anthropogenic impacts, document natural temporal and spatial variability in resource community, improve our understanding of the ecosystem linkages between and among species, trophic levels, and surrounding environmental conditions.	Biannually	Provides long-term monitoring of coral reef ecosystem.
	National Park Service			Benthic assessments and establishment of long-term monitoring sites in Orote and Haputo ecological reserves.	Annually (proposed)	

Table 16.7 (con't). Summary information for Guam's coral reef monitoring, research, and assessment activities (continued).

ACTIVITY	AGENCY	NO. OF YEARS	FUNDING	OBJECTIVE	DATA COLLECTION	FIT IN LARGER EFFORT
Fisheries Monitoring	DAWR	>20	Sportfish Restoration	Conduct creel, participation, and boat-based surveys to obtain information including boating activity, fishermen participation, catch per unit effort, and species composition in order to monitor the health of the fisheries resources	Semi-weekly (on average)	
Associated Biological Communities	Univ. of Guam	6	Coral Reef Initiative Management/ Monitoring Grants	Reef Check	Annually	Provides some long-term monitoring at a very broad level
	Univ. of Guam			Assessment of *Acanthaster planci*	One time	Repeated survey from 1980s to assess change over time of benthic community
Recreational Impacts	Univ. of Guam	1	Coastal Zone Management Grant	Assessment of recreational impacts of underwater activities in Cocos and Piti	One time	Provides an initial assessment of recreational impacts and suggests future courses of action

In addition to Guam's efforts, NOAA initiated the Marianas Archipelago Reef Assessment and Monitoring Program (MARAMP) aboard its research vessel *Oscar Elton Sette* in 2003. The cruise lasted 39 days from August 21 to September 28, 2003. The goals of the MARAMP include improving the understanding of coral reef ecosystems, evaluating and reducing adverse impacts, enhancing coral reef ecosystem-based fisheries management and conservation through cooperation with partners (Federal and local agencies and non-governmental organizations), and providing scientific information needed to establish, strengthen, and manage marine protected areas (MPAs; NOAA Pacific Islands Fisheries Science Center - Coral Reef Ecosystem Division, http://www.nmfs.hawaii.edu/crd). The science team for the Guam leg of the cruise (September 23-28) was comprised of staff from the NOAA Coral Reef Ecosystem Investigation Program, DAWR, U.S. National Park Service, and UOGML. The team conducted a variety of ecological and oceanographic assessments, including (Figure 16.10):

- Benthic habitat mapping: multi-beam surveys, single beam QTC surveys, geodetic control, towed diver surveys, and TOAD towed camera surveys;
- Fish, turtle, and marine mammal surveys: belt transects, stationary point counts (SPCs), towed diver surveys, roving diver surveys, and hydroacoustic surveys;
- Benthic surveys (corals, other invertebrates, algae): belt transects, towed diver surveys, roving diver surveys, and TOAD towed camera surveys; and
- Oceanography: closely-spaced conductivity-temperature-depth measurements, drifters, subsurface temperature, acoustic Doppler current profiler transects, CREWS/SST buoys, and current/wave moorings.

The MARAMP is intended to be a long-term monitoring program with research cruises scheduled bi-annually. The next cruise is scheduled to occur in 2005 (R. Brainard, pers. comm.).

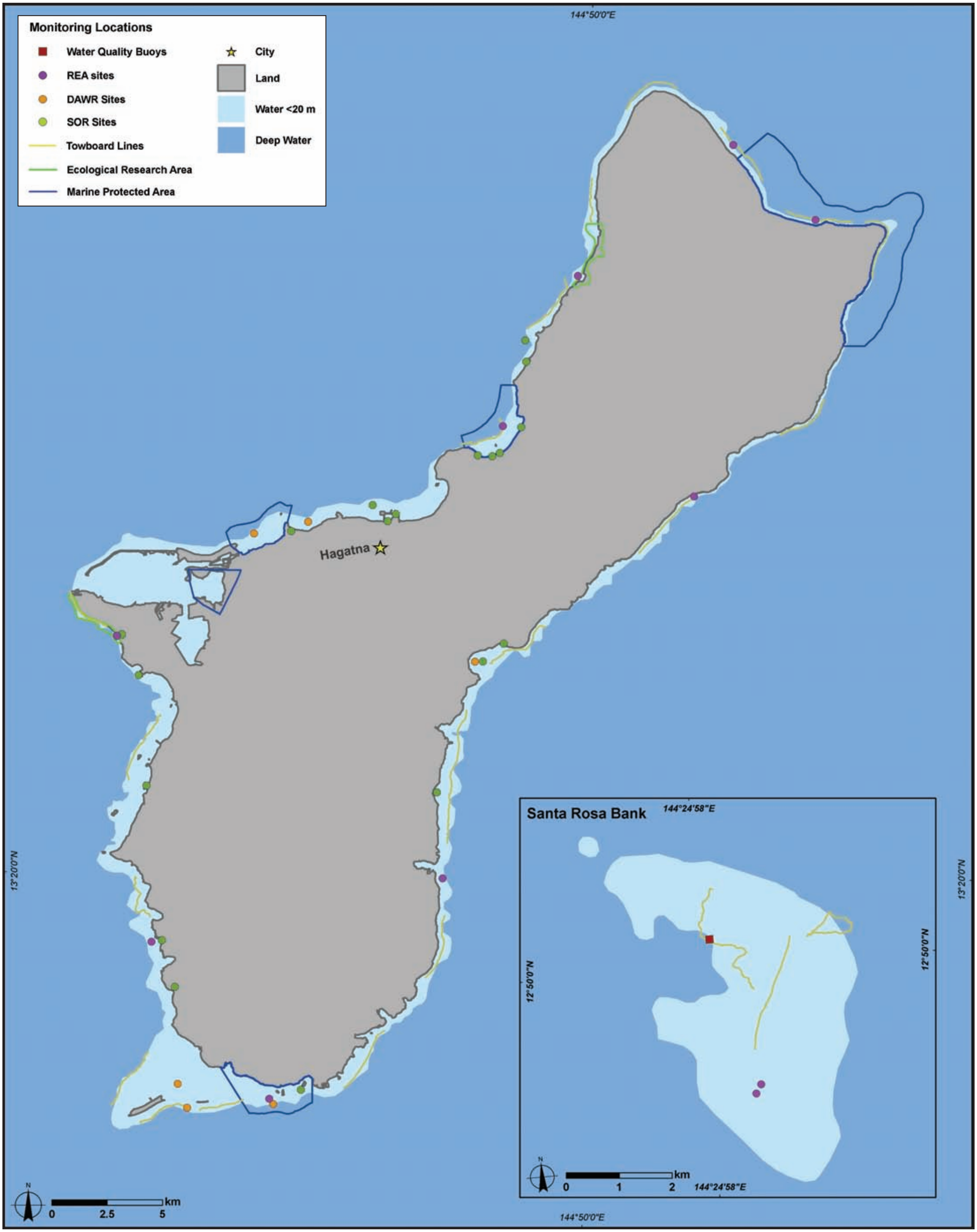


Figure 16.10. The locations of monitoring sites around Guam. Map: A. Shapiro. Sources: DAWR; PIFSC-CRED.

WATER QUALITY

Limited studies have been conducted on water quality indicators important to coral reefs. GEPA regularly monitors point source pollution and tests for *Enterrococcus* indicator bacteria on Guam's beaches, but there is limited information on parameters such as nutrient loads, turbidity, or contaminants. However, this is expected to change in the near future with the implementation of GEPA's Environmental Monitoring and Assessment Program (EMAP).

GEPA Water Quality Sampling

According to U.S. EPA requirements, the GEPA samples coastal recreational waters at 39 stations around the island every week for *Enterococcus* bacteria. A public advisory is issued when an instantaneous measurement of bacterial levels exceeds 104 units per 100 ml of water. In fiscal year 2003, 27% of 2,028 samples exceeded this standard, resulting in 551 advisories. In 2002, GEPA weekly monitoring of the 39 stations resulted in 1,055 advisories (Table 16.8). Despite the apparent improvement in recreational water quality from 2002 to 2003, it is important to consider that water quality in 2002 was unusually poor, with 51% of samples resulting in advisories. Previous years had rates similar to those observed in 2003. However, the validity of basing advisories on *Enterococcus* as a bacterial indicator of sewage pollution is questionable, as it exists in the tropical soils of Guam, independent of sewage pollution. Following rains and stormwater runoff, *Enterococcus* readings always increase in Guam's coastal recreational waters, as the bacteria wash out of the soil (Collins, 1995).

Table 16.8. Water quality advisories issued for recreational areas due to unacceptable *Enterococcus* levels in 2002-2003. Quarters are by fiscal year. Source: GEPA.

REGION	NUMBER OF ADVISORIES PER QUARTER				TOTAL NUMBER OF ADVISORIES
	1ST	2ND	3RD	4TH	
2002 Northern Guam Subtotal	117	124	66	128	**435**
2002 Southern Guam Subtotal	83	70	98	369	**620**
2002 Total	200	194	164	497	**1055**
2003 Northern Guam Subtotal	76	29	63	78	**246**
2003 Southern Guam Subtotal	81	26	77	121	**305**
2003 Total	**157**	**55**	**140**	**199**	**551**

According to PCR Environmental Inc. (2002a, b, c), freshwater springs in Tumon Bay discharge an estimated 64,350 m^3 of freshwater each day. In 2002, samples from eight of these springs were tested for a broad range of pollutants. Of the 35 volatile organic compounds that were measured only methylene chloride was present in amounts exceeding drinking water standards (5 µ/L). Eight different organophosphate pesticide compounds and 25 carbamate pesticide compounds were not detected or were below standards. Of 23 metals tested including mercury, only one metal in one sample exceeded drinking water standards (selenium at 0.0957mg/l, with the standard at 0.05 mg/l). Despite meeting the drinking water standards, the contaminants discharged by the freshwater springs may affect organisms found in the shallow marine waters of Tumon Bay (PCR Environmental, 2002a, b, c).

Other chemical and physical parameters of coastal waters were not tested regularly during 2002 and 2003 due to a shift to the new EMAP system, impacts from typhoons to the GEPA laboratory, and the need to prioritize increased testing of drinking water following the disasters. Sampling results of marine water quality from previous years by GEPA provided the following results.

From June 1997 to November 1998, 57 surface marine water quality samples were tested from San Vitores Beach, Dai Ichi Beach and Ypao Beach in the shallow waters of Tumon Bay (Table 16.9). In the rainy season of 2001 from July to October, GEPA took 89 surface water samples from sites throughout Tumon Bay (Table 16.10). In addition, 30 samples from four surface water stations in Tumon Bay were tested in the rainy season and the dry season from July to December 2001 (Table 16.11).

Table 16.9. Summary of 57 water quality samples from Tumon Bay, 1997-98. Source: GEPA.

	Temp (°C)	DO (mg/L)	pH	Sal. (ppt)	Secchi Disc - Horiz. (meters)	Enterococ. (CFU/100mL)	Ttl Susp. Solids (mg/L)	Turb. (NTU)	Cond. (mmho)	NO_2-N (mg/L 0.000)	NO_3-N (mg/L 0.000)	P-Tot (mg/L)	O-P (mg/L)	N P-Tot (mg/L)S
Mean	28.4	7.08	8.29	34	11.7	11.1	19.7	0.54	43.7	0.002	0.102	0.007	0.003	0.007
Med	28.4	7.35	8.3	35	11	1	20	0.41	42.7	0.001	0.046	0.007	0.002	0.007
Max	30.7	12.08	8.68	37	27	264	40	1.7	65.8	0.006	0.98	0.017	0.025	0.017
Min	26	2.76	7	30	3	1	4	0.15	33.2	0	0.003	0	0	0
Mode	27	7.4	8.5	35	11	1	20	0.3	#N/A	0	0.036	0	0.002	0

Table 16.10. Summary of 89 water quality samples from Tumon Bay, July to October 2001. Source: GEPA.

	Temp (°C)	DO (mg/L)	pH	Sal. (ppt)	Secchi Disc - Horiz. (meters)	Enterococ. (CFU/100mL)	Ttl Susp. Solids (mg/L)	Turb. (NTU)	Cond. (mmho)	NO_2-N (mg/L) 0.000	NO_3-N (mg/L) 0.000	P-Tot (mg/L)	O-P (mg/L)	N P-Tot (mg/L)S
Mean	30.5	6.63	8.20	34.4	0.120	0.33	48.70	0.003	0.077	0.037	0.003	0.003	0.007	0.003
Med	30.5	6.0	8.22	35.0	0.105	0.28	44.70	0.003	0.026	0.013	0.003	0.002	0.007	0.002
Max	32.5	11.8	8.71	35.0	0.463	1.50	431	0.008	0.99	0.321	0.011	0.025	0.017	0.025
Min	28.5	4.6	7.83	23.0	0.027	0.15	30.9	0.001	0.001	0.001	0.001	0	0	0
Mode	31.0	5.5	8.26	35.0	0.064	0.20	45.4	0.003	0.007	N/A	0.002	0.002	0	0.002

Table 16.11. Summary of 30 water quality samples from four locations in Tumon Bay, 2001. Source: GEPA.

	Temp (°C)	DO (mg/L)	pH	Sal. (ppt)	SiO2	Turb. (NTU)	Cond. (mmho)	NO2-N (mg/L)0.000	NO3-N (mg/L)0.000	NH4-N (mg/L)0.000	O-P (mg/L)	O-P (mg/L)	N P-Tot (mg/L)S
Mean	29.82	6.55	8.19	34.8	0.104	0.998	50.78	0.003	0.0376	0.002	0	0.003	0.007
Med	29.75	6.29	8.21	35	0.093	0.425	52	0.003	0.0155	0.002	0	0.002	0.007
Max	32	9.14	8.39	35	0.18	16	53.2	0.008	0.155	0.002	0	0.025	0.017
Min	28	4.57	7.91	33	0.061	0.21	43.4	0.003	0.002	0.002	0	0	0
Mode	29.5	5.9	8.15	35	0.078	0.35	52	0.003	0.004	N/A	0	0.002	0

BENTHIC HABITATS

A number of studies have looked at benthic habitats in Guam's nearshore waters. These studies include studies sponsored by the U.S. Navy at two compensatory mitigation sites, Orote Peninsula ERA and Haputo ERA (Amesbury et al., 2001; Paulay et al., 2001), a thesis study on the effects of *Acanthaster planci* infestations on coral community structure (Bonito, 2002), and the initial interpretation of the macroalgae surveyed during the 2003 *Oscar Elton Sette* cruise to Guam (Vroom, in review).

Orote Peninsula Ecological Reserve Area

The Orote Peninsula ERA contains a diverse assemblage of habitats, including a highly exposed, current-swept point; a silty bay; intertidal fringing reefs; and deep, steep dropoffs and caves. To capture this diversity, the area was divided into 58 representative sub-zones (Figure 16.11). The area was examined using a manta tow and divided into 17 zones based on topography and bottom-type. These zones were then sub-divided based on depth. For the qualitative diversity surveys, divers surveyed each sub-zone and recorded all visible fish, macroinvertebrate, and coral species (Paulay et al., 2001).

Methods

For the quantitative surveys, 10 permanent monitoring stations were established representing the main habitat types found in the ERA. Due to the steep forereef topography in most of the study area, eight stations were located at the 15 m depth contour where the forereef slope is less steep. The other two stations were located in Agat Bay, which has a more traditional forereef slope which allowed for two stations at a depth of 5 m. At each monitoring station, five 50-m transects laid end to end (5-10 m apart) were used to survey an area approximately 270-290 m long. Four types of surveys were conducted along each transect: 1) a benthic cover survey, 2) a coral population survey, 3) a fish survey, and 4) a macroinvertebrate survey.

Quantitative surveys used both the video protocol recommended by English et al. (1997) and point quarter methods used by Birkeland and Lucas (1990). For the video transects, the camera was held 25 cm away from the bottom to record a 25 cm swath along each transect. Five points from 60 equally spaced frames were analyzed for each transect, providing a total of 1,500 points per station. The point quarter method was used to survey one to three transects at each station. Sixteen points were haphazardly selected on each transect. The distance to the center of the closest coral colony center, the length and width of the colony, and the species were recorded in each quadrant.

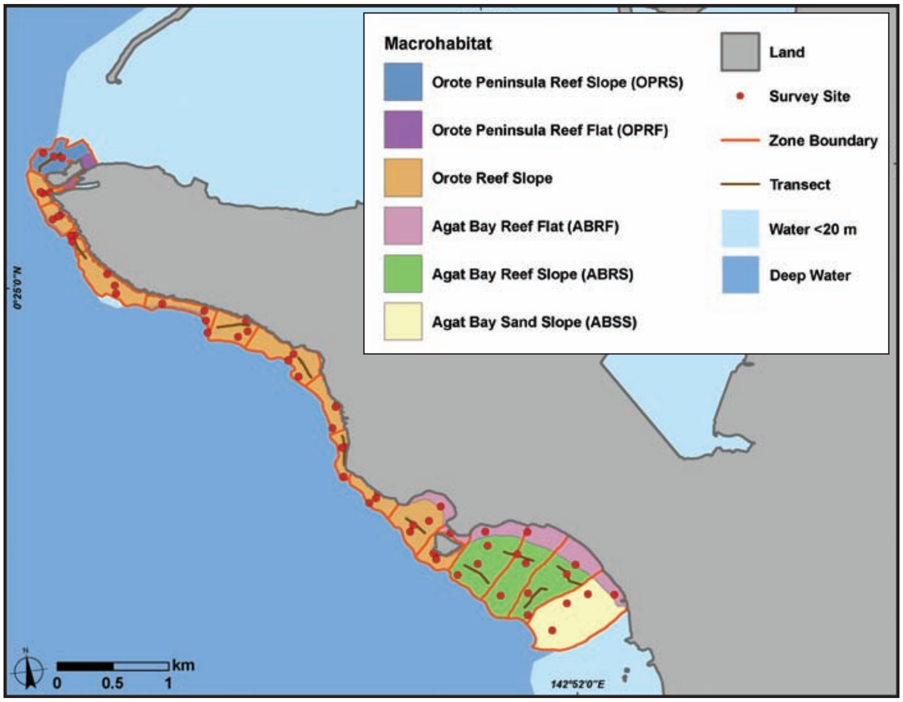


Figure 16.11. Macrohabitat zones, transect sites, and survey sites in the Orote Peninsula ERA. Map: A. Shapiro. Source: Paulay et al., 2001.

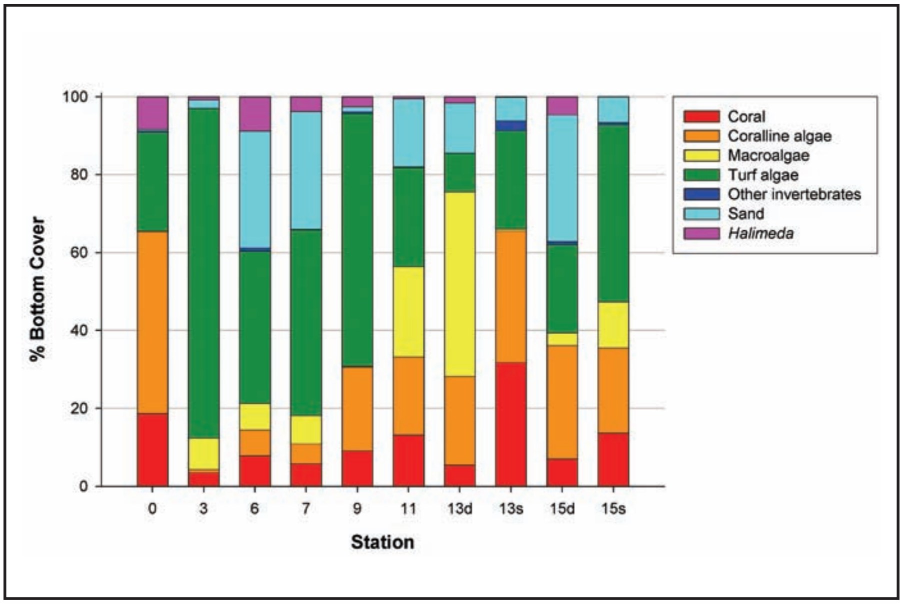


Figure 16.12. The relative composition of each coral cover class at 10 stations in Orote ERA. Coral cover was relatively, with percent coral cover ranging from 4-19%, except at one site dominated by *Porites rus*, which had 32% cover. Other cover types included turf algae, macroalgae, *Halimeda*, and coralline algae. Source: Paulay et al., 2001.

Results and Discussion

During these surveys, 1,252 species of marine animals were reported, including 156 species of scleractinian corals. Two of the coral species documented (*Leptoseris spp.* and *Favia rotundata*) were new records for Guam. Coral cover was relatively low at most Orote Point stations surveyed, ranging between 4 and 19%. One site dominated by *Porites rus* had 32% coverage. Bottom cover varied across the study area (Figure 16.12), and included coral, coralline algae, the green algae *Halimeda*, other macroalgae, turf algae, other invertebrates and sand. Coral demographics also varied by site, with colony size exceeding colony density at only the site dominated by *Porites rus* (Figure 16.13).

Haputo Ecological Reserve Area

The Haputo ERA is located along the northwest coast of Guam, from just south of Haputo Beach to just north of Double Reef. This area is bounded by narrow, supratidal benches or unprotected rock faces, although the study area contains two small, localized reef flats near Haputo Beach and Double Reef. Double Reef, an incipient barrier reef, is a unique feature in this area that creates highly heterogeneous habitat, including a distinct backreef community. Unlike the Orote Peninsula ERA, this study area lacked large-scale transitions along the shore, thus 31 sites were distributed evenly along the coast and along the depth gradient for the qualitative surveys (Figure 16.14). The fauna at each site were surveyed for at least one hour by a team of four or five divers. Two divers focused on corals and fish, which were surveyed during 30 minute diversity surveys. Two to three divers surveyed both exposed and cryptic macroinvertebrates.

Methods

For the quantitative surveys, six permanent monitoring stations were established in areas that provided relatively homogeneous benthic communities and maximal geographic coverage within the study area. Three stations were set at 8 m and three were set at 15 m. At each station, five 50-m transects were laid end to end (5-10 m apart), covering an area 270-290 m long. If there was not sufficient homogeneity for 250+ m of transects, two groups of 2-3 transects were laid, with the second group placed 10 m seaward of the first. Four types of surveys were conducted along each transect: 1) a benthic cover survey, 2) a coral population survey, 3) a fish survey, and 4) a macroinvertebrate survey. Quantitative surveys followed the same protocols discussed in the previous section.

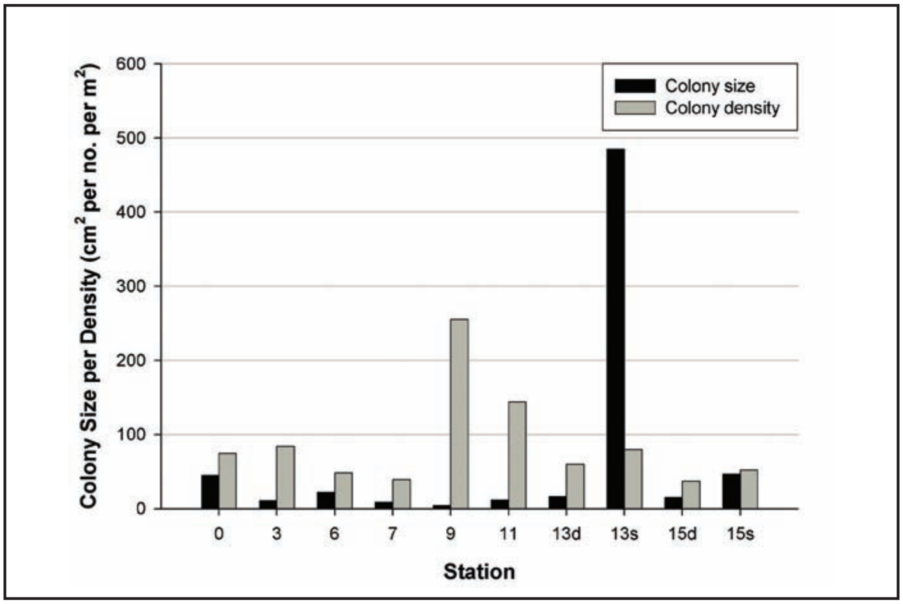


Figure 16.13. Coral demographics at 10 stations in the Orote ERA. Colony density was greater than colony size at all but one site. Source: Paulay et al., 2001.

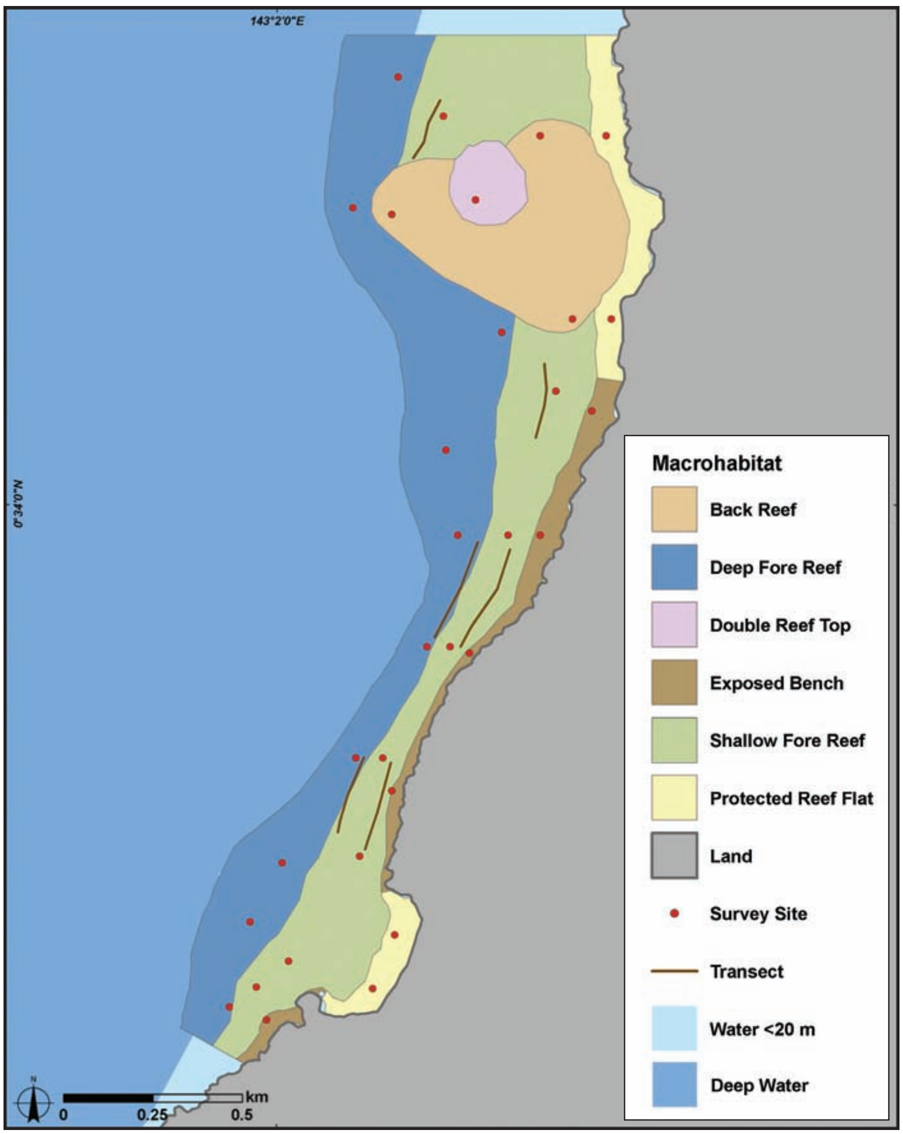


Figure 16.14. Macrohabitat zones, transect sites, and survey sites in the Haputo ERA. Map: A. Shapiro. Source: Amesbury et al., 2001.

Results and Discussion

During these surveys, 944 species of marine animals, including 154 species of scleractinian corals, were recorded. The quantitative studies indicated that coral cover was relatively high at most Haputo stations surveyed, ranging between 37% and 64%. This is higher than most locations in Guam's waters. *Montipora* and *Porites* were the dominant corals at all stations (Figure 16.15). *Montipora* was common at the shallow stations (1-3), but *Porites* dominated in deeper stations (4-6). Station 1 had 64% coral coverage, which was dominated by a diverse assemblage of *Montipora* colonies. In general, the data from this area suggest that the coral communities are thriving. Bottom cover varied across the study area (Figure 16.16), and included coral, coralline algae, macroalgae, turf algae, other invertebrates, and sand/pavement. Corals were the dominant cover, followed by turf algae. It is interesting to note that the coral killing sponge, *Terpios hoshinota,* was an important cover at Station 6 (coded as other invertebrates).

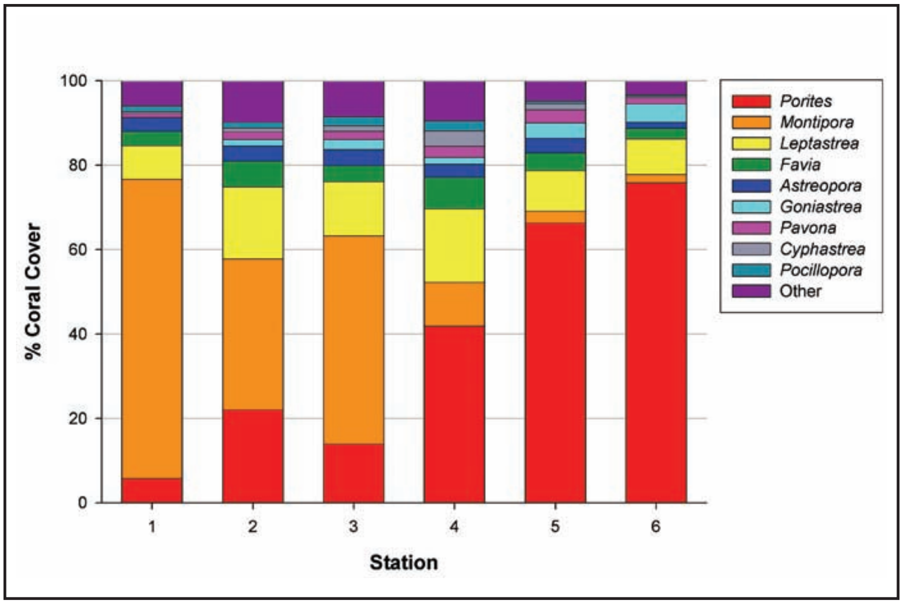


Figure 16.15. Over 150 species of scleractinian coral were documented in the Haputo ERA. Coral cover was dominated by *Montipora* and *Porites* at most of the six sites. Source: Amesbury et al., 2001.

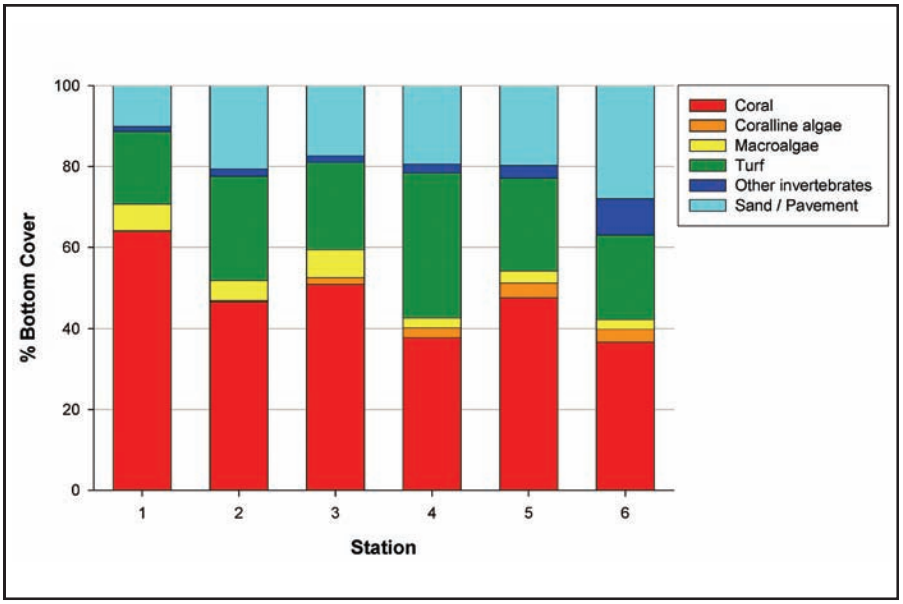


Figure 16.16. Bottom cover within the Haputo ERA. Corals emcompass 37-64% of bottom coer at the six sites. Other cover included turf algae, macroalgae, and coralline algae. There was a high incidence of *Terpios hoshinota*, the coral-killing sponge at site six. Source: Amesbury et al., 2001.

Effects of *Acanthaster planci* on Coral Community Structure

Tanguisson Reef has been studied since the early 1970s, when Randall (1973) monitored the recovery from a 1967 outbreak of COTS (*Acanthaster planci)*. The study indicated that coral coverage increased after the infestation through new coral recruitment and growth of existing corals. By 1980-81, the coverage of corals had increased until it was similar to neighboring reefs unaffected by the outbreak (Colgan 1981a,b; Colgan, 1987). This study also indicated that the community was dominated by *Acropora* and *Montipora* species. Since that time, a number of smaller *A. planci* outbreaks have been reported. Bonito and Richmond (submitted) studied the community again in 2001 to determine if the community structure had changed since the 1980s.

Methods

Tanguisson Reef is located on the northwest coast of Guam and can be divided into three physiographic zones. The reef front is a well-developed spur and groove system in depths of 1-6 m and ranges in width from 50-70 m. Relief in this area can be greater than 3 m, but tapers off at the end of this zone. The submarine terrace covers areas that are 6-18 m in depth. This zone has lower relief and ranges from 40-110 m in width. It is followed by the seaward slope, which ranges from 18-40 m in depth. This zone has an intermediate relief of 1-2 m.

Transects in the 1970s and 1980s were laid perpendicular to shore across the reef to a depth of 10 m. In 1970, 1971, and 1974, Randall (1973) used a quadrat method at 10 m intervals along each transect (Jones et al., 1976). This method measured the width and length of each colony at least 50% within the quadra, and recorded the growth form of each colony. This information was used to determine the live coral cover, colony abundance, small colony abundance, and species frequency. Colgan resurveyed the transects in 1980 using the point-quarter method at 2 m intervals and in 1981 using the quadrat method. The most recent study in 2000 and 2001 used the quadrat method used by Randall in the 1970s; however, the original transects could not be located. Twenty stations were sampled on the reef front, 22 on the submarine terrace, and 15 on the seaward slope. Three additional dives were conducted in each zone to assess overall species richness.

The researchers also studied the feeding preferences of *A. planci* on northwestern reefs. Twelve sites were chosen on the western side of the island. At each site, coral species abundance was surveyed and the site was searched for *A. planci*. Researchers recorded the number of *A. planci* present and the number of freshly eaten colonies of each coral species.

Results and Discussion

The researchers found that *A. planci* preferentially feed on *Acropora, Montipora,* and *Pocillopora* species. *Astreoopora, Cyphastrea, Goniastrea, Pavona,* and *Stylophora* were considered medium-preference corals. *Acanthastrea, Favia, Favites, Galaxea, Goniopora, Leptastrea, Leptoseris, Millepora, Platygyra, Porites, Psammocora,* and *Stylocoeniella* were considered non-preferred corals. They observed that diet depended on relative abundance of corals. If the preferred species were relatively abundant, they were the predominant food source, while medium-preference corals were eaten when preferred species were not abundant. Non-preferred corals were only eaten when the others were relatively rare.

Colgan's study in 1980-81 found that the submarine terrace was dominated by several species of *Montipora*. *Acropora* and *Montipora* species were the second and third most dominant species in the reef front and seaward slope. The newest survey of this area found that *Porites* is now the dominant genus on the submarine terrace and seaward slope, with only negligible contributions from *Montipora* and *Acropora*. The reef front is now dominated by other genera and *Acropora* is only an insignificant contributor. This study found no change in total percent coral cover on the submarine terrace and a slight decrease on the seaward slope. The researchers suggest that this change in community composition may be due to feeding by *A. planci*, as non-preferred corals had significantly greater cover than preferred or medium-preference corals on the seaward slope and submarine terrace. Non-preferred corals are the most abundant in all zones. Preferred corals increased slightly in cover and abundance on the reef front, but not as much as the other preference groups.

This study suggests that large-scale changes in the coral communities at Tanguisson Reef over the last 20 years may have been driven by selective feeding by *A. planci*. The study also identifies seasonal algal blooms as an additional stressor that may impact the settling of larvae produced by *Acropora, Montipora,* and *Pocillopora* species that spawn in the summer. This combination of effects seems to be exacerbated by nutrient influx into Guam's coastal waters and depletion of herbivorous fish stocks due to overfishing. Nutrient influx may be directly affecting the survivorship of *A. planci* larvae, which are dependent on planktonic food supply and can directly assimilate dissolved organic matter. Declines in the herbivorous fish stocks may impact larval settling of corals as algal blooms cover most of the suitable substrate during the summer months when these species spawn. Better land management is suggested as the best means to protect Guam's reefs from future shifts in coral communities.

Algal Communities

Guam's algal communities were surveyed as a part of the MARAMP in September 2003 using a rapid ecosystem assessment (REA) protocol developed specifically for remote island ecosystems (Preskitt et al., 2004). One component of this protocol, a rapid method of analysis using presence/absence and ranked data, was employed for this preliminary assessment (Vroom, in review). These data provide information on prevalence and relative abundance of algae in Guam at the genus level. Prevalence was defined as the percentage of quadrats in which a genus occurs at each site and relative abundance was defined as the abundance of a genus (i.e., the rank) in relation to other algal genera occurring in the same quadrat (Vroom, in review).

Methods

Benthic REAs were conducted at nine sites around Guam, including one site on Santa Rosa Bank, just southeast of Guam. Three 25-m transect lines were set in a single-file row at a constant depth, with each transect separated by 10 m. Ranked abundance of algal genera was collected from a total of 12 quadrats (0.18 m^2) at each site (1 being the most abundant, 2 being the next most abundant, etc.; Vroom et al., in review). Additionally, samples of macroalgae present within each quadrat were collected as voucher specimens (Preskitt et al., 2004).

Results and Discussion

According to Vroom (in review), algae from 28 genera or functional groups (i.e., crustose coralline algae, upright branched coralline algae, turf algae, cyanophytes) were found in quadrats at sites sampled around Guam and Santa Rosa Bank. In addition to the functional groups of turf, cyanophytes, branched coralline algae, and crustose coralline algae, the most prevalent genera found around Guam included green algae (*Halimeda* and *Neomeris)*, brown algae (*Padina*), and red algae (*Trichleocarpa* and an unknown gelid rhodophyte). At the Santa Rosa Bank site, species in the genera *Dictyosphaeria, Halimeda, Udotea,* and the green algal species *Microdicyton okamurai* Setchell were most prevalent. Turf and the gelid rhodophyte were also extremely prevalent. Relative abundance of genera was similar among sites.

Benthic Habitat Mapping

NOAA's Center for Coastal Monitoring and Assessment - Biogeography Team initiated a nearshore benthic habitat mapping project for Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands (CNMI) in 2003. IKONOS satellite imagery was purchased from Space Imaging, Inc. for all three jurisdictions and used to delineate habitat polygons in a geographic information system (GIS). Habitat polygons were defined and described according to a hierarchical habitat classification system consisting of 18 distinct biological cover types and 14 distinct geomorphological structure types. The project, which was completed in 2004, mapped 104.7 km^2 of nearshore habitat in these islands and produced a series of 42 maps that are currently being distributed via a print atlas, CD-ROM, and on-line at: http://biogeo.nos.noaa.gov/products/us_pac_terr/. The benthic habitat maps for Guam are depicted in Figure 16.17.

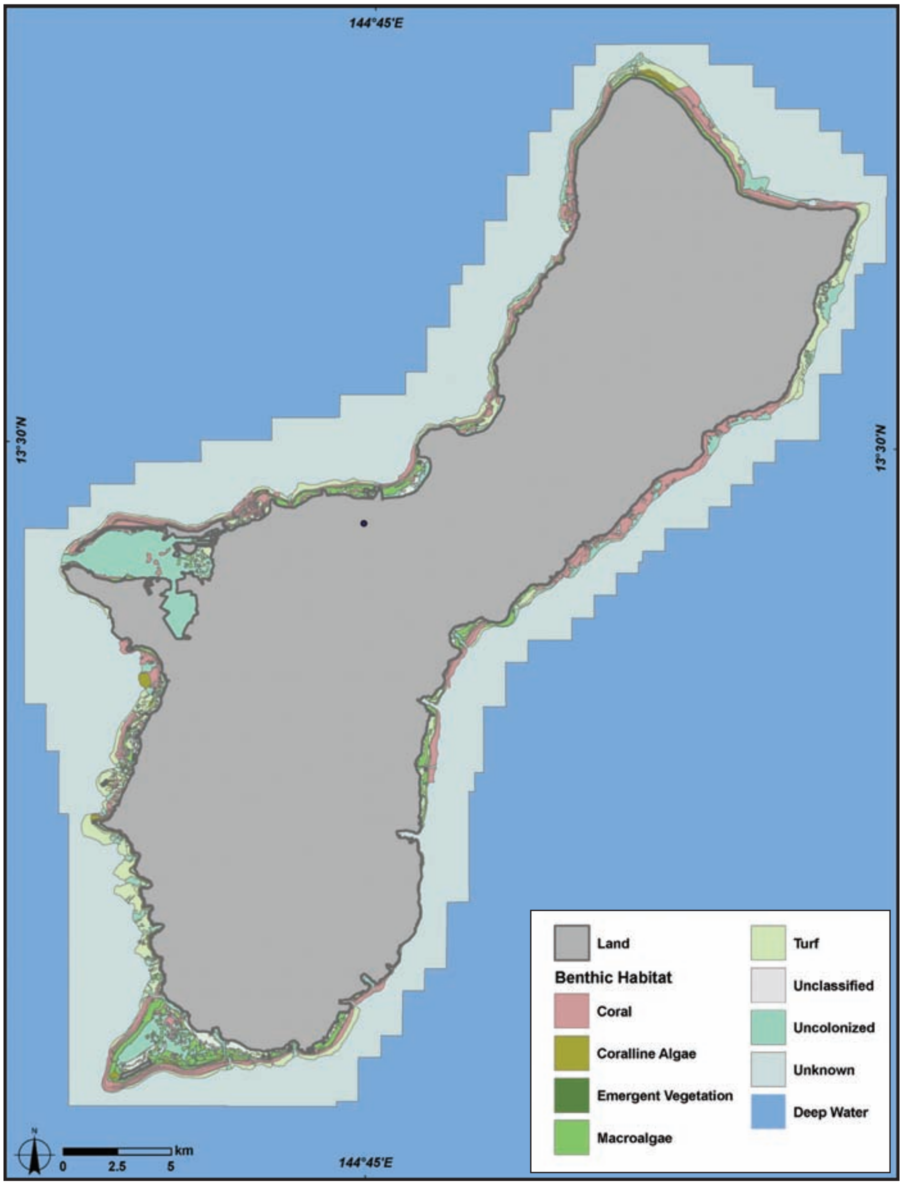


Figure 16.17. Nearshore benthic habitat maps were developed in 2004 by CCMA-BT based on visual interpretation of IKONOS satellite imagery. For more info, see: http://biogeo.nos.noaa.gov. Map: A. Shapiro.

ASSOCIATED BIOLOGICAL COMMUNITIES

Many recent studies on Guam have examined the biological communities associated with coral reefs. The most detailed studies have examined the fish communities. These include the marine preserve monitoring by the DAWR (Gutierrez, in prep.) and UOGML (Tupper, in prep.). The U.S. Navy-sponsored studies at Orote Peninsula and Haputo ERAs discussed in the previous section also examined fish communities and macroinvertebrate populations at the survey sites. Preliminary data for fish communities collected during the MARAMP are included below, although data for other communities are not yet available.

DAWR Marine Preserve Monitoring

In 1997, Guam established five marine preserves around the island, covering 11.8% of the island's shoreline. DAWR sampled the fish populations in two of the preserve areas and suitable control sites prior to the start of full enforcement on January 1, 2001, and has since monitored the fish communities at these sites to determine the effectiveness of the preserve system. These studies focus on fish species targeted for consumption and indicator species such as butterflyfish.

Methods

The Piti Bomb Holes and Achang Reef Flat Marine Preserves are the experimental sites for the stock assessment surveys. Cocos Lagoon and the Asan forereef slope serve as the control sites for the Piti Bomb Holes Marine Preserves, while Pago Bay reef flat and Cocos forereef slope serve as the control sites for the Achang Reef Flat Marine Preserve.

Prior to full enforcement in 2001, 66 permanent belt transects (50 m x 5 m) were surveyed on the reef flats and forereef slopes of two preserve sites, Piti Bomb Holes and Achang Reef Flat Marine Preserves, and three control sites, Asan Bay, Cocos Lagoon, and Pago Bay. Two sets of transects were placed on the forereef slope at the 6, 9, 12 and 15 m depth contours. Eight transects were placed on the reef flat at each site, representing distinct microhabitats (seagrass, coral/algal/rubble, and sandy bottom).

Fish communities were surveyed using two different visual survey techniques along each transect. Density was assessed using a visual fish census along a strip transect. Two fish counters followed the 50 m long permanent transect, each counting all target fish within 2.5 m of the side of the transect. All target fish within this 250 m^2 area were scored on data sheets based on their species and size class. Three size classes were used based on the fork length of the fish (<15 cm, 15 cm-30 cm, >30 cm). The strip transect method was complemented by a timed visual survey in the same area. At each site, fish counters recorded the species and size class of all fish encountered in the area during a 30-minute interval.

Fish surveys were conducted at all sites prior to full enforcement of the preserves and then repeated within two years. Because of poor weather conditions and lack of a boat, only four transects on the forereef slope of Achang Reef Flat Marine Preserve were repeated (one at each depth of 6, 9, 12 and 15 m). Data were analyzed using Statview 4.5 for PC published by Abacus Concepts Inc. A two-tailed paired t-test was used to compare fish densities and diversity over time within each study site (Sokal and Rohlf, 1995). The Shannon-Weiner diversity index was used to calculate an index number for species diversity and evenness at each site for both pre- and post-implementation data. A higher index number indicated greater diversity. When the assumptions of analysis of variance (ANOVA) were not met, even after transformations, a nonparametric test was conducted (Sokal and Rohlf, 1995).

Results and Discussion

The data from the belt transect surveys suggest that fish stocks in the preserve areas are starting to recover, while some non-preserve areas are still declining. Data also indicate that within the Piti Bomb Holes and Achang Reef Flat Marine Preserves, there were significant increases of 113% ($p<0.001$) and 115% ($p<0.001$) respectively, in the number of individuals within the transects after the preserve protections were implemented (Figure 16.18). At non-preserve control sites, significant to minor decreases detected (29% at Asan/Cocos ($p<0.005$) and 4% at Cocos/Pago ($p>0.05$)) in the total number of individuals within the transects (Figure 16.19).

The largest increase appeared to be in the smallest size class. There were significant increases of 123% and

138% within the Piti Bomb Holes Marine Preserve (p<0.001) and Achang Reef Flat Marine Preserve (p<0.001), respectively, for individuals <15 cm after the preserve protections were implemented. In the non-preserve areas, there were significant to minor decreases of 27% at Asan/Cocos (p<0.001) and 5% at Cocos/Pago (p>0.05) for individuals <15 cm during the same period. For larger fish (>15 cm to <30 cm), results were more variable, with an increase of 44% within the Piti Bomb Holes Marine Preserve after preserve implementation and a 10% decrease in the Achang Reef Flat Marine Preserve. However, in the non-preserve areas, there were decreases of 75% (Asan/Cocos) and 33% (Cocos/Pago) in the number of individuals between >15 cm and <30 cm during the same period of time.

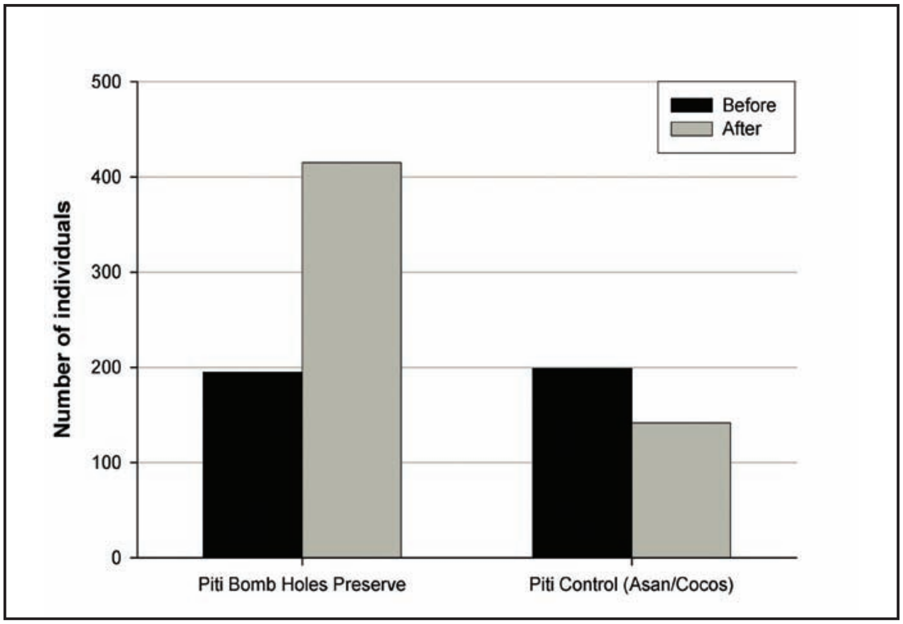


Figure 16.18. Number of individuals counted by DAWR on 16 transects in the Piti Bomb Holes Preserve and control site before and after full enforcement of the preserves. Source: Gutierrez, 2003.

Timed interval surveys indicated that the number of species observed at the study sites after preserve implementation increased by 14% within the Piti Bomb Holes Marine Preserve and 3% at the Asan/Cocos control sites. During the study period, diversity increased significantly (38%) in the Piti Bomb Holes Marine Preserve. Although diversity increased in the Asan/Cocos control sites, the increase was not significant (3%). Diversity indices have not yet been calculated for Achang Reef Flat Marine Preserve and the Pago/Cocos control sites.

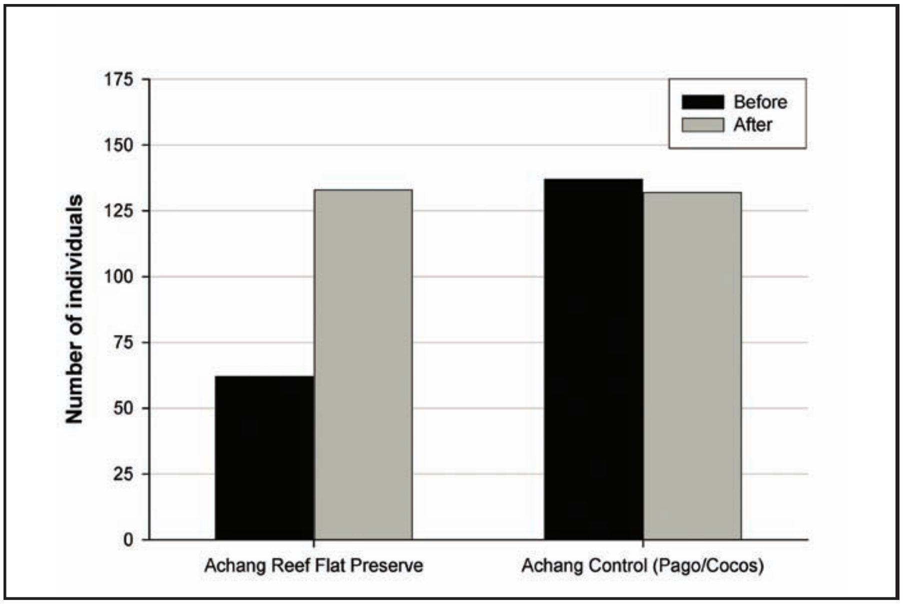


Figure 16.19. Number of individuals counted by DAWR on 16 transects in the Achang Reef Flat Preserve and control site before and after full enforcement of the preserves. Source: Gutierrez, 2003.

After only two years of implementation, there have been significant increases in fish density within the preserves. The majority of fish recruiting into the preserves are smaller than 15 cm. Within the non-preserve areas, fish density has remained the same or has decreased significantly within the same period of time. Preliminary data show that larger size fish (>15 cm) are being observed within the preserve while their numbers are decreasing within the non-preserve areas. Within one preserve, diversity also increased significantly.

University of Guam Marine Laboratory Marine Preserve Effectiveness

The UOGML is also involved with assessing the effectiveness of Guam's marine preserves. Tupper (in prep.) studied the effectiveness of three marine preserves - Achang Reef Flat, Piti Bomb Holes, and Tumon Bay - as compared to adjacent, unmanaged control sites - Cocos Lagoon, Asan Bay, and Agana Bay, respectively. The biophysical indicators chosen for this study were focal species abundance, population structure, and recruitment success.

Focal Species Abundance

Focal species abundance was determined for four species: bullethead parrotfish (*Chlorurus sordidus*), yellow-stripe goatfish (*Mulloidichthys flavolineatus*), orangespine unicornfish (*Naso lituratus*), and bluespine unicorn-fish (*Naso unicornis*). Two sites were chosen within each of the three marine preserves and the three control sites. All sites were near the edge of the reef flat at depths of 2-5 m. Four replicate 50 m x 2 m transects were surveyed at each site to determine the density of each species per 100 m^2 area. The results were analyzed using a nested ANOVA. Location and status were used as model factors with location nested within status.

Densities for all four species were significantly higher in the MPAs than in the control sites, and in some cases, density was an order of magnitude higher in the preserves (Figure 16.20). Further analysis indicated that there were also significant differences among the preserve sites and among the control sites. Density of *Chlorurus sordidus* was highest at Piti Bomb Holes Marine Preserve, possibly due to fish feeding by divers and snorkelers. *Mulloidichthys flavolineatus* density was five to nine times higher in the preserves than in the control sites, with the highest density documented in Tumon Bay. Achang Reef Flat Marine Preserve had the highest densities of *Naso lituratus* and *Naso unicornis*.

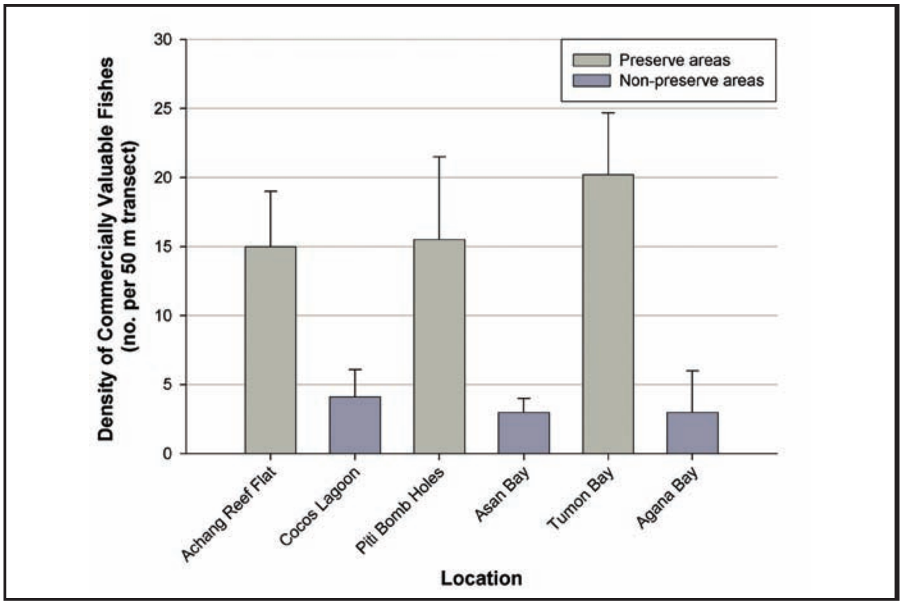


Figure 16.20. Density of commercially valuable food fishes along a 50 m transect at preserve and non-preserve sites following two years of enforcement at preserve areas. Food fish density was noticeably greater in preserve sites. Source: Tupper, in prep.

Population Structure

Population size structure was determined by counting fish and estimating their fork length in situ. As described in the previous section, fish were surveyed on four replicate 50 m x 2 m transects. Eight size classes were used for size estimation: 10-12.5 cm, 12.5-15 cm, 15-17.5 cm, 17.5-20 cm, 20-22.5 cm, 22.5-25 cm, 25-27.5 cm, and 27.5-30 cm. Fish less than 10 cm were not counted. As these small transects did not provide enough data, the method was modified to use a single 100 m x 4 m transect. However, this prevented statistical comparison between sites. The results indicated that *C. sordidus*, particularly the larger size classes, were more abundant at all preserve sites than control sites. *M. flavolineatus* were more abundant in the preserves than the control sites; however, small-medium sized *M. flavolineatus* were less abundant in Achang Reef Flat Marine Preserve than at the control sites in Cocos Lagoon.

The length and abundance data were used to determine the spawning biomass (the weight of the spawning adult fishes per unit area). The length data were used to estimate weight values using published length-weight regressions. Biomass for *C. sordidus* and *M. flavolineatus* was significantly higher in the preserve sites than the control sites (nested ANOVA, $F=8.49$, $p=0.006$, $F=15.7$, $p<0.001$).

Recruitment Success

Two aspects of recruitment success were studied: settlement and recruitment. Four replicate 25 m x 2 m transects were used to enumerate newly settled fish in March 2002. *C. sordidus* were recorded as newly settled if they were 10-15 mm long. *M. flavolineatus* were recorded as newly settled if they were 6-7 mm long. *C. sordidus* had the highest settlement in Cocos Lagoon; however, overall mean settlement was higher in the preserves than the control sites (nested ANOVA, $F=4.1$, $p<0.01$). *M. flavolineatus* settlement was similar across all sites with no significant differences between preserve areas and the control sites (nested ANOVA, $F=0.04$, $p=0.840$).

Transects were revisited three months later to determine the survival rates of the settled fish. On the second visit, the expected length for the previously recorded settlers was recorded: *C. sordidus* at 25-50 mm long and *M. flavolineatus* at 90-120 mm long. The pattern of recruitment changed during the three months that elapsed between surveys. Despite the high settlement in Cocos Lagoon, the second survey indicated that recruitment success was 50% less than in the Achang Reef Flat Marine Preserve. In general, *C. sordidus* recruitment in the marine preserves was significantly higher than in the control sites (nested ANOVA, $F=64.8$, $p<0.001$). *M. flavolineatus* recruited less successfully in the control sites, despite similar settlement (nested ANOVA, $F=9.5$, $p=0.004$). This was expected due to fishing pressure on newly-settled *M. flavolineatus* in the control sites.

Discussion

The results of this study suggest that the marine preserves in Guam have a positive effect on local reef fish populations. Species abundance for four species indicated significant differences between the protected areas and adjacent control sites. Large sizes of *C. sordidus* and *M. flavolineatus* were more common in the preserve areas; however, smaller sizes were more abundant in some of the control sites. Spawning mass was significantly higher in the marine preserves than in the control sites, thus indicating that the marine preserves may function as “egg banks” and provide higher production potential.

Orote Peninsula ERA Fish and Macroinvertebrate Surveys

As described above in the ‘Benthic Habitat’ section, the U.S. Navy sponsored biodiversity studies and baseline reef monitoring surveys at Orote Peninsula ERA (Paulay et al., 2001). Both qualitative biodiversity surveys and quantitative baseline monitoring were conducted for fish and macroinvertebrates.

Methods

Fish and macroinvertebrates were qualitatively surveyed at a site in each of the subzones identified in the study. At least one diver surveyed each category for the duration of one dive. Deep dives occurred at a depth of 27-30 m for 25 minutes, deeper dives were shorter (at least 10-15 minutes), and all other dives were 40 minutes or longer.

Fish surveys were conducted along the three central transects (50 m x 5 m) laid out for the benthic surveys described above. Quantitative surveys were conducted following the methods described in English et al. (1997). The fish surveyor started the transect at least 10 minutes after the transects were laid and before any other surveyor. Large fish within 2.5 m of the transect and within 5 m of the bottom were recorded first. For highly abundant fish, a logarithmic scale was used for estimates of abundance. Abundance statistics were calculated for species, family, and total population at each station. The Shannon-Weiner diversity index and the number of species encountered were also calculated for each station.

Quantitative surveys of macroinvertebrates were conducted along all five belt transects (50 m x 1 m). Surveys included all large, exposed macrofauna. The primary taxa studied were larger mollusks and echinoderms, as cryptic fauna and small species could not be effectively sampled. Abundance was recorded in five 10-m^2 quadrats per transect, which were lumped into 50 m^2 quadrats for analysis. The mean and standard deviation were calculated for each of the transects.

Results and Discussion

The survey recorded 1,252 species of marine animals based only on the exposed macrofauna identified during the limited dives. Fish recorded included 339 species, approximately 37% of the 920 known species from Guam. Macroinvertebrates accounted for 657 species encountered during the qualitative surveys. Diversity appears to be related to habitat, with areas such as the reef flat between Neye Island and the coast, and the patch reefs in North Agat Bay, exhibiting high levels of diversity. In general, diversity declines from Orote Point southeastward and then increases again in the Agat area (Figure 16.21).

The quantitative surveys were conducted at 10 stations. Orote forereef sites had a higher abundance of fish than Agat Bay. Twenty-five fish families were recorded during the quantitative studies. The most abundant family was the Pomacentridae (69%), followed by the Acanthuridae (10.2%), Labridae (4.4%), Chaetodontidae

(3.8%), Scaridae (3.2%), and Balistidae (2.2%), while all other fish species comprised 7.2% (Figure 16.22).

During the quantitative surveys, a total of 26 species of macroinvertebrates were identified. This included 19 echinoderms, six mollusks, and one crustacean. The maximum number of species observed at a single station was 13, with the highest diversity occurring towards Agat Bay (Figure 16.23). These surveys only captured the large, diurnal, exposed species and did not capture the many cryptic and nocturnal species resident at these areas. The most commonly encountered species were: echinoids (*Echinostrephus aciculatus* and *Echinothrix* spp.), the giant clam (*Tridacna maxima)*, and the sea cucumber (*Holothuria edulis)*.

The study indicates that diversity and species composition of Orote Peninsula reefs are strongly influenced by physical factors such as wave exposure, currents, riverine influence, and bottom topography. A number of unique microhabitates and macrohabitats exist in this area, with very different assemblages found within each of them. The researchers indicate that the Blue Hole, Orote Boulder Fields, and Orote Point reef slope were biologically important due to unique species and high biodiversity.

Haputo ERA Fish and Macroinvertebrate Surveys

As described above in the 'Benthic Habitat' section the U.S. Navy sponsored biodiversity studies and baseline reef monitoring surveys at Haputo ERA (Amesbury et al., 2001). Both qualitative biodiversity surveys and quantitative baseline monitoring were conducted for fish and macroinvertebrates.

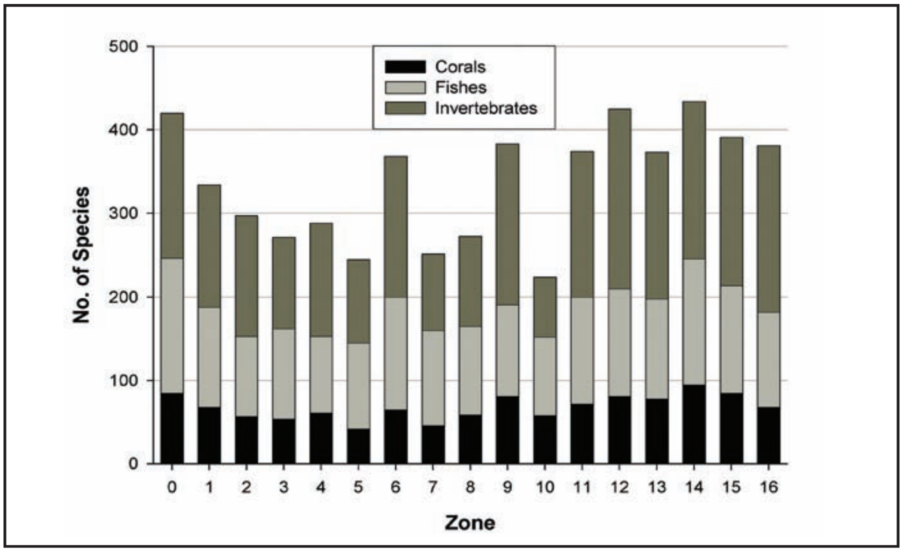


Figure 16.21. 1252 species were recorded during a survey in the Orote Peninsula ERA. Richness varied greatly between subzones. Source: Paulay et al., 2001.

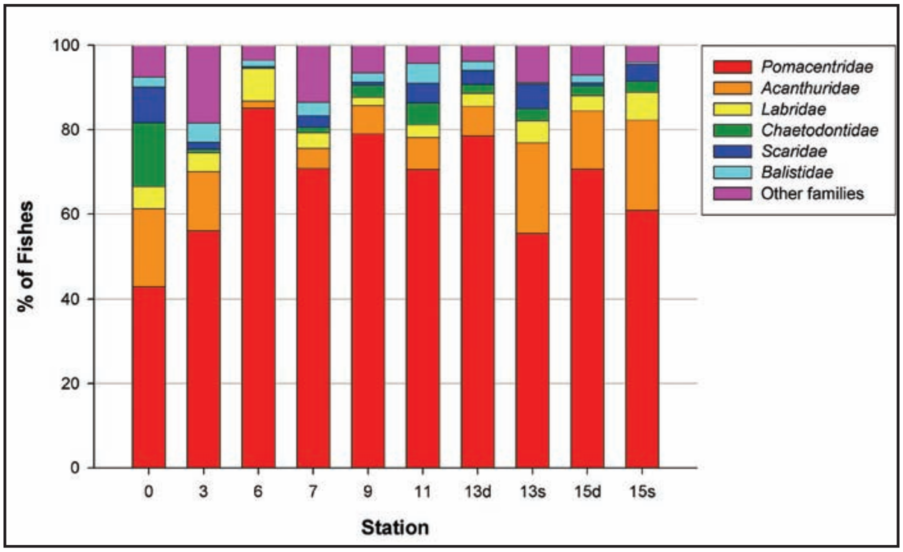


Figure 16.22. Fish family composition in the Orote Peninsula ERA. Source: Paulay et al., 2001.

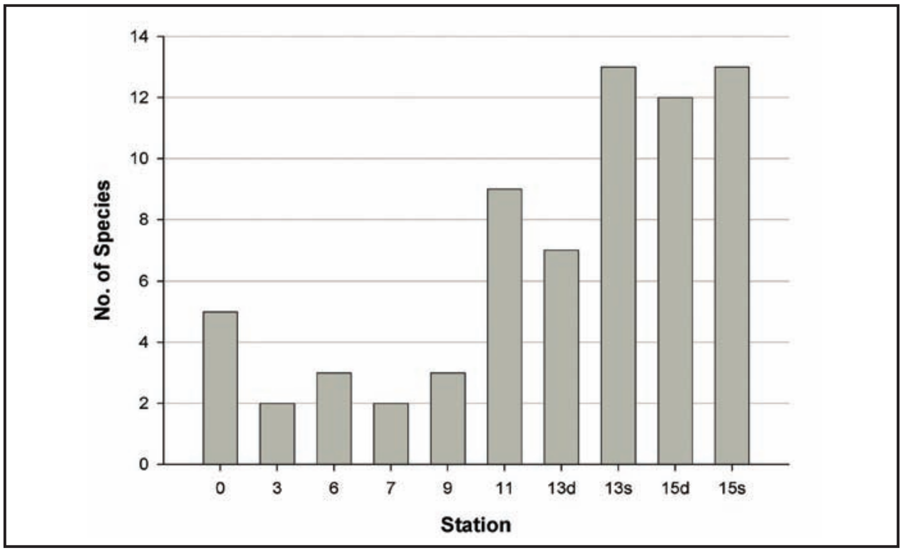


Figure 16.23. Number of macroinvertebrate species at 10 sites in the Orote Peninsula ERA. Macroinvertebrate communities varied greatly over the study sites. Cryptic species were not included in the survey. Source: Paulay et al., 2001.

Methods

Fish and macroinvertebrates were qualitatively surveyed at each of the sites identified in the study using timed surveys (30 minutes) to assess fish diversity and abundance and a timed search (one hour) for large macroinvertebrates. The survey team followed the same methodology for fish as described above in the Orote Point section, but used 2 m-wide transects for macroinvertebrates.

Results and Discussion

This survey recorded 944 species of marine animals. This included only the exposed macrofauana identified during the limited dives. Fish recorded included 207 species, approximately 22% of the 920 known species from Guam. Macroinvertebrates accounted for 583 species encountered during the qualitative surveys. A comparison of surveyed biodiversity between Orote Peninsula and Haputo ERAs showed some interesting results (Table 16.12). Researchers identified a similar number of corals at the two sites; however, they found more species of fish and invertebrates at Orote Peninsula than at Haputo sites. The researchers noted that while the corals are thriving at Haputo, the fish community is not. Large piscivores and herbivores were rare.

The researchers also noted differences among the six macrohabitats identified in the survey. The forereef sites are more diverse than the shallow sites. The shallow sites had fewer coral, fish, and other invertebrate species than the medium to deep macrohabitats (Figure 16.24).

The quantitative surveys were conducted at six stations. Twenty-one fish families were recorded during the quantitative studies. The most abundant family was the Pomacentridae (74%), followed by the Acanthuridae (10.1%), Labridae (6.7%), Lethrinidae (3.1%, *Gnathodentex aurolineatusa* only), Gobiidae (2.7%), Scaridae (1.2%) and Chaetodontidae (1.1%), while all other fish species comprised 3.4% (Figure 16.25).

Table 16.12. A comparison of coral species in the Orote and Haputo ERAs indicated that both areas exhibited similar coral species richness, but different levels of fish and invertebrate species richness. Source: Amesbury et al., 2001.

SURVEY AREA	CORALS	OTHER INVERTEBRATES	FISHES
Orote-Agat	156	757	339
Haputo-Double Reef	154	583	207
Ratio	1.01	1.3	1.64

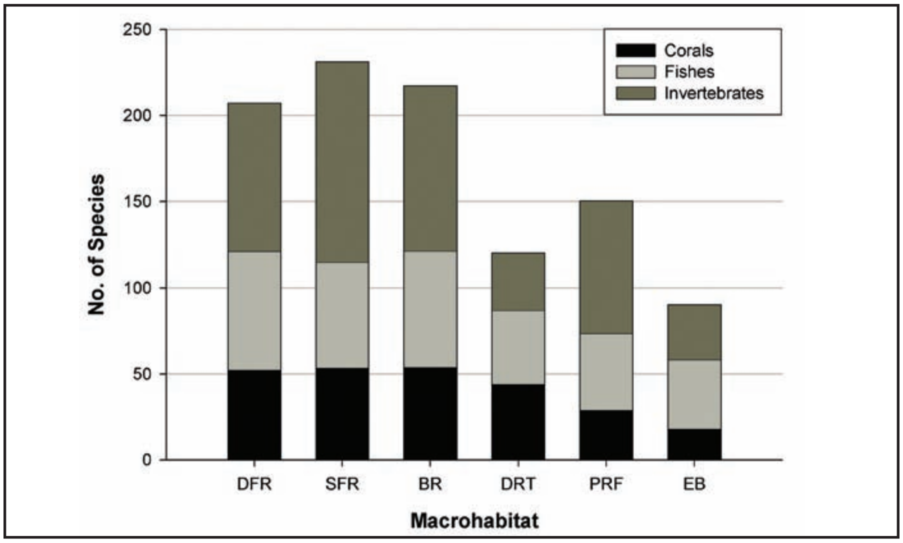


Figure 16.24. Mean number of species in six microhabitats in the Haputo ERA: Exposed Bench (EB), Protected Reef Flat (PRF), Double Reef Top (DRT), Back Reef (BR), Shallow Fore Reef (SFR), and Deep Fore Reef (DFR). Note the large variation in species richness among the six sites. Source: Amesbury et al., 2001.

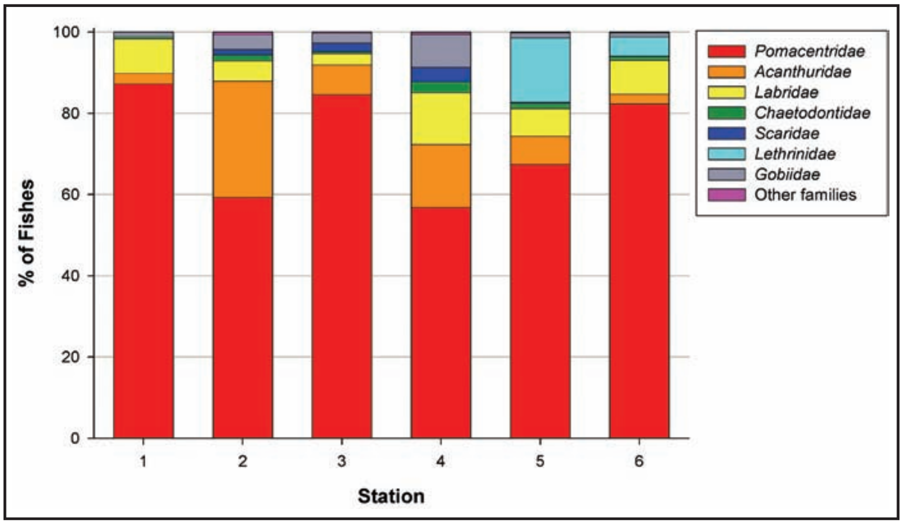


Figure 16.25. Fish family composition in the Haputo ERA. Source: Amesbury et al., 2001.

During the quantitative surveys a total of 24 species of macroinvertebrates were identified. This included 16 echinoderms and eight mollusks. The maximum number of species observed at a single station was 13, with the highest diversity occurring in the shallow stations (1-3) (Figure 16.26). The most commonly encountered species were sea urchins in the genera *Echinometra* and *Echinostrephus*. Giant clams (*Tridacna maxima)*, were found at five of the six sites, but were less common than sea urchins.

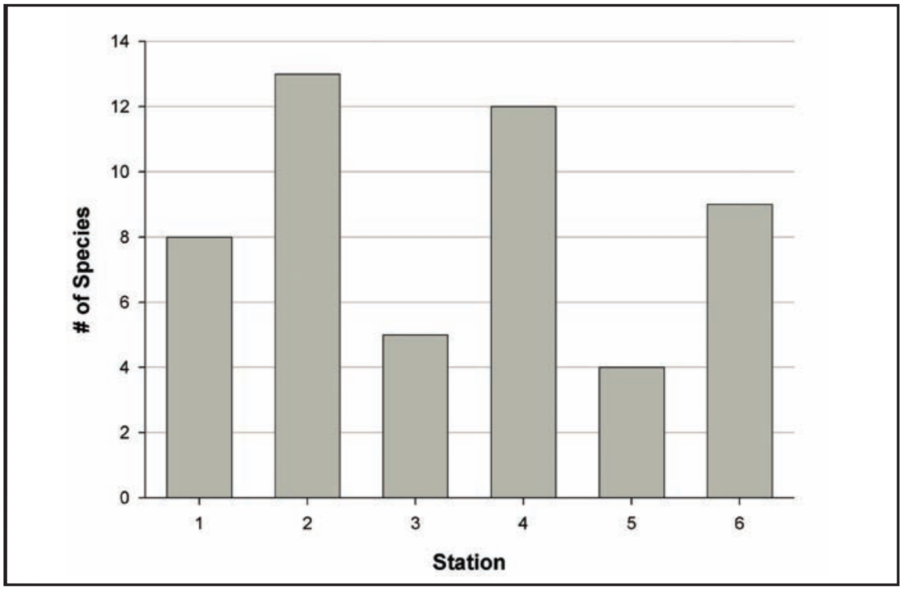


Figure 16.26. Number of macroinvertebrate species in the Haputo ERA. Macroinvertebrate communities varied greatly and included 16 echinoderms and eight mollusks. Cryptic species were not included in the survey. Source: Amesbury et al., 2001.

The study indicated that while corals were thriving, the fish targeted by the local fisheries were less diverse and less abundant than expected. The low abundance of large individuals of these species suggests that overfishing may also be a problem in this area.

MARAMP Fish Surveys

Fish surveys were directed in September 2003 as part of the Guam leg of the MARAMP. Objectives of the surveys included: 1) creating a fish baseline to measure MPA effectiveness; 2) monitoring size-frequency assemblages; 3) assessing the status of target, indicator or keystone species; 4) assessing response by the fish community to possible ecosystem impacts (e.g., overfishing, habitat damage, sedimentation, prey size changes); and 5) assessing species composition and diversity by area and effectiveness of temporal monitoring of managed areas (R. Schroeder, unpublished data).

Methods

Fish were surveyed around the island of Guam and at Santa Rosa Bank. Several types of surveys were conducted, including: 1) REAs to document species diversity at a site; 2) belt transects to estimate densities of relatively small-bodied and abundant fishes; 3) SPCs to estimate densities of relatively larger (≥25 cm total length (TL)) and more mobile fish species; and 4) towed-diver/video surveys to estimate densities of relatively large-bodied (≥50 cm TL), wide-ranging fishes over a broad-spatial scale, in conjunction with a towed-diver/habitat video. Fish length-class was estimated for all quantified fishes to provide an estimate of numerical size structure and biomass density by taxa.

Results and Discussion

Schroeder (unpublished report) provided the following preliminary results. Data from 11 belt transects showed that large fish (≥20 cm) were not abundant, averaging about 2/100 m^2 (compared with over 14/100 m^2 at Uracas and Maug, the two northernmost islands in the Mariana Archipelago). Results from 11 SPC surveys were similar. Medium-sized fish were only common along the north and northeast sides of the island. Densities of larger fish (>50 cm TL) from towboard surveys were also quite low for both Guam and Santa Rosa (less than 0.1/100 m^2). No sharks were observed by the fish census team, although the fish tow-team did see black-tip and white-tip sharks. About 232 species were sighted during the five-day survey. Few juvenile fish were present, unlike the northernmost Mariana Islands, where recruitment for several species was higher. The highest diversity of fish was found at Jinapsan Beach on the northern tip of Guam. Common species observed included brown surgeonfish (*Acanthurus nigrofuscus*), red ribbon wrasse (*Thalassoma quinquevittatum*), bullethead parrotfish (*Chlorurus sordidus*), and orangespine unicornfish (*Naso lituratus*).

Guam sustains a large human population and its waters are heavily fished. Habitat damage and loss may also contribute to these preliminary findings on the status of coral reef fish assemblages. Ongoing analysis of the 2003 data, together with planned biennial monitoring, should help determine the effectiveness of Guam's recently established MPAs, as well as provide the scientific basis for other management initiatives.

Overall Condition/Summary of Analytical Results

Guam's northern reefs are generally in better condition than those affected by erosion and sedimentation in the south, due to the primarily limestone composition of northern Guam. Coral cover and diversity are generally highest in an area beginning roughly at Falcona Beach on the northwest coast, continuing clockwise around the northern coast, and extending down to Pagat Point on the eastern side of the island (Figure 16.27). The areas between Tanguisson Point and Falcona Beach also have high coral cover and diversity; however, they are heavily fished and have higher recreational use than the reefs to the north (Amesbury et al., 2001).

The eastern reefs along the central and southern portions of the island are heavily affected by sedimentation and freshwater runoff near the mouths of rivers that drains Guam's largest watersheds, especially during the rainy season. However, some very diverse and relatively healthy reefs lie adjacent to these heavily impacted spots, especially the forereef slopes off of Achang Reef Flat Marine Preserve and the south side of Cocos Lagoon. Most of the fringing reefs along the southwestern shores are in poor to fair condition, again depending on their proximity to river mouths. Water quality impacts caused by coastal development, wildland arson, and runoff are a serious concern in these areas; however, there are limited water quality data available. GEPA, DAWR, and UOGML hope to address this issue through future monitoring efforts such as increasing water quality monitoring and studying sedimentation of southern reefs in conjunction with upland restoration projects.

Although Apra Harbor is home to the busiest port in Micronesia, a large U.S. Navy base, and numerous recreational facilities, it contains both patch and fringing reefs with some of the highest coral cover on the island (i.e., Jade Shoals, Western Shoals, and Finger Reef). Both hawksbill and green sea turtles frequently forage in the protected waters of the harbor, and the extensive mangroves of Sasa Bay Marine Preserve are also located there. However, corals and reefs near the northeastern part of the harbor have been impacted by thermal discharges from the Guam's main power generation facilities (G. Davis, pers. comm.). The reefs from Orote Point south to Agat include many different microhabitats for a diverse assemblage of reef organisms. The fishing advisory for the areas near the Orote Dump has resulted in a de facto fishing preserve, allowing some stocks to rebound from fishing pressure. Chemicals leaching from the dumpsite do not appear to have significantly impacted the resources (Paulay et al., 2001).

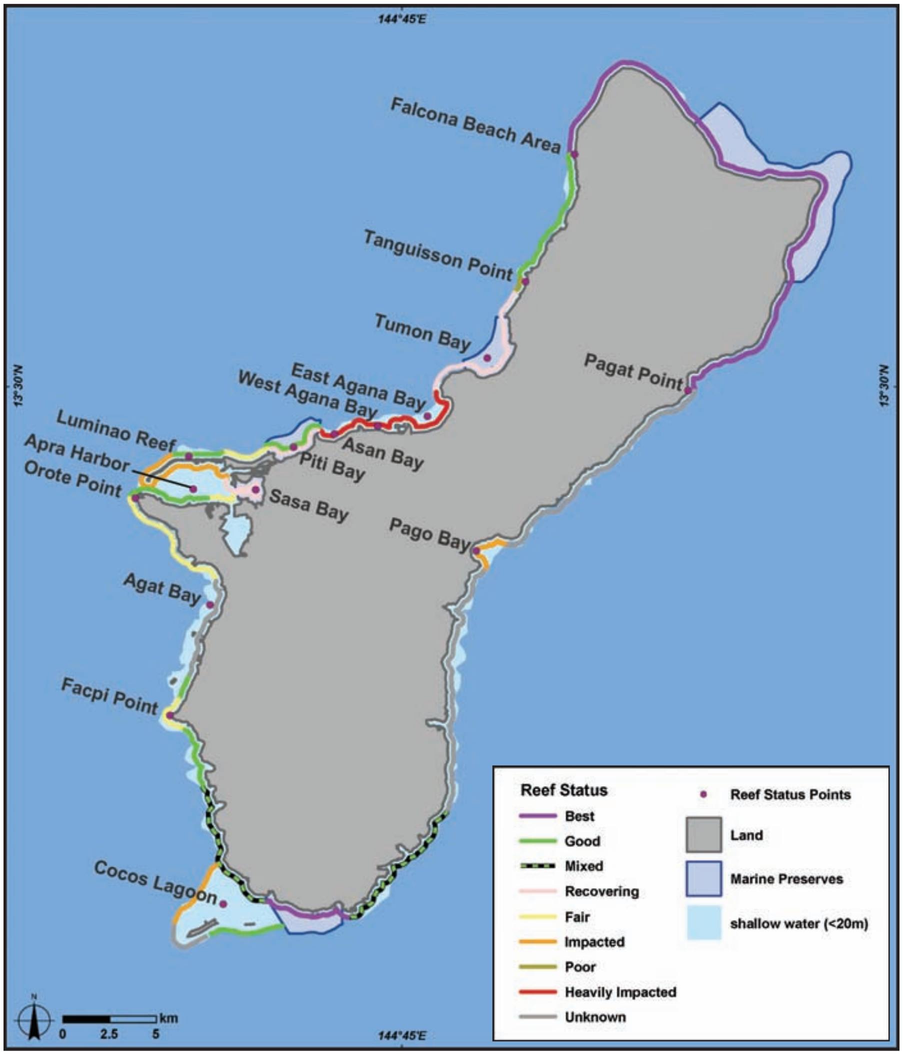


Figure 16.27. Summary map showing the overall condition of Guam's coral reef ecosystems. Map: A. Shapiro. Source: DAWR.

Several large bays - Piti, Asan, West and East Agana, and Tumon - are located along the central western coastline an area that experiences calm conditions for most of the year. According to Gutierrez (in prep.) and Tupper (in prep.), Asan Bay is heavily impacted by fishing, and fish stocks have decreased in this area since monitoring began in 2001. Piti and Tumon Bays were selected to be marine preserves due to their wide diversity of habitat types. Since full implementation of the preserves in January 2001, increases in herbivorous fish densities appear to have better controlled the growth of palatable macroalgae in the two preserves, resulting in healthier looking reefs (T. Leberer, pers. obs.). A study to assess algal abundance and composition in relation to herbivore stocks inside and outside the marine preserves has been proposed for funding in fiscal year 2005.

The overall scarcity of reef fish, especially larger individuals, despite the persistence of some relatively healthy and diverse coral communities around the island, is a serious concern (Schroeder, unpublished report). The exceptions to this are within the marine preserves, where significant increases in fish density and diversity have been observed (Gutierrez, in prep.). Continued fish and habitat assessment surveys within Guam's marine preserves will provide an effective means to monitor their status. In addition, two recently funded projects will assess the amount of spillover - both from larval recruitment and adult migration - occurring into areas adjacent to the marine preserves. This information is crucial to help Guam's resource managers determine whether current MPAs are an effective management tool for restoring depleted coral reef fishery resources island-wide.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

Guam recognizes the important benefits that coral reefs provide, and has developed a diverse assortment of laws, regulations, permits, policies, plans and education programs to serve as mechanisms for the management of human activities that impact Guam's coral reefs (Gawel, 1999). Many of these, such as the environmental impact assessment requirements, were not created specifically to protect coral reef ecosystems, but now serve that purpose. Guam continues to expand and improve its management activities to address the threats identified above.

This process has been facilitated by the creation of the Guam Coral Reef Initiative Coordinating Committee (GCRICC) in 1997 by Executive Order 97-10. This committee prioritized the 13 threats identified in the National Coral Reef Action Strategy and selected the top five on which to focus for the next three years. By February 2003, the GCRICC had identified local navigators and drafted local action strategies (LAS) regarding for the prioritized focus areas of land-based sources of pollution, fisheries management, outreach and education, recreational area misuse and overuse, and climate change and coral bleaching. These LAS have provided a guiding framework for local resource agencies and have facilitated improved management and coordination among agencies. Current conservation management activities can be grouped according to the threat that they address (Figure 16.28).

The LAS process has also served to broaden the network of stakeholder groups working on coral reef issues. Members of the Guam Watershed Planning Committee (WPC), a group of local, Federal, and non-governmental agencies involved primarily with watershed restoration, have become involved in LAS development; members of the GCRICC now participate in the WPC as well. In addition, the UOGML and UOG's Water and Environmental Research Institute, guided by the needs of the local natural resource agencies, have shifted much of their focus toward management-driven research. Recently, another crucial stakeholder group has been engaged. The Guam Visitors Bureau (GVB) and Guam's tourism industry are now working with natural resources agencies to market Guam's coral reefs, and in particular the marine preserves, to the one million visitors that come to the island annually. This new awareness of the economic value of Guam's coral reef resources is beginning to create a sense of stewardship which was absent during the economic boom of the 1980s and recession of the 1990s.

Land-Based Sources of Pollution

Guam identified land-based sources of pollution as its number one priority focus area in 2002 and local and Federal stakeholders have developed a three-year LAS to address this threat. This is the most difficult threat

Current Conservation Management Activities in Guam

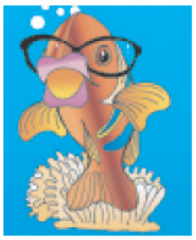
Land-Based Sources of Pollution

- Guam Seashore Protection Plan
- Soil Erosion and Sediment Control Regulations of 2000
- GEPA enforcement of Section 401 and NPDES permits
- Watershed Restoration (DoAg)
- Watershed Planning Group
- Permit Conditions to Limit disturbance during coral spawning (DPW/GEPA)

Fisheries Management

- Marine Preserve Areas (DAWR)
  - Enforcement
  - Education
  - Monitoring
- Creel Surveys (DAWR)
- School Presentations

Lack of Public Awareness



- Coral Awareness Campaign
  - Video
  - PSAs
  - Hotel Tent Cards
  - Coloring Books
- Island Pride Campaign
  - Trash Collections
  - Tree Planting
  - Snorkeling

Recreational Overuse and Misuse

- Informational campaign for Tumon Bay (GCMP/GVB)
- Beach Cleaning Permit Conditions (GVB)
- Eco-Permit for Marine Preserves (DAWR)

Figure 16.28. The Local Action Strategies developed by Guam's Coral Reef Initiative Coordinating Committee include: Land-Based Sources of Pollution, Lack of Public Awareness, Recreational Misuse and Overuse, Fisheries Management. The fifth, Coral Bleaching/Global Warming, is still under development. *Guam Department of Agriculture.

to address as it involves a large number of stakeholders and is complicated by the lack of cooperation from some key Guam governmental agencies.

One of the most effective outlets has been the WPC which was recently strengthened by Executive Order 2004-04. This committee is carrying out a comprehensive watershed planning process to address pollution in each Guam watershed by assessing pollution, determining the total maximum daily loads of particular pollutants that the watershed can withstand and still meet water quality standards, identifying potential pollution sources, and then initiating projects to control or prevent the pollution. In addition, Guam's Clean Marina Advisory Committee has developed an action plan identifying specific projects to manage nonpoint source pollution in Guam's marinas.

This is complemented by recent revisions to Guam's soil erosion and sediment control regulations in 2000. These are applied through clearing and grading permits, which are processed through Guam's Department of Public Works and GEPA. These permits provide protection during coral spawning periods by limiting activities during these times. One of the major topics of Guam's upcoming 2005 land use conference will be the control of pollution, especially stormwater runoff, through better land use planning. A manual for stormwater management is being produced for Guam in 2004, and recently the GCMP funded a workshop for contractors and builders on Guam's soil erosion and sediment control regulations, under GEPA oversight. To address the illegal burning of natural grasslands on mountain slopes carried out by deer hunters, an anti-arson campaign coordinator will be funded in 2005. In the meantime, the FSRD, NRCS, and UOG are working to restore badlands using erosion control fabric and nitrogen-fixing plants and trees such as acacia (Figure 16.30).

The GEPA has a number of permit processes to limit the impacts of nonpoint source pollution. Landfills, including construction material hardfills, must receive GEPA permits and be designed to protect all waters from polluting discharges. A new landfill for public solid waste is being planned and its site will be determined soon, with its construction following an accelerated schedule determined by a Federal court-ordered consent decree. Baseline monitoring is being performed to assess the impacts of leachate that pollutes coastal and river waters below Guam's old landfill, which must be closed when the new one is operable. In addition, injection of stormwater runoff through dry wells is regulated by GEPA underground injection control permits to prevent pollution from entering groundwater and subsequently being discharged to beaches and reefs. The GEPA Water Resources staff also requires golf courses to monitor the quality of their groundwater through monitoring wells. GEPA also locally administers the Water Quality Certification (Federal Clean Water Act Section 401) and NPDES permits for the U.S. EPA. Through its Water Pollution Control Program and in coordination with its Environmental Planning and Review Division, GEPA is responsible for certifying all permit applications, recommending the conditions and abatement schedules for each permit, and providing oversight for the implementation and compliance with the conditions. All permittees are routinely monitored by the GEPA staff to verify compliance with applicable permit requirements and compliance schedules. The Guam Waterworks Authority (GWA), responsible for Guam's public water supply and wastewater systems, is restructuring and improving its facilities and operations in response to U.S. District Court stipulated orders. Required activities include improving the Northern and Agana STPs and building new, deeper outfalls in order for both STPs to meet NPDES requirements.

Figure 16.30. Erosion control fabric and nitrogen-fixing acacia trees shown here are being used to re-vegetate nutrient depleted, highly erodible lands damaged by wildfires in southern Guam. Source: Forestry and Soil Resources Division.

These improvements to Guam's sewage systems involve major expenses - well over $40 million - that are far beyond GWA's current budget. These costs and similar high unbudgeted costs for public facilities for stormwater management and solid waste pollution control are not only a problem for Guam, but also are shared with other U.S. island territories and commonwealths that are members of the U.S. Coral Reef Task Force. At its October 2003 meetings, the Task Force passed a Pacific Islands Water Quality Resolution, directing its attention to seeking a solution to funding the capital improvement needs to provide the infrastructure necessary to manage water pollution in order to protect the islands' coral reefs. Guam's estimate for basic funding for these projects is close to a $100 million. Pacific Islands members of the Task Force await urgent action on this resolution.

The Guam Seashore Protection Commission (GSPC) has review and approval authority over construction projects proposed within the area from 10 m inland of the mean high tide mark out to a depth of 18 m (an area defined in law as the "seashore reserve"). The Application Review Committee, comprised of a large number of Guam's governmental agencies, reviews all project applications, to identify potential impacts. The Committee's comments are submitted to a seven-member commission appointed by the Governor for consideration of approval or rejection.

Presently, the Guam Seashore Reserve Plan Task Force, comprised of several of Guam's governmental agencies, is developing the Guam Seashore Reserve Plan to better guide the decisions of the GSPC. The plan will limit development in the areas designated as the seashore reserves. Zones were designated to identify what types of development, if any, are allowed. The zones were determined based on sensitivity of areas adjacent to the shoreline and the effects of development on the coral reefs. While this task is taking longer than desired, the end product should help Guam make good decisions about future development along its coasts.

In addition to local activities, the U.S. Department of Defense (DoD) has started restoration activities on DoD base sites, cleaning up scores of old dumps and hazardous or toxic pollutants with impacts on the coastal waters of Guam. Contaminated sites, including ammunition dumps on coral reefs that were formerly used by the military but are not on current DoD property, are being identified through the DoD and State/Territorial Memorandum of Agreement program with GEPA, which is the first step to their cleanup.

Fisheries Management

A three-year LAS for coral reef fishery management that focuses on increasing the effectiveness of Guam's marine preserves was developed by DAWR and reviewed by fishers, resource managers, and other stakeholders. The strategy addressed three main issues: the lack of enforcement and prosecution, lack of public awareness and support, and need to assess the effectiveness of the preserves in increasing reef fish stocks. Specific management actions proposed to address these issues include the purchase of vehicles, a vessel, and equipment for conservation officers; implementing a reserve officer program to expand enforcement coverage; hiring of a natural resource prosecutor; implementing a multi-media education and outreach campaign; and funding studies that focus on assessing fish biomass increases and spillover effects.

This has been one of the more successful strategies for Guam. A number of the tasks have been accomplished: the conservation officers have purchased new vehicles and equipment to facilitate better enforcement; the GCRICC has continued education efforts at all levels, from elementary to the territorial legislature and administration; monitoring programs are underway in three preserves; and Guam's legislature recently passed Public Law 27-87 which requires a permit for certain non-fishing activities in the preserves. In addition, the GCRICC is in the process of hiring a natural resource prosecutor to be based in the Office of the Attorney General and DAWR is working on a citation system for marine preserve violators.

Guam has laws (5 GCA, Chapter 63) that regulate the taking of coral and identify penalties for damages inflicted on corals during fishing activities. Coral can only be taken with a permit issued by the Guam Department of Agriculture. The law has provisions for both personal and commercial take, but limits such permits to five days and requires that specific collecting locations be identified. However, no personal or commercial permits have been issued since 1982. The UOGML has been issued a collection permit for scientific research. This law also regulates fishing net mesh sizes used in coastal waters and the use of illegal chemicals and explosives for fishing. In addition, Guam's legislature also delegated the authority and responsibility of management and oversight for all aquatic and wildlife resources to the Guam Department of Agriculture. In 1997, Guam's Department of Agriculture's DAWR used its regulatory authority to amend and expand the existing fishing regulations. Title 16 of the law includes size and gear restrictions for aquatic fauna. Also contained in these regulations is the creation of marine preserves. The penalty for violating both the law and associated regulations is a petty misdemeanor, with a fine of up to $500. The DAWR is currently in the process of converting to a magistrate court system in which citations can be issued rather than requiring a court hearing to collect misdemeanor penalties.

Lack of Public Awareness

In 2003, as part of its Education and Outreach LAS, the GCRICC launched a multi-media coral reef awareness campaign featuring a clownfish character in an educational video and shown on incoming flights, movie theater slides, hotel room tent cards, coloring books, advertisements, and streetside banners (Figure 16.31). An island-wide contest seeking a name from children for the clownfish character was held in conjunction with Earth Week activities from April 17-24, 2004. The Environmental Education Committee selected the top 10 entries from over 600 entries. On April 24, at the Earth Week Island Pride Festival, the public selected 'Professor Kika Clearwater' as the character's name.

GCRICC members have also teamed up for the Island Pride Campaign. This program combines educational and environmental activities with fun events to teach children to love the island's resources and instill a sense of stewardship. Events have included the 2004 Earth Week festival, a trash collection and snorkel tour at Tumon Bay Marine Preserve, a trash collection and kid's fishing derby at the War in the Pacific National Park, and a tree-planting at Paseo combined with the Fishermen's Festival at the Guam Fishermen's Cooperative. The events have been a great success, attracting families from all over the island. The campaign has also strengthened ties among the GCRICC and GVB as well as the private sector which have helped sponsor these events.

Recreational Misuse and Overuse
The GCRICC decided that recreational misuse and overuse were serious threats to Guam's coral reefs. With jet ski users, recreational boaters, scuba divers and snorkelers all using the reef zone, the impacts can multiply. The Committee decided that it is important to address these issues before they cause severe damage to the reefs. While this strategy is still being developed through meetings with stakeholders, positive steps have already been taken to limit recreational impacts in the marine preserves. Public Law 27-87, which was passed in May 2004, creates a marine preserve eco-permitting system to be administered by DAWR, to address non-fishing activities in Guam's marine preserves. The DAWR is currently working with a large group of stakeholders to draft the rules and regulations for this new permitting system.

Figure 16.31. Guam's new multimedia Coral Reef Awareness Campaign includes billboards, print ads, public service announcements, tourism literature, and an upcoming video to be shown on all flights to Guam. Source: GEPA.

Other actions have worked to limit the impact of recreational watercraft. The impacts of jet skis have been addressed through the Recreational Water Use Master Plan, which currently limits these watercraft to three locations within reef areas: East Agana Bay, Apra Harbor, and Cocos Lagoon. A study to examine the impacts of jet skis is underway. In 1999, DAWR installed 35 shallow water mooring (SWM) buoys at popular sites on the western side of the island and in Apra Harbor. While the goal of these buoys was to avoid anchor damage from recreational boaters and fishers only seven of these buoys are still in the water due to storms, theft, and age. DAWR did not have the staff to replace these buoys, so they have teamed up with the Guam Marine Awareness Foundation (GMAF) to replace the missing buoys. DAWR will acquire the buoys and GMAF will use volunteer divers to install them.

GVB, in association with GCMP, is launching a new campaign to educate tourists about Tumon Bay's unique habitat and diverse assemblage of marine creatures. The project will include three educational kiosks placed in northern, central, and southern Tumon Bay and accompanied by underwater guides. The goal is to reduce the impacts of recreational activities by educating divers about the resources and how they can prevent damage. GVB has also assisted with the incorporation of changes for beach cleaning permits in the tourist areas of Tumon and East Agana Bays. These included: 1) requiring contractors to find ways to shake out as much sand and dead coral as possible from algae and place the sand and dead coral back onto the beach and 2) implementing an adopt-a-beach program, in which hotels manually rake the algae from the beach in front of their property. Unfortunately, not all of these changes have currently been implemented. However, GVB is again consulting with DAWR in developing a new request for proposals for beach cleaning and maintenance of Tumon and Agana Bays.

Climate Change and Coral Bleaching
This LAS has had the least development, as it is the most difficult to solve at the local level. Addressing the issue of climate change requires policy decisions at the national and international levels. Locally, current management efforts are focusing on addressing additional anthropogenic stresses on coral reefs such as overfishing and land-based sources of pollution through the development and implementation of the three-year LAS. Outreach and education efforts include the development of posters, pamphlets, public service announcements, and videos addressing the importance of coral reefs and ways to better protect them. One of the greatest challenges facing resource managers in Guam is the reality that, given current regulatory pro-

cesses, management decisions cannot happen in as timely a manner as that dictated by a bleaching event. At the 10th U.S. Coral Reef Task Force Meeting in CNMI and Guam, the steering committee was directed to consider the opportunities to include mass coral bleaching in natural disaster relief efforts. Task Force members endorsed a resolution to address emergency response for environmental impacts of natural disasters. Federal members of the Task Force were also directed to engage the states, territories, and commonwealths of the U.S. and the Freely Associated States, as appropriate, in developing partnership response plans for environmental impacts to coral reef ecosystems following natural disasters, and developing strategies to support implementation of the plans.

While natural disasters can not be managed, responses can be. A hazard mitigation plan is currently being developed for Guam. The intent of the plan is not only to reduce the damages caused by natural disasters to buildings and infrastructure, but also to protect the environment by limiting the effects of flooding on property and subsequent depositing of debris on Guam's coral reefs. Better protection of coral reefs and other natural resources from impacts of Guam's frequent natural disasters is also being sought through development of an environmental emergency response plan. This plan will provide appropriate steps for government agencies to take following a natural disaster, in terms of conducting both damage assessments and debris removal efforts.

OVERALL STATE/TERRITORIAL CONCLUSIONS AND RECOMMENDATIONS

The health of Guam's coral reefs vary significantly. Reefs unaffected by sediment and nutrient loading, such as those in the northern part of the island and in between river outflows in the south, have healthy coral communities. Guam's reefs have been spared from large-scale bleaching events and coral diseases which are prevalent in so many parts of the world. Unfortunately, a number of Guam's reefs are impacted by land-based sources of pollution and heavy fishing pressure. Sedimentation, algal overgrowth due to decreased fish stocks, and low recruitment rates of both corals and fish are important issues that must be addressed.

The GCRICC has made great strides in identifying ways to understand and address these issues, from funding watershed restoration efforts, to conducting innovative education and outreach efforts, expanding monitoring, and increasing support for the five marine preserves. Working groups have been created for each of the five LAS (land-based sources of pollution, fisheries management, outreach and education, recreational area misuse and overuse, and climate change and coral bleaching).

Although Guam has made a great deal of progress in the past two years in terms of coral reef protection, monitoring, and public outreach, many challenges still remain. Wildland arson is still a problem in many watersheds in Southern Guam. STPs in Toguan, West Agana, and Tanguisson discharge primary treated wastewater into coastal waters of 18 m or less. Leaks from aging infrastructure and an increase in impervious surfaces, especially near the coast, have exacerbated the problem of stormwater runoff. In response to the Pacific Water Quality Resolution passed by the U.S. Coral Reef Task Force at its 10th Meeting in CNMI and Guam in October 2003, the GCRICC asked the GEPA to compile a list of priority capital improvement projects that would have direct implications for improved water quality and subsequent coral reef ecosystem health. The estimated cost of the eight identified projects totals more than $90 million and includes such infrastructure improvements as closing the island's municipal dump and replacing it with a fully functioning landfill, renovating and expanding several STPs (including extending their ocean outfalls), and eliminating the discharge of stormwater into Tumon and Agana Bays.

Gaps in Guam's monitoring efforts have been identified and will begin to be addressed in the next few years. However, despite the presence of the UOG (in particular the Marine Laboratory and Water and Environmental Research Institute), Guam still suffers from a lack of capacity to fully implement all of the monitoring gaps. The lack of capacity is not entirely due to a lack of available staff. For example, Guam would benefit greatly from a more streamlined and stable Federal grant process for coral reef effort, in order to secure contractual monitoring assistance (i.e., three year block grants). Local resource agencies would also be better served in their partnerships with valuable Federal programs, such as NOAA's REA research cruises, by a faster turnaround time on data availability and analysis. In addition, although Federal sources of funding have been utilized to support enforcement efforts, local support for additional full-time conservation officers is still nonexistent. To rectify this, local resource agencies have recently spent a great deal of time escorting local policymakers and members of the private sector on snorkel tours of the marine preserves in order to show them the island-wide value of the reef resources. A new economic valuation study commencing in fiscal year 2005 will also provide an effective means to garner support for coral reef protection. With successes like the recently launched Island Pride Campaign, there is certainly reason to hope for an increased awareness of the value of coral reefs to the people of Guam.

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The State of Coral Reef Ecosystems of Palau

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INTRODUCTION AND SETTING

The Republic of Palau, part of the Caroline Islands group, is the westernmost archipelago in Oceania located 741 km east of Mindanao in the southern Philippines and about 1,300 km southwest of Guam. Palau is composed of 12 inhabited islands and 700+ islets, stretching 700 km from Ngeruangel Atoll in the Kayangel Islands in the north to Helen Reef in the south (Figure 17.1). The archipelago consists of a clustered island group (including Babeldaob, Koror, Peleiu, Angaur, Kayangel, Ngeruangel, and the Rock Islands; Figure 17.2) and six isolated islands (Helen Reef, Tobi, Merir, Pulo Anna, Sonsorol, and Fana) that lie approximately 339 to 599 km to the southwest. Babeldaob, the second largest island in Micronesia after Guam, is the biggest island in the Palauan chain; however, the country's capital and greatest population is located on Koror. The volcanic island of Babeldaob and its reefs are separated from Koror and the southern islands of the group by a deep (30-40 m), east-west pass called Toachel El Mid.

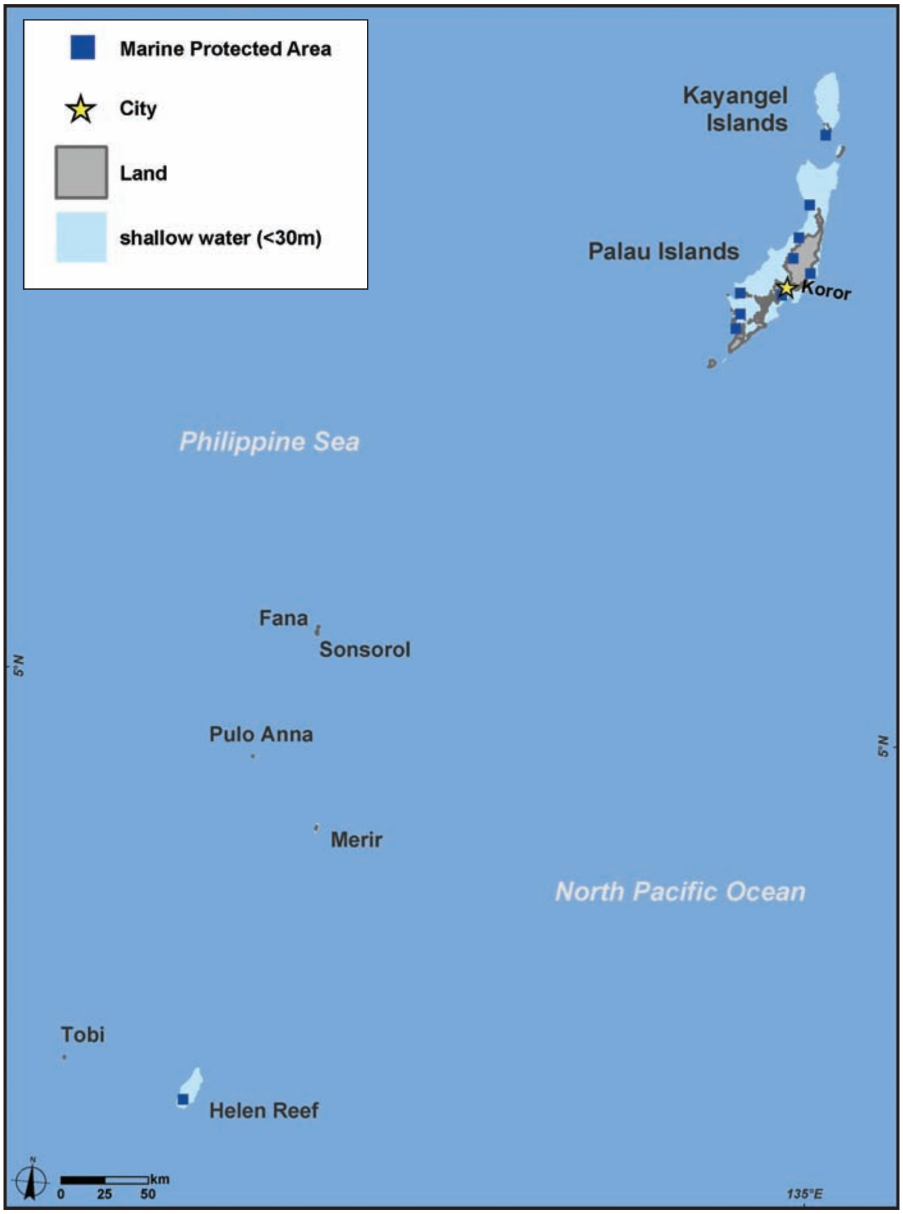

Figure 17.1. The nation of Palau is an archipelago in the Caroline Islands. Most Palauans reside in the cluster of northern islands (see Figure 17.2 for detail of main island group). Map: A. Shapiro.

Palau has numerous island and reef types, including volcanic islands, atolls, raised limestone islands, and low coral islands. A barrier reef surrounds much of the main island cluster, from the northern tip of Babeldaob down to the southern lagoon, merging into the fringing reef with Peleliu in the south. The barrier reef is well-developed on the west and less developed and discontinuous on the east. For example, Babeldaob has a barrier reef in the southeast, a submerged barrier reef (5-10 m below sea level) on the central east coast and no barrier reef in the northeast. The southern lagoon has a much more extensive barrier reef, lacking passages on the west side, while the southeast side has numerous gaps and passes that extend into the lagoon.

Palau has the most diverse coral fauna of Micronesia and the highest density of tropical marine habitats of comparable geographic areas around the world. In addition to coral reefs, mangroves, and seagrass beds, Palau has deep algal beds, mud basins, current swept lagoon bottoms, rich tidal channels, and anoxic basins within the rock islands. Many of these environments contain corals. Additionally, there are more than 70 marine lakes on Palau, many of

1 Palau International Coral Reef Center, Koror, Palau
2 Office of Environmental Response and Coordination, Koror, Palau

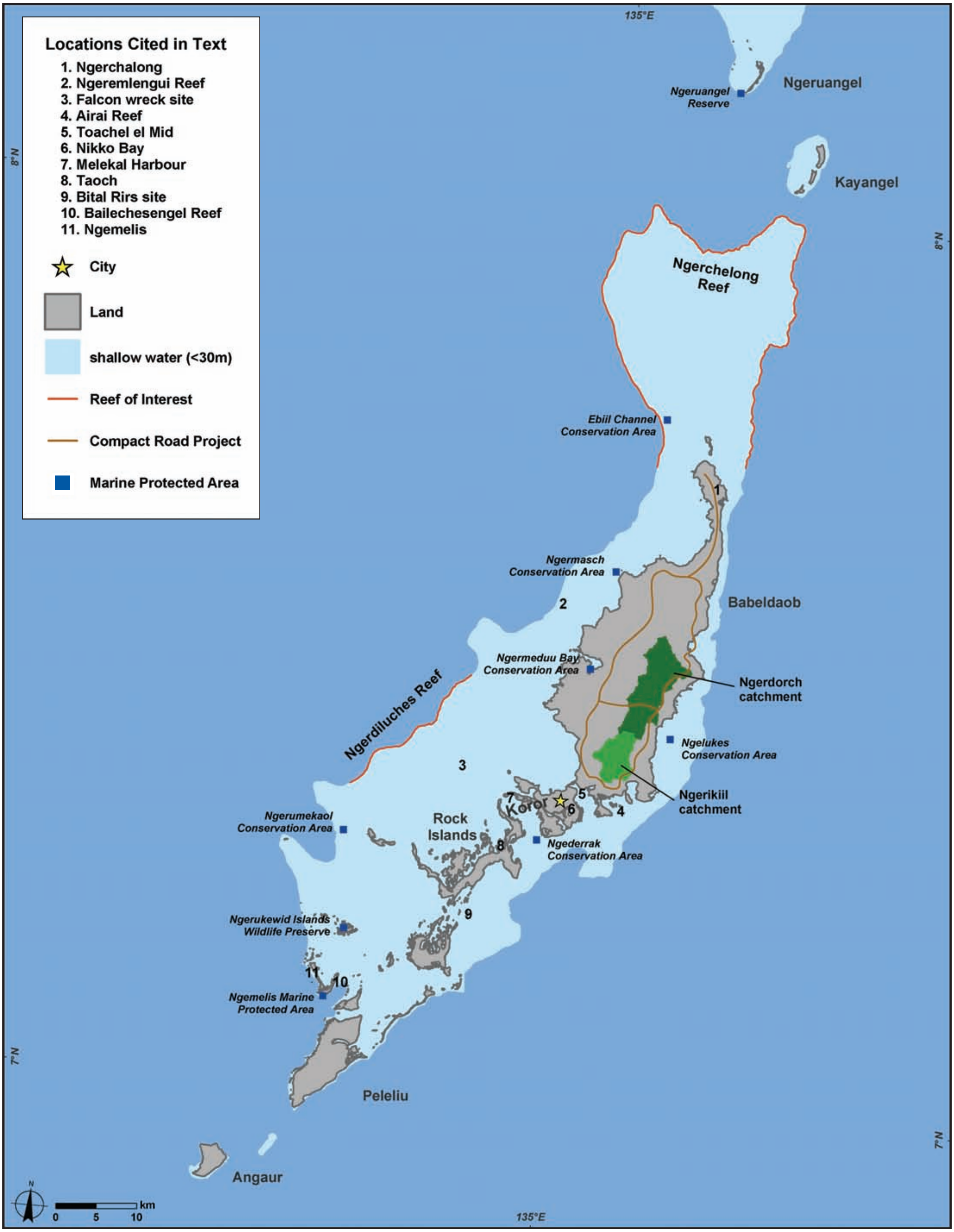

Figure 17.2. A detailed map of Palau's main island cluster, showing the locations referenced in this chapter. Map: A. Shapiro.

which contain scleractinian corals and associated fauna and flora. This high concentration of marine lakes on Palau is unique in the world, and as such, represents a biological treasure which rivals that of the remaining marine environments of Palau.

While no corals are endemic to Palau, the archipelago's coral diversity is comparable to the highest coral diversity areas of the Philippines, Indonesia and Australia. Maragos et al. (1994) estimated Palau's coral diversity at 425 species belonging to 78 genera. Randall (1995) reported a lower number of coral species for Palau at 385 species belonging to 66 genera. The higher estimation by Maragos et al. included observations and a species list, while Randall's lower estimation was based on collections and specimens. Randall noted that greater collecting efforts in Palau are expected to reveal more species since only a relatively small percentage of coral habitats were surveyed.

In addition to corals, fish and other invertebrate groups are highly diverse in Palau. More than 300 species of sponges were documented in Palau (Kelly-Borges and Valentine, 1995), although the total fauna may be as high as 500 if small and burrowing species are included. About 200 species of Cnidarians, other than Scleractinia, are known to exist on Palau, with many smaller species remaining to be documented. The molluscan fauna is not entirely known, but at least 185 species of Opisthobranchs are present on Palau (T. Gosliner, unpublished). Echinoderms are not well documented, but there are at least 21 species of crinoid fauna (Meyer and Macurda, 1980). The ascidian fauna is well over 100 species (P. Colin, pers. comm.). Within Micronesia, Palau has the highest diversity of reef fish with a total of 1,278 known species. Data gaps suggest that reef fish in Palau may number closer to 1,449 species (Myers, 1999).

Endemism is low among Palauan marine organisms. However, true levels of endemism are difficult to estimate because many groups are not well documented. The nautilus, *Nautilus belauensis*, is endemic to Palau and has been the subject of numerous biological studies.

ENVIRONMENTAL AND ANTHROPOGENIC STRESSORS

Climate Change and Coral Bleaching

During the 1997-1998 El Niño event, Palau experienced massive coral bleaching and mortality. Six years after the event, the reefs in Palau have still not fully recovered. The 1997-1998 bleaching event in Palau was widespread and variable among different sites (Bruno et al., 2001). Approximately one-third of Palau's corals died, with coral mortality as high as 90% in some areas. It devastated Acroporid corals, which suffered the highest mortality compared to other coral species. Corals that were found in estuaries closer to shore survived better than corals farther from shore (Golbuu, 2000). Impacts of the elevated water temperature were seen in other habitats such as the famous “Jellyfish Lake,” which experienced a complete mortality of the medusa stage of *Mastigias* spp. Presently, coral bleaching is considered one of the greatest threats to Palau's coral reef ecosystems.

Since 1997-1998, Palau has not had a major bleaching event. Localized episodes of coral bleaching have occurred periodically at various sites in Palau, but none as severe or widespread as the 1997-1998 event. The localized bleaching events are probably due to disease or other localized stress at the microhabitat level.

Diseases

In the past few decades, worldwide increases in coral diseases have become one of the major threats challenging the resilience of coral reef communities (Harvell et al., 1999; Willis et al., 2004). Coral disease impacts have increased on reefs worldwide and are emerging as one of the major causes of coral reef deterioration in the Caribbean. Although the Indo-Pacific encompasses more than 80% of the world's coral reefs, very little is known about the ecology and pathology of coral disease in this region (Bryant et al., 1998).

The first assessment of coral disease prevalence on Palau's reefs was conducted in January 2004 as part of the Targeted Coral Reef Research Project by the World Bank/Global Environment Facility . The purpose of these surveys was to identify and establish baseline information for coral disease at sites representative of the major habitat and community types. Results from this initial study indicate that the mean prevalence of coral disease was relatively low, affecting between 1% and 5.28% of colonies at six sites representative of protected, moderately exposed, and exposed communities on Palauan reefs. A total of twelve diseases and syndromes were recorded across thirteen reefs surveyed during preliminary site-selection visits or disease prevalence surveys (Table 17.1). Eight of these syndromes have been previously observed on Indo-Pacific reefs, in particular on the Great Barrier Reef (Willis et al., 2004). However, four syndromes have not been previously recorded: bleached patches, bleached spots, bleached stripe, and yellow spot. At each of the six survey sites, approximately five to nine diseases or syndromes were observed, with the greatest number being recorded at Malakal Harbour (B. Willis, pers. comm.). A more quantitative assessment of coral disease prevalence within Palau requires further research.

Table 17.1. Diseases and syndromes recorded near six transects in Palau in January 2004. Source: B. Willis, unpublished data.

	NIKKO BAY SPAWNING	NIKKO BAY XXIX	MALAKAL HARBOUR SPAWNING	BITAL RIRS	WESTERN BARRIER NGATBANG	WESTERN BARRIER NGEREMLENGUI
Disease States Recorded on Transects						
Black Band Disease						
Brown Band Disease			x	x		
Skeletal Eroding Band	x	x	x	x	x	x
Other Cyanobacterial Infections	x	x	x	x	x	x
Bleached Spots	x	x	x	x	x	x
Bleached Patches	x	x	x	x	x	x
Bleached Stripe	x					
White Syndrome	x	x	x	x		
Patchy Necrosis	x	x				x
Yellow Spot					x	
Tumors			x	x	x	
Disease States Recorded off Transects						
Black Band Disease			x			
Other Cyanobacterial infections	x (red)					
Yellow Spot			x	x		

Prevalence of Coral Disease

Mean prevalence of disease varied considerably across the six sites surveyed, ranging between 1.16 ± 0.62% of coral colonies at the Western Barrier Ngeremlengui site and 5.28 ± 0.97% of colonies at the Malakal Harbour Spawning site (Figure 17.3). Mean prevalence of bleached colonies was much lower at the Nikko Bay Spawning site and the Bital Rirs site, varying between 0.9 ± 0.09% of coral colonies to 1.24 ± 0.47% of colonies, respectively (B. Willis, pers. comm.).

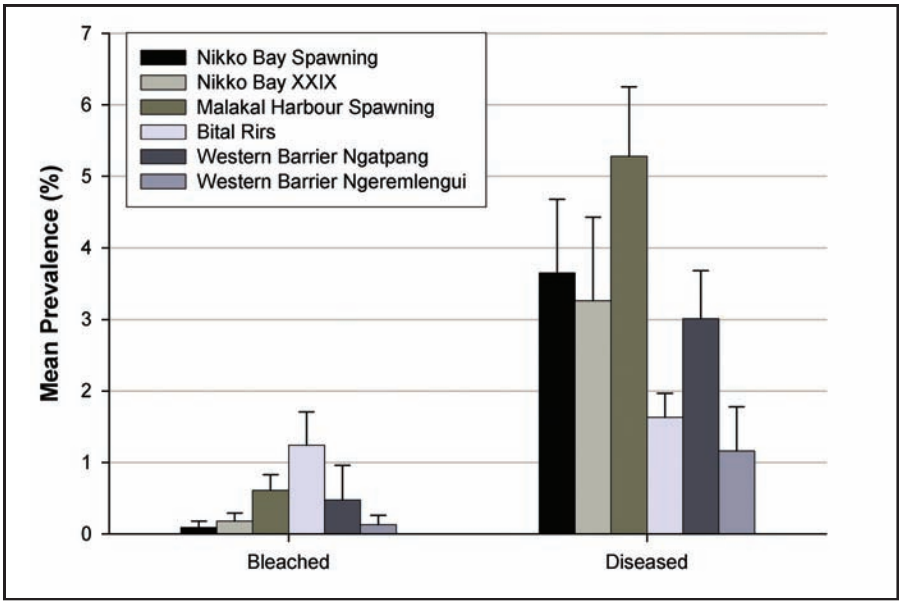

Figure 17.3. Mean prevalence of bleached and diseased coral colonies at six sites surveyed in January 2004. Source: B. Willis, unpublished data.

Tropical Storms

Typhoons, tropical storms, and large waves can affect coral cover. Large waves generated by storms can cause breakage and physical damage. Storm waves can also have beneficial effects on reefs by removing sediments and algae on the reef, thereby making space available for coral recruitment. Palau is outside the typhoon belt and is therefore less likely to experience typhoons compared to other places in Micronesia (Figure 17.4). Areas in Palau that are commonly subjected to high wave energy generally do not have high coral cover and diversity, but the corals that do inhabit these large wave areas are well-adapted to their environment. Encrusting *Montipora*, *Porites*, digitate *Acropora* and massive corals typically dominate the coral fauna in areas exposed to high wave energy.

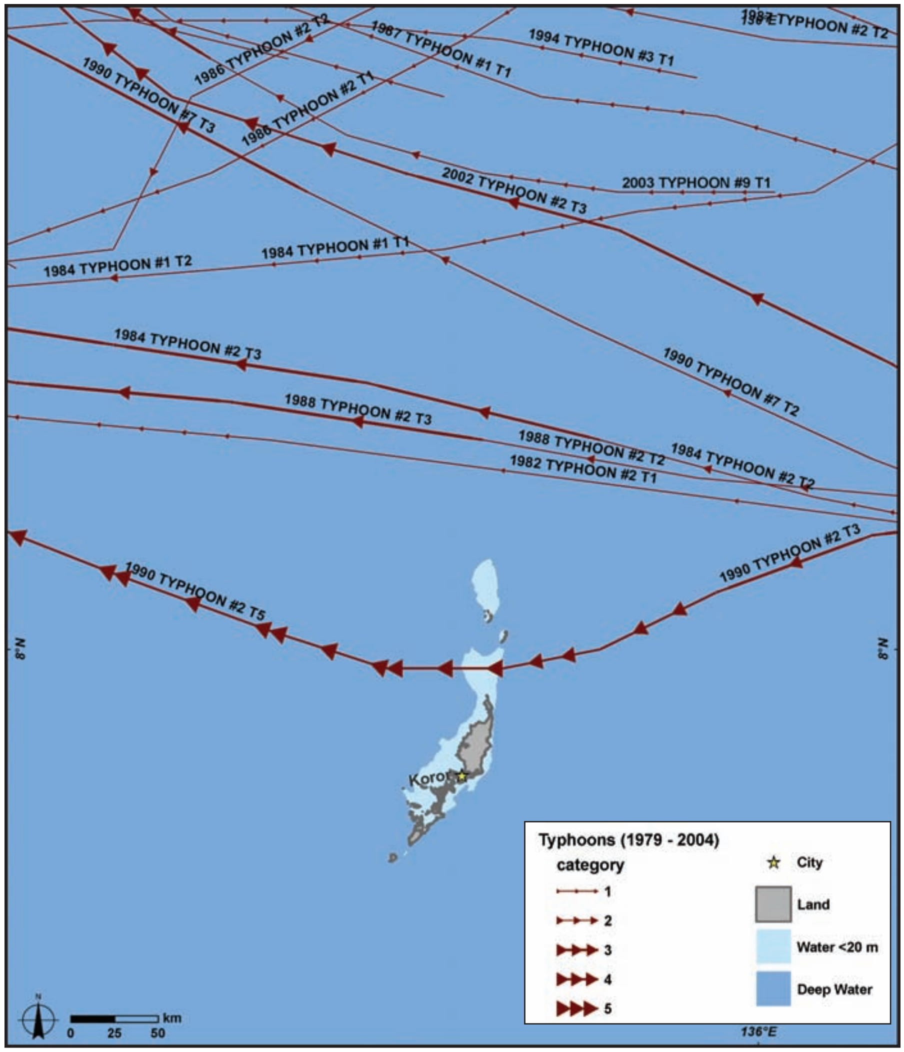

Figure 17.4. The paths and intensities of typhoons passing near Palau from 1979-2004. Many Pacific typhoons are not named or the names are not recorded in the typhoon database. Map: A Shapiro. Data: UNISYS, http://weather.unisys.com/hurricane.

Coastal Development and Runoff

Increased sedimentation is another major threat to coral reef ecosystems worldwide (McCook et al., 2001; Wolanski and Spagnol, 2000; Wolanski et al., 2003), and Palau is no exception. Sedimentation associated with runoff from coastal development poses a serious threat to reefs around Babeldaob, the largest island in the Palau Archipelago.

A study in the Ngerikiil watershed (Figure 17.2) showed an alarming rate of sedimentation (exceeding 1500 mg/L during flood events) which is likely the result of development activities such as road construction and agriculture (Golbuu et al., 2003b). Current sediment monitoring activity in the Ngerdorch watershed shows a direct link between the level of water clarity and runoff from the Compact Road Project (S. Victor, pers. obs.). By comparing the level of activity in the two watersheds (Ngerikiil and Ngerdorch), it is possible to observe a direct correlation between the level of human activity in the area and the observed rate of sedimentation. The Ngerikiil watershed area has experienced an increase in development activity and has a sedimentation rate that is 10 to 19 times higher than Ngerdorch watershed, which is relatively pristine (Victor et al., 2004). These studies also showed that the mangrove systems fringing the estuaries in each watershed can only trap about 30% of the sediment. Increased sedimentation can smother seagrass and coral habitats, causing mortality in some cases (Figure 17.5). Furthermore, sedimentation has the potential to affect coral recovery in Palau by blocking recruitment of coral larvae.

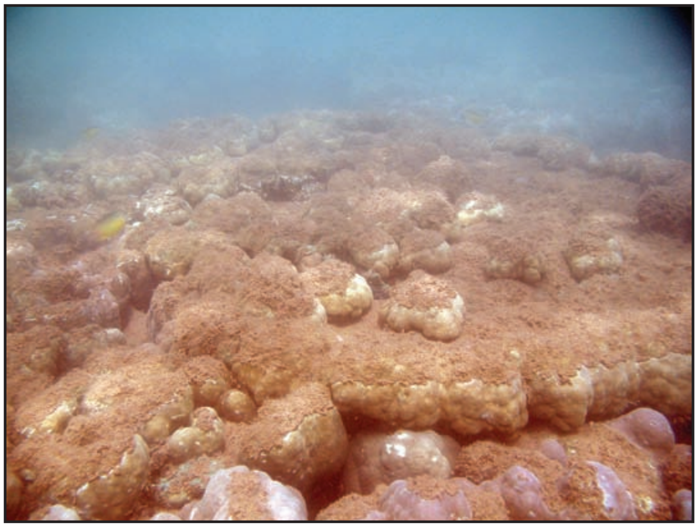

Figure 17.5. Seagrass (left) and corals (right) that are being smothered by sediment. Photos: S. Victor.

Coastal Pollution

The population in Palau is small and pollution is relatively low; however, the potential for increased pollution exists as population and development rises in Palau. Sewage can become a source of pollution to the marine environment if proper waste treatment plants are not in place to handle the increase in population and visitation. In Koror, Palau's hub of population and commerce, raw sewage has been observed on the reefs when sewer substations are not able to handle their loads. A new sewage treatment plant is being constructed in Koror to accommodate the increase in population and tourists. Babeldaob, however, has no sewage treatment plants and many of the households use septic tanks. There is a great need for a sewerage treatment plant in Babeldaob to accommodate the expected rise in development that will occur when the capitol is relocated to this island.

Other potential sources of pollution to the marine environment in Palau are animal wastes, pesticides, herbicides, oil spills, and other chemicals. Many of these potential sources are minimal but if left unchecked, they can potentially become major threats to the fragile marine environment in Palau.

Tourism and Recreation

Palau has limited income generation potential. The government provides strong support for tourism development in hopes that it will generate income and provide a stimulus for other economic activities in Palau. In 1996, Palau derived $67 million or 47% of the Gross Domestic Product (GDP) from its tourism industry. From 1992 to 1997 tourist arrivals doubled from nearly 30,000 to 60,000. However, in 1998 Palau experienced a 3.3% decrease in GDP, which may be attributed to the decline in Palau's coral reef health due to the 1997-1998 coral bleaching event. The numbers of visitors to Palau between 1995 and 2001 are given in Figure 17.6. With the efforts and emphasis placed on tourism development, there is a growing concern that Palau does not have the proper infrastructure to support increased tourism.

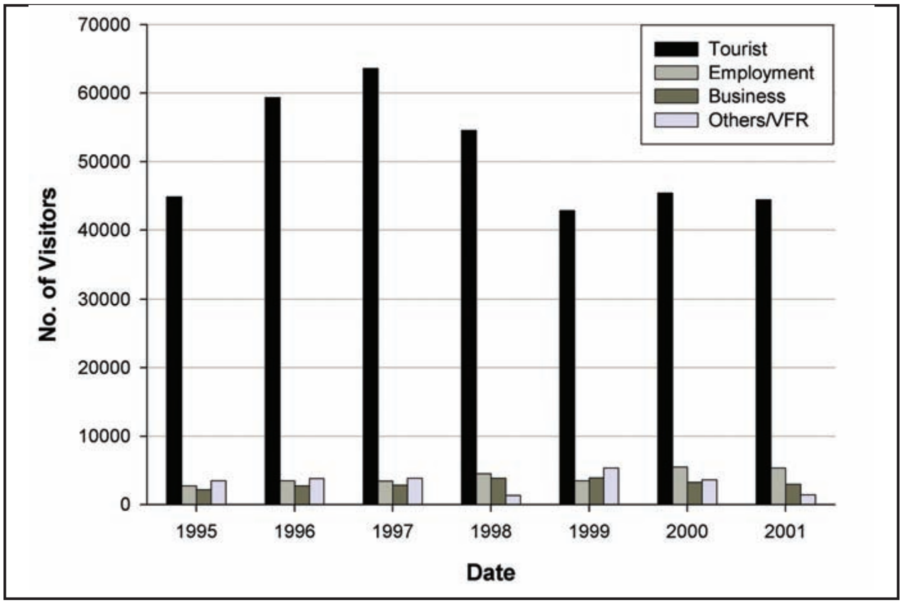

Figure 17.6. Numbers of visitors to Palau from 1995-2001. VFR is 'Visiting Friends or Relatives.' Source: Palau Visitors Authority.

Fishing

Fishing is a popular activity in Palau. In 2001, 835 people (16% of Palau's population) sold their catch to local fish markets at least once during the year (Republic of Palau, Marine Resources Database, 2004). A 2003 survey of subsistence fisheries indicated that 87% of households have someone that fishes either for subsistence or commercial purposes, and often both. Only 13% of Palauan households were not involved in any type of fishing (Palau International Coral Reef Center, unpublished data).

The total annual inshore fisheries production for Palau averaged 1,800 metric tons (mt) over the past 20 years (TEI, 1999). Approximately 360 mt of this total is sold at the local markets, 250 mt is exported, and 1,200 mt is used for direct consumption. Commercial landings data exhibit no significant trend in the amount of catch from 1998 to 2001 (A. Kitalong, pers. comm.). Field surveys (Maragos et al., 1994), fish aggregation studies (Johannes et al., 1999), and observations by fishers all indicate a decline in fish populations (TEI, 1999). In 2002, 31% of fishers and prominent community members perceived that the inshore fisheries were being harvested at unsustainable levels and communities perceived their catch to be at least three times smaller than a decade ago (A. Kitalong, pers. comm.).

Trade in Coral and Live Reef Species

The trade in marine ornamental fish has been rapidly growing worldwide over the past several years. The growing popularity of home aquaria that mimic coral reef ecosystems has made the live fish and marine invertebrate trade a profitable venture in many tropical islands. Many are concerned that this industry can cause reef degradation by targeting important juvenile food fish or species that are ecologically important. The 1994 Palau Marine Act regulates ornamental fisheries through restrictions on the collection of marine resources for aquaria and research, including a prohibition on the export of hard corals, live rock, sponges, and tridacnid clams.

The first ornamental trade company started operation in 1990, changed management in 1994, and went out of business in 1996 due to an unstable market and strict regulation by the Palau Government (Graham, 2001). Prior to 1994, the company traded finfish, tridacnid clams, starfish, rare shrimp, sea slugs, sea urchins, hermit crab with anemone, hard and soft corals, and live rocks. For two years, there was no business in the trade of marine ornamentals until 1998 when Belau Aquaculture was launched. The company originally specialized in the trade of marine invertebrates. In 1999, the company changed management and started trading finfishes as well. In 2000, the company exported 58,000 finfish and 12,000 invertebrates. The top selling finfishes are species of damselfish (Pomacentridae) and the top selling invertebrate is the blue starfish (*Linckia laevigata*; Graham, 2001). Belau Aquaculture is still in operation today, although there are no available statistics on their current export of finfish and invertebrates.

Ships, Boats, and Groundings

In the last several years, there have been several ship groundings on the reefs surrounding Palau. Many of these ship groundings occur on the western barrier reefs and in the southern lagoons. In 2001, the container ship *Falcon* ran aground on the western barrier reef and caused extensive damage to the reef. In 2002, the live-aboard dive vessel *Big Blue Explorer* ran aground and damaged the Bailechesengel Reef, a fringing reef in the Ngemelis complex that is a world renowned dive site (Golbuu et al., 2002). No restoration effort has been undertaken to reclaim these damaged reefs.

Boating is a major recreational activity in the Republic of Palau. Many tourism activities in Palau, including diving, snorkeling, and tours of the Rock Islands, require boat travel. At-sea fishing is a popular activity by locals. The Koror State Government has installed mooring buoys at many dive sites in order to reduce anchor damage to reefs.

The potential effects of motorboat fuel on marine animals have not been studied in Palau. Studies elsewhere have shown that gametes and larvae of many marine animals are susceptible to low levels of pollutants, such as copper, oil, and tributyltin (Heyward, 1988; Negri and Heyward, 2000; Reichelt-Brushett and Harrison, 1999). Many local fishers have complained that increased boating activities around seagrass and mangrove areas may have contributed to the low number of sea urchins (*Tripneustus* spp.) and fish in those areas.

Marine Debris

The impact of marine debris on reefs in Palau has not been documented or studied. The Koror State Government has a regular cleanup program around the Rock Islands to collect marine debris. Currents bring debris originating outside of Palau to the atolls of Ngeruangel and Helen Reef, but these areas do not have a regularly scheduled cleanup. The impact of marine debris on nesting bird and turtle populations in these areas is not known.

Aquatic Invasive Species

Introduction of non-indigenous species is one of the most pervasive and irreversible impacts of human activity on natural ecosystems. In the marine environment, invasive species have been rated as one of the four greatest threats to the world's oceans. Marine ecosystems are particularly vulnerable to alien species invasions. Organisms can spread rapidly in marine environments and are difficult to detect. In addition, control and eradication options used in terrestrial ecosystems often cannot be used in marine environments.

Several marine invasive species have been identified in Palau (Table 17.2; P. Colin, pers. comm.). At present, it appears that none of these invasive species are having a quantifiable effect on fisheries or the marine tourism industry, but marine invasive species do have the potential to become a serious problem in Palau. Relatively little baseline information exists for the groups of marine invertebrates that are invasive species in Palau. Most marine invasive species in Palau belong to a small group of marine invertebrates likely introduced as fouling on ship's hulls or from ballast water pumped out in harbors. The major groups of marine invasive species in Palau are the ascidians or tunicates (Phylum Chordata, Subphylum Urochordata), hydroids and other cnidarians (Phylum Cnidaria), molluscs (Phylum Mollusca), sponges (Phylum Porifera), bryozoans (Phylum Ectoprocta), and other small groups (P. Colin, pers. comm.).

Presently only one marine invasive species, the hydroid, *Eudendrium cameum*, has the potential for becoming a "pest" organism in Palau. This hydroid is a rapid growing species and has been found growing in at least three channels of Palau. *E. carneum* prefers rocky bottom substrates with particularly high currents, and often forms a tangle of branches that tends to accumulate sediment, making it a fairly unattractive "weed." The masses of *E. carneum* tend to make rocky surfaces on the reef less visible, and make the reef look "dirty." As with any marine invasive species, *E. carneum* has the potential to

Table 17.2. Marine species introduced in Palau. Source: P. Colin, pers. comm.

PHYLUM	CLASS	SPECIES
Cnidaria	**Hydrozoa**	*Eudendrium carneum*
		Thyroscyphus fruticosus
Chordata (Subphylum Urochordata)	**Ascidiacea**	*Didemnum perlucidum*
		Diplosoma listerianum
		Lissoclinum fragile
		Ascidia aperta
		Ascidia archaia
		Botryllus tyreus
		Ecteinascidia diaphanis
		Eusynstyela hartmeyeri
		Herdmania insolita
		Herdmania momus
		Microcosmus helleri
		Microcosmus pupa
		Perophora mutliclathrata
		Phallusia philippinensis
		Polyclinum nudum
		Pyura curvigona
		Pyura honu
		Pyura vittata

spread throughout the marine environments (e.g., rocky bottoms) of Palau. *E. carneum* could potentially interfere with the feeding of grazers, such as parrotfishes and surgeonfishes, which scrape algae from rock surfaces. At present, the current knowledge on the status and distribution of *E. carneum* in Palau is unknown.

Security Training Activities

Security training activities do not occur in Palau.

Offshore Oil and Gas Exploration

Offshore oil and gas exploration activities do not occur in Palau.

CORAL REEF ECOSYSTEM—DATA GATHERING ACTIVITIES AND RESOURCE CONDITION

Various data gathering efforts have contributed to the general understanding of coral reef ecosystems in Palau. Table 17.3 provides a tabular summary of the monitoring and assessment activities that have been undertaken in recent years.

Table 17.3. Monitoring and assessment activities occurring in Palau.

AGENCY	PLANNING/ MANAGEMENT	RESEARCH	MONITORING	EDUCATION/ OUTREACH	TRAINING	ENFORCEMENT
Bureau of Natural Resources and Development	X	X	exports and fish markets			
Coral Reef Research Foundation		X	temperature, marine lakes			
Environmental Quality Protection Board			water quality	X		X
Koror State Department of Conservation and Law Enforcement	X	X	marine lakes, rock islands	X	X	X
Palau Conservation Society			MPAs	X		
Palau International Coral Reef Center		X	fish, coral, MPAs, watersheds	X	X	
The Nature Conservancy	X	X			X	

WATER QUALITY

Methods

The Environmental Quality Protection Board of Palau (EQPB) conducts monthly water quality monitoring of marine waters around most of Palau. Turbidity, pH, salinity, dissolved oxygen, fecal coliform, and temperature are collected monthly at 32 permanent sites (Table 17.4). Sampling sites were selected because they are either a popular recreational site or in close proximity to a drinking water station. Results from the monitoring program are added to a database that dates back to the early 1980s.

Table 17.4. Water quality parameters measured by the EQPB of Palau.

PARAMETER	UNITS	COLLECTION METHOD
Fecal Coliform	bacteria/100 ml	Obtain near surface water sample for laboratory analysis
Turbidity	NTU	*In situ* hydrolab multi parameter meter: near surface
pH	scale of 1-14	*In situ* hydrolab multi parameter meter: near surface
Temperature	°C	*In situ* hydrolab multi parameter meter: near surface
Dissolved Oxygen	mg/L	*In situ* hydrolab multi parameter meter: near surface
Salinity	parts per thousand (ppt)	*In situ* hydrolab multi parameter meter: near surface

Results and Discussion

EQPB issues an 'unsafe for swimming' warning for when the fecal coliform count at a site exceeds 20 bacteria per 100 mL. Most of the sites sampled had fecal coliform counts less than this threshold (Figure 17.7). However, in April, May, and August of 2002, at least one-quarter of the monitoring sites had fecal coliform counts over 20 bacteria per 100 mL.

In 2002, the average turbidity was below 4 Nephelometric Turbidity Units (NTU), except in April and September when it exceeded 5 NTU (Figure 17.8). The increase in turbidity in April and September could be the result of increased land earth moving activities or more rain during those months.

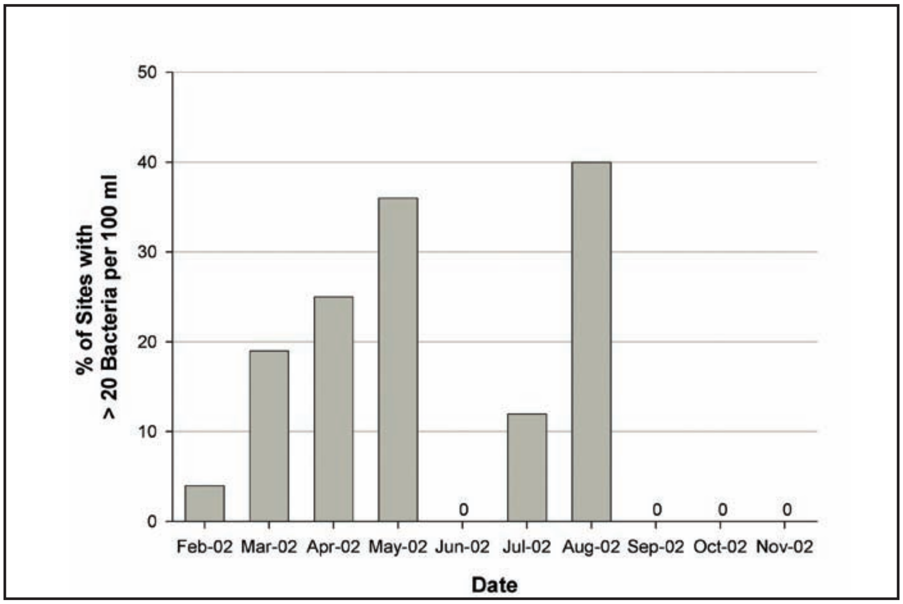

Figure 17.7. Fecal coliform sampling in 2002 at 32 sites around Palau. Source EQPB.

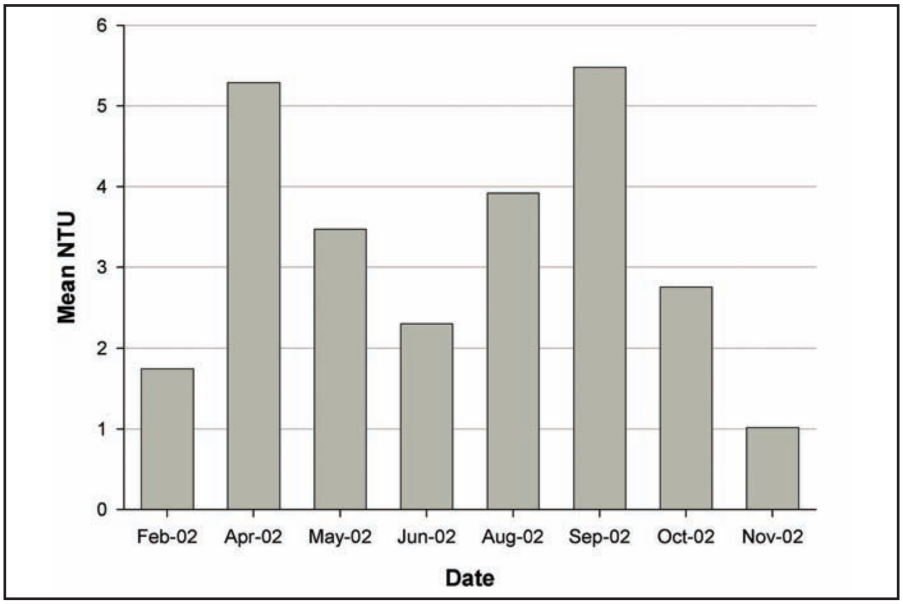

Figure 17.8. Mean turbidity in 2002 at 32 permanent sites around Palau. No samples were collected in March or July 2002. Source: EQPB.

BENTHIC HABITATS

Methods

The Palau International Coral Reef Center (PICRC) launched a nationwide coral reef monitoring program for Palau in 2001. The objectives of the program are to: (1) establish permanent monitoring sites; (2) determine status of Palau's reefs; (3) assess changes to the benthic and fish communities at each site over time; and (4) examine the recovery process from the 1997-1998 bleaching event at each site. The program consists of a rapid assessment of reef habitats using the spot check method and a detailed monitoring survey of benthic organisms, fish size and abundance, and coral recruitment.

The spot check method is a rapid qualitative assessment of bottom substrates, coral cover, and dominant life forms. In 2001-2002, 217 spot checks were performed in Palau (Figure 17.9). Spot check surveys were conducted by making qualitative observations during a 15-minute snorkel survey at each site. Two to three representative pictures of the site were also taken during the survey. Estimated coral cover was classified as *Acropora* or "other" and grouped into one of four density categories: 0-5%, 6-25%, 26-50%, and >50%. Spot check sites were chosen haphazardly along the reef front every few kilometers. While the spot check method provides a good qualitative overview of the condition of Palau's reef, it cannot be used for quantitative analysis.

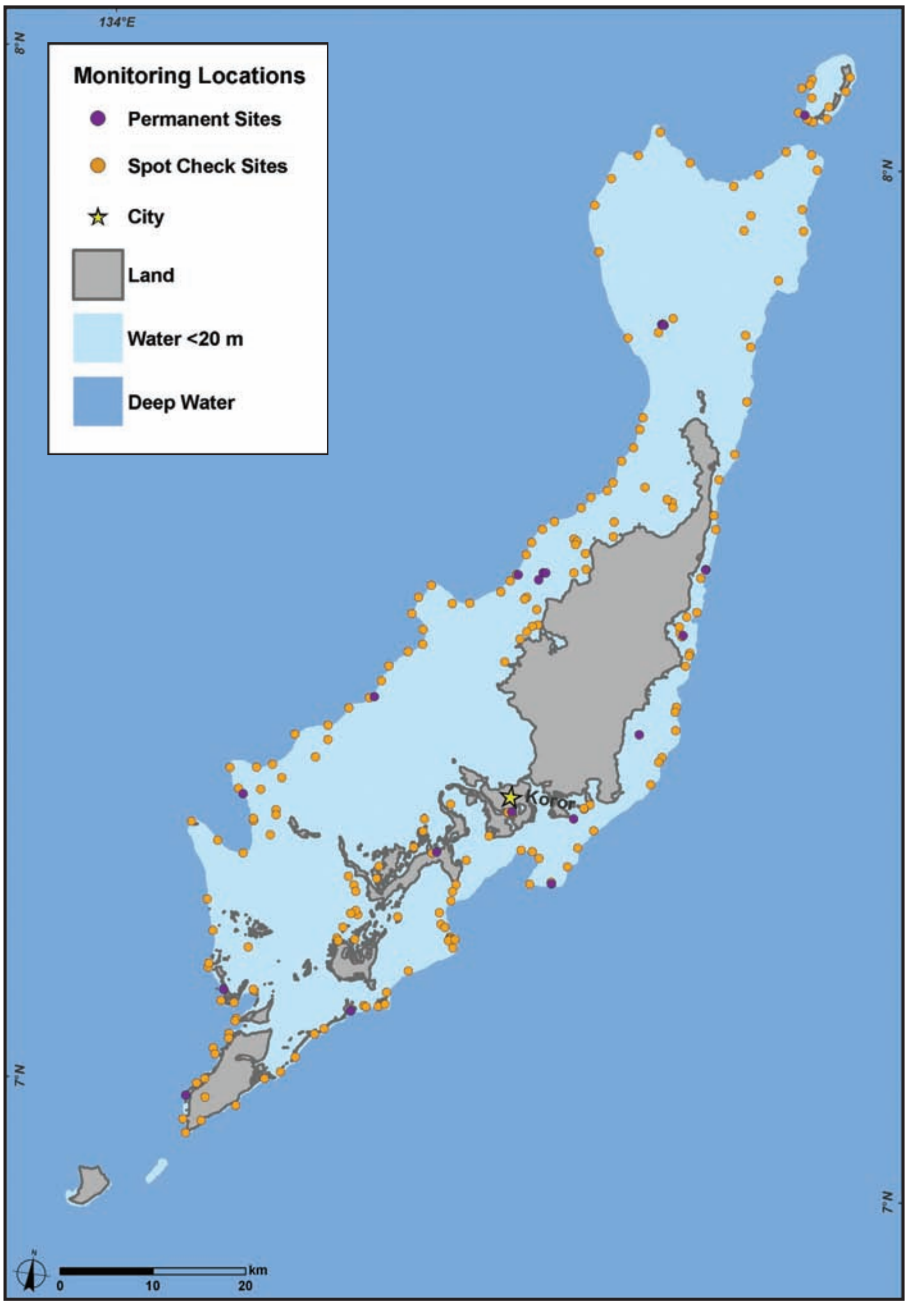

Figure 17.9. Locations of spot checks (orange dots) and permanent monitoring sites (purple dots). Map: A. Shapiro.

In addition to the spot checks, a quantitative assessment examining temporal and spatial changes was conducted at 14 permanent monitoring sites around Palau (Figure 17.9). The monitoring sites utilized in these detailed surveys were representative of Palau's geomorphologic reef types and localities, ranging from sheltered fringing reefs to oceanic atolls. The potential level of human impacts on the health of coral reefs was also taken into account in the selection of sites. Currently the permanent sites are stratified and replicated within habitats, sites, depths and transects. Four sites were surveyed on the western barrier reefs and Rock Island fringing reefs, two sites on the east coast fringing reefs and patch reefs, and one site at the atoll and east coast barrier reefs, for a total of 14 permanent monitoring sites around Palau.

Detailed surveys of benthic communities were conducted using video transects. At each site, five replicate benthic cover surveys were conducted at 3 m and 10 m depths along a 50 m transect. The observer swam approximately 70 cm above the transect line at a constant speed and videotaped the transect for approximately five minutes. Recruitment surveys were conducted using a belt transect (0.30 m wide x 10 m long) along the same transects. Any coral that was smaller than 5 cm in diameter was considered a recruit and its size was recorded. A minimum of three transects were completed for the recruitment surveys; additional transects were surveyed at sites with few recruits.

Results and Discussion

Spot check results shows that 87% of the sites surveyed had low *Acropora* cover in the range of 0-5% (Figure 17.10). 68% of the sites surveyed had coral other than *Acropora* covering less than 25%. Overall, percent coral cover was generally low to moderate; only 1% of spot check sites had *Acropora* cover greater than 50% and only 9% of the sites had non-*Acropora* coral cover greater than 50%.

The quantitative surveys at the permanent monitoring sites show that coral cover was highest along the 3 m depth belt transect at Nikko Bay, a fringing reef site within the Rock Islands (Figure 17.11). Nikko Bay and Ngemelis western barrier reef exhibited the highest coral cover at the 10 m depth. Airai fringing reef on the east coast of Palau and Ngaremlengui patch reef on the west coast had the lowest coral cover at both 3 m and 10 m depths (Figure 17.11). Both Airai and Ngaremlengui are dominated by sandy bottom substrates and experience high levels of sediment resuspension during windy conditions.

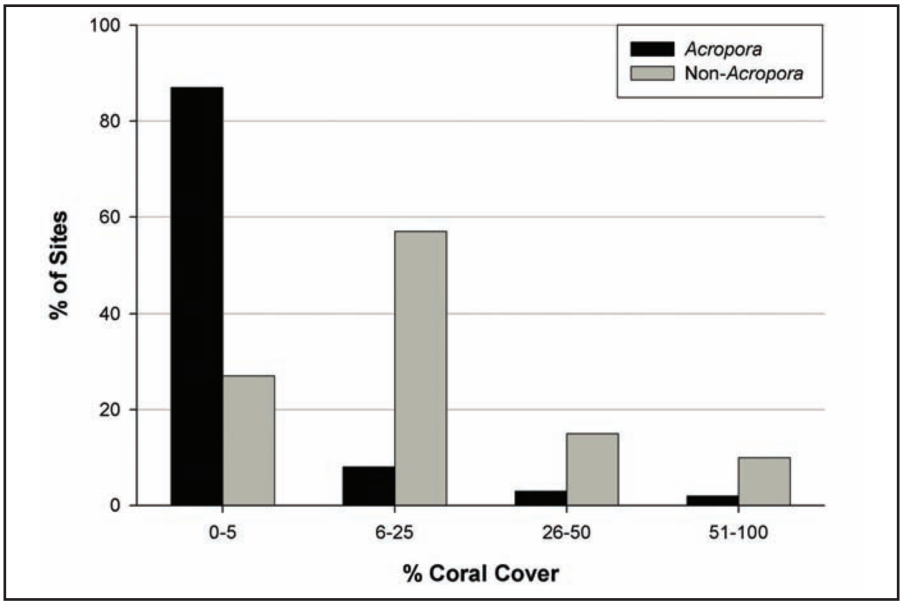

Figure 17.10. Coral cover of reefs at 217 sites around Palau that were surveyed by spot checks. Source: Golbuu et al., 2003a.

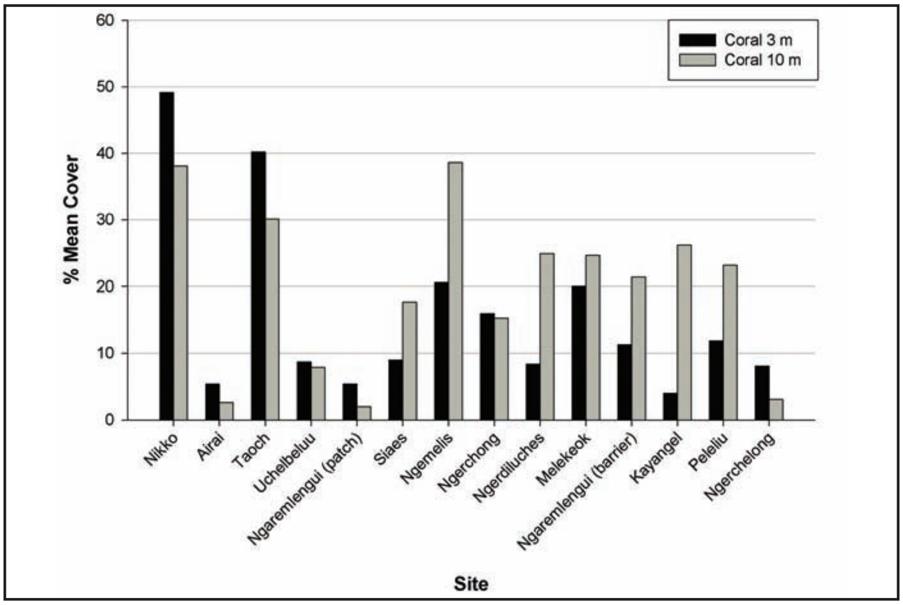

Figure 17.11. Coral cover at established permanent monitoring sites at 3 m and 10 m depths. Source: Golbuu et al., 2003a.

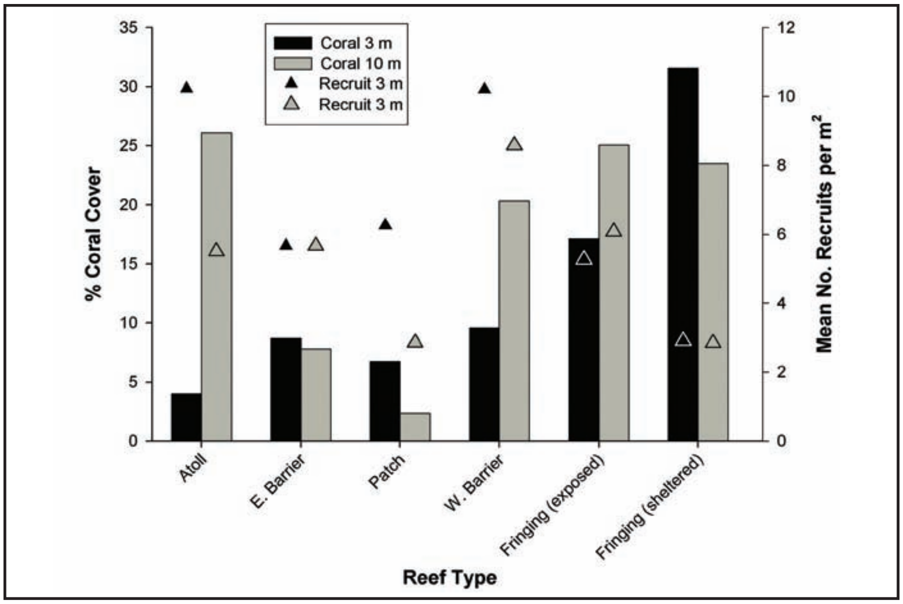

Figure 17.12. Mean coral cover and coral recruitment by reef type at 3 m and 10 m depths. Source: Golbuu et al., 2003a.

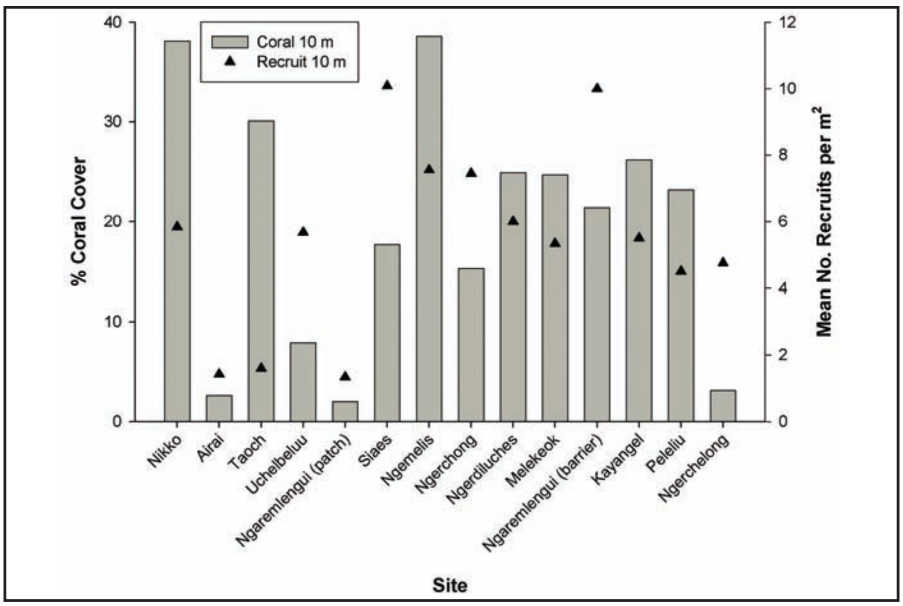

Figure 17.13. Coral cover and recruitment rate at the permanent monitoring sites. Source: Golbuu et al., 2003a.

The monitoring sites were selected to represent the various types of Palauan reefs: Atoll; east coast barrier (east barrier); patch reefs (patch); west coast barrier (west barrier); fringing reefs that are not protected by other reef or land (fringing exposed); fringing reefs that are protected by reef or island (fringing sheltered). There are significant differences in coral cover among reef types and depths. At 10 m depth, coral cover on patch reefs was significantly lower than all other reef types except for east barrier (Figure 17.12). In contrast, at 3 m, both exposed and sheltered fringing reefs had coral cover that was significantly higher than other reef types (Figure 17.12).

Mean coral recruitment varied significantly among the different reef types at both 3 m and 10 m depths (Figure 17.12). West barrier reefs had the highest number of recruits at both 3 m and 10 m depths. At the 3 m depth, the number of recruits at west barrier reefs was significantly different than the number of recruits at both exposed and sheltered fringing reefs. The only significant difference in coral recruitment among reef types at the 10 m depth was between west barrier reefs and sheltered fringing reefs (Figure 17.12).

There was no correlation between coral cover and recruitment at 10 m depths (Figure 17.13). For example, Nikko Bay and Taoch had high coral cover, but low coral recruitment. In contrast, Ngemelis and Kayangel have high coral cover and high recruitment. Airai and Ngeremlengui had low coral cover and low coral recruitment. Other sites, such as Ngerchelong, had low coral cover, but a high number of recruits.

Recruitment patterns can be better explained by the characteristics specific to each of the monitoring sites. In Nikko Bay, low recruitment was due to the lack of available substrates since all suitable substrate was covered by benthic organisms. Even though Ngemelis and Kayangel had high coral cover, there was still suitable substrate available for recuitment. Airai and Ngaremlengui sites have low coral cover and low recruitment because both sites are dominated by sandy bottoms and rubble, which are not suitable for coral recruitment.

The presence of recruits and young juvenile corals at many of the monitoring sites suggests that reefs are recovering. However, percent cover and species diversity remain lower than reef conditions prior to 1998.

ASSOCIATED BIOLOGICAL COMMUNITIES

Methods

Detailed surveys of fish communities were conducted by visual census at each permanent monitoring site. The surveys were conducted at 3 m and 10 m depths along five 50 m transects at each site. An observer swam along the transect line, counting the number of fish within 2.5 m of each side of the transect. Size was also estimated for each observed fish.

Results and Discussion

At the 3 m depth, the greatest number of fish (mean of 80 fish per 250 m^2) was observed at Ngerdiluches (Figure 17.14). Surgeonfishes (Acanthuridae) were the most common fish at all monitoring sites (Figure 17.15). Parrotfish, rabbitfish, and snappers were also found in high abundance. The lowest number of fish was recorded at Nikko for both the 3 m and 10 m depths (Figure 17.14).

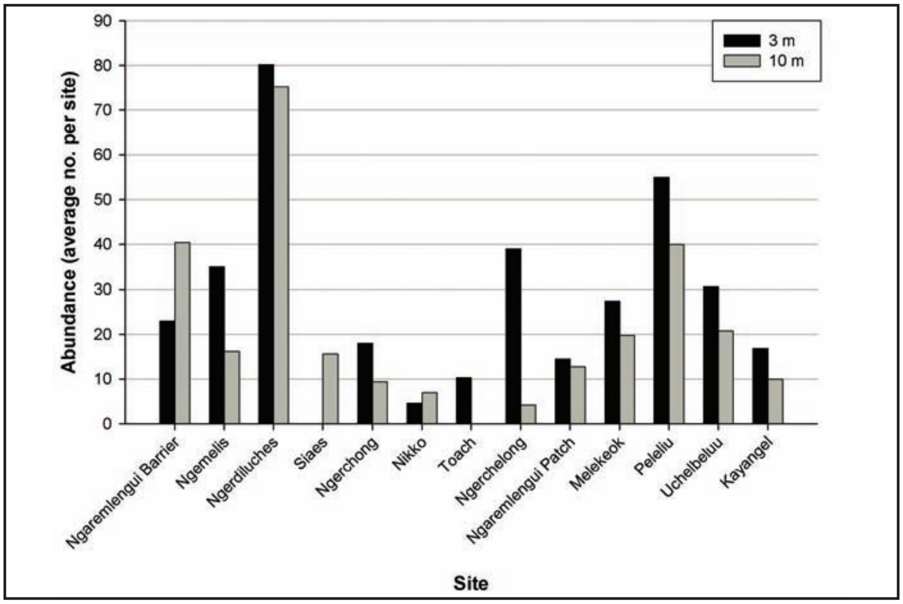

Figure 17.14. Average number of fish at the permanent monitoring sties around Palau. Source: PICRC, unpublished data.

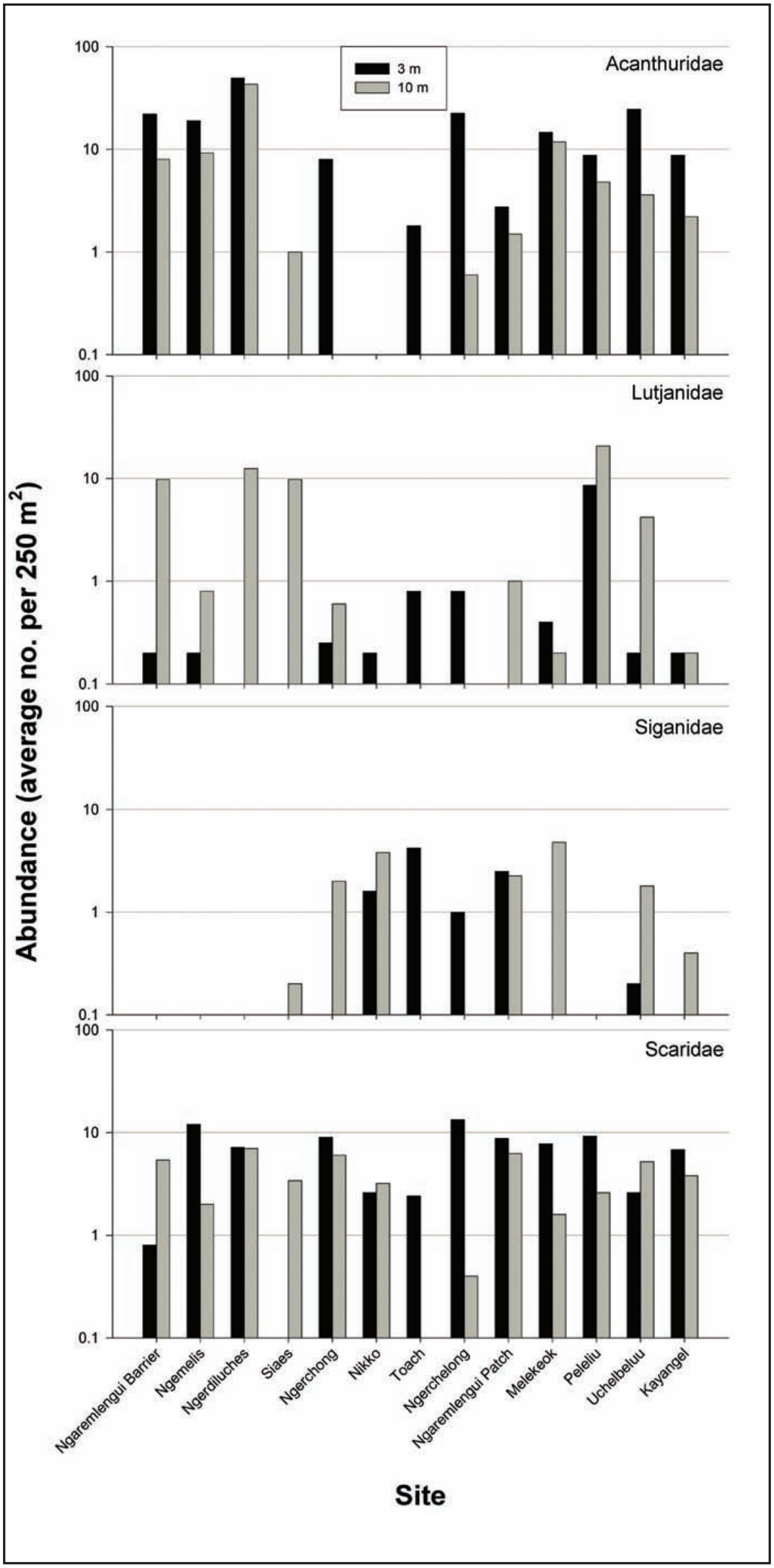

Figure 17.15. Abundance of Acanthuridae, Lutjanidae, Siganidae and Scaridae at the permanent monitoring sites around Palau. Source: PICRC, unpublished data.

Figure 17.15 shows the abundance of four main fish families observed at the permanent monitoring sites in Palau. Sites were grouped by reef type to demonstrate the differences in fish communities at different habitat types. Surgeonfish (Acanthuridae) are the most abundant fish found at the monitoring sites. Sites that are exposed, such as barrier reefs (i.e., Ngaremlengui, Ngemelis, Ngerdiluches, Siaes, and Uchelbeluu) and exposed fringing reefs (i.e., Ngerchong, Melekeok, and Peleliu) have high numbers of surgeonfish, while sheltered fringing reefs (i.e., Nikko and Taoch) have lower numbers (Figure 17.15).

Barrier reefs have high numbers of snappers (Lutjanidae), but few were found on sheltered fringing reefs and patch reefs (i.e., Ngerchelong and Ngaremlengui patch; Figure 17.15). Rabbitfish of the family Siganidae show a pattern opposite to that of snappers. Fringing and patch reefs had high numbers of rabbitfish but none were found on barrier reefs (Figure 17.15). Parrotfishes (Scaridae) were evenly distributed at all sites (Figure 17.15).

Kayangel, the only atoll site, had moderate concentrations of all four of the main fish families surveyed.

CURRENT CONSERVATION MANAGEMENT ACTIVITIES

The Palau Ministry of Resources and Development has overlapping jurisdiction with each of Palau's 16 state governments for all marine areas within 12 nm of the hightide watermark. Various governmental and non-governmental organizations have conducted research and monitoring projects to aid in the management of Palau's coral reef ecosystems. National and state agencies, in coordination with locally based non-governmental organizations, have put a variety of management tools in place to address issues such as fishing, recreational use, and land-based sources of pollution in order to protect the marine resources of Palau.

Marine Protected Areas

Several marine protected areas (MPAs) have been established throughout Palau to provide measures of protection for marine resources tailored to the management goals and intended purpose of the individual MPAs (Table 17.5). Several more of these protected areas have been designated over the years, thereby providing protection for a greater percentage of coral reef ecosystems (Figure 17.1).

Most of Palau's MPAs have been designated by the states and management of these areas falls under the authority of the local governments. In addition, there are MPAs designated by the national government for the purpose of protecting biodiversity and significant habitats. The designation of a MPA by the local governments is initiated by the implementation of a traditional moratorium, or 'bul', on the area, prohibiting all use for a restricted time period (usually one to three years). The majority of these MPAs were designated to address local concerns of decreased commercial reef fish populations. The Palau Conservation Society and The Nature Conservancy have been working in partnership with these state governments to implement community-level monitoring programs within the MPAs and to produce management plans for these areas which will be in effect after the moratorium period has expired. In the last several years, more of these MPAs have also been designated through legislation by the state governments to provide a legal basis for management action.

Table 17.5. Marine Protected Areas of Palau.

MARINE PROTECTED AREAS	OBJECTIVES	MANAGEMENT AUTHORITY	PROTECTED HABITATS
Ngerukeuid Preserve	Preservation of marine habitat biodiversity	National government	Rock islands, inner reef flats, lagoon, patch reefs
Ngerumkaol	Protection of reef fish aggregations	State government	Outer reef wall, reef flat, reef channel
Ngemelis	Protection of marine habitat diversity	State government	Rock island, inner reef flats, lagoon, patch reefs
Sardine Sanctuary	Protection of sardine aggregations	State government	Inner patch and fringing reefs
Ngederrak	Protection of commercial reef fish and invertebrate species populations	State government	Reef flats, inner reef slope, seagrass beds, lagoon
Ngermeduu Bay	Protection of marine habitat biodiversity	State government	Mangroves, mudflats, seagrass beds, fringing reefs, reef channel, inner reef flats, reef slope
Ngelukes	Protection of locally important fish and invertebrate species populations	State government	Patch reef, seagrass beds
Ngermasech	Protection of important nursery areas for fish and invertebrate species	State government	Seagrass beds, fringing reefs
Ebiil Channel	Preservation of grouper spawning aggregations	State government	Reef slopes, reef flats, channel, patch reefs, lagoons
Ngaruangel	Protection of marine habitats and locally important marine species populations	State government	Atoll

Protected Area Network Act

The Protected Areas Network Act of 2003 aims to support Palauan state government efforts directed at protecting marine resources. This law creates a nationally sanctioned framework by which non-governmental organizations and local governments can coordinate marine reserve conservation initiatives through a system of protected areas, which collectively preserve marine biodiversity. It is hoped that the Act will encourage the designation of new MPAs by state governments. Until recently, state governments have designated MPAs, but there was no system for collaboration and support from the national government in identifying appropriate areas, as well as designating and maintaining these resources. The Protected Area Network Act was seen as the necessary tool to ensure that areas representative of the full range of biodiversity in Palau are preserved. A Protected Areas Network coordinator will be appointed to facilitate the implementation of this law. With technical assistance from The Nature Conservancy in the form of a Protected Area Network counterpart, the state governments will have access to technical expertise and financial resources that are often lacking at the local level to properly develop MPAs.

MPA Effectiveness

The Palau International Coral Reef Center (PICRC) is currently conducting research to assess the efficacy of several MPAs in Palau. MPAs will be selected based on the level of management, geographic distribution, size, the protection timeframe, and willingness of managers and community members to be evaluated. The main objective is to improve the management of MPAs in Palau, thereby making MPAs more effective in meeting their goals and objectives.

The Palau Conservation Society, in partnership with The Nature Conservancy, has also established several monitoring sites in four community-designated MPAs in Babeldaob. The monitoring program tracks the abundance of locally important fish and invertebrate species (Table 17.6).

Table 17.6. Community-designated Conservation Areas.

MARINE PROTECTED AREA	STATE GOVERNMENT	INDICATORS
Ngelukes Conservation Area	Ngchesar State	Reef fish and invertebrate species abundance (rabbitfish, snappers, surgeonfish, giant clams, and sea cucumbers)
Ngermasech Conservation Area	Ngardmau State	Reef fish and invertebrate species abundance (rabbitfish, snappers, surgeonfish, giant clams, and sea cucumbers)
Ebiil Channel Conservation Area	Ngarchelong State	Abundance of groupers at spawning aggregation sites
Ngaruangel Reserve	Kayangel State	Fish abundance, occurrence of nesting sea turtle and sea bird poplulations

Other Management Tools

The Palau Bureau of Marine Resources has deployed fish aggregating devices in territorial waters around Palau in order to take fishing pressure off the reefs and promote a shift to pelagic fishes. Mooring buoys have been installed throughout the state of Koror as a management tool to decrease recreational impacts on coral reefs. Mooring buoys are well used by dive operators, recreational fishers and boaters. Outside the MPAs and other managed areas with very specific regulations, fishing is nationally regulated. Size restrictions exist for the humphead wrasse, bumphead parrotfish, and lobster. The harvest of grouper is restricted to non-peak spawning months and the season is well established. Additionally, the commercial export of reef fish and crustaceans is prohibited. Other restrictions are in place such as a closed season on harvesting sea turtles and full protection for the dugongs in Palau.

OVERALL CONCLUSIONS AND RECOMMENDATIONS

Collaboration and coordination among the different agencies and groups involved in coral reef monitoring, management and conservation are important. Interagency working groups (e.g., National Environmental Protection Council, Marine Resources Pacific Consortium, etc.) should be strengthened to ensure the inclusion of local agencies and interest groups and to increase communication and cooperation when addressing priorities and actions outlined in nationally adopted strategies (e.g., National Biodiversity Strategy Action Plan). Information beginning to emerge from studies of important watersheds in Palau suggests that collaboration between land management authorities, legislative bodies, and traditional leadership will be required to develop effective land use regulations. An integrated and transparent approach that recognizes the complexities of managing the coastal zone is considered crucial to this effort. In addition, the incorporation of coral reef ecosystem issues into local education programs will further promote marine conservation. Forming partnerships among relevant agencies that deal with outreach and education in Palau should be initiated to maximize the use of limited resources. The main objective of this effort should be to raise public awareness and appreciation for coral reef ecosystems through targeted and focused communication campaigns.

Specialized advice, technical assistance, and additional data are required in several areas. Most of the work being done in Palau has focused on biological and physical aspects of coral reefs and marine resources. Social, cultural, economic, and political factors, however, are also extremely important to the success of management strategies. Currently, Palau has limited expertise and capacity to address socio-economic issues, and therefore technical assistance and expertise in this area are needed.

Palau recently passed the Protected Areas Network Act which provides a framework for the establishment of an MPA network in Palau. Much of the work on the design, criteria, and regulations are under development, and expertise and technical assistance are needed to assist in implementation. Furthermore, in order to ensure efficiency in resource management, managers require accurate information on ecosystem change. Activities such as monitoring of coral reefs, as well as site selection and monitoring of MPAs require detailed habitat maps. Currently, Palau does not have maps of sufficient detail to support the necessary research and monitoring work. However, nearshore benthic habitat mapping has been initiated by NOAA's Center for Coastal Monitoring and Assessment, Biogeography Team, and preliminary products for approximately 75% of the main island cluster will be available by the end of 2005. In addition, fisheries managers in Palau urgently need reliable information on catch per unit of effort and trends in the population structure of target fish.

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NATIONAL SUMMARY

Overview

The purpose of the national summary is to catalogue results of the preceding jurisdictional chapters into a common assessment framework and provide a broad measure of ecosystem status and response. In addition, this summary identifies key research, monitoring, and management needs that must be addressed in the future to ensure continued refinement of a robust and accurate assessment of the status of coral reef ecosystems. In order to incorporate the diverse information from mapping, monitoring, research, and management efforts, the framework provided here is qualitative. This summary data will form a basis for comparison with future assessments of coral reef ecosystem status. It is important to note that this information has not been developed for interjurisdictional comparisons; rather, it has been designed to track the status of coral reef ecosystems over time. To develop the jurisdiction chapters, writing teams were tasked with identifying, interpreting and summarizing the results of ongoing mapping, monitoring, research, and management activities. Although each team cast a broad net to gather such information, it is likely that some important activities were not identified and therefore are not represented in this report. Much of the information and all of the examples used in this summary chapter are drawn from the content of the jurisdictional chapters.

Background

In June 2002, the National Oceanic and Atmospheric Administration (NOAA) and its U.S. Coral Reef Task Force (USCRTF) partners crafted the National Coral Reef Action Strategy (NCRAS, 2002). This strategy was developed to fulfill the requirements of the Coral Reef Conservation Act of 2000 (CRCA; 16 U.S.C. § 6401 et seq.) and to help track implementation of the National Action Plan to Conserve Coral Reefs that was adopted by the USCRTF in 2000 (USCRTF, 2000). The strategy was divided into two main themes aimed to: (1) provide a better understanding of coral reef ecosystems, and (2) reduce the adverse impacts of human activities. The goals for theme 1 include such objectives as the development of habitat maps of U.S. coral reef ecosystems; assessment, monitoring and research related to ecosystem status; and an increased understanding of social and economic factors relevant to the conservation of coral reef ecosystems. Theme 2 goals focus on, among other things, improving the use of marine protected areas (MPAs) in coral reef ecosystems, reducing adverse impacts of fishing and other extractive activities, and improving education and outreach. The following sections outline some of the many initiatives underway within U.S. jurisdictions and on a national level to address a selection of the goals defined in the NCRAS.

Mapping U.S. coral reef ecosystems

Accurate benthic habitat (e.g., corals, seagrass, sand) maps are necessary for resource managers to make informed decisions about the protection and management of a wide range of marine resources (Monaco et al., 2001; Kendall et al., 2004). Several initiatives are currently underway in the U.S. to map shallow-water benthic habitats to provide an inventory of resources and support ecosystem assessment and monitoring programs (NOAA, 2002). NOAA's Ocean Service (NOS) initiated a coral reef research program in 1999 to map, assess, inventory, and monitor U.S. coral reef ecosystems (Monaco et al., 2001). The mapping activities were outlined by the USCRTF Mapping and Information Synthesis Working Group (MISWG) in the Coral Reef Mapping Implementation Plan (USCRTF, 1999), which charged NOS with leading the production of comprehensive digital coral reef ecosystem maps for shallow-water areas of all U.S. states, territories, and commonwealths. In response to Executive Order 13089 and the CRCA, NOS and its partners are conducting research to digitally map biotic resources and coordinate a long-term monitoring program that can detect and predict change in U.S. coral reefs, as well as their associated habitats and biological communities. This work involves partnerships within NOS and NOAA, as well as with other Federal agencies, states, territories, and commonwealths, universities, research institutes, and the private sector.

The primary outcomes have included: (1) comprehensive and detailed benthic habitat maps for many areas of coral reef in U.S. waters (see Table 18.1); (2) hierarchical habitat classification schemes and methods manuals; (3) advancement of research methods for the digital classification of remotely sensed data for coral reef mapping; and (4) utilization of the map-based data in ecological studies. Products and methods are readily accessible online (http://biogeo.nos.noaa.gov/products, Accessed 02/28/05) and are designed to provide a

Table 18.1. Status of NOS's shallow-water coral reef ecosystem mapping activities that use satellite and aerial imagery to delineate benthic habitats in tropical and subtropical U.S. waters as of January 2005.

REGION	AREA (km²) OF SHALLOW-WATER (≤ 10 FM) *	AREA (km²) OF SHALLOW-WATER MAPPED	PROJECT STATUS
U.S. Virgin Islands	344	318	Completed 2001
Puerto Rico	2,302	1,837	Completed 2001
Navassa	3	0	Planned
Florida	30,801	5,023; 0	Florida Keys maps completed in 1998; larger effort to map South Florida planned for 2006-2009
Flower Garden Banks	0	0	In progress
Main Hawaiian Islands	1,231	681; 0	Initial effort completed 2003; larger effort in progress
Northwestern Hawaiian Islands	1,595	1,238	Completed 2003
American Samoa	55	39	Completed 2004
Pacific Remote Island Areas	252	0	Planned
Marshall Islands	13,456	0	Planned
Federated States of Micronesia	14,517	0	Planned
Northern Mariana Islands	124	111	Completed 2004
Guam	108	84	Completed 2004
Palau	2,529	0	In progress

* Estimate of shallow-water area from Rohmann et al., in press.

spatial framework with which to implement and integrate research programs and provide the capability to effectively communicate information and results to coral reef ecosystem managers (Figure 18.1).

The digital shallow-water benthic habitat maps described above were primarily created through visual interpretation of aerial photographs and satellite imagery. However, some coral reef ecosystems, such as those in areas of high turbidity or deeper than about 30 m, do not lend themselves to a method based on visual interpretation. In such cases, efforts have been undertaken to map benthic habitats utilizing complementary methods, often through the use of multibeam sonar technology. For example, NOS and its partners have undertaken two mapping missions (in 2004 and 2005) to characterize deeper areas in the U.S. Virgin Islands (USVI) near Buck Island Reef National Monument in St. Croix and along the mid-shelf reef south of St. John and St. Thomas. The cumulative result of these and other efforts will be continuous map coverage of benthic cover and bathymetry from the shoreline to deep water areas beyond the insular shelf.

In the Pacific Islands region, significant efforts are also underway to integrate shallow-water maps with multibeam sonar data in areas deeper than 20 m (Figure 18.1). Since 2000, NOAA's Pacific Islands Fisheries Science Center's Coral Reef Ecosystem Division (PIFSC-CRED) has been conducting benthic habitat mapping in the Northwestern Hawaiian Islands (NWHI), Main Hawaiian Islands (MHI), Territory of American Samoa, Territory of Guam, Commonwealth of the Mariana Islands (CNMI), and Pacific Remote Island Areas (PRIAs) of Baker, Howland, Jarvis, Kingman, Palmyra, and Wake Islands. Benthic habitat mapping activities in 20-200 m include the use of single-beam and

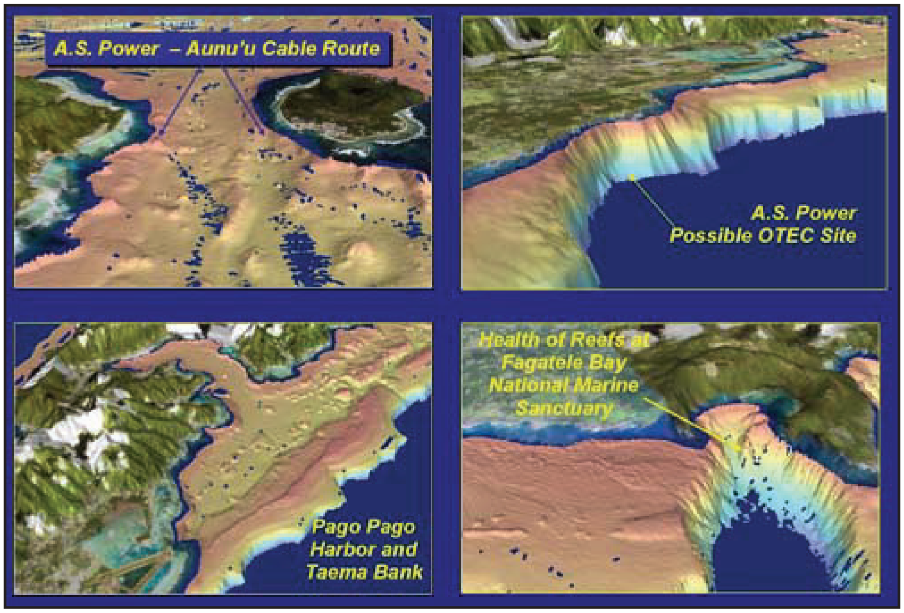


Figure 18.1. Multibeam shaded bathymetry maps (5 m resolution) of areas of American Samoa will facilitate better resource management. Source: PIFSC-CRED.

multibeam sonar instruments and bottom camera towing. In 2005, two multibeam sonars were installed on the recently commissioned NOAA vessel *Hi'ialakai*. These sonars will increase NOAA's Pacific multibeam mapping capabilities to waters deeper than 200 m; multibeam mapping in the MHI and PRIAs will commence in 2005. Table 18.2 provides a summary of Pacific benthic habitat mapping activities conducted by PIFSC-CRED.

Table 18.2. Status of PIFSC-CRED multibeam mapping activities in the Pacific Islands from 2002-2005. Source: PIFSC-CRED.

REGION	ESTIMATED AREA WITH WATER DEPTHS OF 20-200 M (km^2)	AREA WITH WATER DEPTHS OF 20-200 M MAPPED (km^2)	MULTIBEAM PROJECT STATUS
Main Hawaiian Islands	36,261	*	*Synthesis Underway
Northwestern Hawaiian Islands	58,602	13,640	Mapping cruises undertaken in 2002 and 2004; +25,727 km^2 mapped; Approximately 100 mapping days planned in 2005.
American Samoa	1,556	271	Mapping cruise undertaken in 2004; Approximately 45 mapping days planned in 2006.
Guam and the Commonwealth of the Northern Mariana Islands	30,464	244	Mapping cruise undertaken in 2003; Saipan anchorage analysis and report expected in May 2005; Approximately 45 mapping days planned in 2006.

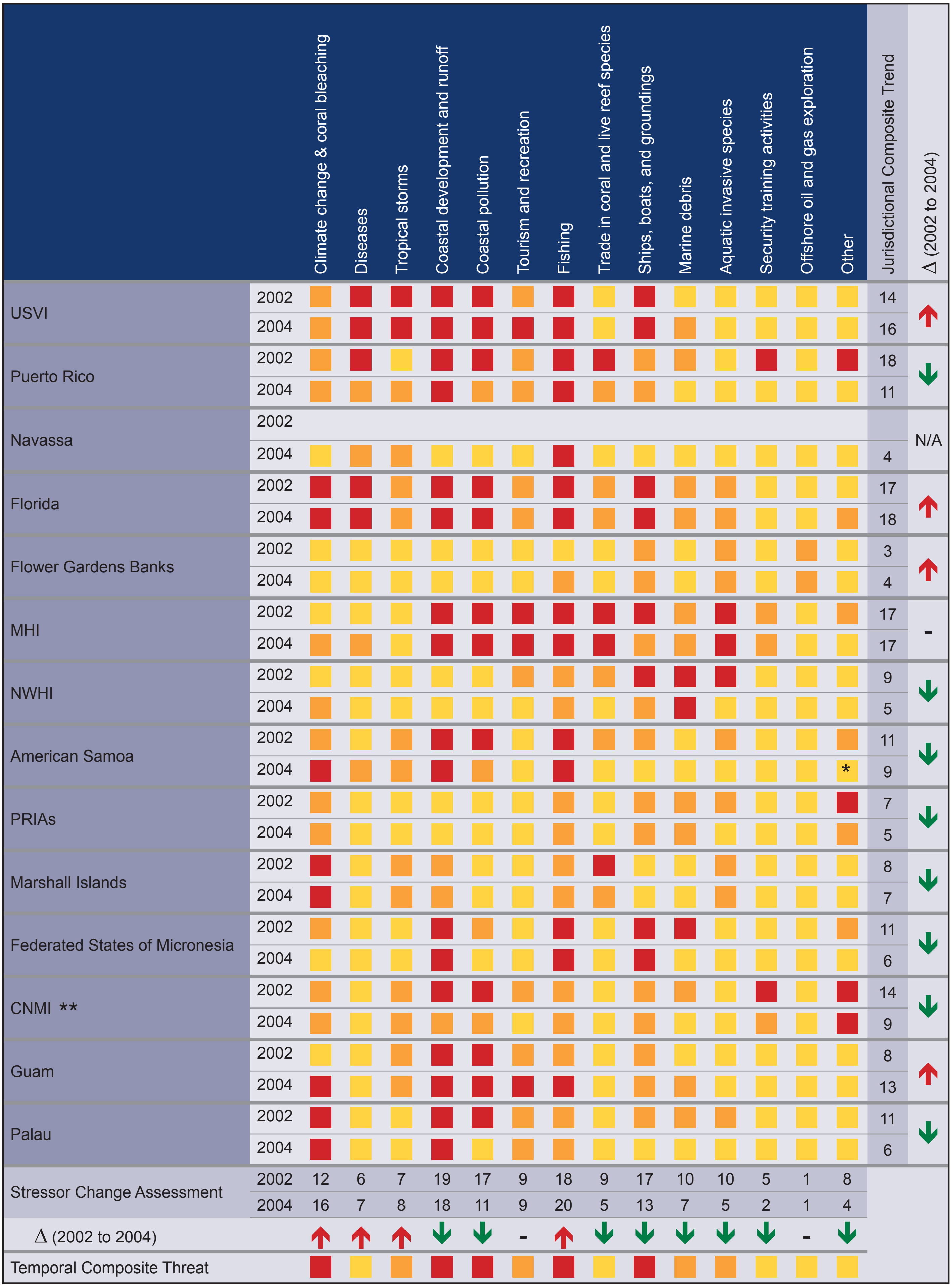
Assessing, monitoring, and forecasting coral reef ecosystem condition

As part of the National Action Plan to Conserve Coral Reefs, USCRTF members solicited extensive input from government agencies, non-governmental organizations, academic scientists, resource managers, and other stakeholders to identify key threats (see 'Threats and Stressors' chapter) to coral reef ecosystems. The perceived level of each of these key threats was then evaluated for all jurisdictions (Turgeon et al., 2002). Results of this effort were also published in the inaugural State of the Coral Reef Ecosystems of the United States and Pacific Freely Associated States report (Turgeon et al., 2002). In this report, threats were again evaluated to allow comparison with the 2002 information (Table 18.3). This current information provides an overview of the suite of key threats for each jurisdiction, their relative importance, and the direction of change, if any, since 2002.

According to expert opinion, 74% of all threats across all jurisdictions remain unchanged from 2002 to 2004, of which 24% remain a high level threat, 24% remain a medium level threat, and 52% remain a low level threat. Twenty-six percent of all threats were perceived to have changed since 2002, of which 18% decreased in threat level and 8% increased in threat level. High level threats to coral reef ecosystems, across all jurisdictions, were considered to have decreased by approximately 6% since 2002 (Table 18.3). Fifty percent of all decreases were changes from a medium to a low threat and 15% were changes from high to low threat levels. The majority (60%) of increases was from a low to medium threat, and 26% increased from a medium to a high threat. Only one jurisdiction, Guam, exhibited a change in threat level from low to high, although this appeared to represent an anticipated increase in climate change-related coral bleaching.

Across all jurisdictions, eight of 14 threat categories were perceived to have decreased in severity since 2002: coastal pollution; trade in coral and live reef species; marine debris; security training activities; and ships, boats, and groundings. Four threat categories were perceived to have increased in severity since 2002: fishing; climate change and coral bleaching; tropical storms; and diseases. Across all jurisdictions, there was no net change in the perceived threat for oil and gas exploration or tourism and recreation. Within jurisdictions,

Table 18.3. A comparison of the 2002 and 2004 perceived levels of threat to coral reef ecosystems in the U.S. and FAS, based on expert opinion. Red squares represent high threat (2 points), orange represents moderate threat (1 point), and yellow represents little or no threat (0 points). Scores were tallied horizontally to calculate the level of threat from individual stressors across jurisdictions and vertically to calculate overall threat by jurisdiction for all stressors combined. Red arrows indicate a net increase in threat level,and green arrows indicate a net decrease in threat level. Horizontal bars indicate no change. Only data for 2004 are available for Navassa. *Following the 2000 census, population growth emerged as a major issue in American Samoa; although this issue is highlighted in the 'Other' section of that chapter, the high threat rating was assigned to the Coastal Development and Runoff threat to be consistent within the table. **For CNMI, 2002 data were based on the southern islands only, while 2004 data include the northern islands; the perceived threat for the southern islands did not change from 2002 to 2004. Note: The actual impacts of each threat category will likely vary widely within and among regions.


Climate change & coral bleaching
Diseases
Tropical storms
Coastal development and runoff
Coastal pollution
Tourism and recreation
Fishing
Trade in coral and live reef species
Ships, boats, and groundings
Marine debris
Aquatic invasive species
Security training activities
Offshore oil and gas exploration
Other
Jurisdictional Composite Trend
Δ (2002 to 2004)
USVI 2002 14 2004 16
Puerto Rico 2002 18 2004 11
Navassa 2002 2004 4 N/A
Florida 2002 17 2004 18
Flower Gardens Banks 2002 3 2004 4
MHI 2002 17 2004 17 -
NWHI 2002 9 2004 5
American Samoa 2002 11 2004 * 9
PRIAs 2002 7 2004 5
Marshall Islands 2002 8 2004 7
Federated States of Micronesia 2002 11 2004 6
CNMI ** 2002 14 2004 9
Guam 2002 8 2004 13
Palau 2002 11 2004 6
Stressor Change Assessment
2002 12 6 7 19 17 9 18 9 17 10 10 5 1 8
2004 16 7 8 18 11 9 20 5 13 7 5 2 1 4
Δ (2002 to 2004) - -
Temporal Composite Threat

eight of 14 jurisdictions perceived an overall decline in the severity of threats since 2002; four perceived an overall increase in threat; and two jurisdictions were perceived no net change. Threats decreased most for Puerto Rico, where coastal pollution, disease, trade in coral and live reef species, and security training activities were considered less severe in 2004. The Federated States of Micronesia (FSM), NWHI, PRIAs, CNMI, Palau, American Samoa, and the Marshall Islands also reported overall decreases in threats to coral reef ecosystems for 2004.

Perceived threats have increased the most in Guam and USVI, followed by Florida and Flower Garden Banks. In Guam, threats from climate change-related bleaching events, tourism and recreation, fishing, and marine debris are perceived to have increased since 2002. In the USVI, threats from tourism and recreation as well as marine debris are perceived to have increased since 2002. In Florida, the increase was represented solely by a perceived increase in threat from human activity in the "Other" category, which included cable laying operations. In both the MHI and American Samoa, high threat levels remained unchanged since 2002.

Of particular concern was the impact of fishing on coral reef ecosystems. Fishing was reported as a high level threat for eight jurisdictions and a medium level threat for the other six jurisdictions, thereby supporting conclusions in several other international reports that have highlighted fishing as a major threat to coral reef ecosystems (Burke and Maidens, 2004; Turgeon et al., 2002; Wilkinson, 2002, 2004). Furthermore, experts who contributed to this report perceived that the threat from fishing has increased since 2002. In addition, for all jurisdictions except the most remote islands, land-based human activity (coastal development and runoff, coastal pollution) was a medium to high level threat, which also supported the conclusions of other reports (Bryant et al., 1998; Turgeon et al., 2002; Wilkinson 2002, 2004). However, in contrast to nonpoint source pollution from runoff, the threat of coastal pollution from point sources was considered to have decreased overall since 2002, especially in Puerto Rico, American Samoa, Palau, and CNMI.

Perceived threat levels were designated through the expert opinion of writing teams with extensive local knowledge. However, interpretations of the perceived threat levels must be undertaken with some knowledge of the caveats associated with this type of information. For instance, the number of threats impacting a region may not accurately reflect the magnitude of the combined threats. Trade in coral and live reef species may have less overall impact on the coral reef ecosystems of the MHI than does the impact of fishing, yet they are both tabulated equally as a high threat. Furthermore, it is difficult to make a definitive assessment accounting for the combined impacts of multiple stressors, as each has a variety of manifestations in coral reef environments. As such, it also is important to interpret the perceived impact change for each threat independently, and to look for context and corroborating evidence in each of the jurisdictional chapters. In addition, while most perceived threat levels were based on data from rigorous monitoring programs, some were based on more casual and infrequent observations. Also, many of the jurisdictions included in this report are comprised of a number of islands, ranging in population density and human activity. Therefore, assessments of perceived threat may, in fact, refer only to a region within a jurisdiction. For example, American Samoa is comprised of six islands, yet most of the population resides on one island.

Monitoring through a continued program of surveys, systematically undertaken to provide a series of observations over time, is an important process in understanding and reducing threats to coral reef ecosystems. Monitoring can also be used to evaluate the effectiveness of specific management strategies, evaluate restoration projects, and serve as an early warning system for identifying declines in ecosystem health. The USCRTF National Action Plan to Conserve Coral Reefs calls for a coordinated national program to assess, inventory, and monitor the health of U.S. coral reef ecosystems.

For this report, monitoring programs across jurisdictions were characterized using a checklist of biotic and abiotic variables including indicators of water quality, indicators of the condition of the benthos, and abundance patterns of ecologically and economically important marine animals (Table 18.4). This selection represents a wide range of variables that are: (1) well-documented as indicators of specific stressors; (2) likely to be of concern if levels change markedly; (3) can be used to define a desired biological condition; and (4) may contribute to the development of an index of biotic integrity. These variables are also easily quantified and widely used in marine monitoring programs, thereby facilitating comparisons through time and space. Many other variables were also measured; however, these 15 were the most widely used across the jurisdictions.

Table 18.4. Key biotic and abiotic variables included within marine monitoring programs across jurisdictions. Circles indicate variables reported in this report. Data collection may occur at a single location on a single occasion or multiple locations on multiple occasions.

	WATER QUALITY					BENTHOS					ASSOCIATED BIOTA					
	Turbidity	DO	Chlorophyll	Nutrients	Bacteria	Live coral % cover	Coral recruitment	Algal % cover	Coral disease	Coral bleaching	FIsh abundance	Commercially important fish	Ecologically important macroinvertebrates	Commercially important macroinvertebrates	Protected species	% of key variables currently being monitored
USVI	●	●		●	●	●	●	●	●	●	●	●	●	●	●	93
Puerto Rico	●	●		●	●	●		●	●	●	●	●	●	●		80
Navassa				●		●	●	●	●	●	●	●	●	●	●	73
Florida	●	●	●	●		●	●	●	●	●	●	●	●	●	●	93
Flower Gardens Banks	●	●	●	●		●		●	●	●	●	●	●	●	●	87
MHI	●	●	●	●	●	●		●	●	●	●	●	●	●	●	93
NWHI	●	●	●			●	●	●	●	●	●	●	●	●	●	87
American Samoa	●	●	●	●	●	●		●	●	●	●	●	●	●	●	93
PRIAs	●	●	●			●	●	●	●	●	●	●	●		●	80
Marshall Islands						●		●	●	●	●	●	●	●	●	60
FSM	●	●			●	●		●			●	●	●	●		60
CNMI	●	●	●	●	●	●		●	●	●	●	●	●	●	●	93
Guam	●	●		●	●	●	●	●		●	●	●	●	●	●	87
Palau	●	●			●	●	●	●	●	●	●	●				67
% of jurisdictions currently monitoring each key variable	86	86	50	64	57	100	50	100	86	86	100	100	93	86	79	

Examination of the monitoring programs detailed in this report indicates that water quality variables were less widely monitored than benthic variables and associated biota. For example, fewer than half of the jurisdictions measured chlorophyll concentrations, but all monitored percentage live coral cover and all but one measured percentage algal cover and fish abundance. Overall, remote islands (excluding the MHI) were monitored less frequently than other regions. For example, Navassa and the Marshall Islands did not report monitoring of water quality variables, while the MHI reported monitoring most of the water quality, benthic, and associated biotic variables. Importantly, the frequency of sampling, which in some regions was sporadic, has been identified as a major limitation in the interpretation of monitoring data. Furthermore, this suite of variables (Table 18.4) will form the basis for more detailed analyses in future assessments of the status of coral reef ecosystems.

Improving the use of marine protected areas in coral reef ecosystems

MPAs are being used nationally and internationally as management tools to protect, maintain, or restore natural and cultural resources in coastal and marine waters (Salm et al., 2000). Examples of MPAs in the U.S. include national marine sanctuaries, parks and wildlife refuges, national seashores, historical monuments, marine reserves, fish reserves, ecosystem reserves, conservation areas, sanctuaries, research reserves, spawning sites, and other critical habitats. Executive Order 13158 defines a MPA as "any area of the marine environment that has been reserved by Federal, State, tribal, territorial, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein" (Federal Register, 2000). As such, the term MPA encompasses a wide variety of approaches to place-based management ranging from complex multi-use strategies, to areas with restrictions on specific types of fishing gear and research reserves with no public access. Most MPAs in the U.S. have one or more conservation goals that focus on natural heritage, cultural heritage, and/or sustainable production of marine resources. These conservation goals are generally derived from the site's statutory mandate and are reflected in the implementing regulations and management plan (National MPA Center, http://mpa.gov/mpa_center/about_mpa_center.html, Accessed 01/10/05). The two primary approaches to protection are multiple-use or no-take. Typically, a multiple-use approach requires zoning, with each zone varying in the types of activities permitted. Marine zoning is being implemented in the Florida Keys National Marine Sanctuary (FKNMS) to assist in the protection of ecologically important areas by ensuring that human activity is dispersed in a way that avoids concentrating impacts on the heavily used coral reefs and minimizes user conflicts (Figure 18.2). Zone types include wildlife management areas to minimize disturbance to sensitive wildlife and their habitats; ecological reserves to protect diverse habitats that are both large and contiguous; sanctuary preservation areas to protect heavily used reefs; and special-use areas for scientific research, education, restoration, or monitoring.

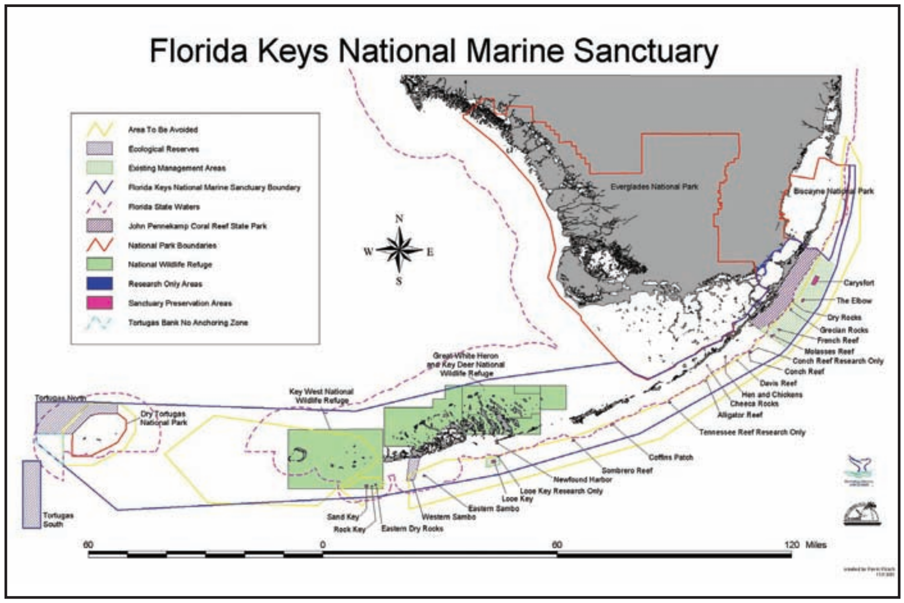


Figure 18.2. A marine zoning plan is being implemented in the FKNMS to protect sensitive habitats and minimize conflicts among various user groups. Source: FKNMS, http://www.floridakeys.noaa.gov/regs/zoning.html, Accessed 02/28/05.

A very small portion of U.S. waters are currently designated as no-take areas (National MPA Center, http://mpa.gov/information_tools/pdf/Factsheets/mpamisconceptions2.pdf, Accessed 04/04/05). In Guam, approximately 11.8% of the coastline has been designated as no-take to protect habitat and allow fish populations, particularly fisheries species, to recover. In these preserves, fishing is either prohibited or restricted to certain cultural use practices that do not threaten restoration goals. No-take zones have often proven successful in protecting and enhancing reef fish populations within protected areas, and in some cases, significant spillover effects in neighboring areas have also been reported (Gell and Roberts, 2002; Halpern and Warner, 2002, 2003; Russ and Alcala, 2004; Williamson et al., 2004).

The National MPA Center is compiling a reference database of marine managed areas (MMA) under U.S. jurisdiction. MMAs encompass a broader spectrum of management purposes, including protection of geological, cultural, or recreational resources that may not fall under the official U.S. definition of MPAs (MMA Inventory Database, http://mpa.gov/inventory/about_inventory.html, Accessed 04/20/05). MMAs exist in all of the jurisdictions containing coral reef ecosystems and are the subject of a forthcoming NOAA report. Individual protected areas in coral reef ecosystems range in size from the 0.05 km^2 national wildlife refuge at Green Cay near St. Croix, USVI to the NWHI Coral Reef Ecosystem Reserve, which covers an area of more than 347,000 km^2. Although several areas are large, many are less than 10 km^2 (MMA Inventory Database, http://mpa.gov/inventory/about_inventory.html, Accessed 04/20/05). The size of a MPA is important in relation to the diversity and quantity of habitat types protected and the life cycle movement patterns of the species of interest (Botsford et al., 2003; Halpern and Warner, 2003; Pittman and McAlpine, 2003).

Executive Order 13158 requires relevant agencies to "develop a national system of MPAs" and to "strengthen the management, protection, and conservation of existing marine protected areas and establish new or expanded MPAs." Central to the success of a MPA network is sustained participation by key stakeholder groups, particularly local communities, in all phases of the design, implementation, and evaluation of the system. In response to the Executive Order, work is underway in the U.S. to ensure representation of major coral reef habitat types and communities in a national system of MPAs. Traditionally, MPAs have not been established specifically to function as part of a network, although in some areas they may already provide connectivity and adequately represent the full range of habitat types. The National Research Council's review of 32 studies estimating the area of marine reserves required to achieve a wide range of conservation or management objectives found that 26 studies recommended areas in the range of 10-40% of all marine habitats (NRC, 2001). Interconnected networks that protect the same species and habitat types through replication in several different sites are likely to increase their resilience to disturbance and boost subsequent recovery through the provision of new recruits. Furthermore, it has been acknowledged that adaptive management, a process for continually improving management policies and practices by incorporating the results of past actions, is needed to monitor and evaluate the adequacy of the design of MPAs for the level of protection provided and efficacy with regard to protecting and improving ecosystem structure and function (USCRTF Working Group on Ecosystem Science and Conservation, http://www.coralreef.gov/whycare/ecowg/marinepro.html, Accessed 05/02/05).

To coordinate its implementation, the Executive Order directed NOAA to create the National MPA Center in collaboration with the U.S. Department of the Interior. The MPA Center, headquartered in Silver Spring, Maryland, is responsible for consultation, coordination, outreach, and education related to MPAs. The headquarters staff also support the MPA Federal Advisory Committee, which consists of 30 stakeholder representatives appointed by the Secretary of the U.S. Department of Commerce. MPA Center regional liaisons are located in Boston, Massachusetts; Monterey, California; and Honolulu, Hawaii. The MPA Center's Science Institute, with offices in Santa Cruz and Monterey, California, focuses on bringing sound science into the MPA policy arena. It fosters targeted research, assessment, and policy analysis on aspects of the design, management, and evaluation of MPAs. The MPA Center's Training and Technical Assistance Institute in Charleston, South Carolina provides training, needs assessments, and technical support to managers and stakeholders involved in MPAs. Information on individual MMAs, including a general description and site characteristics such as location, purpose, and type of site, as well as detailed information on natural and cultural resources, legal authorities, site management, regulations, and restrictions, are available through the MPA Center's on-line database (MMA Inventory Database, http://mpa.gov/inventory/about_inventory.html, Accessed 01/10/05).

The USCRTF has also called for strengthening and expanding the Nation's existing networks of coral reef MPAs and increasing the effectiveness of existing MPAs as part of the National Action Plan to Conserve Coral Reefs (USCRTF 2000) and NCRAS (2002). Since 2000, USCRTF members have made progress towards these goals. Between 2000-2003, for example, 26 new MPAs and reserves have been established in several jurisdictions including the USVI, Hawaii, Puerto Rico, American Samoa, and CNMI. USCRTF members have also conducted activities to strengthen effectiveness of existing coral reef MPAs, including the creation or revision of management plans for coral reef MPAs in Florida, Hawaii, and Puerto Rico.

Reducing adverse impacts of fishing and other extractive uses

In almost all jurisdictions, fishing is an important activity often with a long history and strongly integrated into the culture. Fishing provides food, supplemental income, recreation, and full-time employment for many people. In Palau, for example, surveys showed that 87% of households had someone that fishes either for subsistence or commercial purposes. However, catches from recreational and subsistence fishing are rarely reported or factored into estimates of total catch and in many locations are thought to exceed the commercial reef fisheries catch (F. Magron, pers. comm.).

Experts across all 14 jurisdictions perceived fishing as a medium (6) or high (8) threat to coral reef ecosystems. Reducing the adverse impacts of fishing, therefore, is critical to reducing the overall threat to coral reef ecosystems. Adverse impacts include the alteration of the faunal community structure and composition through direct removal of fauna and the physical damage to benthic habitats through various methods of extraction. Abandoned fishing gear is also of major concern in some jurisdictions, as derelict traps and nets continue to capture fish, mammals, and turtles over time (Figure 18.3). Significant declines, low abundance, or a conspicuous absence of large-bodied species, specifically of species targeted by fisheries, were reported in many regions, even in relatively remote areas. For instance, large-bodied and commercially valuable groupers that were once considered an important component of the fishery catch around Kosrae in the FSM are no longer seen in the area. Declines in large-bodied target species were also reported in areas where the fisheries were considered to be in good condition overall. In some areas, however, no baseline data exist to adequately evaluate their status. At Navassa Island, commercial and recreational fisheries are unmanaged despite its status as a national wildlife refuge.

Figure 18.3. A derelict fish trap encountered on the bank shelf south of St. John in 2005. Photo: M. Kendall.

A wide range of management activities and tools have been developed and implemented to address the impacts of fishing, and preliminary results presented in this report suggest that many have been effective in providing protection for coral reef ecosystems and promoting recovery in local fisheries. For example, in response to substantial declines in its fishery, the Puerto Rico government enacted new regulations, such as improving licensing; prohibiting spearfishing using scuba equipment; eliminating beach seining; and establishing size limits and daily quotas on several species. Elsewhere, closures have been used with measurable success. For example, in the USVI, an important red hind (*Epinephelus guttatus*) spawning aggregation site south of St. Thomas was closed in 1990, and by 2003 the average length of red hind landed had increased by 8 cm. Recent observations in the USVI also reveal that several species of grouper including the Nassau grouper (*E. striatus*) are re-establishing spawning aggregations, although these currently occur in unprotected areas and are being targeted by local fishers.

Reserves have been established in most jurisdictions and measures to reduce fishing pressure have been implemented on several levels, ranging from closures to limits on fish size or abundance. The FKNMS has numerous management zones, some of which restrict or prohibit fishing. Fisheries for Nassau grouper (*E. striatus*), goliath grouper (*E. itajara*), queen conch (*Strombus gigas*), and stony corals (Scleractinia spp.) are closed there. Enforcement and effectiveness of MPAs are the major concerns in most jurisdictions. Reserves have enhanced recovery of local fish communities in Hawaii, Puerto Rico, and the USVI, and are currently being assessed in Guam and Palau. A broad consensus of expert opinion across jurisdictions highlights the need for greater measures of enforcement to improve MPA effectiveness. In Hawaii, for example, a major concern of fishers is a perceived lack of adequate enforcement of fishing and marine resource laws. However, despite illegal fishing in no-take preserves of Guam, significant increases in fish abundance have been recorded.

Mitigation activities, such as stock enhancement, artificial reef deployment, and installation of fish aggregating devices (FADs), have also been used to address fishing impacts. Stock enhancement and artificial reefs were used to improve catch at specific locations, while FADs were used to encourage a shift in fishing pressure from sensitive, overexploited reef fish populations to pelagic non-reef species. These and other opportunities to reduce adverse impacts of fishing and other extractive uses on coral reefs should be explored and monitored for efficacy.

To restrict the harvesting of coral and live reef species, regulations have been passed in the CNMI, Flower Garden Banks, Hawaii, PRIAs, Palau, and USVI, while Puerto Rico plans to design management strategies to address the high exportation of aquarium trade target species. Catch and export data for the trade in live reef animals are limited, often with no monitoring even in areas with a significant industry. Where data are collected, catch is often considered to be underreported. After analyzing the results of several surveys, Puerto Rico is proposing a stock assessment and management strategy to address export of live reef species. In Hawaii, a network of fish replenishment areas established to ensure sustainability of the aquarium fishery has demonstrated success, with increases in the abundance of several targeted species.

Restoring damaged coral reef ecosystems

Coral reefs worldwide are experiencing increasing pressure from a multitude of stressors that have resulted in adverse changes to ecosystem structure and function. Although protection and conservation of coral reef habitats are the preferred approaches, restoration of damaged habitats is an additional tool that may be utilized in cases of physical damage (e.g., ship groundings) to enhance coral ecosystem recovery. Efforts to increase protection of coral reef ecosystems need to be supported by strategies designed to restore functionality and structural integrity to damaged and disturbed habitats. Restoration can be defined as "the process of reestablishing a self-sustaining habitat that closely resembles a natural condition in terms of structure and function" (NOAA, 2003) and must include consideration of the integrity of the surrounding landscape. Restoration of habitats in a coral reef ecosystem is a multidisciplinary effort that includes managers and policymakers and must be supported with hypothesis-driven ecological studies and quantitative long-term monitoring programs.

Clearly defined goals are essential for restoration. Key restoration goals that have been used in wetlands are applicable to the restoration of coral reef ecosystems (as well as rocky intertidal, mangrove, and seagrass ecosystems). These include attempting to restore essential ecological processes, integrating the project with its surroundings, and creating a persistent and resilient system. Generally, restoration should result in the historic ecosystem type, but it may not always result in the historic biological community and structure. Therefore, development of structural and functional objectives and performance standards for achievement should include consideration of these potential departures from pre-injury conditions (SWS, 2000).

Despite the broad scope of stressors that a coral reef ecosystem can encounter, restoration efforts have focused more on physical injuries of anthropogenic origin and of a clearly defined nature, such as vessel groundings. One example of a resource injury documentation and restoration process is in the FKNMS, where vessel groundings have damaged over 12,000 ha and pose a major threat to coral reefs and seagrass beds (FKNMS, 1996). In the FKNMS, depending on the extent of the injury, a vessel grounding can initiate a sequence of restoration activities that includes injury assessment, emergency triage and/or stabilization, possible litigation between the trustee (or primary management entity) and the responsible party, and a restoration project (Figure 18.4; Precht et al., 2003). Acting as trustees for the FKNMS, NOAA and the State of Florida have the legal authority to seek monetary damages for injury to these resources under the National Marine Sanctuaries Act (16 U.S.C. § 1441 et seq.). This Act charges the national marine sanctuaries with a

Figure 18.4. Restoration of seagrass beds damaged by a vessel grounding required the addition of gravel substrate at Calda Bank off Key West, Florida. Photo: A. Farrer.

"strong legal mandate to procure compensatory restoration and an established economic process to calculate damages" (16 U.S.C.§ 1443). The process now entails: 1) collection of a monetary damage claim (Shutler et al., in review) to restore damaged natural resources to a condition as close as possible to their pre-injury condition (i.e., primary restoration), and 2) public compensation for the lost use of those resources until such time as those resources have fully recovered (i.e., compensatory restoration). NOAA has adopted a protocol called the Habitat Equivalency Analysis (HEA) to determine the amount of compensation required for such injuries. HEA combines biological and economic principles to calculate ecosystem services lost in the interim between the time of the injury and return to baseline conditions (NOAA, 2000b). Losses are calculated in perpetuity if no recovery is expected (NOAA, 2000b). The HEA calculation requires an estimate of the time it takes for the injured services to recover, as well as the shape of that recovery function (Fonseca et al., 2000, 2004).

Computer models have been used successfuly to generate recovery horizons for use with the HEA method to prosecute injury cases in Federal courts. A recovery model can also be used as a null model for habitat restoration. In this way, projected recovery horizons can be used to evaluate the effectiveness of a no-action restoration alternative. Recovery prediction models could also be adapted to project recovery from other types of environmental stressors. To date, this type of model has been used for predictions of seagrass injury recovery (Fonseca et al., 2000), and is under development for application to coral reefs (Whitfield et al., 2001; Fonseca et al., 2003).

Restoration techniques for physical injuries of anthropogenic origin on coral reefs, seagrass meadows, and mangrove forests are based on the same general concepts: assessment and mapping of the injury, site stabilization, structural replacement or enhancement if necessary, transplanting, and monitoring. The preferred and selected restoration actions are extremely dependent on the type and scale of injury as well as specific environmental factors (e.g. current, sediment type). A large-scale coral reef injury can not only damage living coral, but also remove physical reef structure, causing habitat loss and reduction in substrate for new recruitment. Some techniques that have been used to replace biotic structure after an injury include the use of artificial structures such as limestone boulders, concrete revetment mats, or structures of various custom designs (NOAA, 2000a, 2002). Materials that have been used to stabilize loose coral include epoxy, concrete, wire ties, or cable ties (Figure 18.5). Coral colonies may be transplanted onto the artificial structures. Effective seagrass restoration techniques include filling the injury to grade (Figure 18.6), transplanting seagrass into the injured area, and increasing nutrient availability to enhance species succession in the area using

Figure 18.5. Living coral fragments are attached to a reef by a diver using wire ties. Photo: NOAA Restoration Center.

bird stakes. The generally accepted technique for mangrove habitat restoration is seedling planting (Ellison, 2000). Because the driving factor for mangrove ecosystem structure and function is the hydrologic regime, site stabilization may also be incorporated into a restoration project (Ellison, 2000).

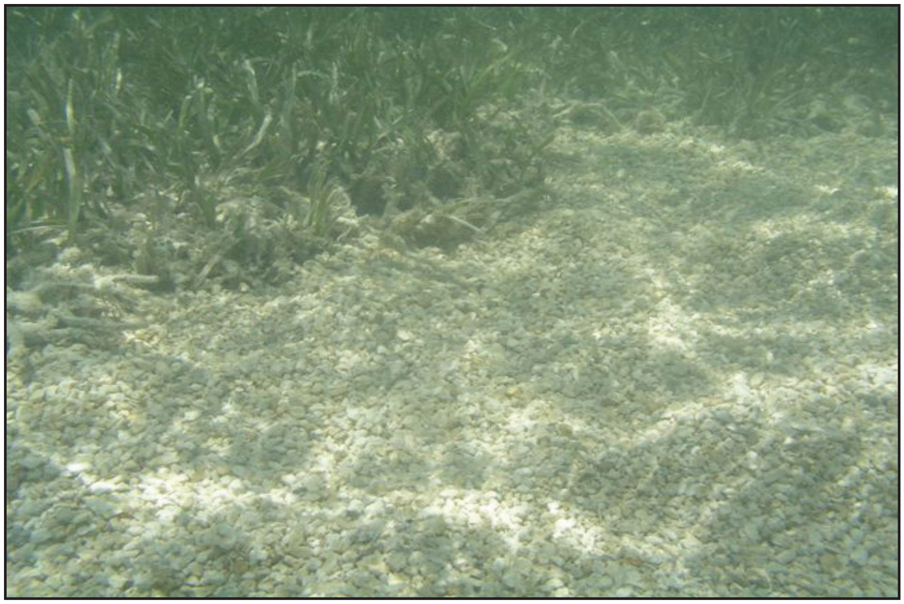


Figure 18.6. The addition of gravel to a grounding site in the Florida Keys levels the injury area to grade and provides a substrate conducive to seagrass recovery. Photo: A. Farrer.

The implementation of restoration projects would be incomplete without a process to monitor and evaluate their effectiveness. Restoration monitoring has been defined by Thayer et al. (2003) as "the systematic collection and analysis of data that provides information useful for measuring project performance at a variety of scales (locally, regionally, nationally), determining when modification of efforts is necessary, and building long-term public support for habitat protection and restoration." Quantitative long-term monitoring of restoration projects provides a unique opportunity to evaluate current projects, improve future projects, and validate and refine the predictive recovery and HEA models being developed. The consistent execution of such evaluative monitoring of coral reef restoration projects remains an important goal.

To improve socioeconomic valuation of injured natural resources and build public support, NOAA has also initiated a Community-Based Restoration Program (NOAA Restoration Center, http://restoration.noaa.gov/welcome.html, Accessed 02/09/05). Conservation and habitat restoration projects, such as those supported by this program, are intended to enhance partnerships at local, regional, and national levels. Projects in tropical coral reef ecosystems have included training volunteers to help recognize and stabilize vessel grounding injuries; establishing a community rapid biotic assessment team; establishing coral nurseries; removing commercial trap debris and derelict fishing gear from seagrass, coral reefs, and mangroves; and replanting mangroves (NOAA Restoration Center, http://restoration.noaa.gov/welcome.html, Accessed 02/09/05).

Figure 18.7. Hands-on learning about nearshore organisms with high school students in St. Thomas, USVI. Photo: N. Sbeih.

Improving outreach and education
Many outreach and education initiatives are reported in the jurisdictional chapters, often with specific personnel employed to increase public awareness of coral reef ecology and issues affecting the condition of coral reefs. Activities are largely aimed at visitors, local school children, and legislators, but also extend to fishing communities and other users of coral reef ecosystems (Figure 18.7).

NOAA's Coral Reef Conservation Program (CRCP) also continues to develop a collection of outreach and educational resources that are available on-line (CRCP, http://www.coralreef.noaa.gov/outreach/welcome.html, Accessed 02/04/05; Coral Health and Monitoring Program, http://www.coral.noaa.gov/cleo, Accessed 02/04/05).

Local action strategies

In 2002, the USCRTF adopted the Puerto Rico Resolution which calls for the development of three-year local action strategies (LAS) by each of the seven member states, territories, and commonwealths. These LAS are locally-driven roadmaps for collaborative and cooperative action among Federal, state, territory and non-governmental partners to identify and implement priority actions needed to reduce key threats to valuable coral reef resources.

The goals and objectives of the LAS are linked to those found in the U.S. National Action Plan to Conserve Coral Reefs. From the 13 goals identified in the Plan, the USCRTF prioritized six threat areas as the focus for immediate local action: overfishing, land-based sources of pollution, recreational overuse and misuse, lack of public awareness, climate change and coral bleaching, and disease. Additional focus areas were identified in some jurisdictions. Florida, Hawaii, Guam, the USVI, American Samoa, Puerto Rico, and the CNMI created specific LAS for locally relevant threats, using the six priority focus areas as a guide. Applying a collaborative decision-making process based on local needs, concerns, and capacities, each jurisdiction developed strategies containing a variety of projects to be implemented over a three-year period (Fiscal Years 2005-2007). For example, Guam has initiated a LAS for coral reef fishery management focusing on increasing the effectiveness of Guam's marine preserves.

The USCRTF is currently working with each jurisdiction to finalize and implement their LAS by inventorying opportunities; identifying resources, gaps, and needs; and seeking ways to increase funding and capacity support. (USCRTF, http://www.coralreef.gov/taskforce/las.html, Accessed 02/04/05).

Looking ahead

This report is the result of a tremendous amount of effort and coordination by the jurisdictional writing teams and attests to their dedication to conserving and protecting coral reef ecosystems throughout the United States and Pacific Freely Associated States. The information contained in the jurisdictional chapters demonstrates the considerable progress that has been made toward the major goals outlined in the NCRAS (2002) of better understanding coral reef ecosystems and reducing the adverse impacts of human activities.

Plans are to continue to improve the quality of future reports in this series through greater incorporation of quantitiative data and peer-reviewed publications. Many jurisdictions are now in position to track changes over time, using metrics that quantify coral reef ecosystem parameters associated with water quality, benthic habitats, and associated biological communities. The timing on development and publication of the next report in this series is under discussion between the USCRTF All Islands Committee and NOAA. In addition, discussions are underway on how to continue to improve the quality of the reports, increase efficiency of report production, and improve communications on the state of coral reef ecosystems based on the experience gained in the development of this report. For now, *The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005* provides the most comprehensive summary of the condition of coral reef ecosystems in the U.S. and Pacific Freely Associated States available, based on the collective efforts of the jurisdictional partners.

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