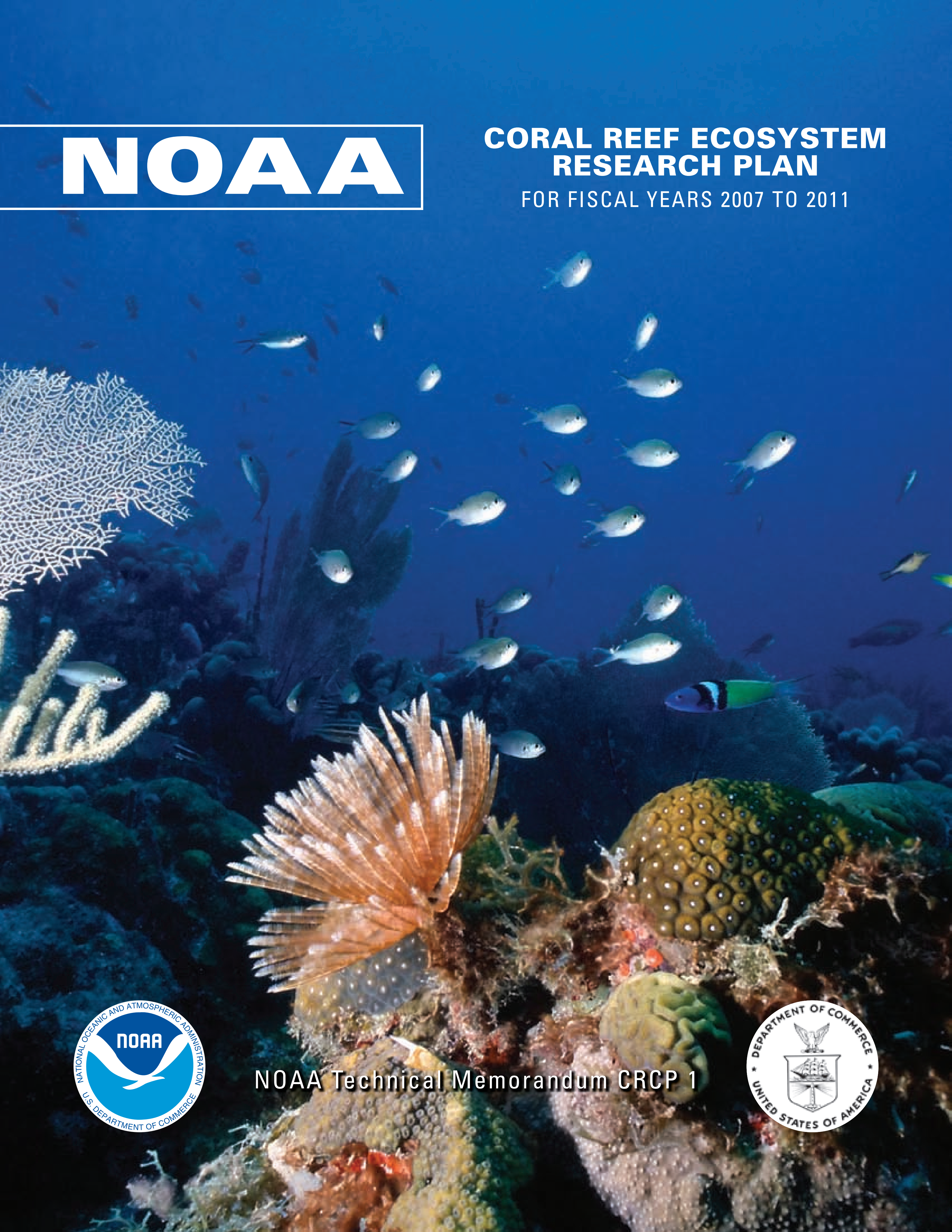
NOAA

CORAL REEF ECOSYSTEM RESEARCH PLAN

FOR FISCAL YEARS 2007 TO 2011



NOAA Technical Memorandum CRCP 1

CITATION:

Puglise, K.A. and R. Kelty (eds.). 2007. NOAA Coral Reef Ecosystem Research Plan for Fiscal Years 2007 to 2011. Silver Spring, MD: NOAA Coral Reef Conservation Program. NOAA Technical Memorandum CRCP 1. 128 pp.

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NOAA Coral Reef Ecosystem Research Plan
for Fiscal Years 2007 to 2011

K.A. Puglise and R. Kelty (eds.)

National Oceanic and Atmospheric Administration

January 2007

NOAA Technical Memorandum CRCP 1

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

We wish to express gratitude to all of the people, named and unnamed, who contributed to this Research Plan. This document truly represents the collective work of several individuals. In particular, thanks go to Andy Bruckner for the many hours spent helping edit the Plan, as well as providing several of the images; Steven Miller for getting the document started; Lynn Dancy for her insightful editing; Aurelie Shapiro for creating the maps; the many authors of *The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2002* and *2005* reports, whose text appears in several of the jurisdictional section's introductory paragraphs; Jenny Waddell for providing assistance with graphics and formatting; John Tomczuk for collecting and organizing the graphics; the Photo Contributors (listed below); the many reviewers who took the time to comment on the document; and most of all to the many individuals who went above and beyond the call of duty in coordinating, drafting, and editing the document – the Section Contributors (listed below). Please note: we have made every effort to ensure that this list is complete and apologize in advance if your name was inadvertently left off the list.

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Acronyms

BMPs... Best management practices
C.F.R.. Code of Federal Regulations
CNMI... Commonwealth of the Northern Mariana Islands
COTS... Crown-of-thorns starfish
CRCA... Coral Reef Conservation Act of 2000
DOI.. U.S. Department of the Interior
E.O.. Executive Order
EPA.. U.S. Environmental Protection Agency
FGBNMS...................................... Flower Garden Banks National Marine Sanctuary
FKNMS.. Florida Keys National Marine Sanctuary
F.R... Federal Register
FSM... Federated States of Micronesia
FWS... U.S. Fish and Wildlife Service
FY... Fiscal year
GIS... Geographic information system
GPRA... Government Performance and Results Act of 1993
HAPC... Habitat Area of Particular Concern
MCD.. Marine Conservation District
MHI... Main Hawaiian Islands
MPA... Marine protected area
NBSAP... National Biodiversity Strategy and Action Plan
NOAA.. National Oceanic and Atmospheric Administration
NWHI.. Northwestern Hawaiian Islands
NWR.. National Wildlife Refuge
PAR.. Photosynthetically active radiation
PRIAs... U.S. Pacific Remote Insular Areas
SPAs.. Sanctuary Preservation Areas
U.S.C... United States Code
USCRTF....................................... United States Coral Reef Task Force
USVI.. U.S. Virgin Islands
UV.. Ultraviolet radiation

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Introduction

Figure 1. School of reef fish at Rapture Reef (French Frigate Shoals, Northwestern Hawaiian Islands). Photo credit: James Watt.

Coral reef ecosystems are highly valued for their biological, ecological, cultural, and economic resources, as well as their aesthetic qualities (Figure 1). Worldwide, coral reef ecosystems provide over $30 billion in annual goods and services (Cesar et al. 2003) and yet cover less than 1% of the earth's surface. Annual goods and services provided by coral reef ecosystems include renewable and non-renewable resources, coastline protection, increased property values, tourism, and marine natural products.

Within the United States, the economic contribution of coral reef ecosystems has been calculated for Hawaii (Figure 2), southeast Florida, American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands. In the Main Hawaiian Islands, coral reefs were estimated to provide annual economic benefits of over $360 million, 85% of which was directly attributed to recreation and tourism (Cesar et al. 2002). In the four-county area of southeast Florida (Palm Beach, Broward, Miami-Dade, and Monroe Counties), artificial and natural reefs supported 28.3 million person-days of recreational diving, fishing, and viewing activities and generated approximately $4.4 billion in local sales, almost $2 billion in local income, and 71,300 full- and part-time jobs (Johns et al. 2001). In American Samoa, where tourism is low, the annual economic value was estimated to be $5 million for coral reef ecosystems and $1 million for mangrove ecosystems (JacobsGIBB Ltd. 2004).

In the past few decades, competing demands on coral reef ecosystems and increasing threats from both natural and anthropogenic stressors, including fishing, pollution, coastal uses (e.g., land and water development and recreational use), invasive species (Figure 3), climate change, and extreme events (e.g., harmful algal blooms and disease), have contributed to a significant decline in coral reef ecosystem health (Wilkinson 2000, 2002). In response to the documented worldwide decline of coral reef ecosystems and in order to preserve and protect the biodiversity, health, heritage, and social and economic

*An **ecosystem** is a geographically specified system of organisms, the environment, and the processes that control its dynamics. Humans are an integral part of an ecosystem.*

value of U.S. coral reef ecosystems, the U.S. took two key actions:

(1) On June 11, 1998, President William Jefferson Clinton issued Executive Order 13089: Coral Reef Protection (E.O. 13089), which set forth policies to enhance the role of Federal agencies in coral reef conservation and established the U.S. Coral Reef Task Force (USCRTF), an interagency group consisting of twelve Federal agencies and governors from seven states, territories, and commonwealths.

(2) On December 23, 2000, the U.S. Congress enacted the Coral Reef Conservation Act of 2000 (CRCA; 16 U.S.C. 6401 et seq.). The CRCA authorized the Secretary of Commerce to establish a national program and conduct mapping, monitoring, assessment, restoration, scientific research, and other activities benefiting the understanding, sustainable use, and long-term conservation of coral reef ecosystems.

As authorized by the CRCA, the Secretary of Commerce established the National Oceanic and Atmospheric Administration (NOAA) Coral Reef Conservation Program to carry out the mandates laid out in the CRCA and the guidelines set forth in E.O. 13089, including supporting effective ecosystem-based management and sound science to preserve, sustain, and restore the condition of coral reef ecosystems. The NOAA Coral Reef Conservation Program is implemented by four NOAA line offices – the National Ocean Service, the National Marine Fisheries Service, the National Environmental, Satellite, and Data Information Service, and the Office of Oceanic and Atmospheric Research.

Figure 2. Raccoon butterflyfish, Chaetodon lunula*, among coral,* Porites *spp. (Hawaii). Photo credit: Andy Bruckner, NOAA Fisheries.*

Working with USCRTF partner agencies, non-governmental organizations, and other stakeholders, the NOAA Coral Reef Conservation Program developed both a national plan and a national strategy to conserve coral reefs in response to E.O. 13089 and the CRCA. In March 2000, the USCRTF's ***National Action Plan to Conserve Coral Reefs*** (National Action Plan) was adopted as the first national blueprint for U.S. action to address the loss and degradation of coral reef ecosystems (USCRTF 2000). In June 2002, NOAA, in collaboration with USCRTF members, published ***A National Coral Reef Action Strategy*** (National Action Strategy) as required by the CRCA to provide information on major threats and needs, identify priority actions needed to achieve the goals outlined in the National Action Plan and the CRCA, and track progress in achieving these goals and objectives (NOAA 2002a). Regarding research, the National Action Strategy identified two necessary actions: (1) conduct strategic research to provide critical information on the underlying causes of reef decline; and (2) increase the understanding of the social and economic factors of conserving coral reefs.

CORAL REEF RESEARCH PLANNING IN NOAA

NOAA is a science-based agency serving a large and diverse community of users and stakeholders in the United States and abroad. Earth system variability is dynamic and occurs at local, regional, and global levels, as well as multiple time scales from minutes to decades and longer. The goal of NOAA's research is to identify and improve the measurement of these many variables; to advance understanding of the physical, chemical, and biological processes in the atmosphere, oceans, and land-surface; and to enable predictions of future events and changes. The expertise needed to do this research encompasses many disciplines; therefore, the research approach must be interdisciplinary and must integrate the study of the natural environment with human activities and societal needs.

NOAA supports internal research to respond to immediate research needs, including those required by legislative and judicial mandates, to sustain long-term monitoring and modeling capabilities, and to ensure that research is forward-looking and responsive to programmatic

Figure 3. The orange cup coral, Tubastrea coccinea*, a native to the Indo-Pacific, has been recorded in Florida waters growing on steel structures. To date, the alien coral has not been documented as invasive, however, very little is known regarding its distribution and abundance in the western Atlantic. Photo credit: Andy Bruckner, NOAA Fisheries.*

needs. While the agency maintains and relies on internal expertise in coastal and ocean sciences, NOAA also relies on external research partners to complement and augment NOAA's internal research capabilities, to provide critical expertise in areas not fully represented inside the agency, and to share new ideas and technologies. NOAA's research partnerships engage other Federal agencies; academia; the private sector; state, territorial, commonwealth, local, and tribal governments; and the international community; and are critical to ensuring that decision-making by resource managers, Congress, and others is based on the best available science.

NOAA has identified research as a major cross-cutting priority in the *NOAA Strategic Plan*, demonstrating its firm commitment to support high-quality research as the underpinning of its environmental assessment, prediction, and ecosystem management missions (NOAA 2005c*)*. Research is the cornerstone on which to build and improve ecosystem-based management and resource management decisions. Research planning and prioritization are key steps to address the information needs of NOAA's users as indicated in both the five-year *NOAA Research Plan* (NOAA 2005a) and the 20-year *NOAA Research Vision* (NOAA 2005b).

This document – the *NOAA Coral Reef Ecosystem Research Plan* – builds on the strategies identified in *NOAA's Strategic Plan*, the five-year *NOAA Research Plan*, the 20-year *NOAA Research Vision*, the National Action Plan, the National Action Strategy, the *Final Report of the U.S. Commission on Ocean Policy* (USCOP 2004), and the Bush Administration's response to the U.S. Commission on Ocean Policy: the *U.S. Ocean Action Plan* (Bush 2004) ; and identifies key directions for NOAA's research on coral reef ecosystems for fiscal years (FY) 2007 through FY 2011. As this Plan only covers five years, it is intentionally focused on research with short-term outcomes of providing coastal and ocean managers with scientific information and tools to help preserve, sustain, and restore coral reef ecosystems. This five-year Plan will also be used as a tool to identify longer-term coral reef research directions.

It is important to note that the majority of coral reefs in the U.S. and Pacific Freely Associated States (i.e., Republic of Palau, Republic of the Marshall Islands, and the Federated States of Micronesia) are not managed solely by NOAA. The primary managers for U.S. coral reefs include state, territorial, and commonwealth government agencies

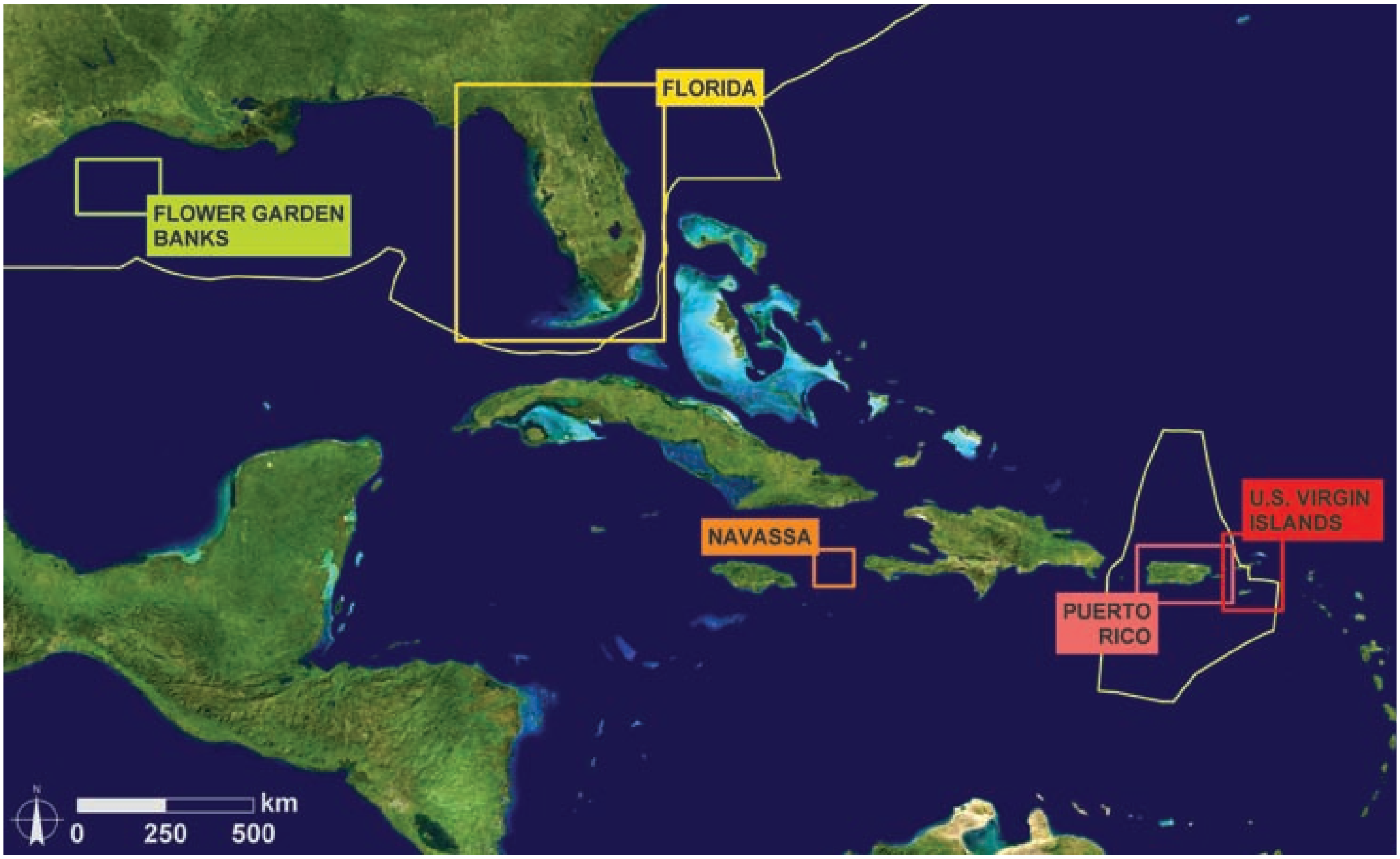


Figure 4. A map depicting the location of U.S. coral reef ecosystems in the Atlantic Ocean, the Gulf of Mexico, and the Caribbean Sea. Map: A. Shapiro. Source: Waddell (2005).

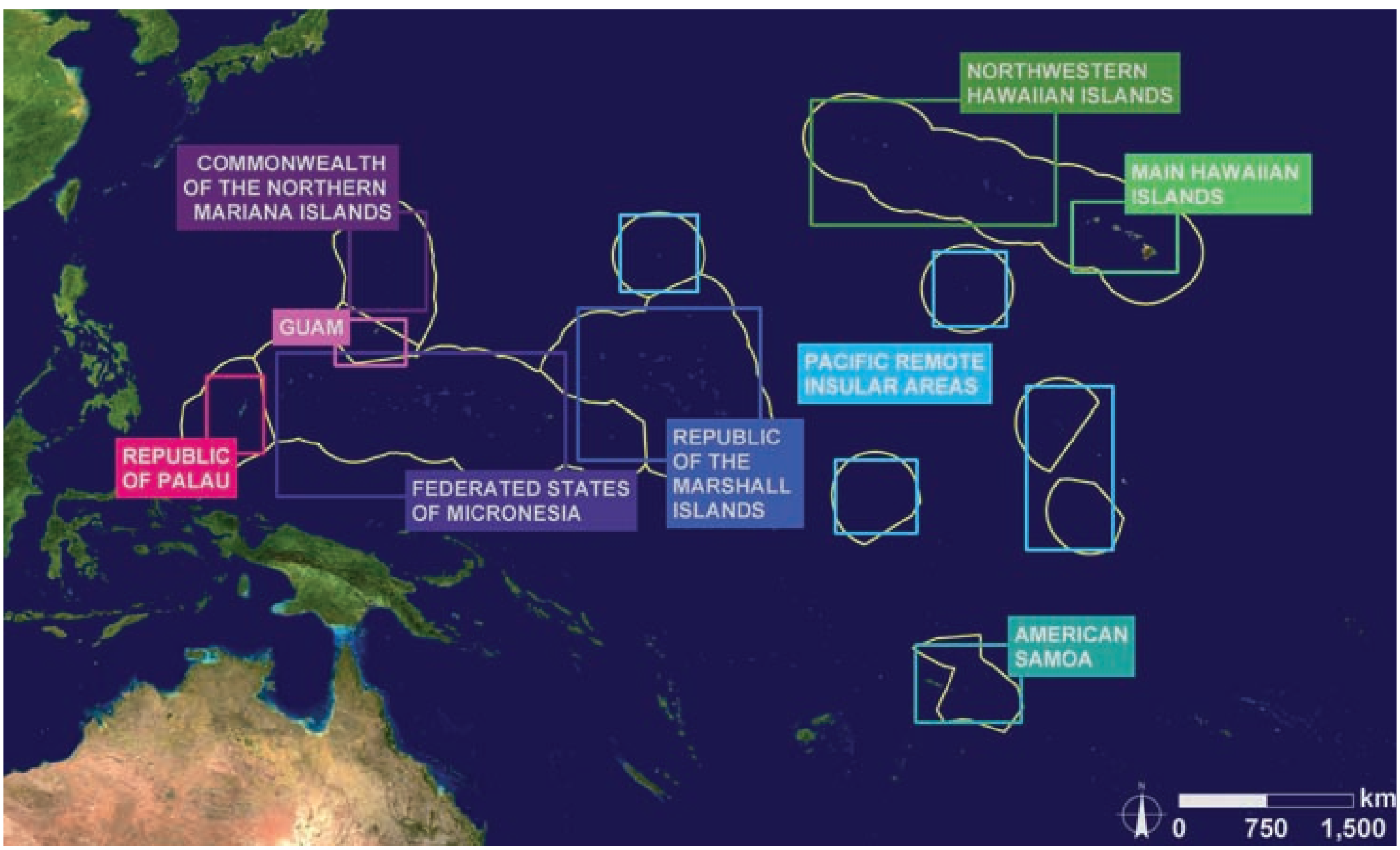


Figure 5. A map depicting the location of U.S. coral reef ecosystems in the Pacific Ocean. Map: A. Shapiro. Source: Waddell (2005).

in Florida, Puerto Rico, the U.S. Virgin Islands, Hawaii, Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands; and several Federal agencies, including the U.S. Fish and Wildlife Service (FWS), the National Park Service, the U.S. Department of Defense, and NOAA. It is not the intent of this Plan to pre-empt any existing management authorities. As the responsibility for managing coral reefs falls on numerous agencies, it is of utmost importance that NOAA works with the primary managers to identify research priorities and coordinate, communicate, and conduct collaborative research projects for which results can be directly incorporated into existing management plans or used as a basis to make major revisions to management plans. Without this type of coordination, coral reef ecosystem research may not target the information needs of resource managers or support the furthering of an ecosystem approach to management.

PURPOSE

The purpose of the NOAA Coral Reef Ecosystem Research Plan is to identify priority research needs and guide NOAA-funded coral reef ecosystem research for FY 2007 through FY 2011, including research conducted through extramural partners, grants, and contracts. The Plan is also designed to be a resource to other non-NOAA entities that fund and/or conduct research in coral reef ecosystems. This Plan is intended to be a flexible, evolving document that allows new requirements for research to be addressed as appropriate. Annual implementation plans will allow refinement of the research needs identified in this Plan to further focus limited research funds, respond to emerging issues and changing priorities, and take advantage of technologies developed during the next five years.

SCOPE

The NOAA Coral Reef Ecosystem Research Plan covers all shallow coral reef ecosystems under the jurisdiction of the United States and the Pacific Freely Associated States (Table 1; and Figures 4 and 5); and is written for a broad audience, including resource managers, scientists, policymakers, and the public.

This Research Plan addresses the USCRTF focus areas – land-based pollution, overfishing, recreational overuse and misuse, climate change and coral bleaching, and coral disease – identified at the eighth meeting of the USCRTF on October 2 to 3, 2002 in San Juan, Puerto Rico (USCRTF 2002), as well as other priority threats to coral reef ecosystems – destructive fishing practices, invasive species, other coastal uses, and extreme events. The Plan's research needs were developed based on recommendations from workshop reports, technical reports, peer-reviewed articles, and direct input and review by the representative government agencies and governments of the USCRTF, coral reef managers, scientists, and other key stakeholders. (See ***References*** and ***Appendix A: Additional Supporting Documents*** for a list of documents that were used to prepare this Research Plan. For information on the process used to develop the Research Plan see ***Appendix B: Developing the Research Plan***.)

This plan identifies research needs to improve the management of tropical and sub-tropical coral reef ecosystems including mangroves, seagrasses, and hard bottom communities, and warm water, light-dependent, hermatypic deep water shelf and slope corals that are typically found between 50 to 100 meters (m). Coral reef ecosystems, as defined in 16 U.S.C. 6409, are corals

Table 1. Regions covered by the NOAA Coral Reef Ecosystem Research Plan.

Atlantic	Pacific

Florida
   Florida Keys
   Southeast Florida
   Eastern Gulf of Mexico (West Florida Shelf)
Flower Garden Banks
Puerto Rico
U.S. Virgin Islands
Navassa Island
	The Hawaiian Islands
	   Main Hawaiian Islands
	   Northwestern Hawaiian Islands
	Commonwealth of the Northern Mariana Islands
	Guam
	American Samoa
	U.S. Pacific Remote Insular Areas
	Pacific Freely Associated States
	   Republic of the Marshall Islands
	   Republic of Palau
	   Federated States of Micronesia

Figure 6. Diver amongst a stand of staghorn corals, Acropora cervicornis*. Photo credit: NOAA's Undersea Research Program.*

and other species of reef organisms (including reef plants) associated with coral reefs and the non-living environmental factors that directly affect coral reefs, that together function as an ecological unit in nature (Figure 6). The following topics are not included in this Research Plan:

- *Deep-Sea Coral Ecosystems:* This Research Plan does not identify research needs for deep-sea coral ecosystems; however, it does recognize the importance of deep-sea coral ecosystems and the need for further research to better understand these ecosystems. Deep-sea coral ecosystems (also referred to as cold-water coral ecosystems) occur deeper than 50 m and often consist of both reef-like structures and/or thickets, other species of organisms associated with these deep-sea coral habitats, and the non-living environmental factors that directly affect deep-sea corals, that together function as an ecological unit in nature (Puglise et al. 2005). Deep-sea corals are not light dependent and do not contain symbiotic algae. *Note: Deep-sea coral ecosystem research priorities will be identified in a separate document.*

- *International Research Priorities:* This Research Plan does not identify research needs for NOAA-supported research on international coral reef ecosystems. However, it does recognize the importance of developing an active dialogue and coordinating research activities with other international efforts so that research findings can be effectively compared with other programs and locations.

- *State of the Coral Reef Ecosystems:* This Research Plan does not review the current state of knowledge on reef condition for each region, except as it applies to specific management objectives and research needs. For information on the status and trends of coral reef ecosystems, refer to the report entitled *The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2005* (Waddell 2005).

CORAL REEF RESEARCH PLAN FRAMEWORK

The NOAA Coral Reef Ecosystem Research Plan is presented in two sections: (1) Part I: National Priorities; and (2) Part II: Regional Priorities (Table 2).

Part I is national in scope and identifies: (1) the role of research in management, including a review of the major stressors and threats facing coral reef ecosystems and an overview of stressor-associated research priorities;

(2) the role of mapping and monitoring in management-driven research programs; (3) a discussion of the tools and technologies necessary to conduct research and to manage ecosystems (e.g., marine protected areas [MPAs] and habitat restoration); (4) a discussion of the importance of transferring science and technology into operations; and (5) the importance of using targeted outreach and education to translate research results to improve management decisions.

Part II is regional in scope and reviews the major stressors for coral reef ecosystems in each region under the jurisdiction of the U.S. and the Pacific Freely Associated States, and identifies key management objectives specific to each region and the research needed to help address the stated management objectives. The discussions of individual jurisdictions in Part II include a list of specific management objectives followed by linked research needs. Several of the identified research needs are national in scope and have been identified in a ***Jurisdiction-Wide*** section in Part II, whereas the individual regional sections identify research needs that are ***Jurisdiction-Specific***. A stand-alone research plan for each region would include both the national and regional research needs.

EVALUATING SUCCESS

Measuring performance and effectively communicating results is critical. Research activities supporting the NOAA Coral Reef Ecosystem Research Plan must include performance measures that are linked to defined management objectives, along with mechanisms to ensure accountability and high quality, including rigorous and independent peer-review procedures.

NOAA is a mission-driven agency with stewardship responsibilities for marine living resources. The activities conducted by NOAA, as well as other Federal agencies, are driven by requirements (e.g., legal mandates, E.O.s, and treaties) and performance measures (i.e., activities are evaluated as required by the Government Performance and Results Act of 1993 [GPRA] and the Office of Management and Budget's Program Assessment Rating Tool). The primary and secondary requirement drivers for the NOAA Coral Reef Ecosystem Research Plan are listed below and detailed in Appendix C:

Table 2. Framework of the NOAA Coral Reef Ecosystem Research Plan.

PART I: National Research Priorities	PART II: Regional Research Priorities
◊ Research Supporting Management ⦿ Fishing ⦿ Pollution ⦿ Coastal Uses ⦿ Invasive Species ⦿ Climate Change ⦿ Extreme Events ◊ Technology Supporting Research and Management ⦿ Marine Protected Areas ⦿ Habitat Restoration ◊ Transferring Science and Technology into Operations ◊ Outreach and Education: Translating Research, Improving Management	◊ Jurisdiction-Wide Research Needs ◊ Jurisdiction-Specific Research Needs – Atlantic Ocean ⦿ Florida ♦ Florida Keys ♦ Southeast Florida ♦ Eastern Gulf of Mexico (West Florida Shelf) ⦿ Flower Garden Banks ⦿ Puerto Rico ⦿ U.S. Virgin Islands ⦿ Navassa Island ◊ Jurisdiction-Specific Research Needs – Pacific Ocean ⦿ The Hawaiian Islands ♦ Main Hawaiian Islands ♦ Northwestern Hawaiian Islands ⦿ Commonwealth of the Northern Marina Islands ⦿ Guam ⦿ American Samoa ⦿ U.S. Pacific Remote Insular Areas ⦿ Pacific Freely Associated States ♦ Republic of the Marshall Islands ♦ Republic of Palau ♦ Federated States of Micronesia

Primary Requirements:

- CRCA (16 U.S.C. 6401 et seq.)
  - National Coral Reef Action Strategy (2002)
  - The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States (2002, 2005)
- E.O. 13089: Coral Reef Protection (1998)
  - National Action Plan to Conserve Coral Reefs (2000)
  - USCRTF Local Action Strategies (2005-2007)
- Magnuson-Stevens Fisheries Conservation and Management Act, as amended by the Sustainable Fisheries Act (16 U.S.C. 1801 et seq.)
- National Marine Sanctuaries Act (16 U.S.C. 1431 et seq.)
- E.O. 13178: Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve (2000)
- E.O. 13196: Final Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve (2001)
- Presidential Proclamation: Establishment of the Northwestern Hawaiian Islands Marine National Monument (2006)

Secondary Requirements:

- Coastal Zone Management Act (16 U.S.C. 1451 et seq.)
- Endangered Species Act (16 U.S.C. 460 et seq.)
- E.O. 13112: Invasive Species (1999)
- E.O. 13158: Marine Protected Areas (2000)
- GPRA (31 U.S.C. 1115 et seq.)
- Marine Mammal Protection Act (16 U.S.C. 1361 et seq.)
- Marine Turtle Conservation Act of 2004 (16 U.S.C. 6601 et seq.)

Links to the NOAA Strategic Plan

The NOAA Coral Reef Ecosystem Research Plan links to the following *NOAA Strategic Plan* outcomes and objectives for the Ecosystem Mission Goal, for which the NOAA Coral Reef Conservation Program activities are directed towards achieving:

Ecosystem Goal Outcomes

- Healthy and productive coastal and marine ecosystems that benefit society.
- A well-informed public that acts as steward of coastal and marine ecosystems.

Ecosystem Goal Objectives

- Increase number of fish stocks managed at sustainable levels.
- Increase number of protected species that reach stable or increasing population levels.
- Increase number of regional coastal and marine ecosystems delineated with approved indicators of ecological health and socioeconomic benefits that are monitored and understood.
- Increase number of invasive species populations eradicated, contained, or mitigated.
- Increase number of habitat acres conserved and restored.
- Increase portion of the population that is knowledgeable of and acting as stewards for coastal and marine ecosystem issues.
- Increase number of coastal communities incorporating ecosystem and sustainable development principles into planning and management.

The NOAA Coral Reef Conservation Program outcomes that contribute to achieving NOAA's Ecosystem Goal outcome and objectives are:

NOAA Coral Reef Conservation Program Outcomes

- The impacts of climate change and coral disease are understood and approaches to enhance coral reef resiliency are developed and implemented.
- Direct physical impacts from maritime industry and natural/non-natural hazards are reduced.
- Impacts from coastal uses and land-based activities are reduced.
- Overfishing in coral reef ecosystems is reduced and other adverse impacts from commercial and recreational fishing are minimized.

Research is not intended to meet the NOAA Strategic Plan and the NOAA Coral Reef Conservation Program outcomes and objectives alone. Rather, research serves as a mechanism to help meet the aforementioned outcomes and objectives. Successful research supported by NOAA will provide information that improves the understanding of coral reef ecosystem function and condition, including the factors (i.e., stressors and natural variability) that determine that condition, and supports development and evaluation of tools and approaches to assess the ecological and economic impacts of stressors, reduce stressors, and restore reefs.

Part I: National Research Priorities

School of Hawaiian squirrelfish (French Frigate Shoals, Northwestern Hawaiian Islands). Photo credit: James Watt.

Coral resource managers should have the most up-to-date scientific information to facilitate management of the resources under their purview. The intent of this Research Plan is to guide the full suite of NOAA's coral reef ecosystem research capabilities, both internal and external, toward meeting this challenge within the context of limited resources.

Importance of Mapping and Monitoring

Sound management of coral reef ecosystems requires scientifically-based information on their status (or condition), the causes and consequences of that condition, forecasts of their future condition, and the costs and benefits of possible management actions to maintain or improve their condition. Even more fundamental is the identification and characterization of each coral reef ecosystem, including the physical location (boundaries), spatial extent, physical and biological characteristics, and characterization of the social and human aspects of coral reef ecosystems. Baseline information on the economic, cultural, institutional, and social values, as well as human use patterns, of coral reef ecosystems should be determined. Because coral reef ecosystems are dynamic, even in their physical attributes, continuous research is required to quantify changes and understand the processes and rates at which they occur. Thus, the map products (mapping) and long-term data collections (monitoring) necessary for sound management decisions are as much a part of the research agenda as the quantitative analyses applied to these products.

Mapping and monitoring provide information fundamental to understanding the history, current state, and future condition of coral reef ecosystems and are cornerstones to ecosystem-based management. Long-term monitoring also provides data to allow a rigorous evaluation of whether or not management programs are working. Historically, monitoring programs have focused on determining the condition of ecologically or economically important species and/or specific habitat types (e.g., emergent reefs) by documenting a combination of static (e.g., cover and abundance at a point in time) and process-oriented (e.g., recruitment, growth, and condition) parameters. Surveys have also recorded the presence and abundance of major corallivores or coral predators (e.g., crown-of-thorns starfish [COTS]) and herbivores (e.g., sea urchins). The development of an ecosystem approach to management will require that programs expand their scope to address the broadest set of management issues across multiple habitat types, including defining the 'natural' ecosystem or what is considered normal, documenting change and environmental conditions (e.g., in situ sea surface temperature, photosynthetically active radiation [PAR], and ocean color), evaluating the effects of environmental stressors, identifying the causes of decline, and analyzing human populations and their use (or non-use) of coral reef ecosystems. An ecosystem approach to management requires knowledge of the natural ecosystem, including the guilds or trophic levels that are normally present and interactions between these; how communities may vary with latitude, season, and geomorphology; what environmental variables define community composition; as well as an understanding of processes and outcomes necessary for sustainability, including the role of surrounding ecosystems.

Mapping and monitoring efforts are most useful when data are integrated at the appropriate spatial and temporal scales and aligned closely with process-oriented research designed to help understand the causes of spatial and temporal variability and change. Additionally, better coordination of mapping, monitoring, and research projects among NOAA, other Federal, state, territorial, commonwealth, and local agencies, coral resource managers, and local reef specialists would allow for the maximum amount of information to be obtained from a single sample or endeavor and increase coverage by reducing overlap among monitoring programs.

Coral reef ecosystems and individual reefs can vary over space (spatially) and time (temporally). Therefore, monitoring programs need to consider: (1) the spatial resolution necessary to document the spatial mosaic defining coral reef ecosystems (e.g., across multiple habitat types moving from nearshore to offshore, among and within reefs, and across depths); (2) the sampling frequency needed to try to understand the causes of ecosystem change; and (3) the variety of data required to make management decisions. Sampling frequency for monitoring programs usually ranges from rapid assessments conducted over relatively short time scales of days and weeks that characterize broad patterns of community structure or episodic and unpredictable events (e.g., physical damage caused by ship groundings or storms, or biological events such as coral disease and coral bleaching) to monitoring that occurs repetitively at the same location(s) over many years.

Figure 7. Tiger grouper, Mycteroperca tigris*, on a star coral colony,* Montastraea franksi *(Flower Garden Banks National Marine Sanctuary). Groupers are harvested Caribbean-wide and in the U.S. The tiger grouper is included under the Grouper Snapper Fishery Management Plan for Federal waters, although there is no specific fishery targeting this species. Photo credit: Andy Bruckner, NOAA Fisheries.*

Decisions about what and when to monitor should be based on the management and scientific questions being asked. Both short-term (less than five years) and long-term (greater than five years) assessments are needed to understand ecosystem variation. For example, short-term monitoring programs intended to provide early warning of coral reef ecosystem changes and document the status of economically and ecologically important reef species (Figure 7). Short-term assessments can document acute changes impacting coral condition, such as El Niño Southern Oscillation events and coastal development (e.g., dredging and beach renourishment projects). Long-term assessments document changes caused by factors that operate at decadal scales, such as the influence of declining fish stocks, as well as the potential impacts of increasing atmospheric carbon dioxide and the potential associated temperature increases.

When linked to targeted research programs, mapping and monitoring programs can improve identification and understanding of threats to coral reef ecosystems by providing baseline characterizations of coral condition and habitat, as well as contributing to solving high priority management issues. Additionally, characterizing and monitoring economic, demographic, and institutional changes may also help resource managers anticipate impacts from anthropogenic influences on coral reef ecosystems. Mapping and monitoring efforts record change and the condition of the resource, and characterize the societal aspects of the resource; while research examines the causes and predicts the impacts of changes on the condition of the resource. The ability to ascribe declines in ecosystem condition to a stressor is often confounded by the fact that stressors often act synergistically. In situations like these, it is important for research to be conducted in tandem with monitoring programs to try to understand the causes of ecosystem decline.

NOAA is committed to working with its partners to support a long-term environmental monitoring program and the mapping of all U.S. shallow-water coral reefs and associated ecosystems. This commitment addresses the USCRTF goal to develop and implement a nationally coordinated, long-term program to inventory, assess, and monitor U.S. coral reef ecosystems. NOAA monitoring and mapping efforts should be coordinated with partners from Federal, state, territory, commonwealth, and local government agencies; non-governmental organizations; and academia to minimize duplication and maximize data collection. NOAA coral monitoring efforts represent a small part of the growing national coastal monitoring network.

RESEARCH SUPPORTING MANAGEMENT

The condition of ecosystems is impacted by the singular or combined effects of five stressors: land and resource use (herein referred to as fishing and coastal uses), climate change, pollution, extreme events, and invasive species (OSTP 2001). Interactions between these stressors, as well as natural variability over space and time can also be involved in determining ecosystem condition. These generalizations are applicable to coral reef ecosystems, and it is the goal of NOAA's coral reef ecosystem research to provide sound science to enable effective ecosystem-based management by identifying the stressors affecting ecosystem condition, determining the processes by which they affect ecosystems, identifying their short- and long-term impacts, identifying strategies to mitigate these impacts, and forecasting future ecosystem conditions with and without management intervention. It is the intent of the NOAA Coral Reef Ecosystem Research Plan to identify priority research needs for NOAA-supported coral reef ecosystem research for FY 2007 through FY 2011. Research priorities are based on management-driven information needs as identified by resource managers, scientists, and other key stakeholders.

Conservation and management of coral reefs require a multidisciplinary approach that acknowledges the complexity and multiple dimensions of coral reef ecosystems (e.g., anthropogenic, ecological, and biological) and their dynamic nature, and the need for cooperatively implementing management measures, as management responsibility for coral reef ecosystems often crosses local, commonwealth, territory, state, Federal, and international jurisdictions. Therefore, maintaining healthy coral reef ecosystems requires a balance between not only ecological functions, but the many different types of human uses of those ecosystems.

Conservation and management of coral reefs also requires recognition that coral reef ecosystems are one piece of much larger marine ecosystems. Within NOAA, ecosystem research and management activities are organized into eight regional ecosystems adjacent to the U.S. coasts (i.e., Northeast Shelf, Southeast Shelf, Caribbean, Gulf of Mexico, Great Lakes, California Current, Alaska, and Pacific Islands). These eight regional ecosystems in turn link into other larger marine ecosystems. For example, the Gulf Stream current links the coral reef ecosystems of the Southeast U.S. to those of the Caribbean and Gulf of Mexico.

Coral reef ecosystem protection and conservation require a strong legal framework that provides managers with a variety of tools, including zoning ordinances, permit programs, water quality criteria and standards, management plans, regulations, and enforcement capabilities that operate across multiple jurisdictions. A strong legal framework will require Federal, state, territory, commonwealth, and local government agencies to coordinate and commit to conducting mapping, monitoring, and research, as well as implementing management measures, cooperatively. This framework should also take into consideration traditional and customary management practices of the U.S. Pacific Islands in revitalization and identification of resource use practices to garner the support of the indigenous communities. Policymakers and the public are also an integral part of the management process.

Understanding societal views and processes and their affects on coral reef ecosystem condition is integral to improving management of coral reef resources. Examples of dynamic societal processes that may have far-reaching impacts on coral reef ecosystems include rapid population growth, global movements of humans, the mixing of cultures and loss of traditional cultural integrity, globalization of economies, and advances in technology. The role of social science in coral reef ecosystem management is to improve the understanding of these changing societal processes by determining how society is currently choosing to use coral reef ecosystems and estimating the social and economic costs and benefits of those uses from an ecosystem perspective, including the biological costs and benefits to the resource associated with these uses. Social science research could also help characterize attitudes, perceptions, and beliefs within different segments of the population and examine how these factors influence human behaviors related to both the use and conservation of coral reef ecosystems.

Traditionally, coral reef ecosystem research has focused on the impacts that human activities have on the ecosystem as measured by one or more environmental metrics. While we are beginning to understand the ecology of these systems more fully, Federal, state, territory, and commonwealth management agencies still lack information on the social, cultural, and economic aspects of coral reef ecosystems. For example, economic valuation of annual and net benefits of goods and services provided by U.S. coral reef ecosystems are key needs for managers to show the importance of the resource in economic terms. Yet economic valuations have only been completed for the four-county area of southeast Florida – Palm Beach, Broward, Miami-Dade and Monroe counties (Johns et al. 2001), the Main Hawaiian Islands (Cesar et al. 2002), American Samoa (JacobsGIBB Ltd 2004), Guam (van Beukering et al. 2006a), and Commonwealth of the Northern Mariana Islands (van Beukering et al. 2006b). This critical information gap jeopardizes the nation's ability to make science-based decisions that include the human environment, as well as the natural environment.

Research of both natural and physical sciences needs to be integrated with socioeconomic research to develop management actions that are compatible with the resources and their users. Many factors contribute to change in coral reef ecosystems (Table 3), but it is difficult to ascribe widespread decline to single factors locally or regionally because stressors can vary in occurrence and severity across regions and sometimes from reef to reef and have possible cumulative and synergistic impacts. The complexity of interactions among stressors that affect coral reefs makes it difficult to sort out the primary stressors responsible. The coral reef ecosystem decline now being witnessed is due to the integrated consequences of many stressors.

The next sections summarize the major threats to coral reef ecosystems as identified by the USCRTF, and identifies key national-level research priorities. The major threats discussed are: fishing, pollution, coastal uses, invasive species, climate change, and extreme events. These categories parallel research categories found in Part II of this Plan.

Key Socioeconomic Research Questions for Coral Reef Ecosystems:

- *Who are the users of coral reef ecosystems?*
- *What are the social and economic uses of coral reef ecosystems?*
- *What are the social and economic costs and benefits of those uses?*
- *What are the impacts of social and economic uses to these ecosystems?*
- *What are the relationships between uses and a series of environmental metrics?*
- *What are the interactions between human use activities in coral reef ecosystems?*
- *How do societal reactions to changes in coral reef ecosystems impact human behavior and how do these behavioral changes affect the coral ecosystem?*
- *How do different laws and policies influence human use and protection of coral reef ecosystems?*
- *In what ways do local knowledge and scientific information influence how adjacent communities use and protect coral reef resources?*
- *What impacts do changing human demographics have on coral reef ecosystems?*
- *What (non-monetary) values does society hold or assign to coral reef ecosystems?*
- *How well do people understand coral reef ecosystems (biological and physical elements, scarcity, and sensitivity)?*

		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	Orange	Red	Red	Red	Red	Orange	Red	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Yellow	14	↑
	2004	Orange	Red	Red	Red	Red	Red	Red	Yellow	Red	Orange	Yellow	Yellow	Yellow	Yellow	16	
Puerto Rico	2002	Orange	Red	Yellow	Red	Red	Orange	Red	Red	Orange	Orange	Yellow	Red	Yellow	Red	18	↓
	2004	Orange	Orange	Orange	Red	Orange	Orange	Red	Orange	Orange	Yellow	Yellow	Yellow	Yellow	Yellow	11	
Navassa	2002																N/A
	2004	Yellow	Orange	Orange	Yellow	Yellow	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	4	
Florida	2002	Red	Red	Orange	Red	Red	Orange	Red	Orange	Red	Orange	Orange	Yellow	Yellow	Yellow	17	↑
	2004	Red	Red	Orange	Red	Red	Orange	Red	Orange	Red	Orange	Orange	Yellow	Yellow	Orange	18	
Flower Gardens Banks	2002	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Orange	Yellow	Orange	Yellow	Orange	Yellow	3	↑
	2004	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Orange	Yellow	Orange	Yellow	Orange	Yellow	Orange	Yellow	4	
MHI	2002	Yellow	Yellow	Yellow	Red	Red	Red	Red	Red	Red	Orange	Red	Orange	Yellow	Orange	17	-
	2004	Orange	Orange	Yellow	Red	Red	Red	Red	Red	Orange	Orange	Red	Orange	Yellow	Yellow	17	
NWHI	2002	Yellow	Yellow	Yellow	Yellow	Yellow	Orange	Orange	Orange	Red	Red	Red	Yellow	Yellow	Yellow	9	↓
	2004	Orange	Yellow	Yellow	Yellow	Yellow	Yellow	Orange	Yellow	Orange	Red	Yellow	Yellow	Yellow	Yellow	5	
American Samoa	2002	Orange	Yellow	Orange	Red	Red	Yellow	Red	Orange	Orange	Yellow	Orange	Yellow	Yellow	Yellow	11	↓
	2004	Red	Orange	Orange	Red	Orange	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow *	9	
PRIAs	2002	Orange	Yellow	Yellow	Yellow	Yellow	Yellow	Orange	Yellow	Orange	Orange	Orange	Yellow	Yellow	Red	7	↓
	2004	Orange	Yellow	Yellow	Yellow	Yellow	Yellow	Orange	Yellow	Orange	Orange	Yellow	Yellow	Yellow	Orange	5	
Marshall Islands	2002	Red	Yellow	Orange	Orange	Yellow	Yellow	Orange	Red	Yellow	Yellow	Orange	Yellow	Yellow	Yellow	8	↓
	2004	Red	Yellow	Orange	Orange	Yellow	Yellow	Orange	Orange	Yellow	Yellow	Orange	Yellow	Yellow	Yellow	7	
Federated States of Micronesia	2002	Orange	Yellow	Yellow	Red	Orange	Yellow	Red	Yellow	Red	Red	Yellow	Yellow	Yellow	Orange	11	↓
	2004	Yellow	Yellow	Yellow	Red	Yellow	Yellow	Red	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Yellow	6	
CNMI **	2002	Orange	Yellow	Orange	Red	Red	Orange	Orange	Yellow	Orange	Orange	Yellow	Red	Yellow	Red	14	↓
	2004	Orange	Yellow	Orange	Orange	Orange	Yellow	Orange	Yellow	Orange	Yellow	Yellow	Orange	Yellow	Red	9	
Guam	2002	Yellow	Yellow	Orange	Red	Red	Orange	Orange	Yellow	Orange	Yellow	Yellow	Yellow	Yellow	Yellow	8	↑
	2004	Red	Yellow	Orange	Red	Red	Red	Red	Yellow	Orange	Orange	Yellow	Yellow	Yellow	Yellow	13	
Palau	2002	Red	Yellow	Yellow	Red	Red	Orange	Orange	Yellow	Orange	Orange	Orange	Yellow	Yellow	Yellow	11	↓
	2004	Red	Yellow	Yellow	Red	Yellow	Orange	Orange	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	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		Red	Yellow	Orange	Red	Red	Orange	Red	Yellow	Red	Orange	Orange	Yellow	Yellow	Yellow		

Fishing

A fishery is comprised of the species sought (including the incidental or unintended catch), the habitat in which they live, and the humans conducting the fishing activities. Coral reef ecosystems support important commercial, recreational, and subsistence food fisheries in the U.S. and around the world. Fishing also plays a social and cultural role in many island communities (Figure 8). The biodiversity of reefs supports the aquarium and aquaculture industries, biomedical industry, and other commercial industries. The management of coral reef fisheries falls across several groups, including NOAA through the regional fishery management councils, and state, territory, commonwealth, and local agencies.

Successful management of coral reef fisheries through the balancing of society's desire to attain the economic benefits from these resources with the biological requirements for sustaining them depends critically upon the best available scientific information. Implementation of an ecosystem-based approach to fisheries management will require the development of practical approaches that support shifting from single species management to an ecosystem approach.

Research is needed to address three key fishing-related threats to coral reef ecosystems — fishing and overfishing, destructive fishing, and the effects of marine aquaculture — and the social and economic costs and benefits of these threats. The social importance of activities such as fishing can mobilize groups to support or oppose different management measures. Thus, it is important to understand inter-group relationships, perceptions, beliefs, and their links to particular behaviors. Additionally, research is needed to better understand the impacts of fishing-related activities on species of concern, including threatened, endangered, rare, and protected migratory species that are dependent on coral reefs (e.g., low reef islets and lagoons) for their survival, such as monk seals, sea turtles, pearl oysters, giant clams, conchs, coconut crabs, humphead wrasse, bumphead parrotfish, groupers, and rare ground-nesting seabirds.

Fishing and Overfishing: Overfishing of high value predators and important herbivores has been documented on nearly all U.S. inshore reefs near populated areas (Figure 9; Turgeon et al. 2002), and is spreading to deeper reefs and more remote locations. In general, we know the causes of this decline — direct overexploitation of fish and invertebrates by recreational, subsistence, and commercial fisheries. However, the full ramifications of overfishing are poorly understood and present a major challenge to resource managers and scientists. There is increasing evidence that overfishing, including historical overfishing of apex predators, herbivores, and keystone species on reefs not only results in shifts in fish size, abundance, species composition, and genotypic diversity, but also is a major driver contributing to the degradation of coral reef ecosystems. Increasing the state of knowledge on the potential cascading effects of reduced predator and herbivore abundances

Table 3. A comparison of the 2002 and 2004 perceived levels of threat to coral reef ecosystems in the U.S. and [Pacific Freely Associated States], 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; the high threat rating was assigned to the Coastal Development and Runoff threat to be consistent within the table.*

***For the Commonwealth of the Northern Mariana Islands, 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.*

This table has been reprinted with permission from Waddell (2005).

and sizes, by using fished and non-fished coral reef ecosystems, are instrumental to understanding the full effect of overfishing on ecosystem functions, designing effective conservation programs, and determining the impact of management actions (e.g., fishing closures) on the sustainability of fish stocks. Understanding the drivers of overfishing (e.g., perceptions of the impacts of overfishing and resource availability), how decisions are made to exceed sustainable limits, and a thorough analysis of existing fisheries data are also key to understanding the impacts of overfishing. Research focused on the perceptions and attitudes about factors including fishery health, gear restrictions, aquaculture versus extraction of wild stocks, market conditions, regulations, and environmental conditions could help shed light on how fishers decide to target a particular species or utilize different fishing techniques.

Destructive Fishing: Indirect impacts associated with some fishing techniques and gear include: (1) physical impacts to reef environments; (2) by-catch, ghost fishing (i.e., lost or derelict fishing gear that continues to catch fish and other species), and mortality of non-target species; and (3) unauthorized fishing in closed areas. Research is needed to predict, prevent, and mitigate these indirect fishing impacts. Research should include identifying and assessing gear impacts, developing new technologies and gear to minimize these impacts, and researching and developing techniques to improve fishing surveillance, enforcement, and management of remote coral reefs.

Marine Aquaculture: Marine aquaculture is growing rapidly in regions with coral reefs, and may provide employment and decrease collection pressure on wild populations. However, if poorly sited or managed,

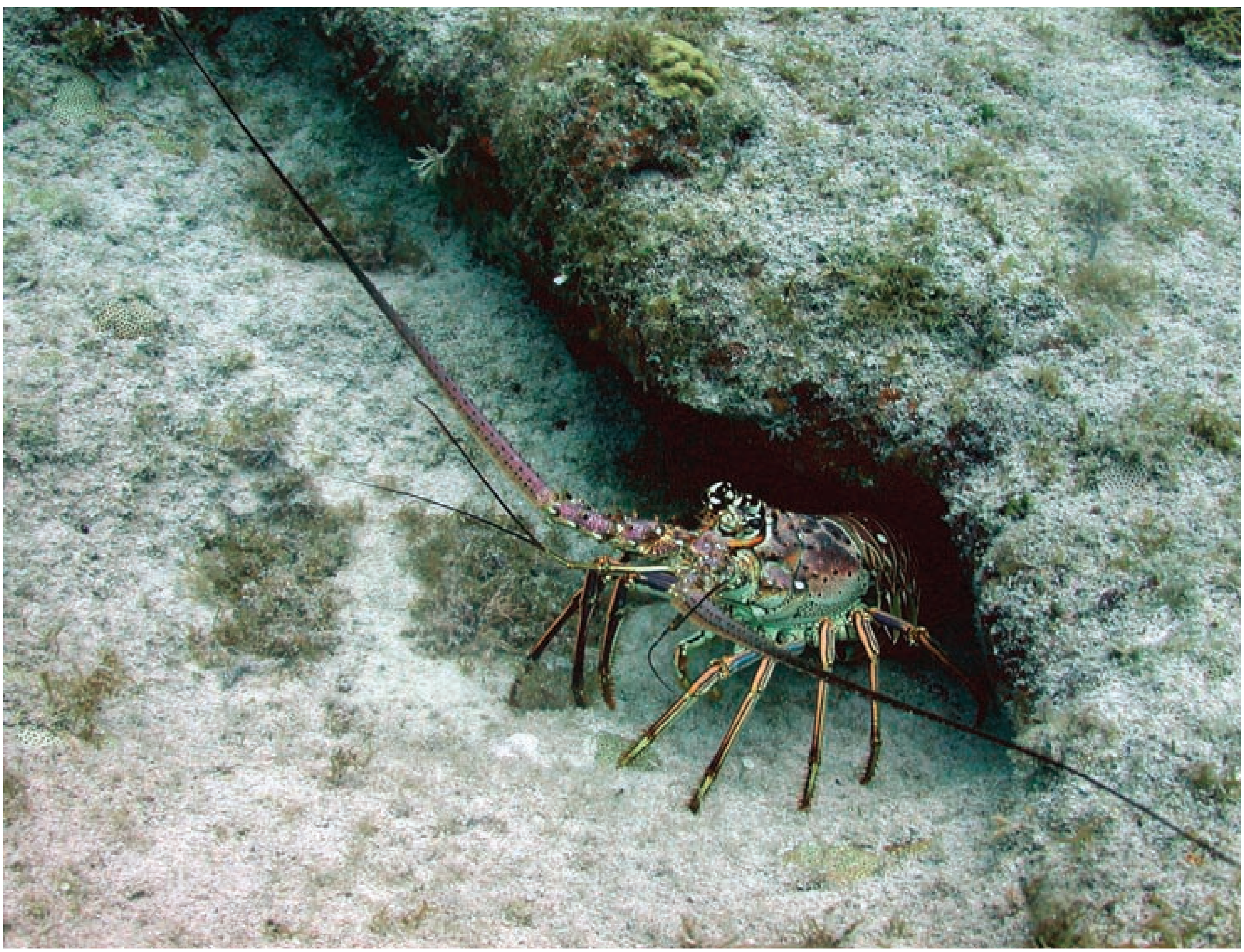


Figure 8. The spiny lobster, Panulirus argus*, is one of the most valuable fishery species in the Caribbean. They are exported from several non-U.S. Caribbean countries. In Puerto Rico and the U.S. Virgin Islands, spiny lobsters are for local consumption only. Photo credit: Deborah Gochfeld.*

Figure 9. Nassau grouper, Epinephelus striatus*, once among the most important fishery species in the Southeastern U.S. and the Caribbean region, have been overfished in the U.S. and are currently protected from fishing in state and Federal waters. Photo credit: Craig Dahlgren.*

marine aquaculture in open systems can adversely affect coral reef ecosystems by disrupting submerged land on and adjacent to reefs, serving as fish aggregation devices, introducing invasive alien species, discharging nutrients, causing disease, and reducing genetic diversity of wild stocks by allowing cultured stocks to escape and mix with wild populations. Research should provide the foundation for science-based decisions on site selections and permitted activities. Research is also needed on culturing corals for restoration activities and early life stages of marine ornamental fishes to enable reliable production of eggs to juvenile stages. Research should also help develop models to address ways to predict, contain, prevent, and mitigate the potential impacts on the genetic diversity of wild stocks and the release of opportunistic pathogens on native populations from aquaculture activities.

General research questions relevant to fishing include: How does the present-day status of fished species compare with historical abundances and sizes? How has overfishing affected trophic interactions among fish species and how have potential changes to food webs affected models used to manage fisheries, including single-species and ecosystem-based models? What is the effect of overfishing predators on ecosystem structure? What are the ecological effects of overfishing and destructive fishing practices, including the effects on non-targeted species and on benthic coral reef habitats? Why do fishers decide to employ destructive fishing techniques? What roles do habitat heterogeneity, living coral, and geographic linkages among coral reef ecosystems play as components of essential fish habitat for economically and ecologically important fisheries? How do the products of aquaculture (including species released purposefully or accidentally and water quality pollution, where it exists) affect the structure and function of surrounding ecosystems? What are the politics associated with increasing aquaculture development and trade in farm-raised seafood (e.g., are special opportunities presented or denied to locals associated with the aquaculture industry)? What are the socioeconomic impacts of existing and proposed fisheries management plans that affect coral reef ecosystems? How do invertebrate fisheries (e.g., octopus, sea cucumbers) impact the coral reef ecosystem? How has the fishing of spawning aggregations affected fish communities? What tools can be developed to predict likely locations of spawning aggregations? How do management activities and regulations influence fishers' attitudes and perceptions? How do perceptions of scientific information, and the agencies disseminating it, shape fishers' attitudes and behaviors?

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, including soil erosion (Bryant et al. 1998). At a local scale, pollution can be the dominant pressure on an ecosystem. 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 (Figure 10). Other pollutants, such as heavy metals and oil, can also be prominent at specific locations. Direct impacts of pollutants include reduced recruitment, the loss of biodiversity, altered species composition (shifting from predominantly phototrophic to heterotrophic fauna), and shallower depth distribution limits (ISRS 2004).

In addition to land-based sources of pollution, chemicals and nutrients (e.g., mercury, iron, nitrogen, and phosphorous) are also introduced via atmospheric deposition following long-range transport from distant origins (e.g., African and Gobi desert dust). It is not yet known how mercury, which is transformed to biologically hazardous methyl mercury after deposition to the ocean surface, might affect corals. Iron, nitrogen, and phosphorus are critical and potentially limiting nutrients on coral reefs. The atmospheric input of iron, nitrogen, and phosphorus represents an increase in the nutrient loading of the water body, with biological consequences that cannot be ignored. For example, too much phosphorus can lead to weak coral skeletons that increase the coral's susceptibility to storm damage (Wilkinson 1996). The primary mechanism of iron deposition is rainfall and it is the sole source of iron to coral reef ecosystems (aside from shipwrecks). In addition to chemical and nutrient deposition, atmospheric transport may also carry disease-producing organisms, such as the soil fungus *Aspergillus sydowii*, which has been thought to be introduced to coral reef ecosystems through African dust deposition (Smith et al. 1996; Kellogg and Griffin 2003).

While pollutants can occur alone, they often occur together and interact synergistically. For example, sediment runoff from land can potentially introduce toxicants and disease-producing microorganisms to coral reef ecosystems which can affect coral function and survival. Additionally, pollutants may be introduced by multiple sources as in the case of reactive nitrogen and phosphorous, which may be introduced via land-based inputs, atmospheric deposition, or upwelling. Pollutants can impair coral function and may make the corals more susceptible to disease, climate change, and the presence of invasive species. Research is needed to better understand the allowable concentrations or thresholds of pollutants and to determine the tolerance of coral reef ecosystems to pollutant concentrations (i.e., at what concentration does an effect occur).

Management actions to address water quality concerns are taken by the U.S. Environmental Protection Agency (EPA), U.S. Department of Agriculture, NOAA, and local, state, territorial, and commonwealth governments, depending on jurisdictions. Research is needed to understand how coral reef ecosystems respond to impaired water quality, and to provide managers with tools to detect, assess, and remedy negative impacts. To this end, the sources of the substances that adversely affect water quality must be identified, and relevant policies and strategies developed and validated. Monitoring of sediment, water, and coral tissue for likely pollutants (e.g., organic contaminants, trace elements, nutrients, and pathogens) in threatened or high pollutant concentration areas can alert managers to changes in pollutant inputs and impacts.

Changing attitudes and behaviors is central to any effort to reduce nonpoint sources of pollution. Thus, understanding the factors influencing individuals' attitudes, and the driving force(s) behind particular behaviors is a critical element of addressing this

Figure 10. Pollutants, such as nutrients from fertilizers, herbicides, pesticides, human-derived sewage, and increased amounts of sediment from coastal development, can have direct impacts on coral reef ecosystems, including increasing turbidity. Photo credit: Deborah Gochfeld.

issue. As addressing pollution concerns requires coordination among an array of Federal, state, territory, commonwealth, and local agencies, research on these institutional features and how data are collected should be linked to reducing the threat of pollution to coral reef ecosystems. Research indicates that knowledge alone does not beget responsible environmental behavior; however, resource managers can be more effective in targeting education and outreach activities with an understanding of how the public perceives impacts of land use and other human activities.

General research questions relevant to understanding and improving water quality in coral reef ecosystems include: What are the economic and social factors that influence the adoption of pollution control measures, the use of agricultural inputs, or perceptions of different nutrient-related best management practices (BMPs) in agricultural areas? Are some corals or coral reef ecosystems more resistant to pollution stress than others? What are the long-term implications of differential resilience on coral reef ecosystem community structure and function? How does pollution affect coral reef ecosystem resiliency to other local and global stressors? How long do impacts caused by pollutants persist once the stressor is reduced or eliminated? How fast does change occur within coral reef ecosystems due to pollution from either chronic low-level inputs (e.g., sewage) or episodic high-level inputs (e.g., storm water runoff, rainfall, and upwelling)? What are the best measures of pollutant impacts on coral reef ecosystems? What are the best ways to reduce pollution and what are the costs and benefits of available options relative to each other and to addressing other stressors? What are the pollution impacts on compromised organisms subjected to additional stressors from both allochthonous (i.e., derived from outside the system) and natural sources? Which watersheds contribute the highest loads of contaminants, including sediment and nutrients, to coral reef ecosystems? What is a system's vulnerability to chronic versus episodic pollution? What are the relationships between coral condition and presence/input of specific and multiple contaminants and the concentrations of those contaminants? How do impacts from contaminants vary with distance from the source of those contaminants? How does increased sedimentation impact coral reproduction and larval recruitment?

Figure 11. A golf course located on the shoreline near a coral reef (Mangilao, Guam). Photo credit: Dave Burdick.

Coastal Uses

Coral reef ecosystems are being damaged — continually and in some cases irreparably — by a number of anthropogenic impacts, some of which are avoidable. Non-extractive human activities that may damage or impact coral reef ecosystems include recreational activities (e.g., boating and scuba diving), shipping, coastal development (Figure 11), weapons testing, vessel groundings, anchor damage, and marine debris accumulation. Scores of shipwrecks exist which may retain fuel, explosives, and/or other pollutants that threaten not only the condition of the reefs, but also the safety of divers. Construction, excavation, and dredging associated with new or expanding facilities (e.g., for ports, navigational channels, bridges, and underwater cables) can also cause direct and indirect damage to coral reef resources, such as sedimentation that can literally smother the corals and turbidity that decreases the amount of light available to the corals (Muller-Parker and D'Elia 1997). Military weapons testing, toxic and hazardous waste disposal, base construction and operation, unexploded ordnance, and warfare can also cause direct and indirect damage to coral reefs and are of key concern in the U.S. Pacific Islands.

Some coastal uses restrict access or prohibit all other uses, as is the case for some areas managed by U.S. military, Federal, state, territory, commonwealth, and/or local resource management agencies. When these areas are managed as limited access sites, whether the goal is to provide security, serve as reference sites for research, or protect sensitive critical habitats, they can serve as de facto MPAs. Research is needed to understand the role of these restricted areas in managing coral reef ecosystem resources. For restricted access areas that are used in a non-sustainable manner (e.g., as ammunition ranges), the role of research is to document resource damage or loss and predict ecological, economic, and societal costs and benefits of that use.

Other coastal activities impact reefs by causing the accumulation of marine debris. Marine debris consists of not readily biodegradable trash, including lost and derelict commercial fishing nets, metals, plastics, and rubber products (Figure 12). Marine debris accumulation is considered a high-level threat by coral reef managers in the Northwestern Hawaiian Islands and the Federated States of Micronesia; and as a medium-level threat in Florida, Puerto Rico, the Main Hawaiian Islands, the Commonwealth of the Northern Mariana Islands, the U.S. Pacific Remote Insular Areas, and the Republic of Palau. Derelict commercial fishing nets can dislodge and break coral colonies and entangle marine mammals, sea turtles, fish, and seabirds. Marine debris is also a vector for exotic species introductions. Removing marine debris is an expensive and difficult task. In 2004 alone, 112 metric tons of debris, primarily derelict fishing gear, was removed from reefs and beaches in the Northwestern Hawaiian Islands at an estimated cost of $2.8 million. Research is needed on how to apply or develop remote sensing techniques to aid in the identification of floating debris and other materials near coral reef areas that can impact the reef.

By increasing resource use, coastal development and tourism increase the potential for recreational overuse and misuse. To better determine the appropriate levels of resource use for both existing and new areas, research is needed to identify mixed and heavy use areas where user conflict and resource damage are most likely to occur, and to quantify the effects of commercial and recreational use of these areas (e.g., loss of coral cover, biodiversity). Additionally, the drivers behind recreational misuse should be identified and used to target education and enforcement. Research needs to focus on institutional arrangements and how laws, policies, and organizational relationships influence the use, management, and protection of reef ecosystems. There has been extensive social science research on "common pool" resources and how institutional relationships can increase or decrease the effectiveness of addressing problems associated with such resources (Ostrom and Ostrom 1972; Ostrom 1988a, 1988b). Findings from these studies have documented the importance of particular institutional arrangements as drivers for conservation and management. This work also emphasizes the importance of examining how different institutions or individuals use scientific and locally-derived information within decision-making processes for natural resource management. This work should serve as the foundation for research assessments on the institutional relationships and how they benefit or impair coral reef ecosystem management.

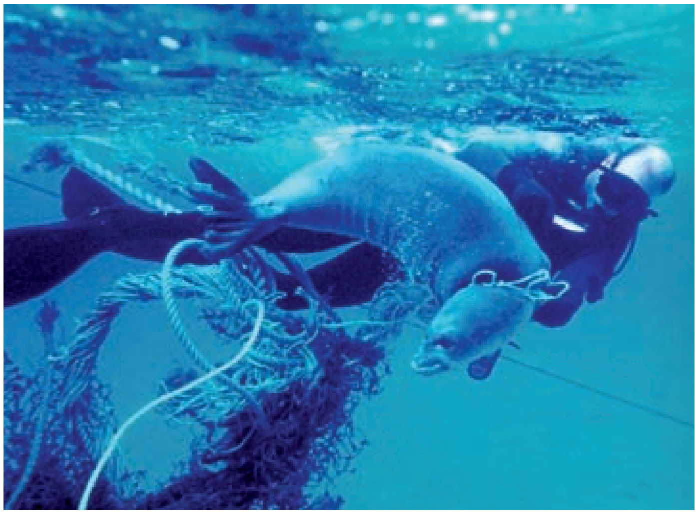


Figure 12. NOAA diver frees an endangered Hawaiian monk seal from marine debris (Northwestern Hawaiian Islands). Photo credit: Ray Boland, NOAA Fisheries.

General questions relevant to coastal uses include: What are the impacts and associated costs and benefits of maintaining navigational access? What are the carrying capacities of different coral reef areas in a variety of coastal situations at local and regional scales? What are the ecological and economic consequences of coastal uses? What are the sources of marine debris? Can technology be developed to locate and remove debris before it gets entangled on reefs? What are the economic and social drivers for particular coastal uses (including conservation activities) that impact coral reef ecosystems? How do changing demographic and economic patterns correlate with particular stressors and the quality of reef habitats? What are the costs and benefits of different approaches to managing coastal uses?

Invasive Species

Alien species (also known as exotic, non-native, introduced, and/or non-indigenous species) are plants, animals, and microorganisms that have moved as a result of human activities from their native geographic range and habitat to a new location. Alien species are considered to be "invasive" if the alien species acts as 'an agent of change and threatens native biological diversity' in its new location (IUCN 2000). It is important to note that not all alien species become invasive or cause economic or ecological harm by displacing, outcompeting, or preying on native species.

Alien species may be introduced to coral reef ecosystems via vectors or pathways such as shipwrecks, ship hulls and ballast water, waterways, aquaculture systems, aquarium discards into coastal waters, marine imports, and marine debris. Recent evidence also suggests that both fungal and bacterial pathogens from terrestrial habitats could also be transferred to coral reef ecosystems (Porter 2001). Intentional and unintentional releases of invasive species have been documented worldwide and are often the focus of expensive control and eradication programs. For example, in Waikiki on the island of Oahu in the Main Hawaiian Islands, there have been 14 volunteer-led cleanups to remove approximately 85 tons of an invasive alga, gorilla ogo (*Gracilaria salicornia*), from August 2002 to February 2005 (Figure 13; Smith et al. 2004; Hunter et al. 2004). In the Atlantic, the lionfish *Pterois volitans*, a

Figure 13. The invasive red alga, Gracilaria salicornia*, washed up on Waikiki Beach after a large summer swell. This alga has become quite abundant on the reefs around Oahu since its introduction in the 1970s. This species poses a threat to the reefs in the Hawaiian Islands as it appears to outcompete many of Hawaii's native species. Photo credit: Jennifer E. Smith.*

native to the Pacific, is now well established and suspected to be reproducing from North Carolina to south Florida (Figure 14; Hare and Whitfield 2003). The potential impact of lionfish on native species is unknown. To date, lionfish have not been sited south of Miami; however, should lionfish make their way to the Florida Keys, the impact to the ecosystem could be significant.

Research can contribute to reversing the trend of increasing invasive species in U.S. coastal waters by improving prevention, detection, prediction, response, and restoration. The science of invasive species is relatively new, but it is clear that prevention is easier and cheaper than eradication. Early detection tools are needed to alert managers of alien species before they become established. As few survey programs exist to monitor for alien species, by the time they are noticed, they are often well established and eradication or control is not an option. When an alien species is detected, research is needed to determine its vectors of origin, potential for future spread, and potential to become invasive. Increased understanding of species tolerances and life cycles can be applied to predict the risks associated with alien species introduction. This is especially important as new geographic areas provide suitable conditions to invasive species as a result of environmental and anthropogenic factors such as climate change, excess nutrients, and overfishing. Predictive risk assessments on species likely to become invasive can forecast their potential ecological and socioeconomic impacts. Researchers should also develop and evaluate new strategies and technologies to prevent introductions, eradicate invasive species, and mitigate their effects. With the information from targeted research, coastal managers can make contingency plans and take coordinated actions to prevent future occurrences and establishment of invasive species and mitigate existing and future species effects.

Figure 14. The lionfish, Pterois volitans*, native to the Pacific Ocean, has been found off the U.S. east coast from North Carolina to north of Miami. Photo credit: Lance Horn, NOAA's Undersea Research Program Center at the University of North Carolina Wilmington.*

As alien species are primarily introduced via human activities either intentionally or unintentionally, documenting the human attitudes and perceptions towards alien species could be important research. For example, aquaria and pet stores play a fundamental role in shaping attitudes related to exotic fish. Understanding how these actors view the threat of exotic species, regulations, and potential environmental impacts is a critical step to reducing the introduction of exotic species into the environment. Similar research on sport fishermen could help reduce the threat from bait fish introductions. Research on institutional and intergroup relationships will also help ensure that managers are targeting the appropriate groups and that their message is positively received.

General research questions with relevancy to the management of invasive species include: What native species occur in each coral reef ecosystem? What is the extent and distribution of existing populations of invasive species? What are the likely vectors for introduction? What ecological factors facilitate successful competition with native species, especially for species that are known to be outcompeting native species? How have anthropogenic or natural changes facilitated the establishment of invasive populations, and can management actions mitigating these changes reduce the introduction and spread of invasive species? What are the predicted and observed ecological, social, and economic impacts of an established invasive species? What are the public's perceptions of non-native species and their impacts on coral reefs?

Climate Change

Climate change, in particular increases in temperature and carbon dioxide levels primarily from the burning of fossil fuels, threatens coral reef ecosystems through increased occurrence and severity of coral bleaching and disease events, sea level rise, and storm activity (Figure 15; Smith and Buddemeier 1992; Hoegh-Guldberg 1999). Climate change may also reduce calcification rates in reef-building organisms by lowering the pH of seawater and reducing the availability of carbonate ions (Feely et al. 2004; Kleypas et al. 2006). Reduction in calcification rates directly affects the growth of individual corals and the reef's ability to maintain itself against forces that cause reef erosion, potentially compounding the 'drowning' of reefs caused by sea level rise (Hoegh-Guldberg 1999; Schiermeier 2004; Langdon and Atkinson 2006).

Figure 15. Shoreline erosion likely due to storm activity. Photo credit: Dave Burdick.

The frequency and severity of coral bleaching events has increased over the last 25 years (Reaser et al. 2000; IPCC 2001a, b; Lackner 2003) and bleaching is considered a major threat to coral reef ecosystems (Table 3; Figures 16 and 17). Coral bleaching (the process in which a coral polyp, under environmental stress, expels its symbiotic zooxanthellae from its body, and appears whitened or "bleached") is caused by a multitude of stressors, such as increasing ocean temperatures and extended light exposure. Predictions call for even greater frequency and severity of bleaching events over the next 50 years (Reaser et al. 2000; IPCC 2001a). There is considerable evidence that global temperature, including seawater temperature, has increased substantially over the last century, in large part, to the burning of fossil fuels (Reaser et al. 2000; IPCC 2001a, b). However, the physiological mechanisms linking climate change to bleaching and the intra- and inter-species variability in bleaching responses are just beginning to be understood (LaJeunesse et al. 2003). For example, little is known about the environmental conditions and mechanisms whereby ultraviolet radiation (UV) and PAR interact with temperature increases to induce coral bleaching (Jones et al. 1998; Dunn et al. 2004). Long-term monitoring and research are needed to understand the underlying causes of coral bleaching (Hoegh-Guldberg 1999), to clarify initial and long-term impacts of coral bleaching events, and to identify factors affecting resistance and resilience to coral bleaching. Monitoring of key physical and chemical data in real- and near-real time at coral reef sites, including temperature, salinity, PAR, UV, water clarity, nutrients, and carbon dioxide, is needed to relate environmental changes with observed

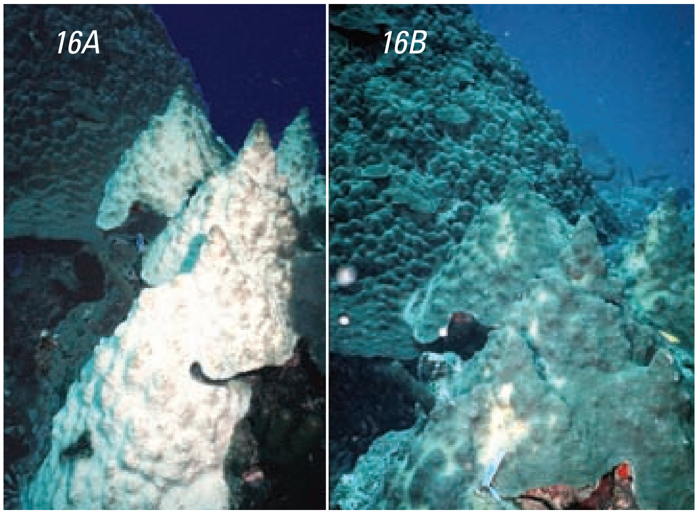


Figure 16. A bleached (A) mountainous star coral colony, Montastraea faveolata*, photographed five months later is shown to be almost fully recovered from the bleaching event (B). Photo credit: Andy Bruckner, NOAA Fisheries.*

responses (Jones et al. 2000), such as coral bleaching, algal blooms, and disease events. Research is also needed to better understand factors that might act synergistically with elevated seawater temperatures to change predicted bleaching responses. For example, high exposure to middle wave UV (or UVB) might lower the seawater temperature thresholds for predicted bleaching events or increased water turbulence might increase predicted seawater thresholds (Dunn et al. 2004).

Long-term records of local sea surface temperatures from coral cores and other paleoclimatic sources may be used to place more recent records of bleaching events and changes in coral communities within a longer temporal perspective. The effects of longer temporal variability, including the Pacific Decadal Oscillation/Variability, the El Niño Southern Oscillation, and other important climate oscillations, should be examined for their role in climate change. Other research should delineate and validate biological impacts of decreased pH on calcifying and non-calcifying organisms.

Given that managing climate change is beyond the scope of coral reef managers, effective management of coral reef ecosystems affected by climate change requires a better understanding of coral reef ecosystem resiliency. Coral reef ecosystem resiliency is defined as "the return of a coral reef ecosystem to a state in which living, reef-building corals play a prominent functional role, after this role has been disrupted by a stress or perturbation" (UNEP 1999, p. 2). One management strategy is to mitigate stress and damage caused by local stressors to improve reef condition and thus, make the ecosystem less vulnerable to local, regional, or global bleaching events. Management actions before, during, and after bleaching events might also reduce local stressors, thus helping to facilitate recovery. For example, fisheries management actions to promote herbivores that reduce algal populations at overfished sites; boating restrictions to reduce anchor damage; and shoreline setbacks, greenbelts, and exclusion zones in areas vulnerable to waves, sea level rise, or flooding may reduce nutrient and pollutant loads to reefs and may be beneficial in reducing stressors when corals are recovering from a bleaching event.

The following questions target climate change research with significant relevance to management issues: How much of the variability in bleaching observed within and among species (and within and among coral reefs) is explained by environmental patchiness (in temperature, light, water motion) compared to phenotypic and genotypic variability in corals and their symbiotic algae? What are the relative contributions of global, regional, and local stressors and their interactions to particular ecosystem responses? What are the most important factors influencing recovery after coral bleaching events? Does the addition of human impacts and the fragmentation of coral reef habitats (affecting gene flow) undermine coral reef ecosystem resiliency and make them more susceptible to coral bleaching? What is the relationship between coral bleaching and non-temperature related stressors such as light and pollutants? How does climate

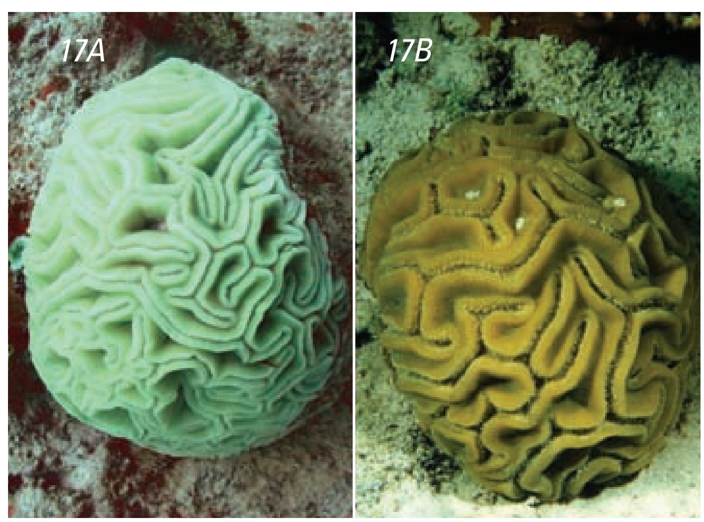


Figure 17. (A) A bleached colony of brain coral, Diploria labyrinthiformis*, during the 2005 Caribbean bleaching event, and (B) a healthy colony of brain coral (Big Point, Lee Stocking Island, Bahamas). Photo credit: Deborah Gochfeld.*

change affect coral exposure to these stressors? How will warming, sea level rise, changing circulation patterns, and increased dissolved carbon dioxide in the ocean affect the way coral reef ecosystems look and function over the next 50 to 100 years? What is the relationship between the decline of coral reef ecosystems caused by bleaching and the condition of reef-dependent fisheries? How have corals responded to climate and carbon dioxide variability in the past? Can methods be developed to detect past coral bleaching events and to better understand how corals respond to changes in temperature and temperature variability? What can be done at a local/regional levels to increase the chances of recovery after a bleaching event? What effect will decreased calcification rates have on ecosystem structure and function?

Extreme Events

Extreme events include abiotic (e.g., volcanic activity, lava flows, hurricanes, floods, droughts, sea level rises, tsunamis, and oil spills) and biotic events (e.g., population die-offs, coral predator outbreaks, and disease). These events can produce profound ecosystem changes both directly and indirectly. For example, extreme abiotic events may remove or cause the mortality of corals (Figure 18), thus, indirectly making the substrate available for the colonization of macroalgae, bioeroding sponges, and other encrusting invertebrates that inhibit the recruitment of stony corals. Research is needed to understand and predict changes resulting from extreme events versus natural variability.

Figure 18. An abraded and overturned elkhorn coral, Acropora palmata*, was detached during a storm. Photo credit: Andy Bruckner, NOAA Fisheries.*

Physical impacts of extreme events can persist for extended periods; for example, strong winds and waves from hurricanes and storms can directly impact reefs by toppling corals, resuspending sediment, and increasing turbidity. Storms, floods, and droughts also affect coral reef ecosystems by changing inputs of freshwater and associated nutrient, sediment, and chemical pollutants. Hurricane and severe storm forecasting capabilities have vastly improved in recent years, but coastal communities are still unsure how to best reduce and mitigate the damage that these storms produce. To help fill this need, researchers should forecast expected coral reef ecosystem changes resulting from extreme abiotic events. Researchers also need to better understand how extreme events influence human use and protection of coral reef ecosystems. For example, if a hurricane damages or destroys particular reef areas on which tourist and fishing activities depend, do the impacts of these activities shift to other reefs, thereby negatively impacting coral areas not directly damaged by the storm? Understanding the use patterns and decision-making processes of stakeholders can help managers proactively protect critical coral reef areas.

Understanding and forecasting how population outbreaks and die-offs affect coral reef ecosystems, and how those events affect change if other stressors are present, are other critical management needs. The long-spined black sea urchin (*Diadema antillarum*) die-off in the 1980s and COTS (*Acanthaster planci*) outbreaks are examples of unanticipated biotic events with far-reaching impacts on coral reef ecosystems (Figures 19 and 20). In 1983, researchers documented an unprecedented Caribbean-wide die-off of the urchin *Diadema antillarum* (Lessios et al. 1984; Lessios 1995). The *Diadema* die-off resulted in a reduction in grazing pressure and has been implicated in the increase in fleshy algal cover on coral reefs where herbivorous fishes had been overfished. The occurrences of COTS outbreaks have been documented when environmental conditions favor larval settlement and have resulted in the sudden occurrence of large numbers of COTS on extensive coral reef areas [note: the Great Barrier Reef Marine Park Authority defines active outbreaks as areas with more than 30 adult COTS per hectare (Engelhardt 1997; Fraser et al. 2000)]. While COTS outbreaks are a natural occurrence, increased nutrients and exploitation of natural predators may favor larval and juvenile COTS.

Figures 19. A crown-of-thorns starfish, Acanthaster planci*, outbreak along a reef track in Guam. Photo credit: Dave Burdick.*

Figure 20. A crown-of-thorns starfish, Acanthaster planci*, shown feeding on a soft coral,* Sinularia polydactyle *(Piti Bomb Holes, Guam). Photo credit: Deborah Gochfeld.*

Disease in corals and associated organisms has dramatically increased in frequency and distribution over the last decade, contributing to unprecedented decreases in live coral and altering the function and productivity of coral reef ecosystems (Figure 21). In the Caribbean, white-band disease has been implicated as the principal cause of mass mortalities of elkhorn coral (*Acropora palmata)* and staghorn coral (*A. cervicornis)*, with losses of 80 to 95% accompanied by an ecological phase shift from a coral-dominated to algal-dominated reef (Aronson and Precht 2001). Some evidence suggests that stress may increase susceptibility to disease. There is also a possible relationship between disease and climate change, as pathogenic organisms are often most virulent at increased seawater temperatures. The potential relationship between anthropogenic stressors and disease suggests that the emergence of disease as a major factor causing high levels of coral mortality is relatively new, and management strategies targeted towards reductions in other stressors (e.g., land-based pollutants) may reduce the likelihood of disease outbreaks. Thus, research is needed to examine the underlying cause(s) of disease in coral reef ecosystems, the mechanisms of infection, and the relationship between disease and stress. In addition, research is needed on the basic biology and physiology of corals to serve as a baseline for coral health and disease investigations and to better distinguish between disease and natural changes (e.g., growth and reproduction).

Beginning in March 2000, the Coral Disease and Health Consortium was established through an interagency partnership between NOAA, EPA, and the U.S. Department of the Interior (DOI), with involvement by over 50 domestic and international partner institutions, to provide a comprehensive approach to understand and address the effects of natural and anthropogenic stressors on corals. The *Coral Disease and Health: A National Research Plan* identifies three major research priorities: 1) standardize terminology, monitoring protocols, collection techniques, reporting standards, and laboratory protocols to provide a consistent, integrated body of scientific information; 2) define baseline measurements of coral health and vitality, examine occurrences of disease, and determine the causes and effects of declines in coral health; and 3) investigate the effects of anthropogenic, environmental, and climatic stressors on coral health (NOAA 2003a). Additional priorities were the dissemination of technical information and practical diagnostic tools to improve the ability of managers and scientists to evaluate, track, predict, and manage coral diseases; and improved multidisciplinary collaborations and cross-disciplinary training for scientists and managers.

The following management-relevant questions target extreme events in coral reef ecosystems: To what extent and by what mechanism is disease affected by other factors, such as temperature, light, sediment, nutrients, and pollutants (and in what combinations)? How many different diseases significantly affect coral reef ecosystems and what are their etiologies? Is there variability in susceptibility and resistance to disease observed within and among species (and within and among reefs)? If so, what are the roles played by environmental patchiness (in temperature, light, water motion) and phenotypic or

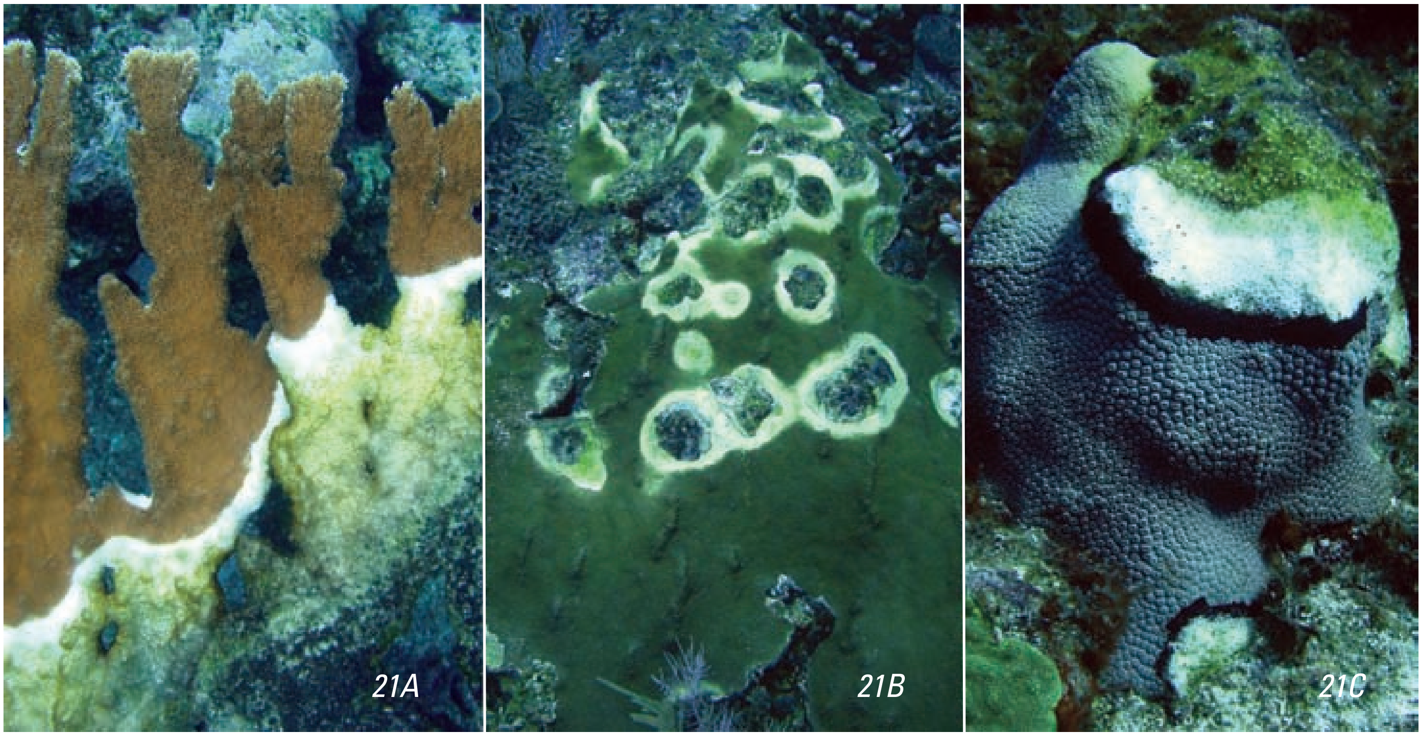


Figure 21. Images of diseased corals. (A) A colony of elkhorn coral, Acropora palmata*, with white band disease (Pajaro Reef, Mona Island, Puerto Rico, 2003). (B) A colony of mountainous star coral,* Montastraea faveolata*, with yellow band disease (Carmelita Reef Mona Island, Puerto Rico, 2006). (C) A colony of mountainous star coral with black band disease (Mujeres Wall, Mona Island, Puerto Rico, 2006). Photo credit: Andy Bruckner, NOAA Fisheries.*

genotypic variability (related to coral defense mechanisms and immune systems)? What are the most important factors influencing recovery after coral disease epizootics (i.e., an outbreak of disease affecting many animals of one kind at the same time)? What is the relationship between the loss of live coral and the condition of reef-dependent fisheries? What is the relationship between extreme events and the use of different reef resources? Are local agencies structured to address the management and information needs associated with extreme events? How do changing quantities of runoff, the timing of extreme events, and the nature and extent of resulting physical damages affect coral reef ecosystems?

TECHNOLOGY SUPPORTING RESEARCH AND MANAGEMENT

Essential components of this Research Plan are the technologies, tools, and techniques used to carry out the research and management objectives. Every day, scientists employ numerous technologies to better understand the world. Many of these technologies are essential to a scientist's ability to view, measure, assess, and evaluate the environment and yet, Federal planning and investment in technology research and development has remained unchanged for the past decade (USCNS 2001; USCOP 2004). It is the purpose of this section to identify technology research and development priorities for improving the monitoring, research, and management of coral reef ecosystems.

Figure 22. Scuba diver cleans marine growth off of NOAA's Aquarius*, an underwater laboratory located in 64 ft. of water at the base of a coral reef in the Florida Keys National Marine Sanctuary.* Aquarius *provides a special diving capability, called saturation diving, which allows scientists to work out on the reef up to nine hours a day, compared to one hour if they had to work from the surface. Photo credit: NOAA's Undersea Research Program Center at the University of North Carolina Wilmington.*

Although many technologies are currently available, improvements are needed. Research and management of coral reef ecosystems could be aided by a national effort to develop low cost technologies for use by resource managers and scientists (Crosby et al. 1996); to disseminate existing engineering and oceanographic concepts or models; and to develop new tools and techniques.

Figure 23. An advanced scuba diver. This diver is carrying four cylinders: two in front (filled with oxygen and mixed gases) and two on his back (filled with air or mixed gases). Advanced diving techniques allow divers to extend the depth limit and bottom time per dive to significantly increase the undersea areas where self-contained wet-diving scientists can make first hand observations, take fine measurements, and conduct experiments. NOAA and its university partners are working to establish diving procedures to extend the safe diving depth limit for scientists from 130 ft. to 300 ft. Photo credit: Doug Kesling, NOAA's Undersea Research Program Center at the University of North Carolina Wilmington.

Priorities for research and development include technologies that:

- improve in situ observations, monitoring, and measuring of coral reef condition and change including: developing low cost chemical and biological sensors that provide resource managers with an "early warning" on declines in environmental condition; improving rapid assessment techniques; developing habitat characterization and sea bed classification schemes, which incorporate management-relevant criteria; advancing diving techniques to enable scientists to spend more time underwater (Figures 22 and 23), including the next generation of underwater laboratories (Figure 22); developing remotely operated observatories and supporting technologies (e.g., in situ sensors, satellite imagery) to allow for observations of remote coral reefs, including monitoring remote coral reefs for unauthorized fishing; assessing populations and behavior using non-traditional means (e.g., stereo video and passive acoustics technologies) by developing new non-destructive, fishery-independent approaches; developing alternative methods to erecting seawalls to mitigate coastline changes; developing algorithms to interpret acoustic and optical remote sensing data for improving the accuracy (>90%) of large island maps; and developing expert computer systems that analyze collected data and provide the results in a format understandable to decision-makers.
- improve the understanding of factors influencing coral reef ecosystem dynamics and change, including developing predictive models or forecasts of ecosystem condition that incorporate management-relevant criteria, and ecosystem response to natural events (e.g., storms, floods) or anthropogenic impacts (e.g., eutrophication, sewage discharges).
- avoid and minimize impacts to coral reef ecosystems by providing resource managers with guidance concerning BMPs and developing new fishing technologies and gear.
- minimize adverse impacts of aquaculture to the environment and wild stocks by developing criteria for aquaculture facility site-selection, permissible discharges, and environmental impact assessments (NOAA 1998).

- improve the ability to grow and reproduce coral reef ecosystem species in captivity to reduce pressure from the aquarium industry on natural stocks and to be used for habitat restoration, including improving the understanding of natural inducers for spawning and larval settlement.
- develop biotechnological techniques to improve the understanding of complex biochemical systems.
- minimize environmental impacts during the research and development of new marine-derived drugs and commercial products.
- improve the management of coral reef ecosystems by using networks of MPAs and establishing drivers for particular human uses of reef ecosystems, including ensuring that incentives exist for environmentally-sustainable alternatives.
- develop coral restoration techniques.

Marine Protected Areas

A MPA is an area of the marine environment that has been reserved by Federal, state, territorial, commonwealth, tribal, or local laws and/or regulations to provide lasting protection for part or all of the natural and cultural resources therein (E.O. 13158, May 26, 2000). A MPA can have various levels of protection, from no-take reserves to multiple-use areas that may allow fishing or other uses and extractive activities, and may include multiple zones with different protection levels across this spectrum. There are many examples of MPAs in the U.S. (Figure 24), including national parks, national marine sanctuaries (Figure 25), national wildlife refuges (NWR), fisheries

Figure 24. A marine protected area (Tumon Bay, Guam). Photo credit: Dave Burdick.

Figure 25. Glassy sweepers, Pempheris schomburgkii*, and a stand of elkhorn coral,* Acropora palmata *(Florida Keys). Photo credit: NOAA Florida Keys National Marine Sanctuary.*

closures, habitat areas of particular concern, and state parks. MPAs with common purposes or contributions to common goals can function as networks to protect specific species and their linked habitats across geographic scales and conditions.

MPAs and MPA networks are considered essential components of marine ecosystem management (NRC 2001). On May 26, 2000, President William Jefferson Clinton issued E.O. 13158: Marine Protected Areas, which set forth policies to strengthen the management, protection, and conservation of existing MPAs and establish new or expanded MPAs. E.O. 13158 also directed NOAA and DOI to work with other Federal agencies and consult with states, territories, commonwealths, tribes, and the public to develop a scientifically-based, comprehensive national system of MPAs. In September 2006, NOAA, in concert with DOI and various stakeholders, released a draft framework in the Federal Register that outlines guidance to develop the national system of marine protected areas (MPAs) in the U.S. (NOAA 2006a).
While the use of MPAs and MPA networks as resource management tools has grown significantly in recent decades, there is still substantial scientific investigation needed to better understand the appropriate design, size, number, and siting characteristics that ensure their effective use. Research focusing on the development of criteria for MPA and MPA network design, including the size, location, connectivity among MPAs, and their ecological and socioeconomic impacts, is needed. Growing scientific and observational evidence

indicates that no-take marine reserves may increase the health and abundance of corals, reef fishes, and other reef-associated species within these sites. However, targeted research is required to better understand the effect of no-take reserves on resources, particularly outside of reserve boundaries (e.g., spillover effects and enhanced reproduction output [Sladek Nowlis and Friedlander 2005]). MPAs do not protect all species equally; for example, animals that move long distances relative to the size of the MPA receive less protection. Nevertheless, mounting scientific evidence shows that MPAs can increase coral reef fish and invertebrate abundance and biomass because protection from fishing allows animals to live longer and grow larger. This has been hypothesized to increase the export of larvae and coral reef ecosystem resilience, although few research projects or monitoring programs address these issues directly. Additionally, there is a need to oceanographically characterize MPAs to enable calculation of larval drift and to better understand migration pathways for better site-selection of MPAs. Research should also be conducted to determine the effects of long-term de facto MPAs (e.g., marine waters within military zones, security zones, harbors, and airports) on surrounding fished areas.

The human dimension of MPAs is critical to the success of planning, development, management, and monitoring of MPAs and MPA networks. Historically, most research on MPAs has focused on natural science; however, recent studies have shown that social factors, as much as or more than biological or physical factors, determine the success of a MPA. In establishing and managing MPAs, managers need to understand how the areas may impact the people who use them, and how users, in turn, impact those areas and non-MPA areas. Social science research is needed to fill information gaps and help MPA programs identify and consider important issues, such as public attitudes and perceptions, relationships between and among uses and users of the marine environment, impacts of MPAs on the character of communities, and direct and indirect economic impacts of MPAs over time.

General research questions related to the effective application of MPAs and MPA networks as management tools of coral reef ecosystems include: How do location, size, and oceanographic processes influence MPA function and efficiency in terms of meeting both biophysical and socio-cultural objectives? Where and what level of protection is needed for MPAs to enhance the resilience of coral reef ecosystems, improve fish stocks, and manage risk associated with multiple stressors? What factors affect and enhance the recovery of exploited species within no-take reserves and how long does it take to see a response for economically and ecologically important species? What are the spillover effects (e.g., export of larvae and fish) from reserves to MPAs and MPA networks? What are the effects of MPAs and MPA networks on commercially or recreationally harvested species inside and outside MPA boundaries? What socioeconomic factors enhance support for and compliance with rules and regulations associated with MPAs by fishers and/or other stakeholders? What factors associated with the processes to design and establish MPAs have the most significant effect on acceptance of MPAs by the public? What impediments exist to adding more MPAs? What ecosystem impacts and benefits are provided by different MPA access restrictions? How can fish spawning aggregations be used in the design of MPAs and MPA networks? How can local knowledge and social capital be utilized to improve MPA acceptance and long-term effectiveness?

Habitat Restoration

The dramatic and widespread loss and alteration of coral reefs have generated discussion about replacing what was lost or accelerating the rate of recovery

Figure 26. A diver prepares to reattach an elkhorn coral fragment, Acropora palmata*, in response to the* Fortuna Reefer *grounding (Mona Island, Puerto Rico, 1997). Photo credit: Erik Zobrist, NOAA Restoration Center.*

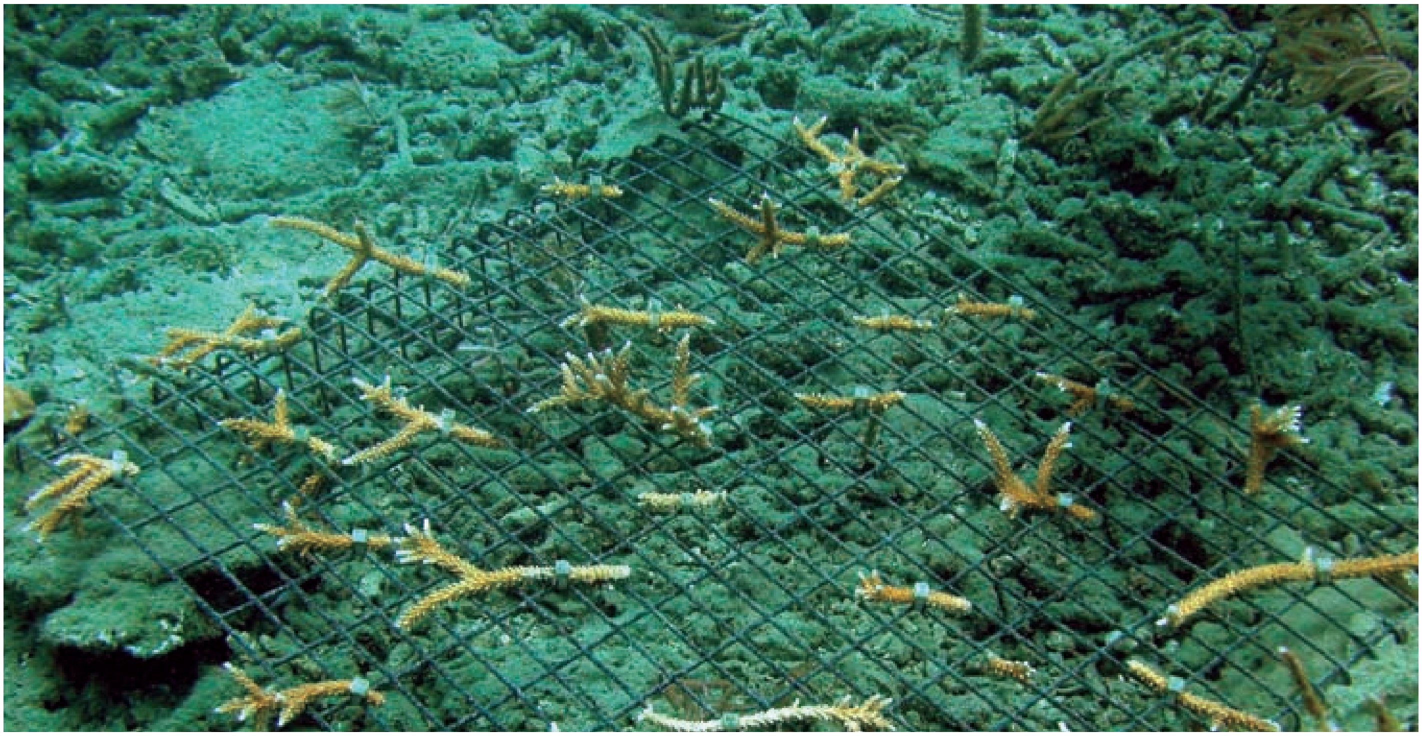


Figure 27. Staghorn coral fragments, Acropora cervicornis, *are attached to a wire frame as part of a restoration effort at the M/T* Margara *grounding site off Guayanilla Bay, Puerto Rico. This staghorn coral nursery shows rapid growth after one month as evidenced by the new branches. Photo credit: Andy Bruckner, NOAA Fisheries.*

from damage. Restoration is defined as the "return of an ecosystem to a close approximation of its condition prior to disturbance" (NRC 1992, p.11). Most projects aim to restore the ecosystem to its condition prior to the disturbance, but in many cases recovery converges on a community that is different from its pre-disturbance state (Aronson and Swanson 1997).

The science behind coral reef ecosystem restoration is still in its infancy. The few restoration efforts that have occurred to date have been relatively small-scale responses to physical damage from vessel groundings, anchorings, dredging, and other coastal development activities. These emergency restoration efforts have included righting and reattachment of displaced and broken coral (Figure 26), and the removal of coral rubble. Some of these restoration efforts have used underwater cements and other substrates in combination with creative engineering to repair structural fractures (e.g., obliterated spurs and holes caused by large propeller excavations) and to stabilize rubble. To date, very few restoration efforts have addressed the living component of the coral reef ecosystem, with the exception of transplanting fragments (Figure 27) or cementing dislodged corals back in place.

One example of a resource injury documentation and small-scale restoration process is in the Florida Keys National Marine Sanctuary (FKNMS). Vessel groundings in the FKNMS have damaged over 30,000 acres and pose a major threat to coral reefs and seagrass beds (FKNMS 1997). Depending on the extent of the injury, a vessel grounding in the FKNMS can initiate a sequence of events that includes injury assessment, emergency triage (i.e., emergency righting and reattachment of displaced or broken corals, and stabilization of the substrate), possible litigation between the natural resource trustee agency and the responsible party or parties responsible for the damage, and a detailed damage assessment and restoration project (Precht et al. 2003). NOAA has a strong legal mandate through the National Marine Sanctuaries Act (16 U.S.C.1443) and the Natural Resource Damage Assessments rule (15 C.F.R. 990) to recover losses of natural resources and their services from the responsible party, including compensation to restore damaged resources and compensation for lost services from the time that the damages occurred until the resources have recovered based on an established economic process to calculate damages. This includes collection of a monetary damage claim to restore the damaged resources as closely as possible to their pre-injury condition (primary restoration), and to replace the services lost over time from the injury (compensatory restoration) (Shutler et al. 2006). It does not include conducting research on how to restore coral reef ecosystems. In 1994, $3.76 million was paid as a settlement for destruction of 345 m^2 of reef area due to a ship grounding. The recovered funds were applied to primary and compensatory restoration, including monitoring of the restoration site (NOAA 1999).

Prior to undertaking restoration, it is important to verify that the factors responsible for the original loss are not still present; the area of interest has the capacity to be restored; and clear restoration project goals, a measurable endpoint, and parameters for measuring achievement have been identified. Additionally, the project design may need to be altered during the restoration process in light of new information or problems (i.e., adaptive management). It is important to note that despite localized efforts to curtail degradation (Patterson et al. 2002; Szmant 2002; Wilkinson 2002; Turgeon et al. 2002; Gardner et al. 2003; Lang 2003; Pandolfi et al. 2005), in general, coral reef loss is ongoing unabated. This loss suggests a broader consideration of global processes (such as the effects of expanding human demands on the environment) might be necessary in coral reef restoration efforts.

Hypothesis-driven research is needed to evaluate and improve coral reef ecosystem restoration efforts including criteria development for determining when restoration is a viable option and assessing the socioeconomic costs and benefits of restoration and its alternatives; the development and comparative evaluation of restoration techniques, including the examination of both unimpacted controls and impacted/unrestored controls; the experimental testing of the efficacy of different restoration options; and quantifiable measurements of restoration project success. Long-term monitoring programs to measure the success of a restoration project should incorporate an experimental design and be based on hypothesis-driven questions. The development of models that predict resource recovery with and without restoration may also guide decisions on where and when to intervene.

Social science research related to habitat restoration and protection should investigate the factors driving support for or opposition to such efforts. This could include an examination of different institutional factors driving both the use and protection of coral reef ecosystems. Study of local attitudes and perceptions regarding habitat conservation efforts could also be important to the long-term success of restoration and conservation efforts.

Management-relevant questions pertaining to habitat restoration include: What do monitoring results from existing restoration projects, compared to results from undamaged coral reefs, tell us about community processes that are important for recovery, such as coral reproductive biology, coral recruitment, algal growth, links between coral health/habitat provision and fish populations, resistance to perturbations, and coral reef ecosystem resilience? What techniques, if any, significantly enhance the rate and trajectory of recovery to predamaged condition or some other defined restoration goal? How do physical oceanographic processes, both large-scale (km) and small-scale (m), facilitate or hinder recovery and restoration efforts? Are instituted management actions preventing vessels from striking previously damaged areas? Do existing policies and institutional arrangements lead to desired restoration outcomes? What institutional/socioeconomic factors impede the implementation of restoration efforts?

TRANSFERRING SCIENCE AND TECHNOLOGY INTO OPERATIONS

Coral reef ecosystems will benefit from the research conducted and supported by NOAA and other organizations only if that research is transferred into operations by management authorities in a timely manner. NOAA relies on research results to develop management actions based on sound science to fulfill its statutory and regulatory responsibilities. Thus, data should be analyzed and disseminated to resource managers quickly. Too often, data collection is completed, but it is years before the information is shared, and by then the information is outdated.

End-to-end research planning outlines the path for the transfer of new technologies, research results, and advances in observation systems into improved operational capabilities. This transition is achieved through close collaboration between researchers and service delivery professionals at all phases of the research and development process. Frequent exchange between managers and researchers will ensure that the direction of research is adjusted to address solutions to management problems.

As indicated in *NOAA's Five-year Research Plan* (p. 8):

> "One tool for enabling the transition of research to operational use is the testbed. Testbeds provide the research community a setting to work directly with NOAA's operational elements through established testing and evaluation protocols with clearly defined goals and decision points for cost-effective and rapid transition of new research and technologies into routine operations. With the goal of accelerating infusion of technology and research results into operations, testbeds provide the opportunity to address the following:
>
> - System design studies for the global observing system network.
> - Assessing scientific breakthroughs and new techniques to identify advanced analysis techniques, numerical forecast models and methods, observational systems, and climate-water-weather linkages having potential for significantly improving forecasts.
> - Using advanced statistical and numerical weather prediction model output (especially model ensemble information) and stimulating further model enhancements.
> - Refining computer-based models, products, and observations in a quasi-operational information technology environment subject to metrics that mandate good scientific performance while meeting ease-of-use, reliability, and operational criteria.
> - Developing enhanced verification capabilities.
> - Exploring societal impacts resulting from improved products and services."

Transferring science and technology into operations includes developing methods for managers to conduct social impact analyses; evaluating alternative management options; and developing information technology to support management decisions, such as data visualization techniques and geographic information systems (GIS). Social science research analyzing the use and evaluation of science and technology is also critical to management efforts and should include assessing the appropriate delivery mechanisms for technical information.

OUTREACH AND EDUCATION: TRANSLATING RESEARCH, IMPROVING MANAGEMENT

Outreach and education are processes used to increase public awareness, appreciation, knowledge, and understanding about coral reef issues in order to promote informed decision-making and increase stakeholder support in reef conservation. Strategic outreach is a critical and underutilized component of effective management, and is an important step in the science-to-management linkage. Just as scientists and managers should collaborate to develop research that supports the information needs of managers, outreach specialists can help identify and achieve tenable management solutions supported by the public.

Socioeconomic research can also elucidate impacts to coral reef ecosystems by providing an understanding of human motivations, which is critical information for policymakers, managers, and outreach specialists. Accordingly, socioeconomic research works hand-in-hand with outreach efforts to inform managers and policymakers of probable responses to management strategies and policy measures. Outreach and socioeconomic studies can also determine mid-course if the public is responding as anticipated to a management measure or if further outreach and feedback mechanisms are needed. In this sense, outreach activities depend on social science research examining multi-stakeholder processes and the institutional arrangements necessary to successfully manage coral reef ecosystems.

Goals of integrating research, management, and outreach to improve effectiveness:

- Promote public awareness of the status and importance of reefs, and foster a stewardship ethic.
- Translate scientific research into information about the condition of coral reefs and the rationale for management decisions that the public can access and use.
- Improve effectiveness and responsiveness of management through information-sharing and two-way dialogues that promote agency understanding of public values related to coral reef ecosystems, and how and why stakeholders use coral reefs.
- Build public support for management initiatives.

Figure 28. Youth learn about sea stars in a hands-on education program in the Bahamas. Photo credit: Staff Photographer, Perry Institute of Marine Science.

Management effectiveness can be directly proportional to public support for a given initiative. For example, a MPA is unlikely to be successful if commercial and recreational resource users do not support or understand the underlying need for the MPA. Accordingly, management initiatives benefit from the broad support of the range of coral reef ecosystem users. Outreach activities should be designed to encourage this broad support and involvement, and to solicit feedback. For outreach to be most effective, the information needs and motivations of stakeholders should be considered at all stages of the research-to-management process, from program design to implementation to performance measurement. Social science research should focus on characterizing the social, cultural, economic, and institutional environments linked to particular reef systems to allow for the development of outreach initiatives targeting specific public concerns and perceptions related to reef management.

Effective planning and coordination of national, regional, and local outreach initiatives are also imperative. Outreach plans should consider the initial and future receptiveness to conservation goals by competing interest groups, and then develop locally- and culturally-appropriate programs that work with communities to facilitate the long-term success of resource management. Outreach activities should stem from and be tailored to an understanding of the motivations and needs of those impacted by management programs. This end-to-end integration of research, management, and outreach may decrease the need for enforcement and restoration activities, and encourage improved stakeholder behavior and participation in the management process.

Wherever possible, full integration of outreach and management strategies should be encouraged and supported by effective research. This integration is guided by the need for increased translation of scientific findings into initiatives that build public support for management goals. Outreach activities should work in tandem with research and management to cause behavioral changes through science-based information.

Established and well-documented social science tools include focus groups, opinion polling, baseline and comparative surveys of public values and awareness, as well as participatory research and planning and citizen advisory groups. NOAA's use of polling and survey work is somewhat constrained, and applying these techniques requires training in social science methods, as well as sound information on the human, social, and economic environments in which management activities are occurring. Therefore, research is needed to define additional ways with which to measure outreach activities and the impact of outreach on management effectiveness.

Examples of outreach activities include encouraging sustainable behavior through skills-building workshops and training programs with constituents; providing access and orientation to current research findings and data through information transfer tools like NOAA's Coral Reef Information System; developing and distributing educational materials and displays; fostering community involvement in conservation and restoration projects; and hosting two-way discussions with stakeholders to improve mutual understanding of resource needs and management goals. Social marketing initiatives, which use traditional marketing methods of public communication to promote sustainable behavior, have also proven quite effective. Marketing expertise can help outreach specialists and managers develop information materials that the public can recognize. Public service announcements on radio and television, billboards, materials placed in hotels and on flights into coral reef areas represent potential options for communicating with the public.

Emphasis should be placed on encouraging effective two-way communication and information-sharing between managers and various stakeholder groups. Successful projects will support local management-to-outreach integration through effective planning and implementation, and should involve key stakeholders throughout the process as appropriate. Constituents are more likely to respond favorably to management and enforcement if they understand, have been able to anticipate, and can continue to be involved with conservation programs, becoming active hands and resources for change rather than being isolated through non-inclusive management processes.

Formal and informal education initiatives are also encouraged where appropriate. Youth education is increasingly recognized as critical to building lifelong environmental literacy and stewardship and as a precursor to a diverse workforce for future generations (Figures 28 and 29; USCOP 2004). Developing partnerships with schools and educational and community organizations can maximize limited educational resources and encourage stewardship throughout the community through service learning projects and other initiatives involving parents and others in the process of student learning. Educational programs should focus on translating the latest research into activities that help students understand the living and evolving nature of science and the need for scientists from diverse backgrounds. Finally, training for educators in the use of coral reef science and education materials is critical to ensuring the effectiveness of education programs. Educators involved with even one-time professional development workshops are many times more likely to use materials and encourage student awareness and stewardship than those who are simply handed materials without hands-on orientation (Fortner and Corney 2002).

Figure 29. Georgetown Police Youth Summer Camp provides the opportunity for local youth to learn about the sea and its creatures through the use of a touch tank (Bahamas). Photo credit: Staff Photographer, Perry Institute of Marine Science.

Part II: Regional Research Priorities

School of white grunts, Haemulon plumieri *(Florida Keys National Marine Sanctuary). Photo credit: Andy Bruckner, NOAA Fisheries.*

Jurisdiction-Wide Research Needs

Broad overarching research needs that apply to all jurisdictions (except where noted) are based on the discussion in Part I of this Plan and are presented below. Research needs that are specific to a jurisdiction are detailed under the sections entitled *Jurisdiction-Specific Research Needs*.

RESEARCH SUPPORTING MANAGEMENT

Fishing

ALL JURISDICTIONS	FISHING
Management Objective	***Research Need***
Conserve and manage fisheries to prevent overfishing, rebuild stocks, and minimize destructive fishing.	Determine the population status of managed reef species using fishery dependent and independent programs.
	Determine the level of fishing pressure and the distribution of effort for subsistence, recreational, and commercial fisheries, and the impact of these activities on fisheries resources and coral reef habitats.
	Determine the effects of habitat degradation and loss of coral on fish community structure and stability.
	Determine the effects of various fisheries (gear and techniques) on coral reef ecosystems, including physical impacts on habitat, trophic effects, and incidental catch; and identify alternatives to minimize impacts.
	Determine the effectiveness of fishery management actions, including size limits and seasonal closures.
	Determine the current status and locations of reef fish spawning aggregations.
	Characterize fish movements and habitat utilization patterns of different life stages to assist in the identification of essential fish habitat.
	Characterize the life histories of important fish species and their movement patterns within and among different habitats.
	Characterize recruitment patterns for commercially and ecologically important species.
	Quantify fish community structure including size, diversity, and abundance among reefs and across multiple habitat types.

Pollution

ALL JURISDICTIONS	POLLUTION
Management Objective	***Research Need***
Reduce the impacts of pollutants on coral reef ecosystems by improving the understanding of their effects.	Ascertain pollutant loads, their primary sources, flow rates, and transport pathways, and net flow rate (flux) to coral reef communities.
	Determine atmospheric deposition rates and concentrations of pollutants on coral reefs.
	Identify the component(s) in air samples from dust sources (e.g., Africa and Gobi Desert) and downwind sites that are toxic to coral reef organisms.
	Identify target concentration loading rates and develop bioindicators for pollutants to detect organismal and ecosystem stress at sublethal levels.
	Develop and test indicators for land-based pollutants and prioritize their use in environmental and injury assessments.
	Identify, evaluate, and track anthropogenic activity through the use of biogeochemical and biological tracers, and indicator organisms.
	Investigate algal community dynamics in response to pollutant level changes to determine their utility as an indicator of future changes in coral reefs.
	Investigate microbial organisms as indicators of nutrient, sediment, and chemical pollutants in coral reef ecosystems.
	Integrate current biological monitoring techniques with water quality monitoring data to assess potential affects of water quality on various habitat types and associated organisms.
Improve water quality by reducing land-based pollutant inputs and impacts on coral reef ecosystems.	Quantify, characterize, and prioritize the land-based sources of pollution that need to be addressed based on identified impacts to coral reefs and develop strategies to eliminate, reduce, and mitigate these impacts.
	Evaluate changes in water quality to determine the success of management actions to reduce sediment, nutrient, and chemical pollutants and other factors that degrade water quality.

Coastal Uses

ALL JURISDICTIONS	COASTAL USES
Management Objective	***Research Need***
Reduce the impacts from recreational use, industry, coastal development, and maritime vessels on coral reef ecosystems.	Quantify and characterize, both spatially and temporally, threats from commercial and recreational non-extractive activities and the impact of these activities on coral reef ecosystems, and develop strategies to eliminate, reduce, and/or mitigate these impacts.
	Develop scientific criteria to determine the carrying capacity of the reef ecosystem, and determine the level of recreational use (e.g., diving, snorkeling, and boating) that specific areas can support.
	Design and conduct demonstration projects to evaluate science-based management options for improving shoreline stability, while maintaining coral reef ecosystem functions.
	Identify and apply biological indicators toward quantification and characterization of impacts associated with coastal uses.
	Develop new technologies, construction practices, and management measures to eliminate, reduce, and/or mitigate impacts from coastal uses.
	Conduct research to better understand the economic and social factors of the human dimension and their impact on coral reef ecosystems.
	Quantify and track vessel discharges, spills, and anchor damage, and their impacts on coral reef ecosystems; and recommend mitigation measures.
Protect, conserve, and enhance the recovery of protected, threatened, and other key species. *Research needs related to acroporids are for the Atlantic Ocean only.*	Acroporids
	Identify the historical and current distribution of acroporids, compile this into a GIS database, and analyze spatial changes and relationships with physical, environmental, and anthropogenic factors.
	Assess (region-wide) the abundance and condition of acroporids incorporating colony size and counts per unit area of the different life stages (i.e., colonies, fragments, and new recruits).
	Evaluate the efficacy of measures to reduce anthropogenic stressors (including sedimentation, pollution, eutrophication, climate change, overfishing, and ship groundings) in enhancing recovery of existing populations of acroporids and promoting sexual recruitment.
	Evaluate the effects of storms and other natural stressors (e.g., coral predators) on the destruction and recovery of coral populations, and determine how anthropogenic disturbances may affect these natural processes.
	Evaluate the costs and benefits of various acroporid restoration strategies at promoting recovery of degraded populations, including efforts to reseed areas with larvae, optimal reattachment methods for fragments, and strategies to treat colonies affected by disease, predators, and other natural stressors.
	Identify microbial communities associated with diseased and healthy acroporid colonies; identify how these microbial communities change spatially, temporally, and under varying environmental conditions; and determine relationships between these communities and the health and mortality of colonies.
	Characterize the genetic structure and conduct demographic modeling of acroporid populations to predict population response to future disturbances and stresses encompassing a range of spatial and temporal scales.

ALL JURISDICTIONS	COASTAL USES
Management Objective	***Research Need***
Manage coral reef ecosystems and their uses in a holistic manner.	Assess the extent and condition of deep-water hermatypic coral reef ecosystems and their importance as essential fish habitat.
	Expand ecological and taxonomic understanding of functionally important, but understudied, coral reef ecosystem groups, such as sponges, octocorals, mollusks, polychaetes, crustaceans, echinoderms, tunicates, seagrasses, algae, and microbial diversity.

Invasive Species

ALL JURISDICTIONS	INVASIVE SPECIES
Management Objective	***Research Need***
Minimize the introduction and spread of alien species.	Identify possible vectors and pathways of alien introductions and develop prevention measures, where applicable.
	Determine the threat and impact of hull fouling and ballast water as mechanisms for introducing and dispersing invasive species.
Control or eradicate invasive species that have the potential to cause damage to coral reef ecosystems.	Quantify the presence and evaluate the impact of invasive species on coral reef ecosystems.
	Establish protocols for early detection and eradication of invasive species.
	Develop methods to mitigate impacts of invasive species on coral reef ecosystems and evaluate the efficacy of these methods.
	Develop and evaluate methods to monitor, contain, and sterilize ballast water to prevent introduction of invasive species to coral reef ecosystems.

Climate Change

ALL JURISDICTIONS	CLIMATE CHANGE
Management Objective	***Research Need***
Minimize the effects of climate change on coral reef ecosystems.	Bleaching of Coral Reef Organisms
	Assess the spatial and temporal scales of bleaching of coral reef organisms during identified bleaching events.
	Quantify the relationships between severity of bleaching events and mortality including factors that exacerbate bleaching impacts or confer resistance and resilience.
	Quantify the socioeconomic impacts of coral bleaching events on user groups and the economy and investigate user group perceptions of coral bleaching events.
	Identify factors and their thresholds that cause coral bleaching (including physical parameters, environmental factors, and anthropogenic stressors) and investigate interactions between factors and the severity of bleaching events and the ability of corals to recover from bleaching.
	Identify the potential for coral reefs to adapt to future bleaching events through changes in clades of zooxanthellae in individual species and shifts in taxonomic composition of symbiotic organisms.
	Develop early warning systems for coral reef bleaching based on known or predicted relationships with environmental factors (e.g., temperature and light) and catastrophic pollution events (e.g., oil spills and toxic discharges).
	Develop models to predict long-term impacts to coral reef ecosystems from coral bleaching events and climate change incorporating relationships with environmental and anthropogenic stressors.
	Calcification
	Investigate variations in rates of coral calcification among species, temporally and spatially, and within different life stages, and how those variations may affect survivorship.
	Investigate how differing levels of atmospheric CO_2 will affect ocean pH, carbonate saturation state, and coral calcification and growth rates.
	Quantify the effects of temperature, pH, and aragonite saturation state on calcification, reproduction, and recruitment.
	Measure biogenic $CaCO_3$ production, seawater chemistry, $CaCO_3$ dissolution and accumulation, bioerosion, and off-shelf export of $CaCO_3$ to improve the accounting of coral reef carbonate budgets and predict how reef accretion may change in the future.
	Determine how variations in calcification rates affect associated organisms, food web dynamics, carbon and nutrient cycling, and ecosystem services.
	Examine how reduced saturation states of $CaCO_3$ affect rates of bioerosion.
	Waves
	Determine the relationships among wave energy, coral reef damage, and factors that increase or minimize damage to reefs and coastal communities.
Mitigate the impacts from climate change on coral reef ecosystems.	Determine the effectiveness of management strategies to reduce anthropogenic stressors in mitigating the severity of bleaching.
	Evaluate available tools and develop new tools to quantify and mitigate the impacts of climate change on coral reef ecosystems.
Predict the future composition and condition of coral reefs under various climate change scenarios	Quantify organism and ecosystem responses to climate change and determine their relationships with stressors and pertinent physical, biological, and chemical parameters.
	Examine the impacts of past climate fluctuations on coral community structure.
	Develop tools to detect and describe decadal changes in relation to natural and anthropogenic disturbances.

Extreme Events

ALL JURISDICTIONS	EXTREME EVENTS
Management Objective	***Research Need***
Identify and reduce the incidence of disease in coral reef ecosystems.	Determine temporal and spatial variations in disease prevalence among reef-building coral species across habitats, depths, and varying distances from land and their relationships with environmental factors and anthropogenic stressors.
	Quantify the rates and extent of partial and whole colony mortality from diseases, the effect of partial mortality on individual colonies (e.g., effect on reproduction and growth), and long-term impacts on affected coral reef ecosystems.
	In the event of a major die-off of corals resulting from disease, quantify the ecological and socioeconomic impacts.
	Identify external sources of pathogens (e.g., human sewage and dust) and disease vectors and quantify their distribution and abundance.
	Determine the distribution, abundance, and impact of diseases affecting other ecologically important benthic coral reef invertebrates (e.g., sponges and urchins) and fishes.
	Identify factors that increase the prevalence and impact of diseases (e.g., toxins, pollutants, sedimentation, temperature, and biotic agents), including factors and processes that increase the virulence of pathogens, increase host susceptibility and/or reduce resistance, and contribute to the transmission and spread of diseases.
	Identify and characterize the etiology of key coral diseases, including identification of biotic and abiotic causes.
	Characterize microbial communities associated with corals and coral mucus; the variations among species, seasons, and locations; identify factors that cause variations in microflora; and characterize the consequences of these changes to the host (e.g., shift from a symbiotic association to a disease-causing state).
	Develop standardized nomenclature, diagnostic characteristics, standardized field and laboratory methodologies, and rapid response protocols to enhance the comparability of data, improve capacity to respond to disease outbreaks and report on findings, and to identify viable management responses.
	Develop early warning systems for disease outbreaks based on known or predicted relationships of coral reefs with environmental factors (e.g., temperature and hurricanes) and catastrophic pollution events (e.g., oil spill and toxic discharge).
	Develop models to forecast long-term effects of disease on population dynamics, community structure, and ecosystem function incorporating information on biotic agents, environmental factors, and anthropogenic stressors known or predicted to affect disease prevalence and incidence.
	Characterize healthy and diseased corals on a cellular and physiological level (e.g., histological changes, immunological responses, and production of stress proteins).
	Develop tools to reduce the prevalence of diseases, mitigate their impacts, and treat affected corals.

TECHNOLOGY SUPPORTING RESEARCH & MANAGEMENT

Marine Protected Areas

ALL JURISDICTIONS	MARINE PROTECTED AREAS
Management Objective	***Research Need***
Evaluate and improve the effectiveness of MPAs as a management tool.	Develop site-selection criteria for MPAs to assist in the conservation of coral reef ecosystems and management of commercially important fishery species, taking into account: o Species diversity, trophic structure, and abundance of economically or ecologically important species. o Habitat utilization patterns of different life stages. o Larval recruitment, dispersal, and connectivity (including sources and sinks). o Connectivity between habitat types (including seagrass beds, mangroves, and other associated communities), spawning aggregations, and nursery areas. o Environmental factors and anthropogenic stressors.
	Develop models to predict changes to coral reef resources that may occur under different zoning schemes, taking into account ways to conserve and possibly enhance marine resources.
	Evaluate the effectiveness of MPAs, including no-take reserves and other marine zoning schemes, taking into account: o Abundance of ecologically and economically important species. o Spillover of fishery species into adjacent habitats. o Improvements in the condition of the sessile benthic community and abundance of mobile invertebrates. o Cascading effects on non-target species.
	Develop useful indicators (biophysical and socioeconomic) of management effectiveness.
	Determine the socioeconomic and ecological costs and benefits of MPAs as a management tool, including relationships between levels of compliance and achieved benefits.

Habitat Restoration

ALL JURISDICTIONS	HABITAT RESTORATION
Management Objective	***Research Need***
Restore injured and degraded coral reef habitat.	Identify and test new coral reef restoration strategies, including transplantation and attachment techniques; optimal fragment size, shape, and orientation; ability to withstand high-energy events; and use of environmentally-friendly exotic materials.
	Determine the effectiveness of efforts to collect and settle coral larvae as a restoration tool.
	Design and evaluate techniques to control or eradicate organisms that may inhibit recovery of damaged or degraded habitats.
	Evaluate the effectiveness of current strategies to restore degraded reefs (e.g., culturing corals in a laboratory, transplanting fragments, and creating coral nurseries), taking into account the ability to maintain genetic variability, mitigate source(s) of the damage, maintain the historical distribution of the species within that habitat, and restore habitat function.
	Evaluate effectiveness of restoration techniques for associated habitats, including mangroves, seagrass beds, sandy beaches, and riparian habitats.
	Determine the impacts of exotic materials (e.g., iron, cement, rubber, and fiberglass) on recruitment efficiency, biodiversity, and community structure.
	Evaluate the ecological recovery of restored areas.
	Evaluate the effectiveness of restocking ecologically important species (e.g., *Diadema* and herbivorous fishes), and the costs and benefits of restocking using species raised in captivity versus wild populations.

Jurisdiction-Specific Research Needs: Atlantic Ocean

Nassau grouper, Epinephelus striatus *(Cayman Islands, 2006). Photo credit: Diana Schmitt.*

FLORIDA

The Florida Section of this research plan is divided into three subsections: the Florida Keys, Southeast Florida, and the Eastern Gulf of Mexico (Figure FL-1).

Florida Keys

Coral reefs in the Florida Keys stretch south from Miami to Key West, and continue to the Dry Tortugas, covering over 220 miles of continuous shallow-water habitat. The flora and fauna existing in this region are heavily influenced by the warm tropical waters of the Gulf Stream current and the temperate waters of the Gulf of Mexico.

In the Florida Keys (Monroe County), reef based-recreation and tourism are a significant part of the economy. In 2001, a socioeconomic study showed that natural and artificial reefs in the Florida Keys contributed $490 million in sales, $139 million in income, and 10,000 jobs to the local economy over one year (Johns et al. 2001). Therefore, a decline in coral reef condition could have far reaching impacts on the economy of Monroe County.

The decline of coral reefs in the Florida Keys is well-documented. Public perception is strong that poor water quality is the primary reason for the decline, but the scientific evidence suggests that a combination of geography, multiple stressors acting synergistically, and natural factors explain the condition of the reefs.

Because coral reefs in Florida represent the northern extension of a rich Caribbean flora and fauna, they are subject to many of the same problems that have caused coral decline throughout the Caribbean. For example, both white band disease affecting the branching corals *Acropora palmata* (elkhorn coral) and *A cervicornis*. (staghorn coral), and an urchin disease have reshaped the condition of the offshore reefs in the Keys and the Caribbean. Coral bleaching has affected the Keys multiple times in the past 15 years. In 1997 and 1998, significant bleaching was observed during the El Niño Southern Oscillation (Causey 2001). Large numbers of corals are presumed to have been killed by this bleaching event.

Overfishing is also a significant problem in the Keys. Between 1965 and 1993, the commercial fishing fleet grew by 25%, and the recreational fleet increased by six fold (Ault et al. 1998). These trends are a consequence of a burgeoning south Florida population which brings increased fishing and all of the attendant problems associated with coastal development that can be detrimental to coral reefs.

Against this background of multiple stressors and other disturbances (e.g., hurricanes, ship groundings, and coral diseases), there are three pieces of good news: the recovery of urchins (the major algal grazers) appears to be occurring at some sites in the Dry Tortugas (Chiappone et al. 2001), which may reduce algal cover and help corals recover; the management plan for the Florida Keys National Marine Sanctuary includes 23 marine zones (known as Sanctuary Preservation Areas, Special-Use Areas, and Ecological Reserves) that provide "no-take" protection from fishing and other forms of extraction; and the Tortugas Ecological Reserve was created in 2001 to conserve deep-water reef resources and fish communities. While these "no-take" marine zones were established primarily to manage multiple user-groups rather than a fishery management tool, preliminary results suggest positive fishery benefits as well.[1]

Southeast Florida

The extensive reef system of southeast Florida is a northward continuation of the Florida reef tract extending approximately 150 km from Miami-Dade County, through Broward and Palm Beach Counties, to Martin County. There are generally three reef lines, running parallel to the shore and separated by sand deposits – one that nominally crests in 3 to 4 m of water depth (i.e., Inner Reef or the First Reef), another in 6 to 8 m (i.e., Middle Reef or the Second Reef), and one in 15 to 21 m depth (i.e., Outer Reef or the Third Reef). On the shoreward side of the Inner Reef, a series of hard ground ridges often occur.

The reef resources in southeast Florida have considerable economic value. In the four-county area (Monroe, Miami-Dade, Broward, and Palm Beach), users spent over 18.4 million person-days from June 2000 to May 2001 using natural reefs, with economic impacts of $2.7 billion in sales and $1.2 billion in local income (Johns et al. 2001).

In southeast Florida, there are a variety of natural and anthropogenic stressors impacting the coral reef ecosystems. Natural stressors that can effectively limit coral reef growth include frequent exposure to hurricanes, weather, extreme water temperatures (both hot and

1 Research needs identified for the Florida Keys are based on the Comprehensive Science Plan for the Florida Keys National Marine Sanctuary (NOAA 2002b).

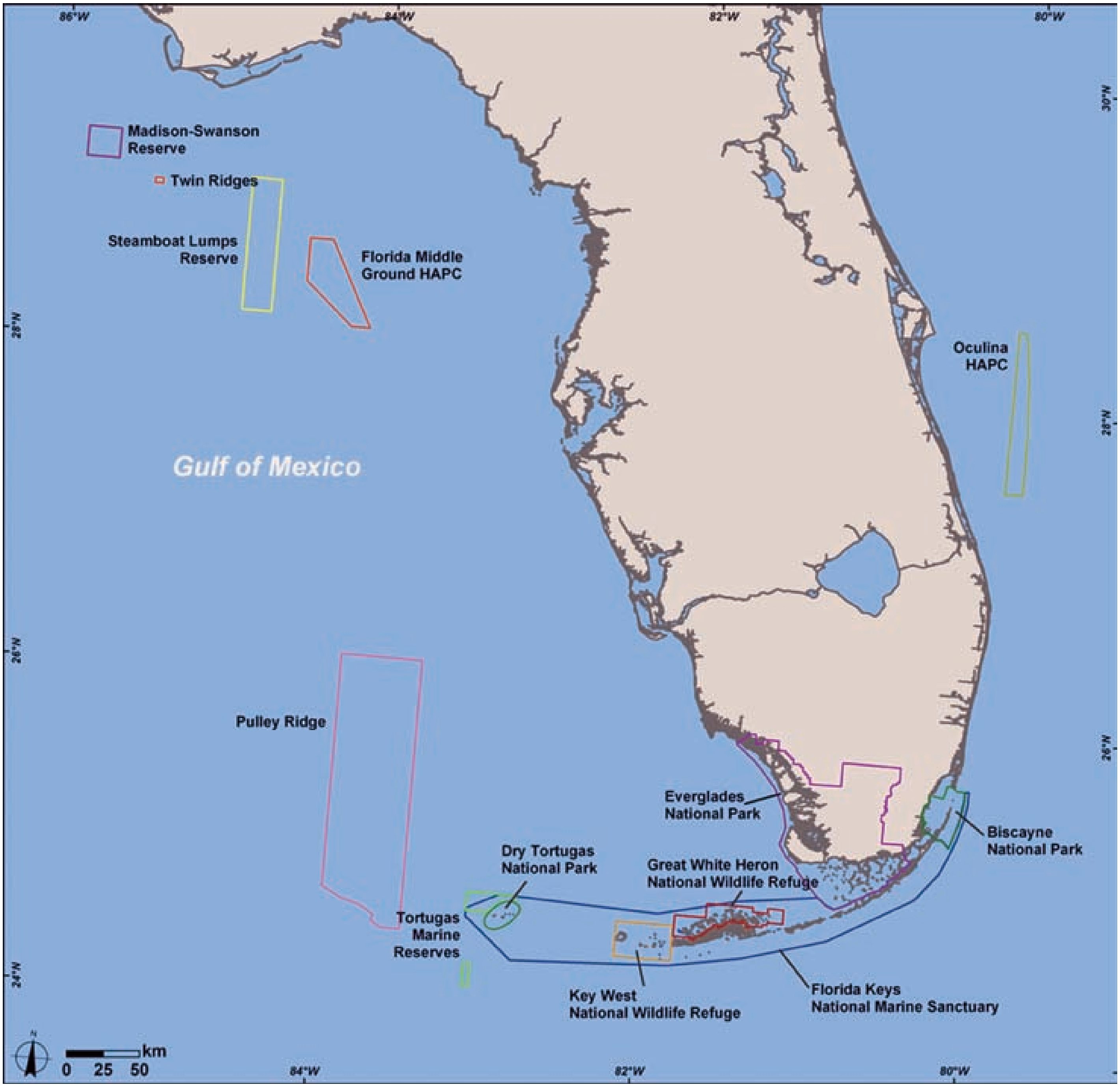


Figure FL-1. Locator map for Florida. Map: A. Shapiro.

cold), and deepwater upwelling. Potentially detrimental human activities include effects from offshore and onshore construction (e.g., pipelines, fiber optic cables, beach renourishment, channel dredging, and coastal development), large and small ship groundings, anchor and anchor chain damage, fishing, non-extractive recreational activities, and pollution from sewage and other land-based sources, including groundwater seepage, discharge from navigational inlets, and general runoff.

Coral diseases in southeast Florida are present across habitats and depth gradients. The main diseases observed in the region include black band disease, white band disease (mainly affecting *A. cervicornis*), white plague, and octocoral aspergilliosis, although numerous other conditions also occur. Bleaching also affects corals in the region; however the scale and severity of these events are not well documented. Because mean live coral cover in Miami-Dade, Broward, Palm Beach, and Martin Counties is low, coral disease and coral bleaching-related mortality demand further attention.

Overfishing appears to be a major problem for snappers and groupers. During a four-year period (August 1998 to November 2002), 667 sites on the three reef tracts were censused for fishes. There was a surprising scarcity of legal size groupers (19) and snappers (198) over the entire survey area (Ferro 2005).

While coral reefs south of Miami enjoy various levels of Federal protection in the form of national parks, state parks, and national marine sanctuaries, there is only one established formal protected area north of Biscayne National Park, the Oculina Habitat Area of Particular Concern (HAPC). The Oculina HAPC, a 1029 km^2 area located off central Florida, is closed to bottom-associated fishing gear to protect the ivory tree coral, ***Oculina varicosa***, an azooxanthellate coral with a fragile branching structure (NOAA 2003b). Within the Oculina HAPC, a 92 nautical square mile (nm^2) area known as the Oculina Experimental Closed Area is also closed to the snapper and grouper fishery. It should be noted that the Oculina HAPC does not protect the more shallow-water reefs of Southeast Florida (Dade, Broward, Palm Beach, and Martin Counties).

Eastern Gulf of Mexico (West Florida Shelf)

The eastern Gulf of Mexico, or west Florida Shelf, has a broad continental shelf (140,000 km^2) dominated by sedimentary bottom types. The hard bottom habitat typically consists of ridge or ledge rock formations (Lyons and Collard 1974), which serve as essential fish habitat for both snappers and groupers. The coral reefs and live hard bottom habitats consist of warm-temperate species in the northern area and hardy Caribbean species in the southern area. The northern area comprises the Florida Middle Ground, Madison-Swanson Reserve, Steamboat Lumps Reserve, and Twin Ridges; the southern area consists of Pulley Ridge and the Dry Tortugas.[2]

<u>Northern Area</u>:

- The Florida Middle Ground is a 1,193 km^2 area in the northeastern Gulf of Mexico that represents the northernmost extent of hermatypic coral reefs in the United States.
- Madison-Swanson Reserve is a 394 km^2 area located south of Panama City, Florida and Steamboat Lumps Reserve is a 356 km^2 area located west of Tarpon Springs, Florida. Both Madison-Swanson and Steamboat Lumps Reserves lie at the margin of the continental shelf and slope in 60 to 140 m of water and are sites of spawning aggregations of gag (*Mycteroperca microlepis*) and other reef fish species (Koenig et al. 2000).
- Twin Ridges is an area adjacent to Madison-Swanson and Steamboat Lumps Reserves which is unprotected and used as a reference site to measure the impact of the reserves.

<u>Southern Area</u>:

- Pulley Ridge is a drowned barrier island approximately 100 km in length located off the southwest Florida Shelf at 60 to70 m in depth (Halley et al. 2003), and is believed to be the deepest hermatypic coral reef dependent on light off the continental U.S. (Halley et al. 2005). The ridge itself is 5 km wide with 10 m of relief. Coral cover in some sites may be as high as 60% (Jarrett et al. 2005). The fragile corals of Pulley Ridge remain at risk to bottom tending fishing gear and more habitat delineation is needed to assess the extent of coral habitat. As no coral bleaching events have been observed on Pulley Ridge to date, this area could serve as a control site for investigations of similar species in shallower waters which have experienced bleaching.

The major stressor in the eastern Gulf of Mexico is fishing pressure on grouper and snapper stocks and shrimp. The region has three prominent fisheries: the Penaeid shrimp, snapper and grouper, and a commercial sponge. Other important stressors are annual red tides or harmful algal blooms of phytoplankton that are toxic to many fish, birds, and marine animals that last from four to five months; pollutant loads from the Mississippi River and other rivers during spring runoff; occasional upwelling of cold, high nutrient water on the northern areas; positioning gas pipelines over the shelf that impact benthic organisms; ocean dumping; climate change; coastal development; and bottom tending commercial fishing gear. In 2005, extreme events heavily impacted the condition of benthic communities and fish stocks, including an extreme red tide and increased Mississippi River runoff from Hurricanes Katrina and Rita.

The coral reef ecosystems and spawning aggregations in the Gulf of Mexico have differing levels of protection. The Florida Middle Ground HAPC was designated in 1982 and encompasses most of the high-relief and live bottom habitat (Coleman et al. 2004). Although protected from coral harvest and bottom-associated fishing gear, this region's reef fish populations are fished using hook and

2 The Dry Tortugas are addressed in the Florida Keys section.

line. The level of commercial and recreational fishing pressure is unknown for this area and is a priority research need. Madison-Swanson and Steamboat Lumps Reserves were established in 2000 to protect gag and other fish spawning aggregations. These reserves were initially closed to all fishing (except highly migratory species) for a period of four years. These closures have since been extended to 2010 to evaluate the effectiveness of the reserves; however, surface trolling is now allowed for coastal pelagic and highly migratory species. Continued evaluation of the efficacy of the reserve determined through monitoring of reef fish abundance and distribution in and near the reserves remains a high priority as the species of interest are long-lived and late maturing. Enforcement of the fishing restrictions is complicated by the remoteness of the reserves and the level of illegal fishing is not being fully evaluated.

Research Needs

FLORIDA	FISHING	Florida All	Florida Keys Only	Southeast Florida Only	E. Gulf of Mexico Only
Management Objective	***Research Need***				
Conserve and manage fisheries to prevent overfishing, rebuild stocks, and minimize destructive fishing. *See Jurisdiction-Wide Section for additional research needs.*	Produce habitat maps with adequate bathymetric and habitat resolution to manage and understand the region's nearshore and offshore reefs, hard bottom and soft bottom communities, estuaries, inlets, and the Intercoastal Waterway. Whenever possible, use existing maps to streamline new acquisition efforts.	√			
	Assess the distribution, abundance, and ecological role of aquarium trade species and the impacts associated with their extraction.	√			
	Characterize the trophic dynamics of the ecosystem relevant to key fisheries species.	√			
	Develop spatially explicit bioeconomic models for important commercial and recreational fisheries incorporating ecosystem attributes such as predator-prey relationships, habitat characteristics, environmental parameters, and fishing effort.	√			
	Experimentally examine the potential for enhancement of degraded inshore habitat and concomitant change in associated fauna.	√			
	Determine the levels of fishing pressure and associated impacts on deepwater hermatypic coral reef ecosystems.	√			
	Determine whether the source of recruits of commercially important groupers and snappers in the Upper Florida Keys are from localized spawning sites or elsewhere in Florida or the wider Caribbean.		√		

FLORIDA	FISHING	Florida All	Florida Keys Only	Southeast Florida Only	E. Gulf of Mexico Only
Management Objective	***Research Need***				
Protect, conserve, and enhance the recovery of protected, threatened, and other key species.	Queen Conch				
	Identify the specific toxins or pollutants that inhibit reproduction and/or recruitment, develop options to mitigate these factors, and determine the effectiveness of implemented management actions on conch recovery.		√	√	
	Evaluate the status and trends of conch populations (spatial distribution and abundance of different life stages) to determine whether management measures are helping to rebuild populations.		√	√	
	Identify reliable methods to assess conch population dynamics, including size, age, and reproductive structure.		√	√	
	Characterize habitat use patterns of different life stages of conch, and movement patterns between reproductive and feeding grounds.		√	√	
	Identify natural factors that contribute to the recovery of conch populations, including reproductive potential (e.g., optimal densities), recruitment, predator-prey relationships, and food sources.		√	√	
	Spiny Lobster				
	Assess the relationships between habitat types and quality, and abundance of different life history stages of lobsters.		√	√	
	Identify the natural factors affecting the population dynamics of lobsters, including recruitment, predator-prey relationships, and ontogenetic shift in habitats.		√	√	
	Determine whether the source of spiny lobsters recruitment in the Florida Keys is from adults spawning in the Florida Keys or elsewhere (e.g., Central or South America).		√		
	Assess the impacts of the recreational and commercial lobster fisheries on lobster populations and coral reef habitats.		√	√	
Evaluate and improve the effectiveness of MPAs as a fisheries management tool. *See Jurisdiction-Wide Section for additional research needs.*	Evaluate benefits of the Tortugas Ecological Reserve, including whether the reserve is: improving the quality of habitat and the recovery of fish stocks; helping replenish the fish stocks in the surrounding non-MPA areas; and supporting societal needs.		√		
	Determine the effect of management measures in the Oculina Experimental Closed Area and other southeast Florida MPAs on commercial and recreational fishery stocks.			√	
	Determine the effectiveness of Madison-Swanson and Steamboat Lumps Reserves in protecting gag and other fish spawning aggregations.				√
	Determine the level of commercial and recreational fishing pressure in the Florida Middle Grounds HAPC.				√
	Determine short- and long-term costs and benefits of marine zoning in the Florida Keys National Marine Sanctuary to displaced commercial fishers.		√		

FLORIDA	POLLUTION	Florida All	Florida Keys Only	Southeast Florida Only	E. Gulf of Mexico Only
Management Objective	***Research Need***				
Reduce the impacts of pollutants on coral reef ecosystems by improving the understanding of their effects. *See Jurisdiction-Wide Section for additional research needs.*	Produce thematic maps for outlining habitat landscaping patterns for Miami-Dade, Broward, Palm Beach, and Martin Counties using existing laser airborne depth sounder mapping data.			√	
	Determine residence time of pollutants in specific areas.	√			
	Identify pollutant loads associated with episodic events (e.g., upwelling and major storms) and their impacts.	√			
	Identify sources and signals of sewage contamination by using appropriate tracers (e.g., stable isotopes as a signal in octocorals and macroalgal/***Lyncbya*** tissue, and human enteroviruses).			√	
	Determine whether the rivers feeding into the Gulf, including Suwannee, Withlacoochee, Crystal, Homosassa, Chasshowitzka, Wiki Wachee, Anclote, Hillsboro, Alafia, Little Manatee, Manatee, Myaka, Peace, Fenholloway, and Caloosahatchee Rivers, are adding significant pollutants, nutrients, pesticides, and other contaminants to the Eastern Gulf of Mexico coral reef ecosystems.				√
	Determine the amount and flux of pollutants from: exiting ocean inlets, oceanic sources, and atmospheric sources to coastal waters and coral reef communities.			√	
	Determine the amount and flux of effluent and pollutants from wastewater outflow pipes and net flux to coral reef communities along the coast.			√	
	Quantify the amount and flux of pollution transported by groundwater to coastal waters and coral reef communities.			√	
	Develop a mass balance pollution budget for southeast Florida reefs from both point and nonpoint sources, including nutrients, carbon, and other pollutants. Identify the sources and quantify their relative and absolute contributions.			√	
	Identify and model impacts of freshwater discharges from the Everglades on coral reef ecosystems.			√	
	Understand the dynamics of water and waterborne chemicals as they move from source areas to the Eastern Gulf of Mexico and the Florida Keys reefs.	√			
	Assess the impact of shallow injection wells and stormwater on coral reef ecosystems.		√		
	Evaluate the impact of large-magnitude rainfall and water releases from Lake Okeechobee on nutrient and contaminant levels in the Eastern Gulf of Mexico on coral reef ecosystems.	√			

FLORIDA	POLLUTION	Florida All	Florida Keys Only	Southeast Florida Only	E. Gulf of Mexico Only
Management Objective	***Research Need***				
Improve water quality by reducing land-based pollutant inputs and impacts on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Investigate effectiveness of real-time management of controlled runoff, including dams or other effluents, to reduce stress on coral reefs ecosystems during disease outbreaks, coral bleaching episodes, and spawning events.		√		
	Develop methods to improve water quality in Florida Keys canals.		√		
Improve the understanding of the economic benefits of improved water quality.	Conduct cost and benefit analyses of wastewater infrastructure upgrades and conservation land acquisition.	√			
	Determine how changes in water quality due to pollution may impact different economic uses, including potential fishery and habitat impacts.	√			

FLORIDA	COASTAL USES	Florida All	Florida Keys Only	Southeast Florida Only	E. Gulf of Mexico Only
Management Objective	***Research Need***				
Reduce the impacts from recreational use, industry, coastal development, and maritime vessels on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Determine the impact of coastal development on seagrass and mangrove habitats and how changes in the quality of these habitats as a result of human uses affect the condition of the associated reef habitat.	√			
	Assess the impact of development on the Indian River Lagoon Estuary and associated tropical peripheral species.			√	
	Design and conduct demonstration projects to evaluate science-based management options for improving shoreline stability while maintaining coral reef ecosystem functions.	√			
	Evaluate ecological and socioeconomic costs and benefits of artificial reefs, including public perception and their effects on fish communities and neighboring coral reef environments.		√	√	
	Determine the appropriate structural configuration (considering ability to withstand hurricanes) and develop criteria (e.g., location, amount of light, and current) for creating a diverse fish and invertebrate community for artificial reefs.			√	
Balance resource use to minimize user conflicts, provide equitable uses, and ensure optimal benefits to present and future generations.	Perform geographic and sector use assessments for the various habitats.			√	
	Determine the socioeconomic costs and benefits of different management strategies on different user groups.		√	√	
	Determine decadal changes in recreational and commercial uses (e.g., scuba diving, snorkeling, boating) of coastal waters and their habitats, and the economic impact of these changes.		√	√	

FLORIDA	COASTAL USES	Florida All	Florida Keys Only	Southeast Florida Only	E. Gulf of Mexico Only
Management Objective	***Research Need***				
Protect, conserve, and enhance the recovery of protected, threatened, and other key species. *See Jurisdiction-Wide Section for additional research needs.*	Acroporids				
	Identify critical habitat for *Acropora* spp. in Florida, including the historical and current distribution of acroporid populations, and factors that affect their spatial extent.		√	√	
	Assess the abundance, population structure, and condition of Florida acroporids, including documenting threats affecting these species, relationships between coral condition/abundance and human impacts, and the potential for recovery under different management regimes.		√	√	
Restore injured and degraded coral reef habitat. *See Jurisdiction-Wide Section for additional research needs.*	Develop economic models relating various habitats to economic value to assist in quantifying costs of resource impacts associated with vessel groundings and other human impacts.	√			
	Evaluate the efficacy of current protocols used in seagrass and coral reef restoration efforts.	√			
Reduce impacts from and restore habitat damaged by vessel anchoring and groundings.	Determine the extent and impact of vessel groundings, anchoring, and anchor chains on coral reef and associated habitats, including the cumulative impacts of daily groundings of recreational vessels and the impacts surrounding designated large vessel anchorages, such as Port Everglades.		√	√	
	Evaluate the effectiveness of existing mooring buoys and channel markers in reducing the impact of anchoring, anchor chains, and groundings to coral reefs.		√	√	
	Characterize patterns of recovery in unrestored areas affected by anchorings and groundings, and compare to restored areas.		√		
Evaluate and improve the effectiveness of MPAs as a management tool. *See Jurisdiction-Wide Section for additional research needs.*	Conduct periodic assessments of stakeholder's knowledge, attitudes, and perceptions of the Florida Keys National Marine Sanctuary management strategies and regulations, and identify ways to improve public support.		√		
	Determine whether *Oculina varicosa* habitat will recover throughout the Oculina Experimental Closed Area without human intervention, and predict the time frame for significant recovery to occur.			√	
	Identify what and where the major habitat types are in the Oculina Experimental Closed Area, the Oculina Bank HAPC, and adjacent hardbottom areas.			√	
	Assess the effectiveness of special preservation areas and ecological reserves in resolving conflicts between extractive and non-extractive users of the Florida Keys National Marine Sanctuary.		√		

FLORIDA	INVASIVE SPECIES	Florida All	Florida Keys Only	Southeast Florida Only	E. Gulf of Mexico Only
Management Objective	***Research Need***				
Minimize the introduction and spread of alien species.	*See Jurisdiction-Wide Section for research needs.*	√			
Control or eradicate invasive species that have the potential to cause damage to coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Document the distribution, abundance, and population dynamics of non-native ornamental marine fish such as orbicular batfish, orange spine unicorn fish, raccoon butterfly fish, several varieties of tang and angelfish, and the lionfish.		√	√	
	Determine the distribution and abundance of the green mussel in the Eastern Gulf of Mexico and its current and potential impacts on the ecosystem.				√
	Identify potential methods to control/eradicate the green mussel without impacting native species or introducing alien species.				√
	Characterize the distribution and patterns of the spread of benthic invasive algae, such as *Caulerpa* and cyanobacteria.		√	√	
	Determine the distribution and abundance of *Tubastrea coccinea* and its impact on benthic communities.	√			

FLORIDA	CLIMATE CHANGE	Florida All	Florida Keys Only	Southeast Florida Only	E. Gulf of Mexico Only
Management Objective	***Research Need***				
Minimize the effects of climate change on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Hindcast and forecast climatic trends for the region to determine what the potential impact of climate change was and will be on the region.		√	√	
	Identify potential environmental and anthropogenic factors that may influence the long term resilience of Florida's coral reef ecosystems to maximize benefits of reefs that are not susceptible to bleaching while seeking to improve the condition of those that are more likely to bleach.	√			
	Investigate differential impacts of coral bleaching between shallow and deeper hermatypic coral reefs, including the extent of bleaching and the relationships between coral bleaching impacts and environmental factors.	√			

FLORIDA	EXTREME EVENTS	Florida All	Florida Keys Only	Southeast Florida Only	E. Gulf of Mexico Only
Management Objective	***Research Need***				
Identify causes and consequences of diseases in coral reef ecosystems and mitigate their impacts. *See Jurisdiction-Wide Section for additional research needs.*	Characterize the prevalence, incidence, and impact of emerging diseases in deeper reef communities such as those off the Dry Tortugas.		√		
	Understand the etiology of diseases affecting *Acropora* spp. populations and identify potential pathogen sources.		√	√	
	Evaluate damselfish, butterflyfish, parrotfish, and invertebrate corallivores as potential vectors for coral diseases.		√		
Reduce impacts to and promote restoration of coral reef organisms affected by extreme events.	Characterize the impacts of hurricanes and other natural and anthropogenic disturbances on coral reefs, and identify restoration options for the affected ecosystems.	√			
Reduce the occurrence and intensity of harmful algal blooms.	Investigate factors that contribute to blooms of dinoflagellates (e.g., *Karina* spp.), cyanobacteria (e.g., *Lyngbya* spp.), and other phytoplankton, and benthic algal populations and their potential role in reef degradation.	√			

FLOWER GARDEN BANKS

The Flower Garden Banks National Marine Sanctuary (FGBNMS) consists of three geographically separate underwater features – the East and West Flower Garden Banks, and Stetson Bank (Figure FGB-1). The Sanctuary is located approximately 100 miles south of the Texas-Louisiana border in the northwestern Gulf of Mexico and contains some of the northernmost coral reefs on the continental shelf of North America. The coral reefs of the

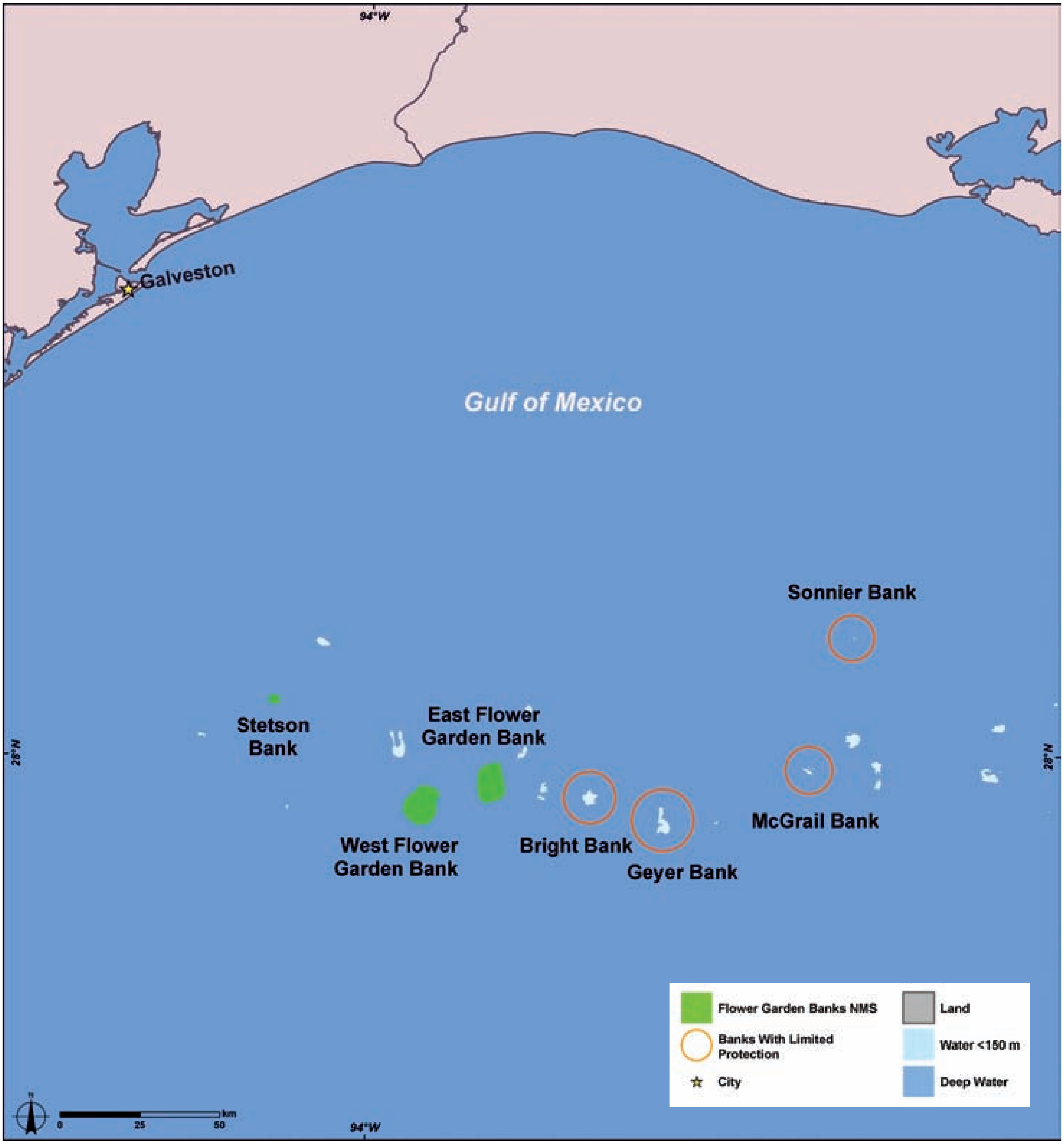


Figure FGB-1. Map showing the locations of the coral banks of the Gulf of Mexico. While some of the banks are protected by the provisions of the Flower Garden Banks National Marine Sanctuary, unprotected coral communities are present at Bright, Sonnier, Geyer, and McGrail Banks. These banks are part of the network of reefs and banks which are biologically and ecologically associated with the ecosystems of the sanctuary. Map: A. Shapiro. Source: Hickerson and Schmahl (2005).

East and West Flower Garden Banks are presently in good condition, compared to most other reef systems of the Caribbean and western Atlantic. Over 20 years of long-term coral reef monitoring at the East and West Flower Garden Banks indicates that the reefs have maintained approximately 50 to 70% coral coverage within the coral zone - an extraordinary coverage in a global climate of coral reef decline. The reefs are dominated by extremely large boulder corals (*Montastraea* spp., *Diploria strigosa*, and *Colpophyllia natans*). Branching corals are dominated by *Madracis mirabilis* fields in the deeper portions of the reefs. The coral cap ranges in depths from 17 to 49 m and covers an area of approximately 0.55 square miles (350 acres). Fish populations appear to be in good condition, although scuba divers encounter fishing debris and bycatch on a regular basis. This reef system appears to be thriving in spite of the fact that the FGBNMS is located in the middle of one of the most productive oil and gas fields in the world. Stetson Bank is a colorful, geologically exciting feature, dominated by sponges, several species of corals, and algae.

In addition to the FGBNMS, there are dozens of other reefs and banks in the northwestern Gulf of Mexico. The three banks within the Sanctuary are accessible to recreational scuba divers (within 130 ft depth), whereas the other reefs and banks are generally deeper. Coral reef communities are thriving on several of the other northwestern Gulf of Mexico features, including but not limited to McGrail Bank, Sonnier Bank, and Bright Bank. Evidence suggests that the coral reef communities of McGrail, Sonnier, and Bright Banks are biologically and ecologically linked to those found in the FGBNMS. These coral communities have historically been unprotected from threats other than those related to the oil and gas industry.

Due to the remote location of the banks, limited recreational activities occur (e.g., approximately 3,000 scuba divers per year visit FGBNMS). Hook and line fishing, both recreational and commercial, is allowed at the FGBNMS. However, the level of fishing pressure is not known, mainly due to the logistics of monitoring this activity at the site, and due to the manner in which commercial data is collected and managed.

The Gulf of Mexico Fisheries Management Council recently identified 13 reefs and banks in the northwestern Gulf of Mexico as HAPCs. While HAPC designation does not offer regulatory protections, a number of measures to regulate fishing gears and protect sensitive habitats were identified for these areas within specific fishery management plans. This includes prohibitions on bottom anchoring in coral reef areas; and prohibitions on trawling gear, bottom longlines, buoy gear, and fish traps in some areas.

Research Needs

FLOWER GARDEN BANKS	**FISHING**
Management Objective	***Research Need***
Conserve and manage fisheries to prevent overfishing, rebuild stocks, and minimize destructive fishing. *See Jurisdiction-Wide Section for additional research needs.*	Assess the status and trends of fish populations within FGBNMS and on other banks in the northwestern Gulf of Mexico.
	Assess temporal dynamics of coral reef fish trophic structure, including interactions with varying levels of fishing and other stresses.
	Assess larval fish dynamics in and around the FGBNMS.

FLOWER GARDEN BANKS	POLLUTION
Management Objective	***Research Need***
Reduce the impacts of pollutants on coral reef ecosystems by improving the understanding of their effects. *See Jurisdiction-Wide Section for additional research needs.*	Determine the sources, types, concentrations, and effects of pollutants on important coral reef species in the FGBNMS.
	Model the water circulation patterns of the northern Gulf of Mexico.
	Assess the potential impacts of oil and gas exploration and production on neighboring related coral reef communities.
	Assess the levels of toxins in commercially fished species within the FGBNMS.
	Assess the level of landborne and industry generated pollutants, including nutrients and hydrocarbon-associated contaminants in coral reef environments and in indicator organisms.

FLOWER GARDEN BANKS	COASTAL USES
Management Objective	***Research Need***
Reduce the impacts from recreational use, industry, development, and maritime vessels on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Determine the annual number of violations of Sanctuary "no-anchoring" regulations by both commercial and recreational vessels, and evaluate their impact on the resource.
	Compare current bathymetric data to historical seismic and multibeam data to assess possible changes in bank topography due to natural processes or industry impacts.
	Evaluate the location and placement of artificial reefs proposed by the Texas Parks and Wildlife Department's Artificial Reef Program.
Balance resource use to minimize user conflicts, provide equitable uses, and ensure optimal benefits to present and future generations.	Assess the level of demand for recreational diving from commercial diving operators and private recreational boats, and the impacts of recreational diving on coral reef resources.
	Determine the effectiveness of mooring buoys in reducing physical impacts to coral reef resources.
Restore injured and degraded coral reef habitats. *See Jurisdiction-Wide Section for additional research needs.*	Determine the feasibility of deep water coral restoration.
Evaluate and improve the effectiveness of MPAs as a management tool.	*See Jurisdiction-Wide Section for research needs.*

FLOWER GARDEN BANKS	COASTAL USES
Management Objective	***Research Need***
Manage coral reef ecosystems and their uses in a holistic manner. *See Jurisdiction-Wide Section for additional research needs.*	Determine the level of vulnerability and exploitation of coral reef resources that are currently unprotected using deepwater survey techniques.

FLOWER GARDEN BANKS	INVASIVE SPECIES
Management Objective	***Research Need***
Control or eradicate invasive species that have the potential to cause damage to coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Identify and remove introduced species from natural coral reef areas (e.g., *Tubastrea coccinea*).
	Investigate growth rates and reproductive potential of identified invasive species on artificial structures and nearby natural hard bottom features.
	Determine whether nearby oil and gas platforms serve as “stepping stones” for the introduction of invasive species.

FLOWER GARDEN BANKS	CLIMATE CHANGE
Management Objective	***Research Need***
Minimize the effects of climate change on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Characterize bleaching events (including the extent, impact, and causes) on deeper reef communities in the northwestern Gulf of Mexico, and identify factors that affect recovery/mortality.

FLOWER GARDEN BANKS	EXTREME EVENTS
Management Objective	***Research Need***
Identify causes and consequences of diseases in coral reef ecosystems and mitigate their impacts. *See Jurisdiction-Wide Section for additional research needs*	Characterize the types of diseases and other direct sources of coral mortality (e.g., damselfish and parrotfish predation) on deeper reef communities in the northwestern Gulf of Mexico, including their impacts and relationships with known stressors.

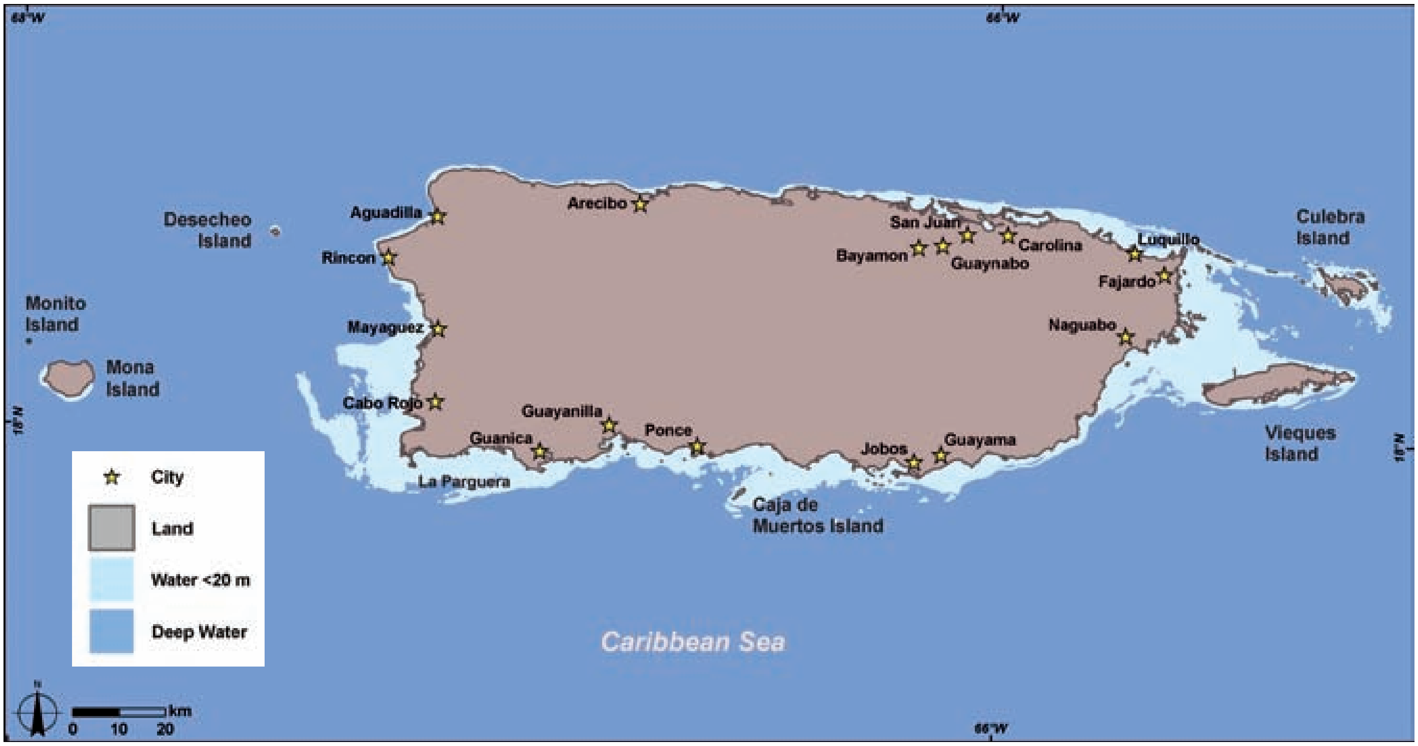


Figure PR-1. A map of Puerto Rico. (See Figure 4 for geographical context.) Map: A. Shapiro. Source: Garcia-Sais et al. (2005).

PUERTO RICO

The Commonwealth of Puerto Rico is a six island archipelago in the north-central Caribbean between the island of Hispaniola and the U.S. Virgin Islands. Puerto Rico has 3,370 km^2 of fringing coral reefs surrounding the island's east, south, and west coasts, as well as the two inhabited (Culebra and Vieques) and three uninhabited (Mona, Monito, Desecheo) small islands off Puerto Rico (Figure PR-1). Other parts of the shelf consist of hard ground areas, algal plains, and soft bottom communities with isolated coral colonies.

Reefs are characterized by a high diversity of corals (i.e., about 65 species of stony corals and 112 species of soft corals and gorgonians), although most nearshore locations have been badly degraded over the last 30 years. Most inshore reefs have a high cover of macroalgae with live coral cover ranging from 4 to 49% (mean 16%). While many offshore reefs are in better condition, these and other locations experienced massive losses of living coral cover during the 2005 bleaching event.

There are 242 reported reef fish species, many of which are targeted by commercial, recreational, and ornamental fisheries. Reef fish catches have plummeted during the last 20 years indicating classic signs of overfishing: reduced total landings, declining catch per unit effort, shifts to smaller fish, and recruitment failures (e.g., commercial fish landings fell by 69% between 1979 and 1990). In one study, reef fish density (individuals per 30 m^2) ranged from 93.2 near Desecheo Island to 12.6 near Caja de Muertos, with both reef fish density and species richness correlated with coral cover and rugosity. In 2003, 219,910 recreational anglers made over 1.1 million fishing trips in Puerto Rico. Most (56 to 64%) recreational fishing was from the shoreline, 35 to 40% was from private boats, and the rest (1 to 3%) were charter trips. In 2002, there were 1,163 active commercial fishers. Between 1995 and 2002, commercial fishers caught 1.6 million tons of fish per year, with 87% of the fishers targeting reef fish and invertebrates, including conch and lobster.

One of the major factors contributing to coral reef degradation is accelerated urban and industrial development on the coast combined with a lack of effective coastal zone management. Massive clearing of mangroves, dredging of rivers for sand and harbors, runoff from large-scale agricultural developments, deforestation in large watersheds, raw sewage disposal, and building of power plants have contributed to coral reef damage. Other major anthropogenic impacts include oil spills, anchoring of large cargo vessels, overfishing, uncontrolled recreational activities, eutrophication, and military bombing activities (at Vieques and Culebra Islands). Additionally, anthropogenic factors are exacerbating the impacts from a number of natural stressors such as hurricanes, coral bleaching, and coral diseases.

The coastal zone is managed by the Puerto Rico Department of Natural and Environmental Resources, but the determination of consistency with the Coastal Zone Management Plan for Puerto Rico is the responsibility of the Puerto Rico Planning Board. The Environmental Quality Board monitors water quality, in part through its water quality certification program, and the Regulations and Permits Administration governs land use regulations. Development in the coastal zone that may result in impacts to water bodies, including wetlands, is also regulated by the U.S. Army Corps of Engineers. The Puerto Rico Department of Natural and Environmental Resources and the Caribbean Fishery Management Council share responsibility for managing 24 MPAs. In an effort to convert a collapsing fishery into a sustainable one, the Government of Puerto Rico has enacted new fishing regulations that require recreational fishing licenses, prohibit recreational spearfishing with scuba, eliminate beach seine nets, establish size limits and daily quotas on several species, require species-specific permits for high-value and sensitive species, and create MPAs around Mona, Monito, and Desecheo Islands, and the Condado Lagoon.[3]

3 Introductory material was taken, with slight modifications, from Kelty (2004).

Research Needs

PUERTO RICO	FISHING
Management Objective	***Research Need***
Conserve and manage fisheries to prevent overfishing, rebuild stocks, and minimize destructive fishing. *See Jurisdiction-Wide Section for additional research needs.*	Produce high resolution bathymetric and habitat maps to 200 m in depth.
	Evaluate the bioeconomic costs and benefits of current fishing regulations (i.e., size limits, closed areas, and closed seasons associated with spawning aggregations) and the effectiveness of these regulations.
	Assess the distribution, abundance, and ecological role of aquarium trade species and the impacts associated with their extraction.
	Identify areas that are essential as nursery grounds for exploited fisheries.
	Determine the economic value of commercial and recreational fisheries.
	Determine the level of engagement and dependence of communities on coral reef ecosystems and stakeholder attitudes, perceptions, and preferences regarding their utilization and identify methods to integrate fishery dependent information into the management process.
Protect, conserve, and enhance the recovery of protected, threatened, and other key species.	<u>Queen Conch, Spiny Lobster, and Octopi</u>
	Evaluate commercial, subsistence, and recreational fishing pressure on conch, lobster, and octopi and the adequacy of existing regulations.
	Characterize the population dynamics, habitat utilization, recruitment and ontogenetic movement patterns of conch, lobster, and octopi in key locations.

PUERTO RICO	FISHING
Management Objective	***Research Need***
Develop and support aquaculture projects that minimize impacts to coral reef ecosystems, fishery stocks, and existing fishing communities.	Evaluate the socioeconomic impacts of aquaculture projects on existing fishing communities.
	Determine the viability of restocking reef fish populations of commercial and recreational importance to aid in their recovery.
	Evaluate the impacts of new and existing aquaculture operations (especially offshore fish pens) with emphasis on the introduction of diseases, escapees, genetics, habitat impacts, and status as fish aggregating devices.

PUERTO RICO	POLLUTION
Management Objective	***Research Need***
Reduce the impacts of pollutants on coral reef ecosystems by improving the understanding of their effects. *See Jurisdiction-Wide Section for additional research needs.*	Develop internal circulation models for Puerto Rico to understand and predict the fate and effect of nutrients and other pollutants.
	Determine the impact of the Culebra municipal landfill to the eastern side of the Canal Luis Peña Natural Reserve.
	Determine the impacts of high-use marinas in areas with poor water circulation.
	Evaluate the effects of wastewater discharges from treatment plants and untreated sewage entering water bodies on adjacent coral reef ecosystems.
Improve water quality by reducing land-based pollutant inputs and impacts on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Develop BMPs with relevance to tropical areas to reduce or eliminate the highest priority sources of pollution and evaluate the effectiveness of implemented measures (e.g., erosion and sediment control regulations).
	Evaluate the role of coastal wetlands in reducing contaminants before they are released into the marine environment.
	Evaluate water quality and its impacts on coral reef ecosystems in relation to changes in land and marine use in coastal areas.

PUERTO RICO	COASTAL USES
Management Objective	***Research Need***
Reduce the impacts from recreational use, industry, coastal development, and maritime vessels on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Design and conduct demonstration projects to evaluate science-based management options for improving shoreline stability while maintaining coral reef ecosystem functions.
	Determine the impact of onshore and offshore coastal development on coral reef ecosystems.

PUERTO RICO	COASTAL USES
Management Objective	***Research Need***
Balance resource use to minimize user conflicts, provide equitable uses, and ensure optimal benefits to present and future generations.	Conduct an economic valuation of coral reef ecosystems (including mangrove and seagrass habitats) in Puerto Rico.
Protect, conserve, and enhance the recovery of protected, threatened, and other key species. ***See Jurisdiction-Wide Section for additional research needs.***	Acroporids
	Identify critical habitat for ***Acropora*** spp. in Puerto Rico, including the historical and current distribution of acroporid populations, and factors that affect their spatial extent.
	Identify the direct causes of mortality (e.g., disease, predation, and storms) to acroporids, the role of anthropogenic stressors in increasing their susceptibility or resistance to these factors, and benefits of existing and new management measures at mitigating threats and rebuilding acroporid populations.
	Evaluate the effectiveness of ***Acropora cervicornis*** nurseries as a restoration tool, including potential implications of translocation of these corals from the south coast to Culebra.
	Sea Turtles
	Determine the impact of continuing development around Culebra Island on green sea turtles and their habitat.
Reduce impacts from and restore habitat damaged by vessel anchoring and groundings.	Assess the extent and impact of damage caused by grounding, anchoring, or human trampling in coral reefs and associated habitats.
	Evaluate the effectiveness of restoration at the grounding sites of the *Fortuna Reefer* (Mona Island), *Magara* (Guayanilla), and other recent restoration efforts at promoting biological and ecological recovery.
Restore injured and degraded coral reef habitats. ***See Jurisdiction-Wide Section for additional research needs.***	Develop recommendations for coral reef habitat restoration measures based on the quality of the habitat and the potential for success.
Evaluate and improve the effectiveness of MPAs as a management tool. ***See Jurisdiction-Wide Section for additional research needs.***	Evaluate the effectiveness of existing management plans for natural reserves to determine whether strengthening of these plans is warranted.
	Determine if existing managed areas are facilitating the recovery of protected, threatened, and other key species, including conch, grouper, and lobster.

PUERTO RICO	INVASIVE SPECIES
Management Objective	***Research Need***
Minimize the introduction and spread of alien species.	*See Jurisdiction-Wide Section for research needs.*
Control or eradicate invasive species that have the potential to cause damage to coral reef ecosystems.	Determine the distribution and abundance of the paperbark tree and identify its impact on coastal wetlands.
	Determine the distribution and abundance of the green iguana and identify its impact on mangrove habitats and potential methods to control/eradicate it without introducing alien species.
	Determine the effect of Casarina Pine trees on nesting turtle populations around Mona Island, and the benefits of removal programs at improving the quality of coastal habitats.

PUERTO RICO	CLIMATE CHANGE
Management Objective	***Research Need***
Improve the capacity to forecast and respond to bleaching events. *See Jurisdiction-Wide Section for additional research needs.*	Develop and implement a rapid response protocol to characterize and manage future bleaching events.

PUERTO RICO	EXTREME EVENTS
Management Objective	***Research Need***
Identify causes and consequences of diseases in coral reef ecosystems and mitigate their impacts. *See Jurisdiction-Wide Section for additional research needs.*	Assess the differences in disease prevalence, incidence, and impacts between deeper and shallower reefs at nearshore and offshore locations, and their relationships with other environmental stressors.
Reduce impacts to and promote restoration of coral reef organisms affected by extreme events.	Develop a model to predict the potential impact of storms to coral reef habitats including factors such as spatial extent and degree of storm damage; storm strength, speed, and path; and benthic habitat characteristics.
	Identify the factors that need to be addressed to enhance the recovery of coral reefs following hurricane and storm damage.

U.S. VIRGIN ISLANDS

View of a bay from St. John, U.S. Virgin Islands.

The U.S. Virgin Islands (USVI) includes three main islands – St. Croix, St. Thomas, and St. John – and several smaller islands (Figure USVI-1). St. Thomas and St. John are geologically part of the Lesser Antilles and sit on the same shelf platform as Puerto Rico. The shelf platform ranges from 40 to 60 ft, with fringing, patch, and spur and groove reefs distributed patchily. Extensive coral reefs lie in water along the shelf edge in depths from 120 to 200 ft. These deeper reefs are dominated by plating forms of the *Agaricia* spp. and *Montastraea* spp. complexes, while corals in shallower water vary from columnar forms of *Montastraea* spp. to *Acropora* spp. to gorgonian dominated habitats. Maps of USVI benthic habitats (to 30 m) show that 61% of the 485 km^2 area is coral reefs and coral on hard bottom; 33% is predominantly seagrass beds, and 4% is sediment or rocky bottom.

St. Croix is part of the Greater Antilles and sits on a narrow, shallow shelf platform that drops off into the 4,000$^+$ m deep Virgin Islands Trough. The shallow (46 to 60 ft) shelf edge is relatively close to shore in many places with classic back bay/lagoons to reef crest and fore reef habitats. The eastern and southern ends of the island are protected by a barrier reef system. Stocks and resources do not appear to move across the Puerto Rico Trench, whereas St. Thomas and St. John have fish populations more similar to Puerto Rico. Thus, St. Croix and St. Thomas/St. John are not considered a single management unit.

Many stresses affecting marine resources in the Caribbean may be causing degradation of USVI coral reef ecosystems. Over the past 40 years, living coral cover has decreased, while macroalgal cover has increased. Intensive fishing along with habitat degradation has been blamed for the loss of spawning aggregations and decreases in mean size and abundance of reef fish. Groupers and snappers are far less abundant now, while herbivorous fishes comprise a greater proportion of samples in traps and visual surveys than they did in the 1960s. Other damage to marine resources results from natural stresses such as hurricanes and coral diseases, as well as land-based pollution and other anthropogenic factors.

The jurisdiction over these coral resources is shared by several U.S. agencies and the Virgin Islands Government. In 2001, the Virgin Islands Coral Reef National Monument off St. John was established, and the Buck Island Reef National Monument off St. Croix was expanded. Both areas are managed by the National Park Service. In 2002, the St. Croix East End Marine Park, which is managed by the USVI Department of Planning and Natural Resources, was established as the first in a series of marine parks for the territory. These areas are designed to provide protection for important marine resources, including coral reef areas, thus allowing depleted populations of certain marine organisms (groupers, snappers, corals) to recover. Other managed areas in St. Thomas and St. John include: the Hind Bank Marine Conservation District (established in 1999) and Lang Bank designated by the Caribbean Fishery Management Council to protect spawning aggregations and coral habitats; the Grammanik Bank, established as a temporary seasonal closure area for 2005 (permanent regulations are pending); and the Cas Cay/Mangrove Lagoon and St. James Marine Reserves, established in 1994 to protect juvenile reef fish and associated habitat. In St. Croix, MPAs include the seasonal Mutton Snapper Spawning Area Closure, the seasonal Lang Bank Red Hind closure, and the Salt River Bay National Historical Park and Ecological Preserve. The latter was designated in 1995, but the regulations have yet to be signed.[4]

4 The sources for the introduction are Vasques (2005), Kelty (2004), and Jeffrey et al. (2005).

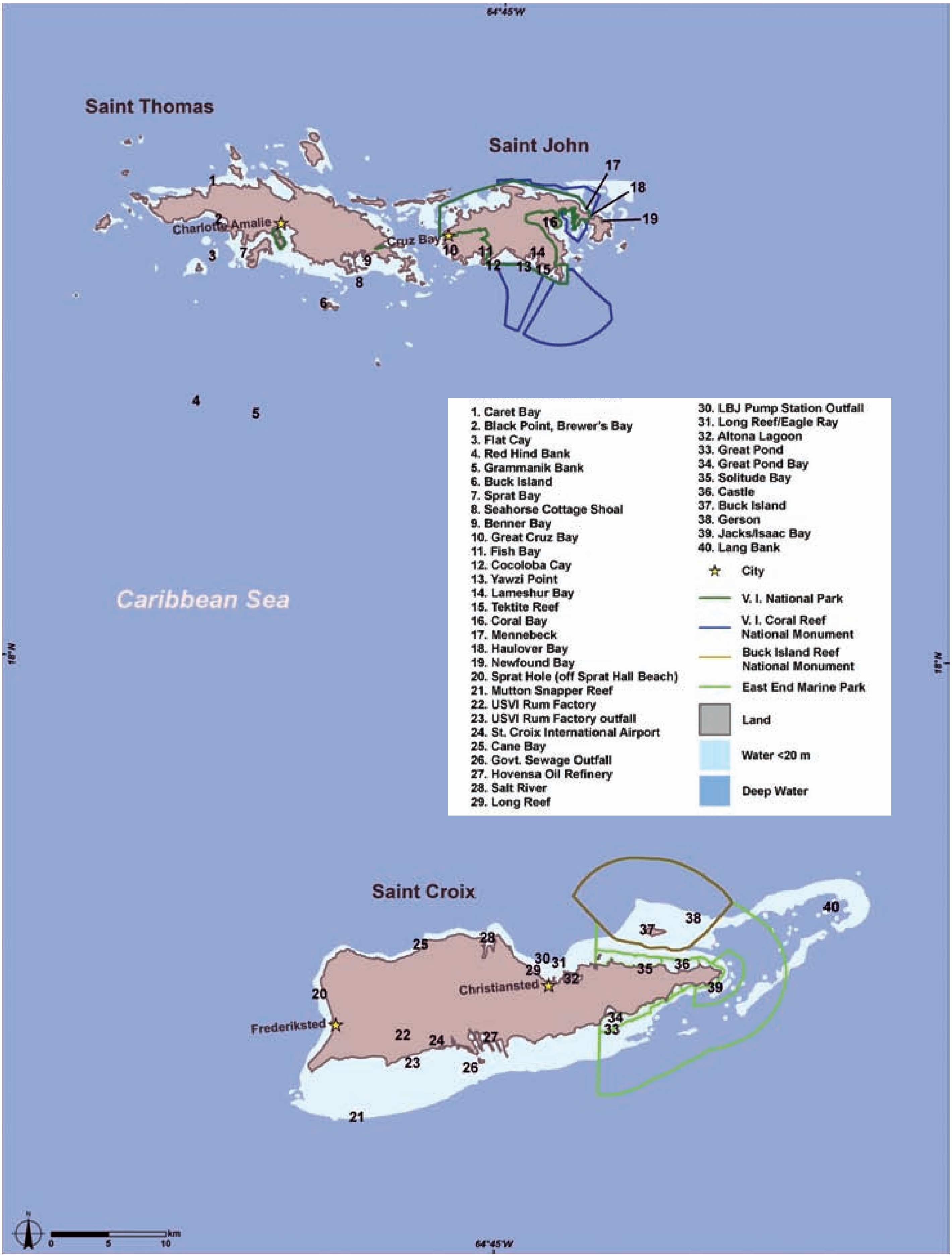


Figure USVI-1. A map of USVI showing managed areas, municipalities, and other locations of interest. (See Figure 4 for geographical context.) Map: A. Shapiro. Source: Jeffrey et al. (2005).

Research Needs

U.S. Virgin Islands	FISHING
Management Objective	***Research Need***
Conserve and manage fisheries to prevent overfishing, rebuild stocks, and minimize destructive fishing. *See Jurisdiction-Wide Section for additional research needs.*	Assess the impacts of fishing on spawning aggregations and monitor their recovery after regulations are enacted, especially at Grammanik Bank off St. Thomas.
	Assess the total catch and the value of local fisheries and the number of fishermen employed.
	Investigate the viability and effectiveness of enhancement programs (e.g., use of fishery aggregating devices to remove fishing pressure away from reefs) to mitigate fishing pressure on target organisms of commercial and recreational importance.
	Investigate expansion of pelagic fisheries within user groups affected by the establishment of MPAs, including benefits to coral reef ecosystems, socioeconomic implications, and other factors.
	Compare the population status of managed reef species in representative coral reef areas in St. Croix and St. Thomas, and identify environmental and anthropogenic factors that may explain differences in population dynamics of these species.
	Characterize fish assemblages on gorgonian dominated habitats and determine their importance as essential fish habitat.
Protect, conserve, and enhance the recovery of protected, threatened, and other key species.	Identify factors that promote or inhibit the recovery of key species and identify those factors which can be managed.
	Queen Conch, Spiny Lobster, Octopi
	Evaluate commercial, subsistence and recreational fishing pressure on conch, lobster, and octopi and the adequacy of existing regulations.
	Characterize the population dynamics, habitat utilization, recruitment patterns, and ontogenetic movement patterns of conch, lobster, and octopi in specific locations.
Evaluate and improve the effectiveness of MPAs as a fisheries management tool. *See Jurisdiction-Wide Section for additional research needs.*	Evaluate the level of enforcement and assess what effect increased enforcement would have on juvenile reef fish stocks and reef habitat.
	Quantify abundance and size structure of different life stages of commercially and ecologically important fish and invertebrate species, coral condition, and major reef processes (e.g., herbivory and recruitment) within and outside protected areas in Buck Island Reef National Monument, Virgin Islands Coral Reef National Monument, the St. Croix East End Marine Park, St. Thomas Marine Conservation District, Cas Cay/Mangrove Lagoon Marine Reserve, St. James Marine Reserve, and the Salt River Bay National Historical Park and Ecological Preserve.
	Determine whether user groups displaced by the establishment of MPAs have shifted to pelagic fish species.
	Evaluate the efficacy of the marine reserves in St. Thomas and determine if additional management measures are necessary.
	Determine if existing managed areas are facilitating the recovery of protected, threatened, and other key species including, conch, grouper, and lobster.
	Assess the costs and benefits of the Marine Conservation District on the commercial fishing community of St. Thomas.

U.S. Virgin Islands	FISHING
Management Objective	***Research Need***
Develop and support aquaculture projects that minimize impacts to coral reef ecosystems, fishery stocks, and existing fishing communities.	Determine the viability of restocking populations of commercially and recreationally important reef species to aid in their recovery.

U.S. Virgin Islands	POLLUTION
Management Objective	***Research Need***
Reduce the impacts of pollutants on coral reef ecosystems by improving the understanding of their effects. *See Jurisdiction-Wide Section for additional research needs.*	Quantify the impacts of sewage and sedimentation associated with accelerated coastal development and assess temporal changes in the abundance of key organisms, such as macroalgae and corals.
	Quantify the impacts on coral reef ecosystems of effluents from Cruzan Rum Distillery and Hovensa Oil Refinery in St. Croix.
	Quantify the impacts of run-off or effluents from land fills, rum distilleries, and other industrial effluents on sensitive habitats (e.g., Mangrove Lagoon).
	Develop internal circulation models for USVI to understand and predict the fate and effect of nutrients and other pollutants.
	Investigate the effects of sewage and sedimentation on USVI coral reefs. Adapt the GIS-based sediment delivery model developed for St. John for application to St. Croix and St. Thomas and implement the model to predict effects of future coastal development.
Improve water quality by reducing land-based pollutant inputs and impacts on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Develop BMPs to reduce or eliminate the highest priority sources of pollution and evaluate the effectiveness of implemented measures (e.g., erosion and sediment control regulations).
	Determine the effectiveness of upgrading regional primary sewage treatment facilities and monitor the long-term effects of upgrading on water quality and coral reef ecosystems.
	Evaluate the role of coastal wetlands in reducing contaminants before they are released into the marine environment.

U.S. Virgin Islands	COASTAL USES
Management Objective	***Research Need***
Reduce the impacts from recreational use, industry, coastal development, and maritime vessels on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Investigate the effects of oil pollution, cruise ship discharge, sedimentation (and resuspension), and other factors and assess whether they offset the benefits associated with designation of MPAs.
	Investigate the impacts of vessel traffic, including cruise ships, and the lack of designated anchorages on coral reef ecosystems in St. Thomas and St. Croix.
	Investigate changes in coastal land use and benthic habitat over time to determine whether and how increased development in certain areas has impacted coral reef ecosystems.
Balance resource use to minimize user conflicts, provide equitable uses, and ensure optimal benefits to present and future generations.	Examine coral reef-related recreation and tourism links to the economy and the environment.
	Determine the effectiveness of management efforts, such as the installation of mooring buoys in seagrass and reef areas and the elimination of fishing by assessing changes in seagrasses, macro and turf algae, and coral cover.
	Assess the costs and benefits of protective management tools (e.g., the installation of mooring buoys in seagrass and reef areas and the elimination of fishing) on the community.
Protect, conserve, and enhance the recovery of protected, threatened, and other key species. *See Jurisdiction-Wide Section for additional research needs.*	Acroporids
	Identify critical habitat for *Acropora* spp. in USVI, including the historical and current distribution of acroporid populations, and identify factors that contributed to the expansion/reduction in the spatial extent of these corals.
	Sea Turtles
	Determine the impact of rum distilleries and other anthropogenic impacts on sea turtles, their food sources (e.g., sponges and grasses), and their habitat.
Reduce the impacts from and restore habitat damaged by vessel anchoring and groundings.	Investigate the impacts of recreational vessel anchoring to benthic habitats to determine whether management measures, such as the installation of mooring buoys, are necessary.
	Assess the damage of large vessels (e.g., propeller damage) on the shallow water habitats of St. Thomas.
	Quantify the impacts of ferry and recreational vessel groundings.

U.S. Virgin Islands	COASTAL USES
Management Objective	***Research Need***
Restore injured and degraded coral reef habitat.	*See Jurisdiction-Wide Section for research needs.*
Manage coral reef ecosystems and their uses in a holistic manner. *See Jurisdiction-Wide Section for Additional Research Needs.*	Develop and evaluate ecosystem or trophic models for use in ecosystem management. Identify the connectivity of resources between eastern Puerto Rico and northern USVI, focusing on larval dispersal and movement of reef fish species that travel long distances to spawning aggregations (i.e., grouper and snapper).
	Identify the connectivity of resources between the British Virgin Islands and USVI to inform management practices that address the sharing of resources.
	Characterize interactions among reefs, mangroves, and seagrass beds and how deterioration of these contributes to changes in reef communities.
Evaluate and improve the effectiveness of MPAs as a management tool. *See Jurisdiction-Wide Section for additional research needs.*	Evaluate the ecological impacts of the de facto marine reserve (no transit zone) off the oil refinery in St. Croix.
	Conduct socioeconomic studies of recreational and commercial user groups affected by closures and restrictions in East End Marine Park.

U.S. Virgin Islands	INVASIVE SPECIES
Management Objective	***Research Need***
Minimize the introduction and spread of alien species.	*See Jurisdiction-Wide Section for research needs.*
Control or eradicate invasive species that have the potential to cause damage to coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Investigate the status of known invasive species within coastal waters of USVI, and establish a response network and protocol in the event of new invasive species introductions.

U.S. Virgin Islands	CLIMATE CHANGE
Management Objective	***Research Need***
Minimize the effects of climate change on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Develop and implement a response plan to address bleaching events in the USVI.

U.S. Virgin Islands	EXTREME EVENTS
Management Objective	***Research Need***
Identify causes and consequences of diseases in coral reef ecosystems and mitigate their impacts. *See Jurisdiction-Wide Section for additional research needs.*	Determine the spatial and temporal distribution and abundance of the different coral diseases present in the USVI and their effects on affected corals and overall reef condition (e.g., species diversity and community composition).
	Examine coral community structure and impacts of disease and predation on coral reefs found in deeper areas such as Red Hind Bank Marine Conservation District.
	Inventory which diseases are present, their associated pathogens, and possible correlations with environmental factors such as temperature and nutrients.
	Assess the recovery of coral species impacted by disease (particularly acroporids).
Reduce impacts to and promote restoration of coral reef organisms affected by extreme events.	Examine the role of hurricanes in the decline of *Acropora* and how hurricanes influence patterns of recovery, including synergies with other stressors.
	Develop a model to predict the potential impact of storms to coral habitats including, factors such as spatial extent and degree of storm damage; storm strength, speed, and path; and benthic habitat characteristics.
	Identify anthropogenic factors that need to be addressed to enhance the recovery of reefs following hurricane and storm damage.
	Develop a system of coral mariculture farms as a strategy to maintain propagule sources through a wide geographic range and evaluate the value of these sources of corals for use in coral reef restoration projects in response to storms and ship groundings.

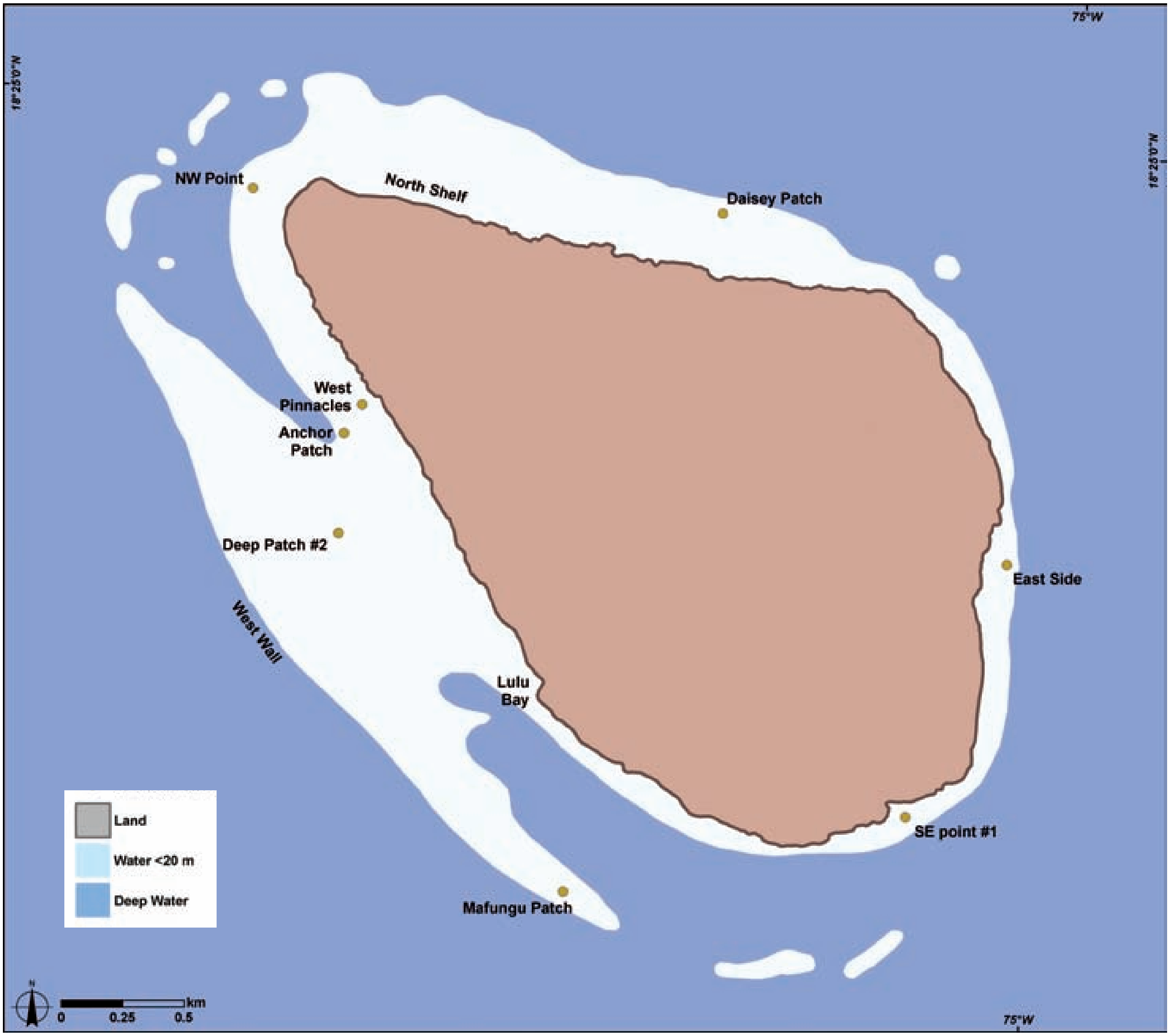


Figure NI-1. A map of Navassa Island. (See Figure 4 for geographical context.) Map: A. Shapiro. Source: Miller et al. (2005).

NAVASSA

Navassa Island is a small (5 km^2), uninhabited, oceanic island between Jamaica and Haiti (Figure NI-1). Navassa Island is under the jurisdiction of the FWS and has been managed as a component of the Caribbean Islands NWR since 1999. The dolomite island's cliffs plummet to about 25 m deep before a submarine terrace slopes out gradually. Thus, Navassa lacks typical Caribbean patterns of reef zonation and inshore and backreef habitats including mangroves, sandy beaches, and seagrass which are important in the life history of several reef fish groups. Small shoulders of shallow reef habitat (10 to 15 m) are found at the northwest point and Lulu Bay, but the primary reef habitats are reef walls formed by the cliffs and large boulders that have been dislodged from the cliffs. A 2002 survey documented 10 to 20% live coral cover in shallow habitats (10 to 20 m) and 46% live coral cover at the 25 to 30 m terrace; deeper reef slopes at shelves greater than 30 m farther offshore have not been well described. Dominant corals are *Montastrea* spp., *Agaricia* spp., *Porites porites*, and, at shallow sites, the elkhorn coral, *Acropora palmata.*

Because of its isolated and uninhabited status, Navassa has been presumed to provide a relatively pristine example of an unimpacted reef that may serve as a valuable reference site for determining Caribbean coral reef structure and function. Land-based pollution and recreational uses are essentially absent. However, reefs on the east coast (and to a lesser extent, the southwest and west coasts) are exposed to persistent swells and seemingly regular storms and hurricanes. A fall 2004 NOAA/FWS research cruise documented storm damage to *A. palmata* colonies in the shallow shoulder of Lulu Bay. The same cruise documented relatively high prevalence of coral disease, despite the lack of land-based pollution and other anthropogenic stressors.

Fishing is the primary threat to Navassa's reefs. Subsistence fishing appears to have been ongoing since at least the 1970s and current activity by migrant Haitian fishers is substantial (but unquantified). A 2002 survey noted the virtual absence of large fish – the average total length was 4.6 cm and only 11 of 1,227 fish were longer than 24 cm. A less extensive survey in 2000 found that 92% of snapper and 23% of parrotfishes were longer than 40 cm. These results suggest that fishing impacts are substantial and rapidly increasing. Interviews with Haitian fishers in 2004 provided preliminary data on catch, frequency of fishing, and gear types. Large commercial foreign flagged fishing trawlers have been observed within NWR waters, which include a 12 mile area of open ocean around the island. The primary research priority in Navassa is the assessment of reef status and fishing activity and impact over time.[5]

5 Introductory material was taken, with slight modifications, from Miller et al. (2005).

Research Needs

NAVASSA	FISHING
Management Objective	***Research Need***
Conserve and manage fisheries to prevent overfishing, rebuild stocks, and minimize destructive fishing. *See Jurisdiction-Wide Section for additional research needs.*	Conduct capture-recapture studies to provide estimates of total population numbers of large resident species.
	Interview local fishers to provide anecdotal information in order to discern trends in catch effort and perhaps size shifts in target species.
	Collect size data for the most commonly taken species as they are landed in the nearest fishing villages in Haiti.
	Determine usage patterns of Navassa marine resources (i.e., catch and effort data for fishing activities).
	Determine what other fishery sectors (besides the Haitian subsistence sector) are active in Navassa and the impact they are having on the resource.
	Conduct a sociocultural assessment of Haitian communities from which primary fishing activity originates.
	Understand the relationship of declining fish assemblage and reef benthic community structure and condition.
	Develop a habitat map for the 12-mile radius around the island that is under Federal jurisdiction to identify essential fish habitat.

NAVASSA	POLLUTION
Management Objective	***Research Need***
Reduce the impacts of pollutants on coral reef ecosystems by improving the understanding of their effects.	Understand physical oceanic processes affecting Navassa water quality.

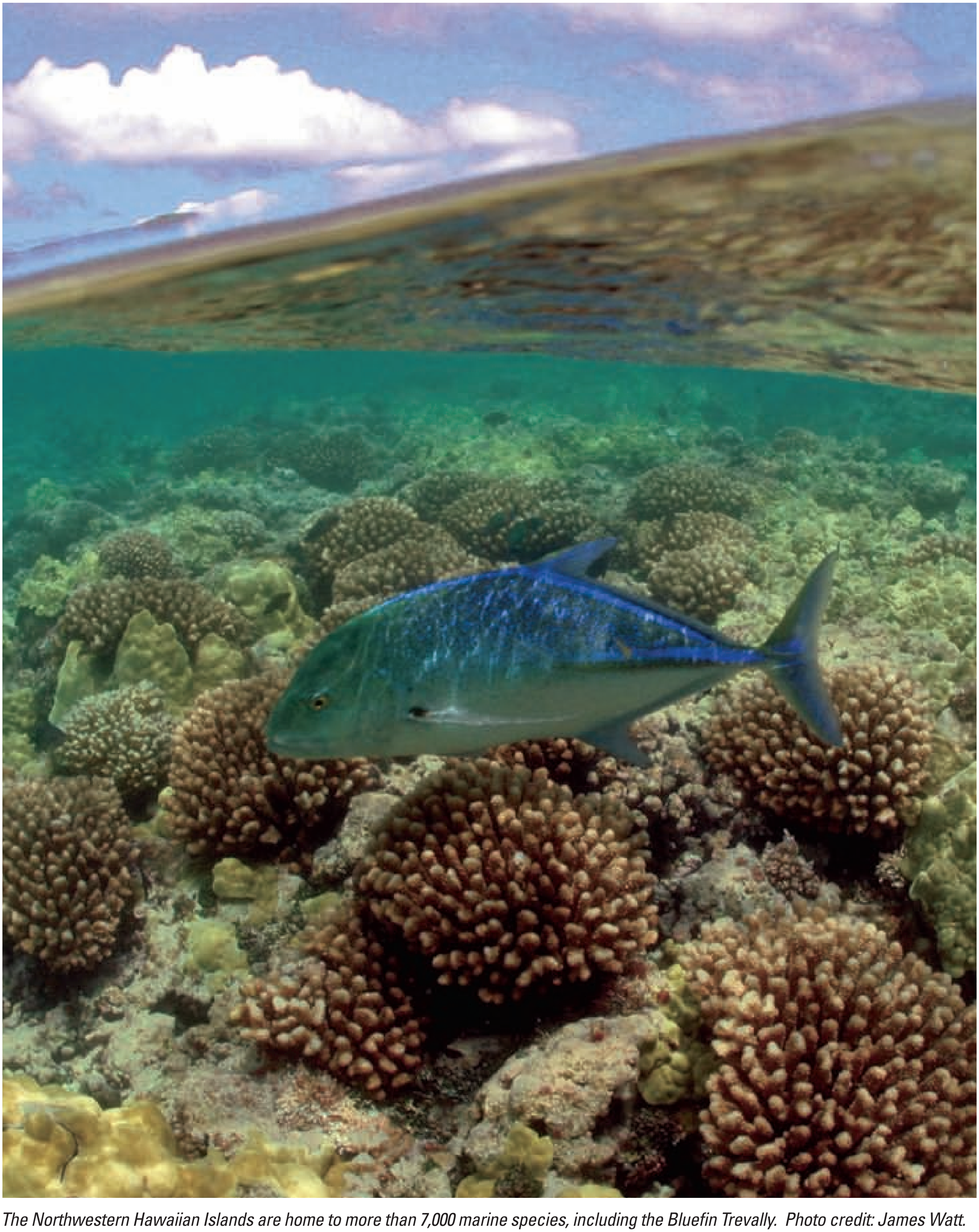
NAVASSA	COASTAL USES
Management Objective	***Research Need***
Not Applicable to Navassa. Aside from subsistence fishing, there are no coastal uses.	

NAVASSA	INVASIVE SPECIES
Management Objective	***Research Need***
Minimize the introduction and spread of alien species.	*See Jurisdiction-Wide Section for research needs.*

NAVASSA	CLIMATE CHANGE
Management Objective	***Research Need***
Minimize the effects of climate change on coral reef ecosystems.	Compare and contrast the prevalence of and impacts from bleaching events in Navassa with other U.S. jurisdictions, using Navassa as a reference site due to its low level anthropogenic impacts, other than fishing.

NAVASSA	EXTREME EVENTS
Management Objective	***Research Need***
Identify causes and consequences of diseases in coral reef ecosystems and mitigate their impacts.	*See Jurisdiction-Wide Section for research needs.*

Jurisdiction-Specific Research Needs: Pacific Ocean



The Northwestern Hawaiian Islands are home to more than 7,000 marine species, including the Bluefin Trevally. Photo credit: James Watt.

THE HAWAIIAN ISLANDS

The Hawaiian Archipelago stretches for over 2,500 km from the island of Hawaii in the southeast to Kure Atoll (the world's highest latitude atoll) in the northwest. Hawaii is located in the middle of the Pacific Ocean (Figure HI-1), making it one of the most isolated archipelagos in the world. As a result of its location, Hawaii's coral reefs possess some of the highest marine endemism recorded for a number of taxa, and are structurally influenced by exposure to large open ocean swells. Within the archipelago, there are two distinct regions: the Main Hawaiian Islands (MHI) made up of populated, high volcanic islands and the Northwestern Hawaiian Islands (NWHI) consisting of mostly uninhabited atolls and banks.

Early Hawaiians recognized that coral reefs were a building block of the islands and used coral in religious ceremonies to demonstrate honor and care for ocean resources. Coral reefs were important to the ancient Hawaiians for food, cultural practices, recreation, and survival. Today, coral reef communities continue to provide Hawaiians with food and protection from storm waves, and are critically important to the state's approximately $800 million per year marine tourism industry (Cesar and van Beukering 2004).

Although the MHI and NWHI are one ecosystem, resource management and research for these regions have historically differed. This separation or regionalization has been maintained in this research plan when developing research priorities for the Hawaiian Archipelago.

Main Hawaiian Islands

Coral reef communities in the MHI range from newly formed colonies at the edges of recent lava flows to established fringing reefs (Figure HI-2). Many of these reef communities are located near urban areas. Over 70% of the State's 1.2 million people live on Oahu, mostly concentrated in the Honolulu metropolitan area. In addition to this resident population, nearly seven million tourists visit Hawaii each year. This large number of people has put pressure on Hawaii's coral reefs through various direct and indirect means. Many coastal areas adjacent to urban centers are impacted by land-based sources of pollution, fishing pressure, recreational overuse, and invasive species. Despite these stressors, Hawaii's coral reefs, especially those far from urban centers, remain in good to fair condition compared with other reefs around the world.

Coral reef ecosystems in the MHI are managed through MPAs with varying levels of protection. These include marine life conservation districts, fisheries management areas, a marine laboratory refuge, natural area reserves, NWRs, and the Hawaiian Islands Humpback National Marine Sanctuary. One of the most well known marine life conservation districts is Hanauma Bay, established in

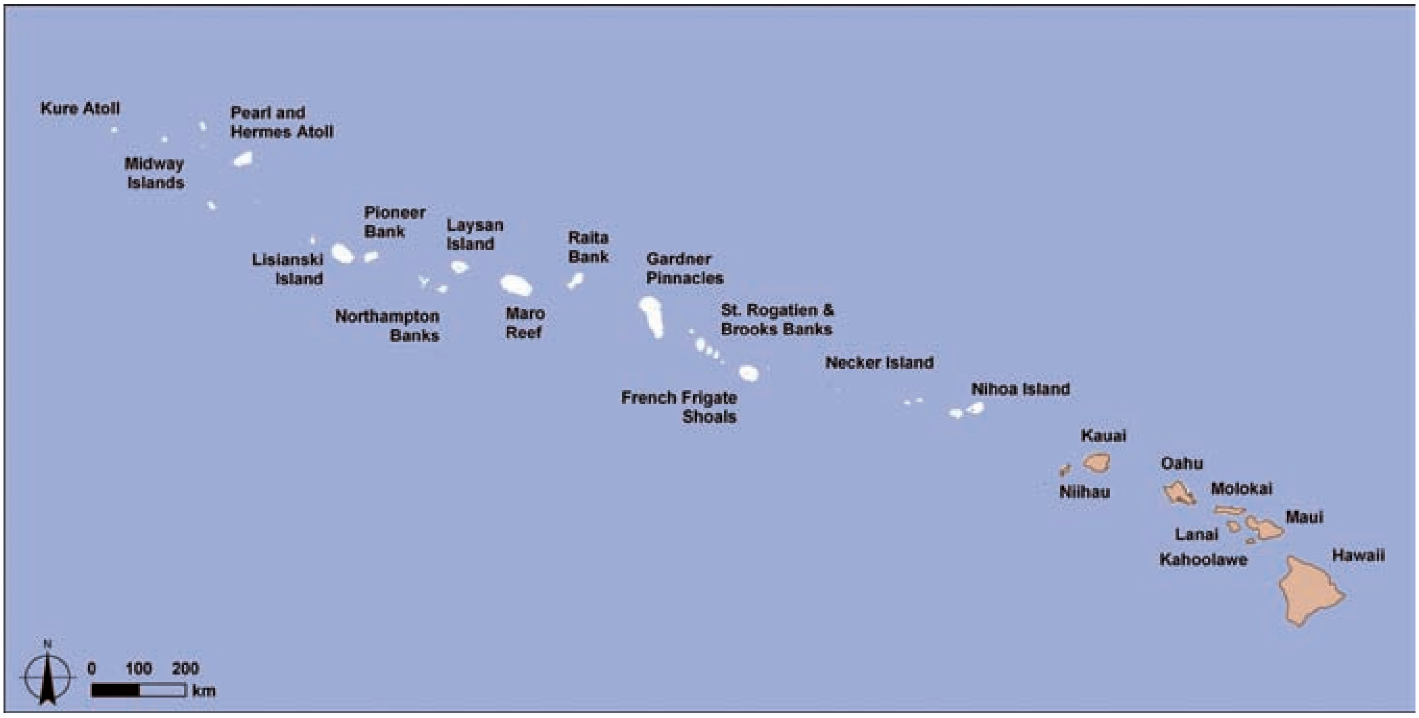


Figure HI-1. Locator map for the Hawaiian archipelago. (See Figure 5 for geographical context.) Map: A. Shapiro.

1967. Marine life conservation districts with strict no-take restrictions have been established at specific locations in Hawaii to help restore fish stocks and have met with some success. Even with all of these protections in place, Hawaii's coral reef MPAs are not as effective as they could be due to difficulties enforcing current regulations and laws, as well as recreational overuse of these MPAs by the tourism industry. [6]

6 Introductory material was taken, with slight modifications, from Gulko et al. (2002) and Friedlander et al. (2005a).

Research Needs

The research needs detailed below represent both MHI-specific research needs, and archipelago-wide research needs focused on identifying linkages between the NWHI and MHI. Understanding the linkages between the NWHI and MHI is critical because the knowledge gained can be applied to the management of the entire archipelago. NWHI-specific research needs are detailed in the next section.

Hawaiian Islands	FISHING	Hawaiian Archipelago	Main Hawaiian Islands Only
Management Objective	***Research Need***		
Conserve and manage fisheries to prevent overfishing, rebuild stocks, and minimize destructive fishing. *See Jurisdiction-Wide Section for additional research needs.*	Assess the ecological impacts of non-extractive activities conducted in coral reef ecosystems on managed fisheries species.		√
	Evaluate the potential of restocking ecologically important species (e.g., parrotfish, jacks, spiny lobster).		√
	Develop affordable ciguatera test kits that would allow a viable fishery for roi.		√
	Assess the ecological impact of aquarium collection on species of special concern, such as endemics, and develop scientific guidelines for aquarium fishery management.		√
Evaluate and improve the effectiveness of MPAs as a fisheries management tool. *See Jurisdiction-Wide Section for additional research needs.*	Evaluate the effectiveness of Hawaii's MPAs to determine how differing levels of protection improve catches of economically important coral reef resources and identify optimal MPA design under various scenarios.	√	
	Compare the benefits of fishery replenishment areas for the aquarium fishery in West Hawaii and determine additional management measure needed to rebuild stocks of species that have not rebounded within the fishery replenishment areas and surrounding fished areas.		√
Increase fishers' participation in fisheries management.	Document historical and cultural knowledge of Hawaiian coral reef resources and their ecology, as well as their historical trends in abundance size, distribution, and community composition.		√

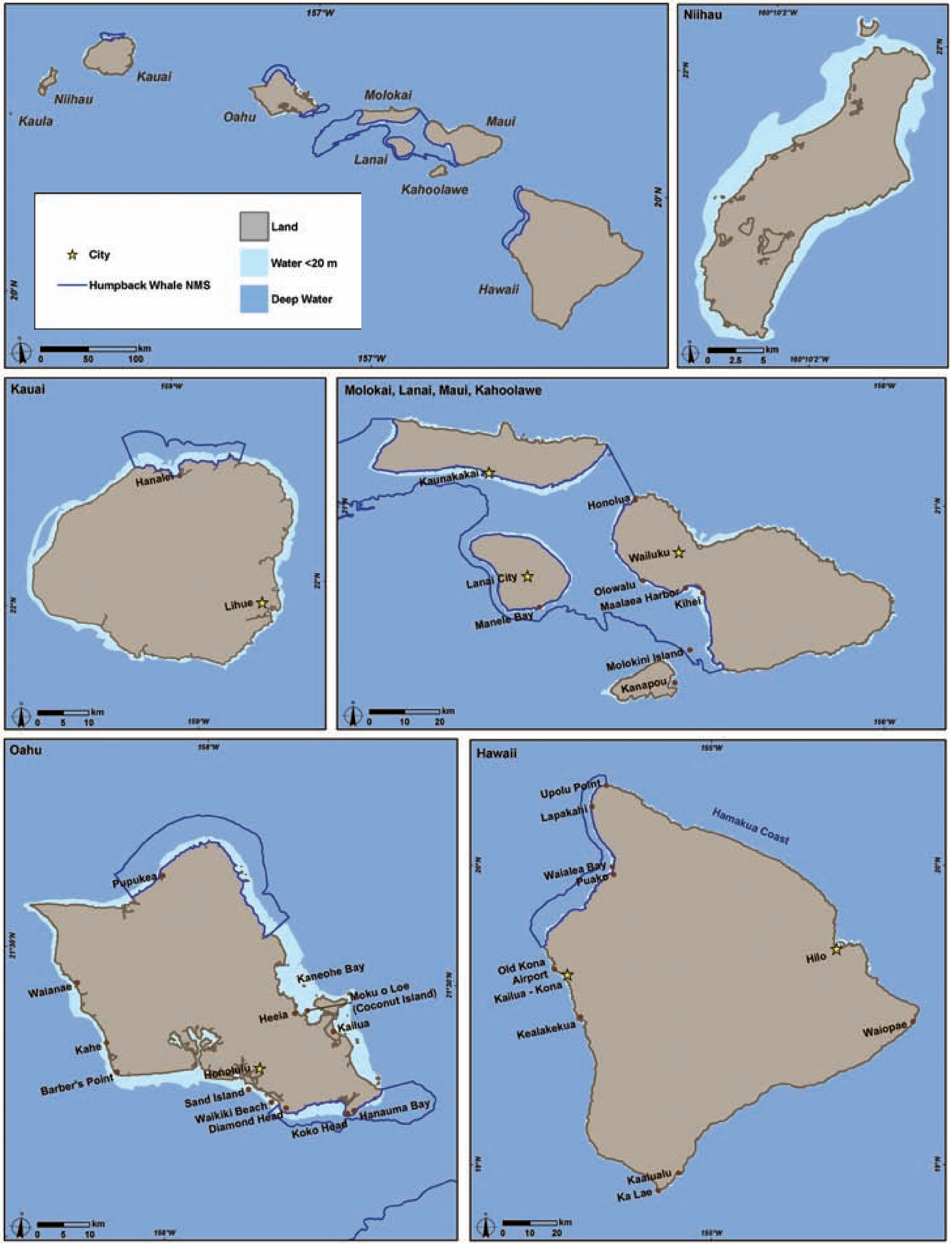


Figure HI-2. Locator map for the Main Hawaiian Islands. Map: A. Shapiro. Source: Friedlander et al. (2005a).

Hawaiian Islands	POLLUTION	Hawaiian Archipelago	Main Hawaiian Islands Only
Management Objective	***Research Need***		
Reduce the impacts of pollutants on coral reef ecosystems by improving the understanding of their effects. *See Jurisdiction-Wide Section for additional research needs.*	Quantify the individual and synergistic impacts of nutrients, chemicals, and pathogens from sewage on reef condition.		√
	Develop effective tools for tracking sewage-borne pollutants from cesspools and injection wells.		√
	Quantify nutrient, fertilizer, and sediment inputs from different sources (e.g., surface water, groundwater, injection wells, septic systems, and cesspools) and determine their impacts on coral reef ecosystems.		√
	Develop sediment transport models for critical reef areas.		√
Improve water quality by reducing land-based pollutant inputs and impacts on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Develop low-cost tools to assess concentrations and loads of nearshore water pollutants that can be easily implemented by managers and volunteers.		√
	Develop protocols to evaluate the effectiveness of land-based pollution management methods.		√
	Create science-based guidelines for the evaluation, improvement, and/or development of permitting and regulatory tools for protecting coral reef ecosystems from pollution stress.		√
	Identify biological criteria for coral reefs that could be incorporated into state water quality standards.		√

Hawaiian Islands	COASTAL USES	Hawaiian Archipelago	Main Hawaiian Islands Only
Management Objective	***Research Need***		
Reduce the impacts from recreational use, industry, coastal development, and maritime vessels on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Determine the ecosystem impacts of current and proposed non-extractive activities (e.g., snorkeling, wading, scuba diving, boating, and anchoring) and prioritize areas for protection based on their economic and ecological importance.		√
	Evaluate the effectiveness of current management efforts at reducing impacts from non-extractive activities.		√
	Identify BMPs that should be incorporated into relevant development permits to protect coral spawning and recruitment events, and determine their effectiveness.		√
	Examine the economic and legal factors contributing to destructive development and construction practices, and recommend economic incentives, regulatory changes, and BMPs to mitigate these impacts.		√
	Assess the loss of coral reef productivity and potential reef fish biomass as a result of large-scale harbor development, dredging projects, and beach replenishment activities.		√
	Evaluate Hawaii's artificial reef program. Provide scientifically-based recommendations for expanding the program if it is deemed effective and shown to have minimal impacts.		√
	Determine the extent of damage due to anchorage of large vessels.		√

Hawaiian Islands	COASTAL USES	Hawaiian Archipelago	Main Hawaiian Islands Only
Management Objective	***Research Need***		
Protect, conserve, and enhance the recovery of protected, threatened, and other key species.	Continue conducting research aimed at the protection, conservation, and recovery of protected species (i.e., marine mammals, sea turtles, and birds) that utilize coral reef ecosystems.	√	
Restore injured and degraded coral reef habitat. *See Jurisdiction-Wide Section for additional research needs.*	Develop coastal and beach restoration techniques (e.g., stream channels, beach replenishment, and harbor development) that minimize impacts on adjacent reefs.		√
Manage coral reef ecosystems and their uses in a holistic manner. *See Jurisdiction-Wide Section for additional research needs.*	Characterize and assess oceanographic factors that influence the distribution and abundance of biotic components of coral reef ecosystems.	√	
Evaluate and improve the effectiveness of MPAs as a management tool. *See Jurisdiction-Wide Section for additional research needs.*	Evaluate the effectiveness of Hawaii's MPAs to determine how differing levels of protection influence effectiveness and identify optimal MPA design under various scenarios.	√	
	Develop coupled ecosystem-hydrodynamic models to simulate and examine various management options.		√
	Assess population replenishment and connectivity among islands, banks, and associated coral reef ecosystems.	√	
	Improve hydrodynamic, ecosystem, and resource assessment models that capture the dynamics, structure, and function at appropriate temporal and spatial scales.	√	
	Identify indicator species (i.e., those which are indicative of the overall condition of the ecosystem) and keystone species (i.e., those of importance in structuring the composition of the ecosystem) for use as monitoring tools.	√	

Hawaiian Islands	INVASIVE SPECIES	Hawaiian Archipelago	Main Hawaiian Islands Only
Management Objective	***Research Need***		
Minimize the introduction and spread of alien species. *See Jurisdiction-Wide Section for additional research needs.*	Assess connectivity among islands and banks to determine the rate at which alien species spread between islands.	√	
	Assess the distribution of alien marine species in Hawaii, including reefs located outside of harbors.	√	
	Determine how invasive alga species are spreading (e.g., ***A. spicifera*** spreads via spores, and ***H. musciformis*** via fragments, but it is unknown if these and other invasive species spread only by these methods).		√
	Identify alternative methods for ballast water treatment for inter-island barges, vessels, and towed platform traffic.		√
Control or eradicate alien species that have the potential to cause damage to coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Develop protocols and tools to detect invasive species and assess their potential impacts.	√	
	Determine factors (including natural and anthropogenic stressors) that contribute to the success of alien species.	√	
	Develop and test approaches, including biological (e.g., native urchins, bacteria, and fungi) and mechanical tools, to remove and control alien species and restore damaged habitats.		√
	Quantify the effects of invasive algae on reef building corals, other invertebrates, and fishes, and identify taxa of particular concern.		√
	Determine why certain coral reefs or parts of reefs are affected by invasives more than similar reefs in the same area.		√
	Determine habitat and nest preferences of native blennies and gobies, and determine their interactions with non-native blennies and gobies.		√
	Determine the epidemiological and parasite vector relationships to enhance the understanding of interactions with native species.		√
	Determine the ecological interactions between established invasive species and native species (e.g., ta`ape and juvenile snappers), and their impacts on native populations.		√
	Evaluate socioeconomic impacts of established alien species problems.		√
	Determine the distribution, abundance, and impact of the snowflake coral, ***Carijoa riisei***, on black coral populations and identify measures (including eradication techniques and potential restrictions on harvesting black coral) to conserve and sustainably manage the black coral fishery.		√
	Create a risk analysis of alien species introductions to facilitate appropriate management.		√

Hawaiian Islands	CLIMATE CHANGE	Hawaiian Archipelago	Main Hawaiian Islands Only
Management Objective	***Research Need***		
Minimize the effects of climate change on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Assess the resistance and resilience of specific populations, locations, and habitats to episodic events (e.g., coral bleaching), emphasizing areas that may serve as sources of reproductive propagules.	√	
Improve the capacity to forecast and respond to bleaching events.	Develop a predicative capability to identify potential impacts of climate change.		√
	Develop response protocols to mitigate and reduce damage to coral reefs from stressors during bleaching events		√
	Assess the extent and severity of bleaching in Hawaiian waters.		√

Hawaiian Islands	EXTREME EVENTS	Hawaiian Archipelago	Main Hawaiian Islands Only
Management Objective	***Research Need***		
Identify causes and consequences of diseases in coral reef ecosystems and mitigate their impacts. *See Jurisdiction-Wide Section for additional research needs.*	Characterize the types, distribution, and prevalence of diseases in coral reef ecosystems at sites included in the Hawaii's monitoring program.		√
	Determine links between coral disease and anthropogenic stressors (including fishing effort and marine recreational activities).		√
	Develop protocols to assess community level changes through time following a coral disease outbreak.		√
Reduce impacts to and promote restoration of coral reef organisms affected by extreme events.	Develop models to predict how increasing storms (in both number and severity) may alter the structure and distribution of reefs in Hawaii.	√	

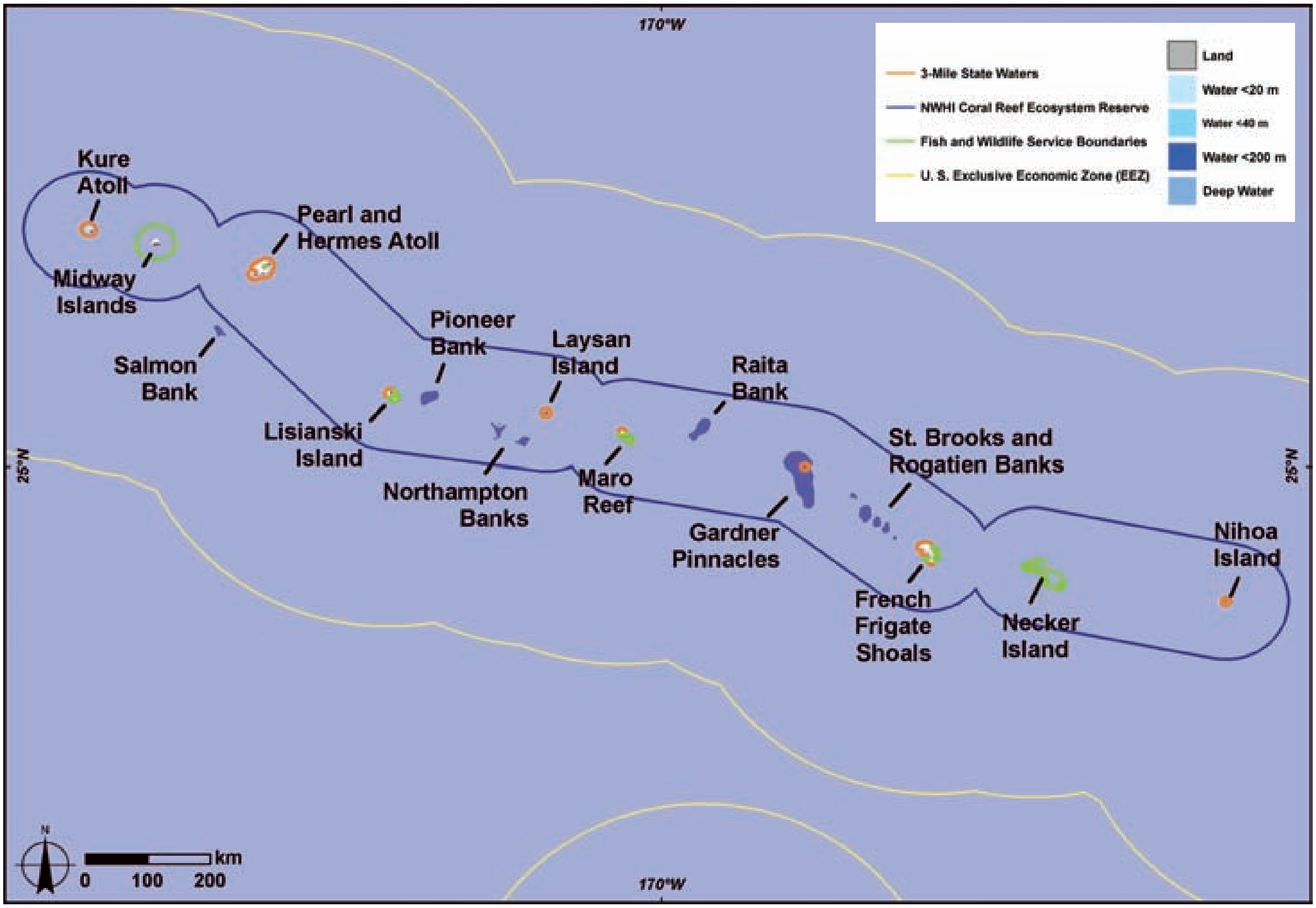


Figure HI-3. The Northwestern Hawaiian Islands, which extend across the north central Pacific, represent a vast, remote coral ecosystem that has been subjected to relatively minimal anthropogenic impacts. Map: A. Shapiro. Source: Friedlander et al. (2005b).

Northwestern Hawaiian Islands

Management Goal

Maintain ecosystem integrity by implementing ecosystem-based management principles.

The NWHI consist of small islands, atolls, submerged banks, and reefs, and stretch for more than 2,000 km northwest of the high windward MHI (Figures HI-3 and HI-4). The majority of the islets and shoals remain uninhabited, although Midway, Kure, and Laysan Islands and French Frigate Shoals have all been occupied for extended periods over the last century by various government agencies.

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. 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 scientists 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 discrete ecological subunits that can be used as replicates to examine large-scale ecological processes,

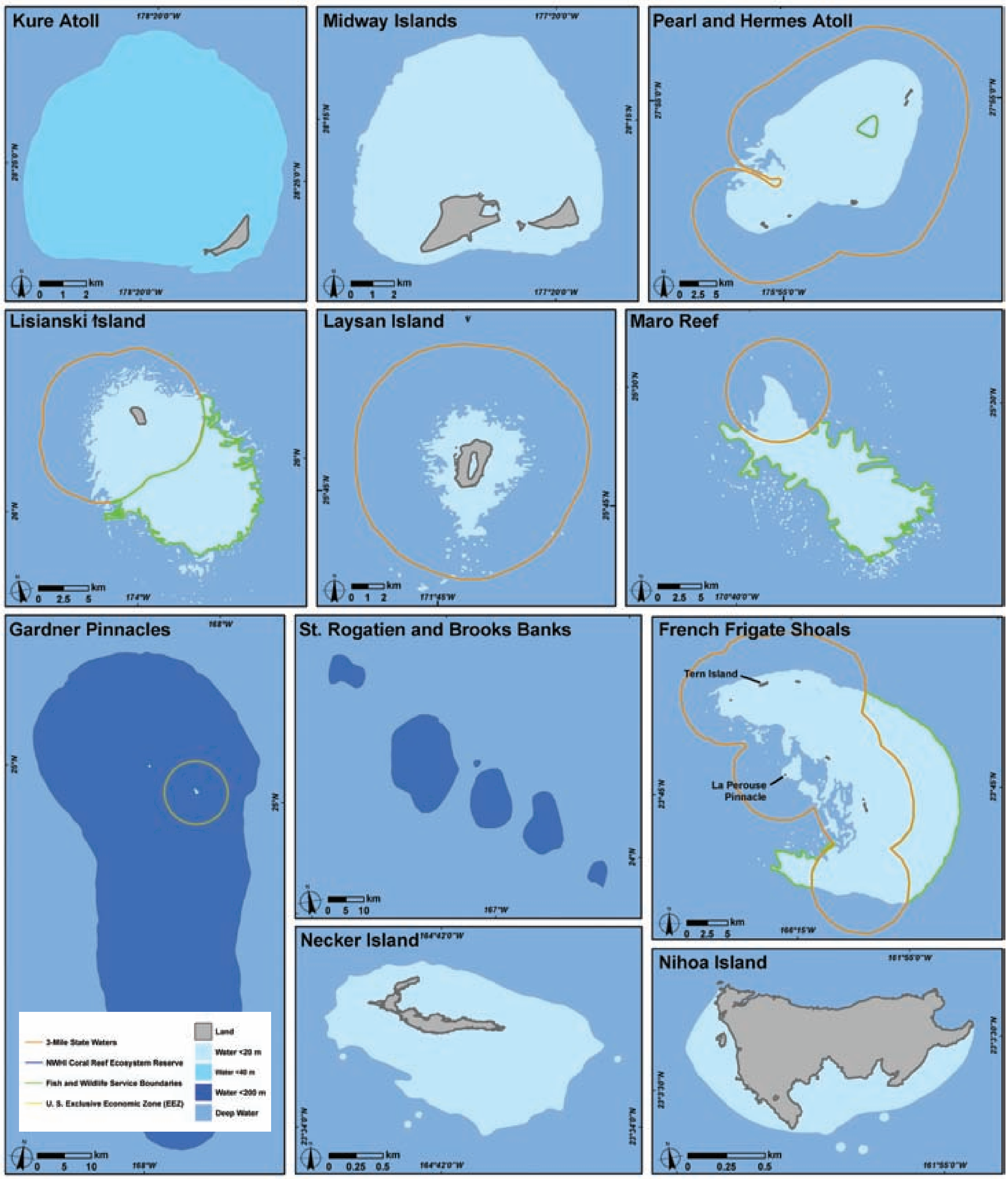


Figure HI-4. Locator map for the Northwestern Hawaiian Islands. Map: A. Shapiro. Source: Friedlander et al. (2005b).

while the scale of the existing fisheries allows for adaptive management strategies that can address questions related to stock decline and recovery. The NWHI represent a baseline within which to understand 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.[7]

To preserve and protect the NWHI for future generations, President Bush signed a Proclamation on June 15, 2006 creating the Northwestern Hawaiian Islands Marine National Monument (Bush 2006). The national monument was created to preserve access for Native Hawaiian cultural activities; provide for carefully regulated educational and scientific activities; enhance visitation in a special area around Midway Island; prohibit unauthorized access to the monument; phase out commercial fishing over a five-year period; and ban other types of resource extraction and dumping of waste.

Research Needs

The research needs described herein are for light-dependent coral reef ecosystems in the NWHI. This section was jointly developed by a working group consisting of NWHI resource managers and affiliated researchers, including the State of Hawaii, FWS, NOAA's Pacific Islands Fisheries Science Center, NOAA's National Marine Sanctuary Program, and the University of Hawaii. As a result of a working group process, it was determined that the format of this section should differ from the other regional sections in this document. Because of the remote nature of the NWHI, many of the threats and stressors that typically impact coral reef ecosystems are not present (e.g., coastal uses). To account for this, the format of the plan was modified. Also, only management objectives with associated research needs are included in the plan. This resulted in the removal of two important management objectives that need mentioning: outreach activities and improving coordination and collaboration among agencies, institutions, and scientists. Outreach activities, while generally not considered to be research, are pivotal to the implementation and success of management actions. Improving coordination and collaboration between agencies, institutions, and individual scientists conducting research in the Hawaiian Archipelago is critical to the success of this research plan, but clearly not a research priority.[8]

7 Introductory material was taken, with slight modifications, from Friedlander et al. (2005b).

8 While this research plan focuses on the shallow coral reef ecosystems in the NWHI, connectivity with the deep coral ecosystems has been documented. This connectivity is acknowledged in this plan by supporting ongoing research in the deep coral ecosystems of the NWHI.

NWHI	An Ecosystem Approach[9]
Management Objective	***Research Need***
Characterize NWHI shallow coral reef ecosystems and function.	Map, characterize, and assess coral reefs and their associated habitats.
	Catalogue existing data sets, document current data collection programs, and assess the quality (e.g., statistical rigor) of these data/programs.
	Describe species diversity, trophic structure, and associated dynamics (including habitat linkages with other ecosystem components) of coral reef ecosystems.
	Characterize critical oceanographic factors that influence the distribution and abundance of biotic components of coral reef ecosystems.
	Assess population replenishment and connectivity among islands, banks, and associated coral reef ecosystems.
	Improve hydrodynamic, ecosystem, and resource assessment models that capture the dynamics, structure, and function at appropriate temporal and spatial scales.
	Develop decision support analysis tools that incorporate the complexity, dynamics, and uncertainty associated with NWHI processes to assist managers in resource decision making processes.
	Identify the distribution and occurrence of deepwater hermatypic coral reefs, including identification of the extent and distribution of these habitats at each island.

NWHI	An Ecosystem Approach[9]
Management Objective	***Research Need***
Understand human impacts, natural variability, and episodic events.	Evaluate and assess impacts (direct and indirect) of human activities (e.g., recreational fishing, subsistence, research, and ecotourism) on coral reef ecosystems.
	Understand the potential effects of coral disease on population dynamics, community structure, and ecosystem function.
	Assess resistance and resilience of specific populations and locations habitats to episodic events (e.g., coral bleaching), emphasizing areas that may serve as sources of reproductive propagules.
	Establish long-term monitoring programs that incorporate biotic and abiotic data to document and assess spatiotemporal changes in biota.
	Document and remediate hazardous waste that poses a threat to fish, wildlife, or their habitats.
Maintain and, where appropriate, restore natural shallow coral reef ecosystems.	Identify and implement effective restoration, recovery, and remediation strategies to address human impacts, including marine debris accumulations, ship groundings, and hazardous waste.
	Restore, where possible, anthropogenically degraded coral reef habitats that are important for sustaining vertebrate and invertebrate stocks.
Identify robust ecosystem-based management indicators that reflect trophic interactions, community composition, biodiversity, and other metrics of ecosystem status.	Identify robust metrics to assess coral reef ecosystems (e.g., biodiversity and other statistical measures of assemblage structure; biomass size spectra; and life history responses to keystone species such as apex predators) that are consistent with existing mandates.
	Identify indicator species (i.e., those which are indicative of the overall condition of the ecosystem) and keystone species (i.e., those of importance in structuring the composition of the ecosystem) for use as monitoring tools.
Evaluate the effectiveness of MPAs as a management tool.	Assess the effectiveness of MPAs in conserving ecologically important species and their habitats.
	Evaluate the costs and benefits of MPAs, including compensation or assistance programs for those displaced from these areas.
	Assess the connectivity among MPAs within the NWHI and between adjacent ecosystems (e.g., Johnston Atoll).
Reduce the threat of alien species to shallow coral reef ecosystems in the NWHI.	Characterize biological and ecological requirements of specific alien species and develop effective prevention and eradication methods.
	Conduct research to support the detection, removal, and control of alien species in coral reef ecosystems in the NWHI.
Protect, conserve, and enhance recovery of protected, threatened, and other key species.	Characterize the role of protected species (i.e., marine mammals, sea turtles, and birds) in coral reef ecosystems and the threats impacting these species, and develop measures to enhance their conservation.

9 As a result of a working group process, it was determined that an ecosystem-based approach would be more appropriate for the NWHI than a threat-based approach. Because of the remote nature of the NWHI, many of the threats and stressors that typically impact coral reef ecosystems are not present.

COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS

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 CNMI-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, are volcanic in origin, they are nearly all covered with uplifted limestone derived from coral reefs. The West Mariana Ridge is a series of seamounts, lying 145 to 170 km west of and parallel to the main island chains. The southern arc islands have the oldest and most developed reefs in CNMI, which are predominantly located along the western (leeward) sides. The majority of CNMI's residents live on Rota, Tinian, and Saipan (the capital). The volcanic islands north of Saipan make up the northern island arc region. In general, limited modern reef development exists along this active arc, although recent surveys show numerous patches of extensive reef growth are found on Maug, Asuncion, Agrihan, Pagan, Alamagan, and Guguan. 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. [10]

Coral reef ecosystems in CNMI are, on the whole, in reasonably good condition. However, it must be recognized that coral reef ecosystems in 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. Based on fisheries information, 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 sea surface temperature, and crown-of-thorns starfish, *Acanthaster planci*, predation have clearly had localized negative effects on coral reefs in the Marianas (Figure CNMI-2). Past military activity in the northern part of Tinian has had an impact on the condition of the island due to improper waste disposal, but current military activities have shown minimal damage to the coral reefs themselves.

Establishment of MPAs 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 1994, the first no-take MPA was established in CNMI at Sasanhaya Bay Fish Reserve in Rota. In the late 1990s, a bill was introduced to create two additional MPAs – Tinian Marine Sanctuary (Tinian Island) and Managaha Marine Conservation Area (Saipan Lagoon). The Managaha Marine Conservation Area was established by law in 2000, but the Tinian Marine Sanctuary has yet to be created.[11]

Figure CNMI-2. Crown-of-thorns starfish, Acanthaster planci, *feeding on live coral adjacent to an artificial reef. Photo credit: James P. McVey, NOAA Sea Grant Program.*

10 It should be noted that residents have resettled several of the northern islands since 1981.

11 Introductory material was taken, with slight modifications, from Starmer et al. (2002, 2005).

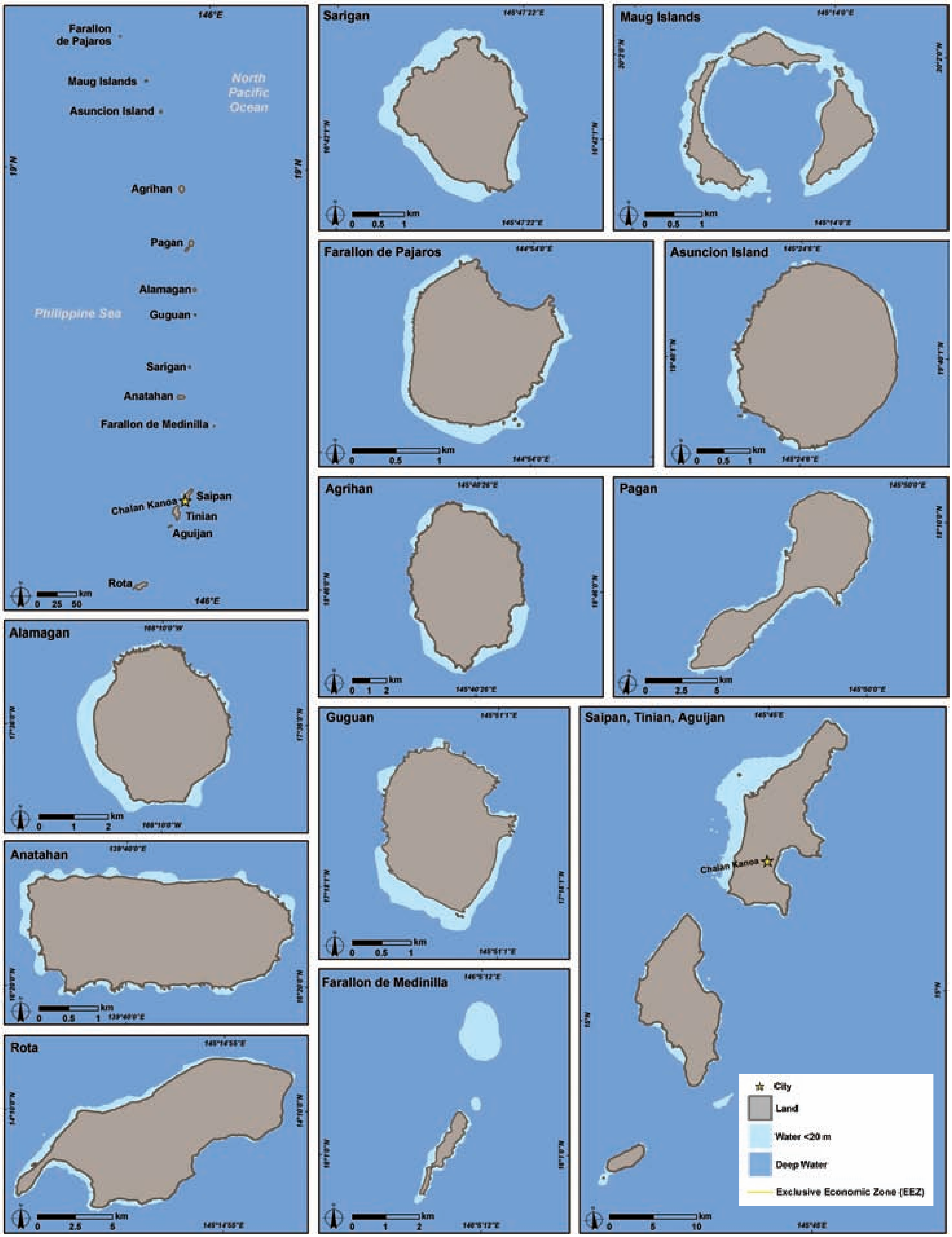


Figure CNMI-1. Locator map for the Commonwealth of the Northern Marianas Islands. (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Starmer (2005).

Research Needs

CNMI	FISHING
Management Objective	***Research Need***
Conserve and manage fisheries to prevent overfishing, rebuild stocks, and minimize destructive fishing. *See Jurisdiction-Wide Section for additional research needs.*	Evaluate fishing effort and catch per unit effort in the Saipan Lagoon.
	Conduct stock assessments in the Saipan Lagoon and other selected nearshore locations and compare to 2005 fish stock assessments to evaluate the effectiveness of the net ban.
	Conduct a socioeconomic valuation of recreational and subsistence coral reef fisheries.
	Determine the archipelago-wide population status of managed reef species using fishery dependent and independent programs.
	Establish the home ranges of key target or indicator species.
Evaluate and improve the effectiveness of MPAs as a fisheries management tool. *See Jurisdiction-Wide Section for additional research needs.*	Evaluate the impact of establishing a user fee structure for MPAs and fishing activities based upon willingness to pay and economic valuations of uses and users.
Increase fishers' participation in fisheries management.	Evaluate the current level of participation by fishers in fisheries management and determine the desired level of participation to best manage fisheries.
	Document historical and cultural knowledge of CNMI coral reef resources and their ecology, and their historical trends in abundance, size, distribution, and community composition.

CNMI	POLLUTION
Management Objective	***Research Need***
Reduce the impacts of pollutants on coral reef ecosystems by improving the understanding of their effects. *See Jurisdiction-Wide Section for additional research needs.*	Identify the effects of pollution and other anthropogenic factors on CNMI's coral reef ecosystems.
	Determine the concentration and impacts of pollutants on nearshore water quality between Taga Beach and Barcinas Bay on Tinian.
	Evaluate the ability of monitoring programs to detect ecosystem change associated with land-based pollutants.
	Identify the sources and impacts of pollutants (e.g., sewer outfalls, Puerto Rico dump site, and golf courses) on coral reef condition.
Improve water quality by reducing land-based pollutant inputs and impacts on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Develop and test methods for improving water quality.
	Model the impacts of land-use activities on nearshore water quality to predict the efficiency of various management schemes.
	Identify appropriate methods and plants for Talakaya watershed to stabilize soil and provide a habitat conducive to the restoration of the native terrestrial ecosystem.
	Assess effectiveness of revegetation in reducing soil erosion in Talakaya watershed.
	Evaluate effectiveness of management actions to restore (and in some cases create) mangrove and wetland areas to reduce and-based pollutants.
Improve the understanding of the economic benefits of improved water quality.	Identify reasons for low stakeholder participation in management opportunities and means to increase support.

CNMI	COASTAL USES
Management Objective	***Research Need***
Reduce the impacts from recreational use, industry, coastal development, and maritime vessels on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Develop criteria to use in the review of environmental assessments and environmental impact statements.
	Determine resource base and human pressure (including land-based pollution and fishing pressure) trends in the northernmost islands.
	Identify the environmental impacts associated with existing marine-related activities and user conflicts among these activities.
	Assess the impacts from non-extractive activities on coral reef condition.
	Evaluate the effectiveness of management measures to reduce pressures from coastal uses on CNMI's coral reef ecosystems.
Balance resource use to minimize user conflicts, provide equitable uses, and ensure optimal benefits to present and future generations.	Conduct an economic valuation of coral reef ecosystems in CNMI.
Reduce impacts from and restore habitat damaged by vessel anchoring and groundings.	Assess the identity, location, condition, and ownership of derelict and grounded vessels and determine their impacts to assist in prioritizing vessel removal.
Restore injured and degraded coral reef habitats. *See Jurisdiction-Wide Section for additional research needs.*	Evaluate the effectiveness of management actions to restore shoreline, sandy beach, and nearshore water quality.
Manage coral reef ecosystems and their uses in a holistic manner. *See Jurisdiction-Wide Section for additional research needs.*	Compare the historical extent and condition of mangroves, grass beds, and coral reefs with their current status to determine if conservation measures are necessary.
Evaluate and improve the effectiveness of MPAs as a management tool. *See Jurisdiction-Wide Section for additional research needs.*	Conduct specific valuation of the impact of MPAs on resident fishing populations.
	Evaluate the effectiveness of current MPAs to protect the long-term stability of CNMI's coral reef ecosystems.
	Evaluate the impact of establishing a user fee structure for MPAs and fishing activities based upon users' willingness to pay and economic valuations of uses.

CNMI	INVASIVE SPECIES
Management Objective	***Research Need***
Minimize the introduction and spread of alien species.	*See Jurisdiction-Wide Section for research needs.*
Control or eradicate invasive species that have the potential to cause damage to coral reef ecosystems.	Identify those species in CNMI waters with the potential for invasive behavior (e.g., *Tilapia*) and develop appropriate management plans for each species.

CNMI	CLIMATE CHANGE
Management Objective	***Research Need***
Minimize the effects of climate change on coral reef ecosystems.	*See Jurisdiction-Wide Section for research needs.*

CNMI	EXTREME EVENTS
Management Objective	***Research Need***
Identify causes and consequences of diseases in coral reef ecosystems and mitigate their impacts. *See Jurisdiction-Wide Section for additional research needs.*	Determine the distribution, abundance, and types of coral diseases prevalent in CNMI and their impacts on coral reef condition.
Reduce the collateral impacts from harmful algal blooms on nearshore areas.	Assess the relative importance of ground water and surface water discharges in contributing to harmful algal blooms in Saipan.
Identify and reduce the negative impacts of *Acanthaster planci*.	Determine the ecological and economic impacts of *Acanthaster planci* populations and identify strategies to minimize outbreaks.

GUAM

Guam, a U.S. territory located at 13º 28' N, 144º 45' E, is the southernmost island in the Mariana Archipelago (Figure GUAM-1). It is the largest island in Micronesia, with a land mass of 560 km^2 and a maximum elevation of approximately 405 m. It is also the most heavily populated island in Micronesia with a population of about 164,000 people (est. July 2003). 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; and is recharged from rainfall percolating through surface soils (Guam Water Planning Committee 1998). The southern half of the island is primarily volcanic, with more topographic relief and large areas of highly erodible soils (Young 1988). This topography creates a number of watersheds throughout the southern areas which are drained by 96 rivers (Best and Davidson 1981).

The condition of Guam's coral reefs (including fringing reefs, patch reefs, submerged reefs, offshore banks, and barrier reefs) varies considerably, depending on a variety of factors including geology, human population density, degree of coastal development, levels and types of marine resource uses, oceanic circulation patterns, and frequency of natural disturbances (e.g., typhoons and earthquakes). Many of Guam's reefs have declined in health over the past 40 years. The average live coral cover on the fore reef slopes was approximately 50% in the 1960s (Randall 1971), but by the 1990s had dwindled to less than 25% live coral cover and only a few having over 50% live cover (Birkeland 1997). Still, in the past, Guam's reefs have recovered after drastic declines. For example, an outbreak of the crown-of-thorns starfish, *Acanthaster planci*, in the early 1970s reduced coral cover in some areas from 50 to 60% to less than 1%. Twelve years later, greater than 60% live coral cover was recorded for these areas (Colgan 1987). A more distressing indicator of the condition of Guam's coral reefs is the marked decrease in rates of coral recruitment.

Guam's coral reefs are an important component of its tourism industry. The reefs and the protection that they provide make Guam a popular tourist destination for Asian travelers (70 to 80% from Japan). 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 hosted nearly 1 million visitors in 2003 (GVB 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. Reef fish, although somewhat displaced from the diet by westernization and declining stocks, 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 part of their diet (Amesbury and Hunter-Anderson 2003). Sea cucumbers, sea urchins, mollusks, marine algae, and a variety of crustaceans 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 by local law in 1997 in 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 NWR; the two Naval Ecological Reserve Areas, Orote and Haputo; and the Guam Territorial Seashore Park. While the five marine preserves are enforced, the other areas currently have limited management and enforcement. [12]

12 Introductory material was taken, with slight modifications, from Porter et al. (2005).

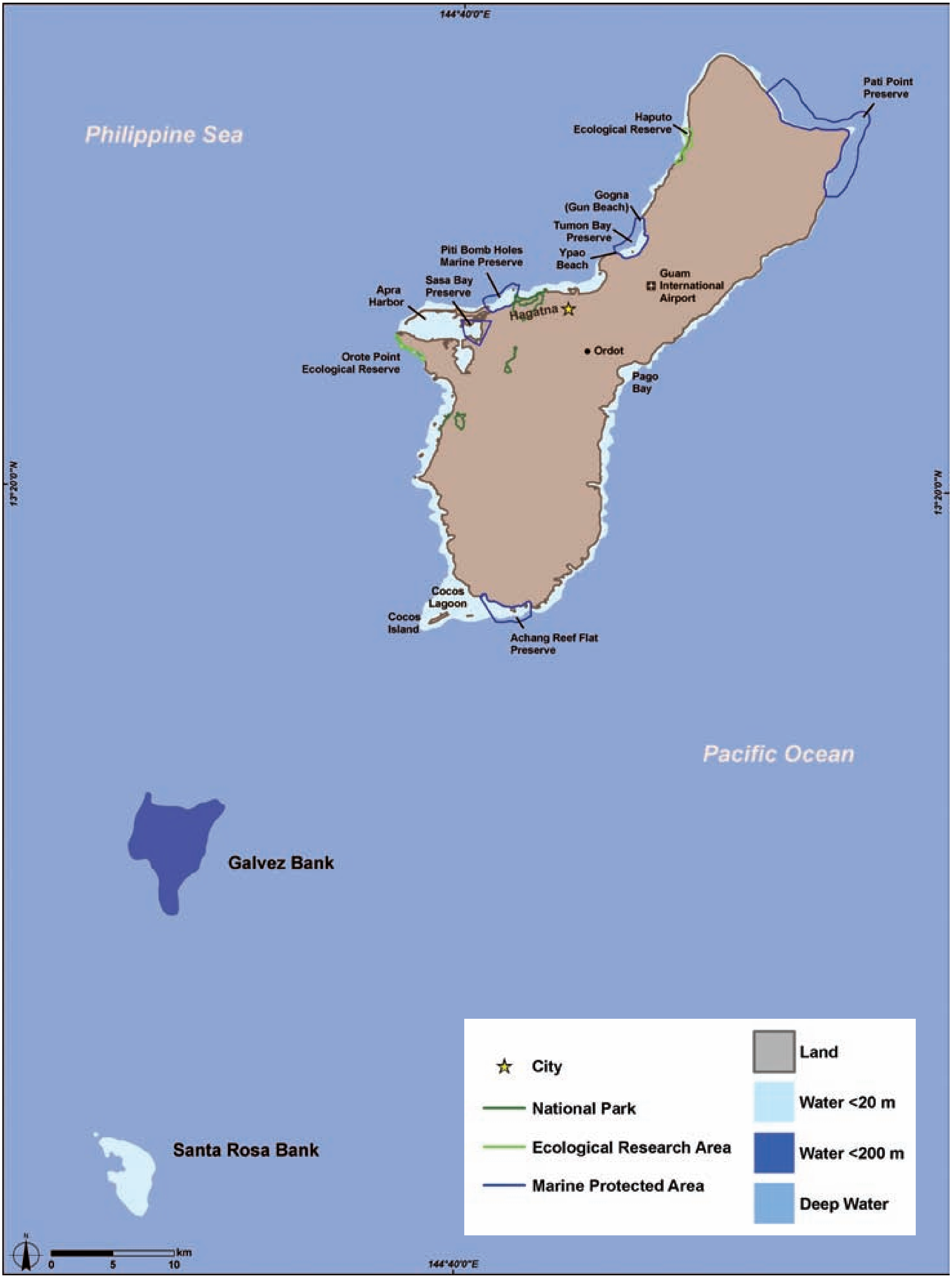


Figure GUAM-1. Locator map for Guam. (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Porter et al. (2005).

Research Needs

GUAM	FISHING
Management Objective	***Research Need***
Conserve and manage fisheries to prevent overfishing, rebuild stocks, and minimize destructive fishing. *See Jurisdiction-Wide Section for additional research needs.*	Analyze fisheries stock assessment data, including creel surveys and in situ visual assessments, to determine the condition of different functional groups (e.g., herbivores, detritivores, and piscivores) and determine possible causes of any community shifts, if present.
	Study the role of soft corals as reef fish habitat.
Evaluate and improve the effectiveness of MPAs as a fisheries management tool. *See Jurisdiction-Wide Section for additional research needs.*	Evaluate the effectiveness of marine preserves in enhancing fish populations in adjacent areas (i.e., spillover) using inshore creel and participation surveys.
	Assess, inside and outside MPAs, the relationship between herbivorous fishes and algal abundance, composition, chemical defense, and other environmental factors on Guam reef flats.

GUAM	POLLUTION
Management Objective	***Research Need***
Reduce the impacts of pollutants on coral reef ecosystems by improving the understanding of their effects. *See Jurisdiction-Wide Section for additional research needs.*	Model water circulation patterns around reefs and adjacent inshore habitats.
	Develop a digital watershed atlas for Guam.
	Develop a GIS-based erosion potential model to estimate sediment delivery to estuarine and coral reef environments of southern Guam.
	Determine the status of the waters found in each of Guam's 20 watersheds.
	Conduct primary screening for chemicals of environmental concern in Guam's coastal waters.
	Conduct screening for heavy metals in marine organisms in Pago Bay into which the Ordot Dump Watershed drains.
	Evaluate the effectiveness of using soft corals as bioindicators of persistent contaminants in Guam's coastal waters.
Improve water quality by reducing land-based pollutant inputs and impacts on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Study the effects of tree planting and erosion control measures in reducing pollution from Fouha Watershed.

GUAM	COASTAL USES
Management Objective	***Research Need***
Reduce the impacts from recreational use, industry, coastal development, and maritime vessels on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Characterize and assess the major threats to and use of Guam's coast.
	Conduct an assessment of all recreational activities along Guam's coastline and their effects on coral reef ecosystems, including seagrass beds.
	Determine the effects of motorized personal watercraft on coral reef ecosystems.
	Evaluate the effectiveness of the implementation of the New Seashore Reserve Plan.
	Determine the effectiveness of the existing public awareness and outreach materials and programs.
Balance resource use to minimize user conflicts, provide equitable uses, and ensure optimal benefits to present and future generations.	Expand Guam's coral reef valuation study to better capture the value of the coral reef to Guam's traditions and culture.
	Assess the societal costs of coral reef ecosystem degradation.
	Conduct a feasibility study of instituting a recreational user fee for management and monitoring parameters.
Restore injured and degraded coral reef habitat. *See Jurisdiction-Wide Section for additional research needs.*	Assess the effectiveness of coral restoration efforts that are coupled with watershed restoration, MPA designation, and pollution abatement programs.
Protect, conserve, and enhance the recovery of protected, threatened, and other key species.	Characterize the role of protected species (i.e., marine mammals, sea turtles, and birds) in coral reef ecosystems and the threats impacting these species, and develop measures to enhance their conservation.
Manage coral reef ecosystems and their uses in a holistic manner. *See Jurisdiction-Wide Section for additional research needs.*	Characterize the size, condition, productivity, and seasonal changes in seagrass beds and impacts associated with human activities.
Evaluate and improve the effectiveness of MPAs as a management tool. *See Jurisdiction-Wide Section for additional research needs.*	Conduct a study of the non-extractive value of icon species in marine preserves.
	Assess the connectivity and replenishment among the offshore banks and the island of Guam with particular attention to the role of marine preserves.
	Identify additional protections needed to provide long-term stability and resilience of Guam's coral reef ecosystems.
	Assess socioeconomic factors influencing the effectiveness of Guam's MPAs.

GUAM	INVASIVE SPECIES
Management Objective	***Research Need***
Control or eradicate alien and native invasive species that have the potential to cause damage to coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Develop protocols and tools to control the growth of the native green alga, *Enteromorpha clathrata*, in the intertidal zone of Tumon Bay and East Agana Bay.
	Assess the population and distribution of the native invasive red algae, *Gracilaria salicornia* and *Acanthophora spicifera*, in Pago Bay and in reefs of Tumon Bay, East Agana Bay, and Cocos Lagoon; and develop protocols and tools to control the growth of the algae.

GUAM	CLIMATE CHANGE
Management Objective	***Research Need***
Minimize the effects of climate change on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Assess and quantify the impacts of bleaching on corals during and after bleaching events.
	Identify areas to protect to ensure long-term stability of coral reef ecosystems.

GUAM	EXTREME EVENTS
Management Objective	***Research Need***
Identify causes and consequences of diseases in coral reef ecosystems and mitigate their impacts. *See Jurisdiction-Wide Section for additional research needs.*	Conduct a baseline assessment of coral diseases.
	Establish a protocol for rapidly identifying, assessing, and mitigating disease epizootics, bleaching episodes, and predator outbreaks.
Reduce the occurrence and intensity of harmful algal blooms.	Investigate the relationship between cyanobacteria, pollution, and reef condition, including elements (e.g., nutrients, iron, and temperature) which may trigger or cause cyanobacterial blooms.

AMERICAN SAMOA

American Samoa is a U.S. Territory located approximately 4,200 km south of Hawaii (Figure AMSAM-1). It is 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. 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. Rose Atoll is uninhabited, while Swains Island is inhabited by a subsistence population (of about 10 people). 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 to 500 m); depths of 1000 m are reached within 2 to 8 km from shore.

Coral reefs in American Samoa provide an important source of food for villagers through daily subsistence use and sales at local stores. They also provide infrastructure and shoreline protection from storm wave action, and are important to the Samoan culture. Other potential uses of the reefs are low at present (e.g., tourism or the aquarium trade).

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, *Acanthaster planci*, 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 fishing pressure has occurred, the Territory's coral reef ecosystem cannot be considered healthy based on the resilience of the corals alone. Furthermore, climate change impacts (e.g., coral bleaching and 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.

American Samoa has several MPAs, three Federal, one territorial, and several village-managed. Rose Atoll is designated as a NWR under the joint jurisdiction of the FWS and the Department of Commerce in cooperation with the Territory of American Samoa (WPRFMC 2001). Fagatele Bay National Marine Sanctuary encompasses a small embayment, and the National Park of American Samoa administers land and coral reef areas on four islands. The territory has also established Ofu Vaoto Marine Park. For the past three years, several villages have instituted community-based fisheries management regimes, banning fishing in part or all of their adjacent reef. Each village writes its own fisheries management plan with the assistance of the American Samoa Department of Marine and Wildlife Resources, but the primary goal overall is to enhance fisheries resources on the reefs. Territorial coordination of coral reef decision-making resides with the Coral Reef Advisory Group, a collaboration of Federal and territorial agencies including NOAA, DOI, the local Department of Commerce and the local Department of Marine and Wildlife Resources, American Samoa Environmental Protection Agency, and the American Samoa Community College's Sea Grant Program. [13]

13 Introductory material was taken, with slight modifications, from Craig (2002) and Craig et al. (2005).

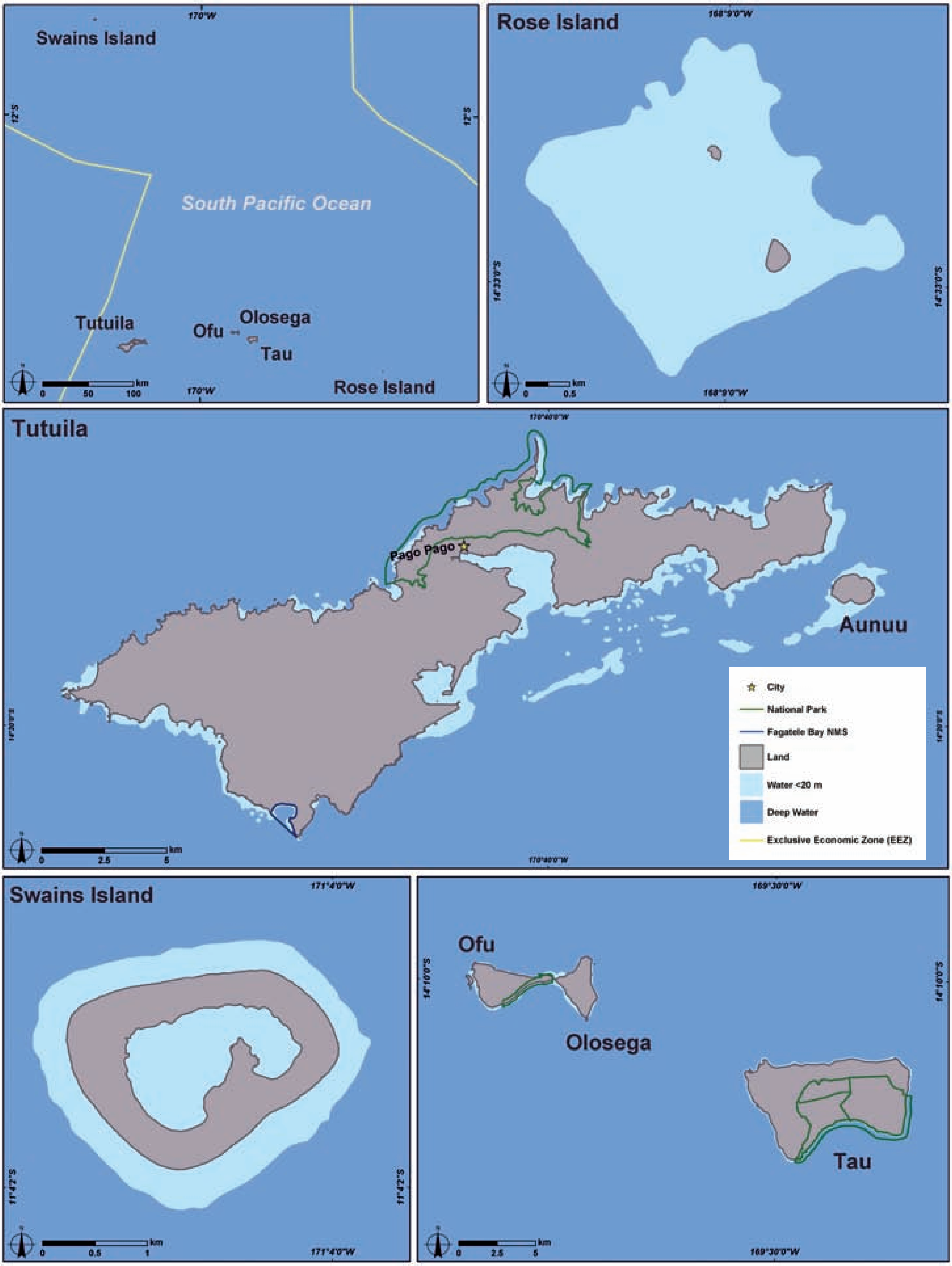


Figure AMSAM-1. Locator map for American Samoa. (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Craig et al. (2005).

Research Needs

American Samoa	FISHING
Management Objective	***Research Need***
Conserve and manage fisheries to prevent overfishing, rebuild stocks, and minimize destructive fishing. *See Jurisdiction-Wide Section for additional research needs.*	Determine sustainable harvest levels and fishing limits for the various fisheries.
	Assess the socioeconomic and biological implications of the recent ban on scuba spearfishing.
	Assess the impact of harvest in subsistence, artisanal, and export fisheries.
Evaluate aquaculture projects that minimize impacts to habitats, fishery stocks, and existing fishing communities.[14]	Assess the cost and benefits of aquaculture of local organisms with regard to their ease of production, economic potential (for local markets and export), and environmental impact.
	Conduct a socioeconomic survey to determine the level of acceptance of aquaculture products in the local market, appropriate products and potential economic returns, and interest levels of potential aquaculture farmers.
	Evaluate a demonstration aquaculture facility(s) that promotes environmentally-friendly culture systems (e.g., green water tank culture and aquaponics) that can be used for training, education, and research.

American Samoa	POLLUTION
Management Objective	***Research Need***
Reduce the impacts of pollutants on coral reef ecosystems by improving the understanding of their effects. *See Jurisdiction-Wide Section for additional research needs.*	Clarify the role of pollution in causing degradation of coral reef ecosystems.
	Evaluate the ability of monitoring programs to detect ecosystem change associated with inputs of land-based pollutants.
	Develop a circulation model for the main islands in the territory, including nearshore waters.
Improve water quality by reducing land-based pollutant inputs and impacts on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Analyze and evaluate coral reef condition and water quality of reef sites adjacent to selected watersheds to help determine the efficacy of the nonpoint source program.
	Develop criteria to use in the review of environmental assessments and environmental impact statements.
	Identify potential modifications to water and sewer facilities and evaluate their effectiveness in preventing cyclones from spilling contaminants into nearshore waters.

14 While managers and scientists in American Samoa take a cautious view of aquaculture, based on negative experiences elsewhere and the industry's potential to harm coral reef ecosystems, the Territory's homogenous economic base makes it attractive to small-scale aquaculture ventures similar to those found elsewhere in tropical areas. It has therefore been recognized that management-driven research, while not currently a priority, may be desired on an as-needed basis in the future.

American Samoa	COASTAL USES
Management Objective	***Research Need***
Reduce the impacts from recreational use, industry, coastal development, and maritime vessels on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Evaluate the effectiveness of land use permits aimed to mitigate impacts on adjacent reefs.
	Quantify soil erosion resulting from coastal development on steep volcanic soils and associated impacts to coral reef ecosystems.
	Evaluate and update BMPs for watersheds.
Restore injured and degraded coral reef habitat.	*See Jurisdiction-Wide Section for research needs.*
Reduce rapid population growth in American Samoa.	Evaluate social, economic, and population impacts on coral reef ecosystems and model the future of these ecosystems with continued population growth.
Evaluate and improve the effectiveness of MPAs as a management tool.	*See Jurisdiction-Wide Section for research needs.*

American Samoa	INVASIVE SPECIES
Management Objective	***Research Need***
Minimize the introduction and spread of alien species.	*See Jurisdiction-Wide Section for research needs.*

American Samoa	CLIMATE CHANGE
Management Objective	***Research Need***
Minimize the effects of climate change on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Identify populations or communities that have endogenous factors which make them less susceptible to the effects of climate change.

American Samoa	EXTREME EVENTS
Management Objective	***Research Need***
Identify causes and consequences of diseases in coral reef ecosystems and mitigate their impacts.	*See Jurisdiction-Wide Section for research needs.*

U.S. PACIFIC REMOTE INSULAR AREAS

The U.S. has sovereign Federal jurisdiction over eight low coral islands, atolls, and reefs in the central Pacific that are not under the control of other U.S. territories or states. They are Rose Atoll (see American Samoa Section's Figure AMSAM-1), at the east end of American Samoa; Wake Atoll, north of the Marshall Islands; Johnston Atoll, southwest of the Hawaiian Islands; Kingman Reef, Palmyra Atoll, and Jarvis Island, all in the northern Line Islands; and Howland Island and Baker Island, northwest of the Phoenix Islands (Figure PRIA-1). The U.S. Pacific Remote Insular Areas (PRIAs) span latitudes from 19°N to 14°S, include three islands on the Equator, and serve as natural reef laboratories to monitor the effects of oceanic processes and climate over time and space because of minimal anthropogenic impacts. All of the PRIAs were free of human habitation at the time of their discovery by Americans and Europeans two centuries ago, although Rose and Wake Atolls have local island names (Nu'u O Manu and Enen Kio, respectively) and were periodically visited by Samoans and Marshallese, respectively. These eight remain among the most remote and pristine coral reefs in the world.

All eight PRIAs except Wake Atoll are NWRs administered by the FWS, and are among the Nation's most important MPAs. Rose Atoll is under the joint jurisdiction of the FWS and the Department of Commerce in cooperation with the Territory of American Samoa (WPRFMC 2001).[15] Wake Atoll is under the jurisdiction of DOI and presently serves as a military base under the administration of the U.S. Air Force.

The PRIAs provide key habitats for many native species of plants, insects, birds, reptiles, marine mammals, and thousands of reef species. Many nationally and internationally recognized threatened, endangered, migratory, vulnerable, and depleted species thrive and are protected at the PRIAs, including the green turtle, hawksbill turtle, coconut crab, pearl oyster, giant clams, reef sharks, groupers, humphead wrasse, bumphead parrotfish, whales, and dolphins.

Although historically spared of impacts that degrade reefs near more populated U.S. areas, these remote oceanic and reef ecosystems have suffered from a variety of human impacts since the mid 19th century, including guano mining, feather gathering, sea turtle harvest, alien species predation, fishing, temporary settlements, ship groundings, World War II era military occupation, and atmospheric missile and nuclear weapons testing. Remoteness was a blessing in past centuries, keeping these areas generally free of anthropogenic effects, but now they are the targets of fishers and trespassers beyond the watchful eye and reach of enforcement and surveillance authorities, and threatened by unauthorized harvests and the invasive species that accompany them (J. Maragos, personal communication). Derelict debris, ship groundings, fuel spills, hazardous/toxic waste, and climate change are additional impacts. Although the FWS has been successful in eradicating alien rats and cats from most PRIA refuges, rats and mice remain at Palmyra, and invasive ants and scale insects are now decimating rare beach forest stands at Rose and Palmyra.

Lagoon, reef, and island habitats at Palmyra, Wake, Johnston, and Baker still suffer from the residual effects of coastal construction and dumping of contaminants, toxics, and debris, exacerbating some of the adverse effects of climate change and degrading the resilience of resident species, populations, and habitats.

The remoteness of the PRIAs has also thwarted access to and scientific characterization of these areas, including terrestrial, shallow reef, and deep sea habitats surrounding the islands. Before NOAA-sponsored research cruises began in 2000, there was little information available for proper management, recovery of species, and restoration of habitats, especially in marine waters. Even today very little is known about marine habitats below diving depths of about 30 m. Scuba diving at the PRIAs is also constrained by the great distance to the nearest medical facilities, and scuba divers must emphasize safety and accident prevention via limitations on maximum depth, duration, and frequency of diving. Hence, future data collection must rely more on alternatives to scuba, especially remote sensing data collection. Moreover, FWS terrestrial wildlife biologists, coral reef biologists, and ecotoxicologists have relied on NOAA research vessels and the U.S. Coast Guard to provide access to evaluate, monitor, and restore wildlife and habitats, which presently is the only reliable means of access to the PRIAs.

15 Note: Elements of the American Samoa regional sections of this plan may apply to Rose Atoll, if they are consistent or complementary to the research needs identified in this section.

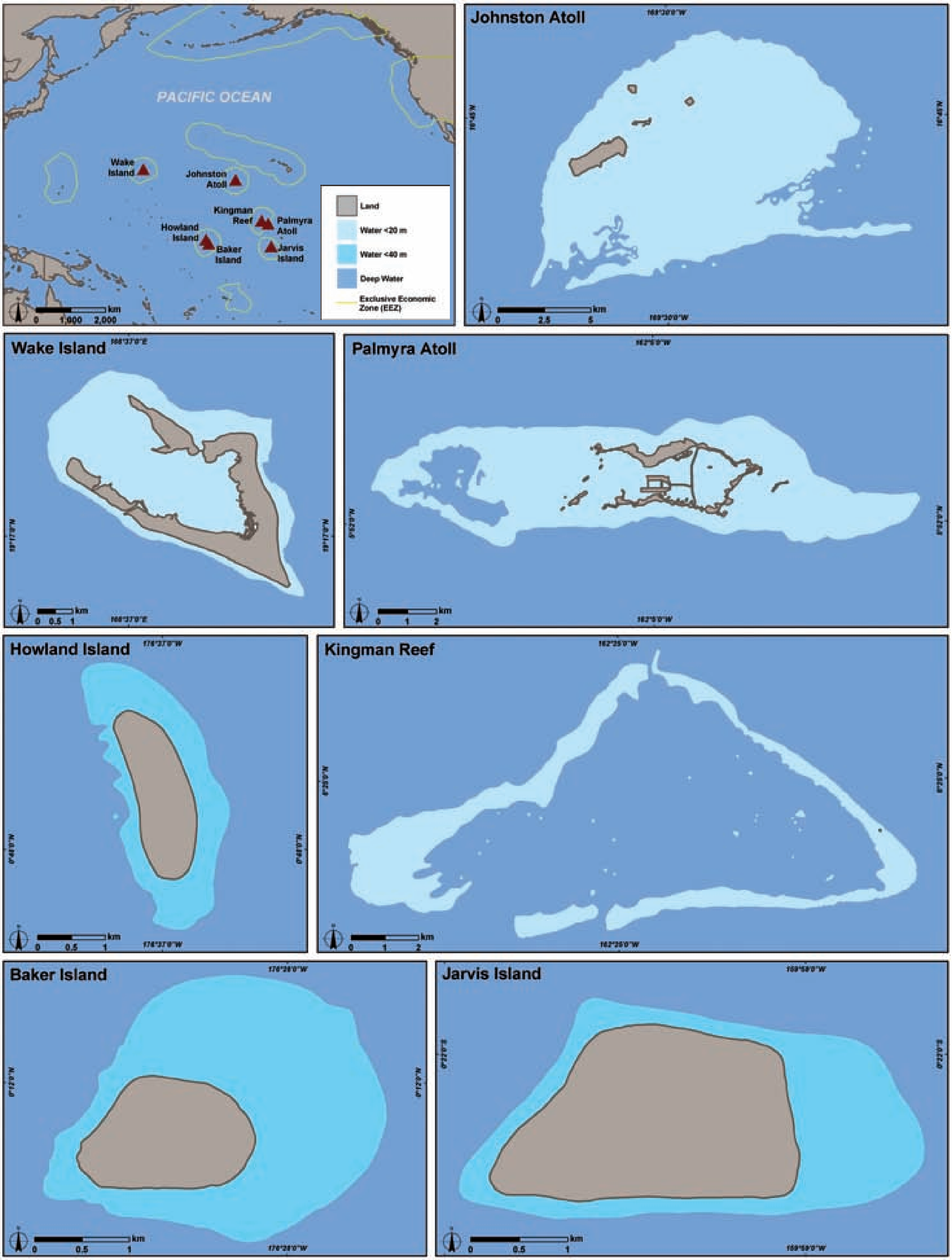


Figure PRIA-1. Locator map for the U.S. Pacific Remote Insular Areas. (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Brainard et al. (2005).

The research needs for the PRIAs address the issues of reduced access, surveillance, enforcement, research, monitoring and management capacity, and takes advantage of NOAA research vessels, satellites, bathymetric mapping platforms, oceanographic buoys, instrumentation, remotely operated and towed vehicles, deep-diving submersibles, and other NOAA assets to address these deficiencies in a spirit of cooperation with FWS, DOI, the U.S. Department of Defense, and other collaborating institutions.

Research Needs

U.S. Pacific Remote Insular Areas	FISHING
Management Objective	***Research Need***
Conserve and manage fisheries to prevent overfishing, rebuild stocks, and minimize destructive fishing.[16] *See Jurisdiction-Wide Section for additional research needs.*	Determine the natural fluctuation of fishery species in the PRIAs to enable comparison with exploited populations outside the NWRs.
	Compare fishery-independent assessments of species in the Samoan archipelago to non-fished stocks at no-take Rose Atoll NWR.
	Evaluate the feasibility of the low-level, catch-and-release recreational bone-fishery at Palmyra NWR[17] and recommend measures to sustain the fishery.
	Assess the recovery of fish populations at Johnston Atoll NWR since closure of the recreational fishery in 2004 when the U.S. military abandoned its presence at the atoll.
Evaluate and improve the effectiveness of MPAs as a fisheries management tool. *See Jurisdiction-Wide Section for additional research needs.*	Develop and establish visual and sonic sensors that can be remotely activated and monitored via satellite to document and discourage unauthorized access and harvest of fish and wildlife resources within the no-take PRIAs, and for application to manage fisheries outside refuges.
	Assess targeted fishery species within and outside refuges to demonstrate the values of no-take areas in replenishing overfished stocks outside the refuges.

U.S. Pacific Remote Insular Areas	POLLUTION
Management Objective	***Research Need***
Reduce the impacts of pollutants on coral reef ecosystems by improving the understanding of their effects. *See Jurisdiction-Wide Section for additional research needs.*	Characterize the ecological impacts of land-based discharges on lagoon water quality at Palmyra Atoll NWR, and evaluate potential ecological benefits of restoration alternatives.
Improve water quality by reducing land-based pollutant inputs and impacts on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Determine the need for remediation of contaminants (i.e., unexploded ordnance, fuel spills, other toxic and hazardous waste, material disposal, and historic sewage discharges in lagoon, reef, and coastal areas) on Johnston, Palmyra, and Baker NWRs, and at Wake Atoll.
	Evaluate the impacts of pollutants at Palmyra, Johnston, Midway, and Baker NWRs, and at Wake Atoll, and evaluate the efficacy of alternative measures to restore habitats.
	Assess, model, and monitor planned restoration of water quality and circulation within the lagoon at Palmyra Atoll NWR degraded by World War II military construction.

16 Note: commercial fishing is prohibited within the eight remote Pacific NWRs.

17 Researchers working at Palmyra Atoll should consult with the FWS, NOAA, the Western Pacific Regional Fishery Management Council, The Nature Conservancy, and researchers at Scripps Institution of Oceanography.

U.S. Pacific Remote Insular Areas	POLLUTION
Management Objective	***Research Need***
Monitor coral reef condition to understand and address unexpected changes or events related to land-based and atmospheric pollution.	Implement a detailed monitoring program, in collaboration with FWS at the eight NWRs and Department of Defense and DOI at Wake Atoll, including multiple depth regimes and permanently-marked sites to determine the impact of previous disturbances and characterize future changes.

U.S. Pacific Remote Insular Areas	COASTAL USES
Management Objective	***Research Need***
Assess the impacts from former recreational use and coastal development on coral reefs.	Assess lagoon and shoreline impacts attributed to World War II era military construction on Johnston and Wake Atolls, and evaluate the efficacy of possible remedial measures.
Balance resource use to minimize user conflicts, provide equitable uses, and ensure optimal benefits to present and future generations.	Provide data to support the preparation and coordination of comprehensive conservation plans by the FWS for the eight PRIAs refuges.
Reduce impacts from and restore habitat damaged by vessel anchoring and groundings.	Evaluate the use of deep sea in situ assets to survey possible shipwreck sites at Baker and other PRIAs.
	Develop a response plan with the FWS and U.S. Coast Guard to conduct initial damage assessments of fuel spills and ship groundings in the NWRs.
	Assess the impacts of fuel spills and ship groundings on PRIA reefs during and after shipwreck removal and other restoration actions.
	Assess the ecosystem recovery after the completion of wreckage removal in 2005 of a 1993 fishing vessel grounding offshore at Rose Atoll.
	Assess the ecosystem recovery of the 1991 fishing vessel grounding at Palmyra Atoll.
Protect, conserve, and enhance the recovery of protected, threatened, and other key species.	Conduct research aimed at the protection, conservation, and recovery of protected species (i.e., marine mammals, sea turtles, and birds) that utilize coral reef ecosystems.
Restore injured and degraded coral reef habitats. *See Jurisdiction-Wide Section for additional research needs.*	Evaluate the deep sea World War II era dumping of military material off Baker Island NWR, and possibly off other refuges.
Manage coral reef ecosystems and their uses in a holistic manner. *See Jurisdiction-Wide Section for additional research needs.*	Describe species diversity, trophic structure, and associated dynamics of shallow coral reef ecosystems in the eight islands in the PRIAs.

U.S. Pacific Remote Insular Areas	INVASIVE SPECIES[18]
Management Objective	***Research Need***
Minimize the introduction and spread of alien species.	*See Jurisdiction-Wide Section for research needs.*
Control or eradicate invasive species that have potential to cause damage to coral reef ecosystems.	Document the diversity, distribution, and abundance of invasive species, identify impacts on coral reef ecosystems, and identify ways to prevent their spread.

U.S. Pacific Remote Insular Areas	CLIMATE CHANGE
Management Objective	***Research Need***
Minimize the effects of climate change on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Collect and analyze coral cores for past climatic events, and conduct assessments to identify active coral bleaching events denoting bleached vs. non-bleached species.
Mitigate the impacts from climate change on coral reef ecosystems.	Restore lagoonal circulation at Palmyra degraded by World War II construction and track the ability of these actions at preventing a repeat of the massive bleaching event and coral die-off on the western terrace that was associated with the discharge of heated lagoonal waters.
	Model the effectiveness of various measures to maximize lagoon circulation and flushing at Palmyra and reduce water residence time in the lagoon to reduce heating of lagoon waters before exiting the lagoon.

U.S. Pacific Remote Insular Areas	EXTREME EVENTS
Management Objective	***Research Need***
Identify causes and consequences of diseases in coral reef ecosystems and mitigate their impacts. *See Jurisdiction-Wide Section for additional research needs.*	Evaluate the impacts of episodic wave events and the role of these events in forming and maintaining spatial and vertical distributions of corals, algae, and fishes.
	Characterize the prevalence of disease, and document affected species and the types of diseases present at each site to serve as a baseline.

18 To prevent introduction of alien species during research activities in the PRIAs, the hulls of NOAA research ships should be scrubbed and cleaned of fouling organisms just prior to departure to the PRIAs. Also, scuba gear should be decontaminated when diving in different areas to prevent introduction of pathogens.

PACIFIC FREELY ASSOCIATED STATES

The Pacific Freely Associated States include the Republic of the Marshall Islands (the Marshalls), the Federated States of Micronesia (FSM), and the Republic of Palau (Palau). These islands are all independent countries that at one-time were governed by the U. S. as part of the Trust Territory of the Pacific Islands after World War II. Although these countries are independent, they still maintain close ties with the U.S. and are eligible to receive funds from U.S. Federal agencies, including NOAA, DOI, EPA, and the National Science Foundation.

The coral reef resources of these islands remain mostly unmapped.

Republic of the Marshall Islands

The Marshall Islands encompasses approximately 1,225 individual islands and islets, with 29 atolls and 5 solitary low coral islands (Figure FAS-1). The Marshalls have a total dry land area of only about 181.3 km^2. However, when the Exclusive Economic Zone (from the shoreline to 200 miles offshore) is considered, the Republic covers 1,942,000 km^2 of ocean within the larger Micronesia region. There are 11,670 km^2 of sea within the lagoons of the atolls. Land makes up less than 0.01% of the area of the Marshalls. Most of the country is the broad open ocean with a seafloor depth that reaches 4.6 km. Scattered throughout the Marshalls are nearly 100 isolated submerged volcanic seamounts; those with flattened tops are called guyots. The average elevation of the Marshalls is about 2 m above sea level. In extremely dry years, there may be no precipitation on some of the drier atolls.

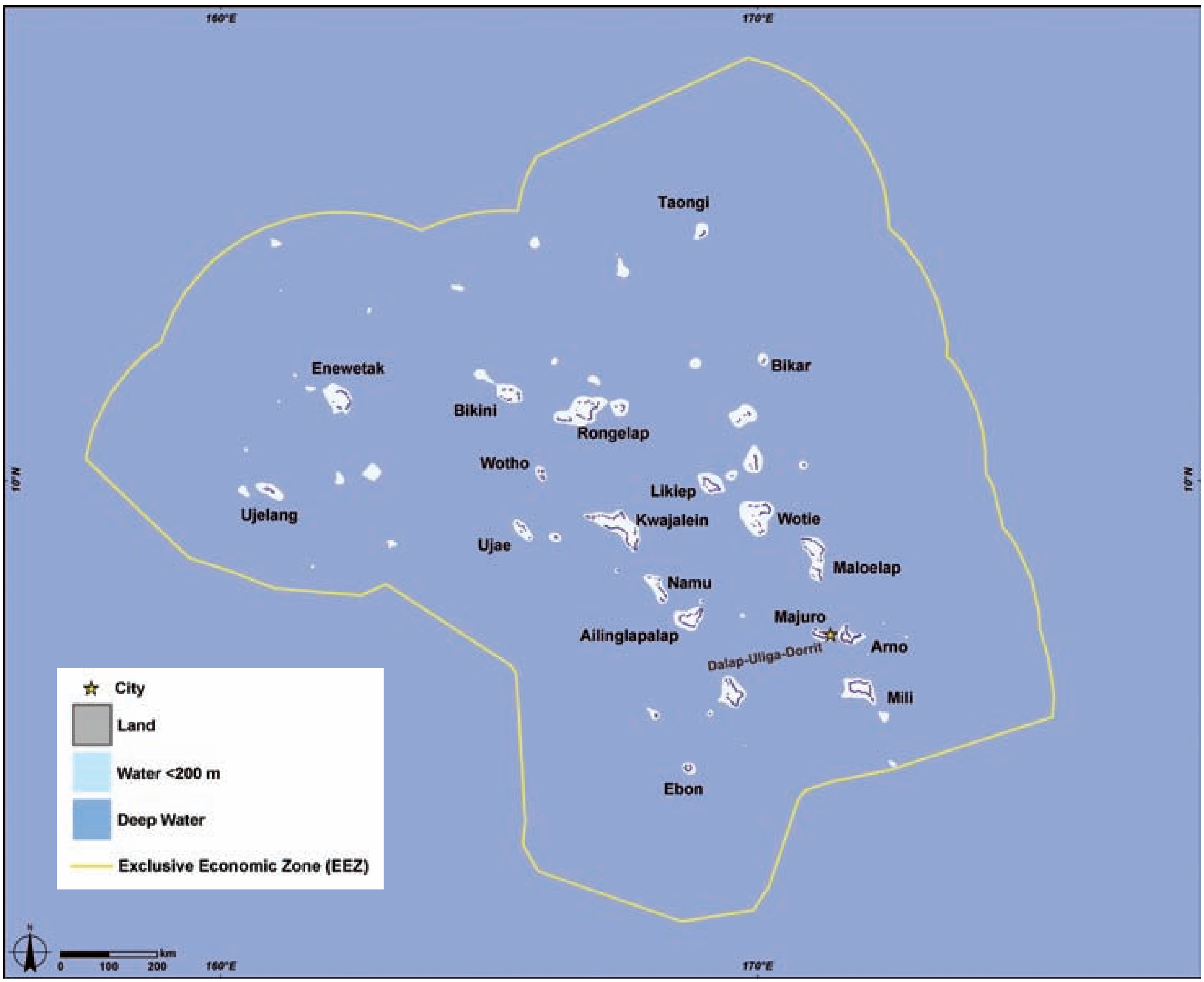


Figure FAS-1. Locator map for the Marshall Islands. (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Pinca et al. (2005).

Tropical storms (typhoons) are relatively rare, but can be devastating. Lagoons within the atolls typically have at least one deep-pass access; however, some, such as Namdrik, have no natural passes.

In general, the reefs of the Marshalls are in good condition and have experienced minimal damage from bleaching, destructive fishing techniques, and sedimentation. Even those in the former nuclear test sites show remarkable recovery, although many of the larger bomb craters may not fill in for years, if at all. However, there is some evidence of unsustainable resource exploitation – the largest giant clams have been harvested and the current take of grouper, reef shark, and Napoleon wrasse may not be sustainable. The reefs near the urban areas of Majuro are stressed, but still have an abundance of fish and invertebrates. Localized outbreaks of crown-of-thorns starfish, ***Acanthaster planci***, and coral disease were observed around Majuro in 2005. Recent information on the status of coral reefs of the Marshalls can be found in Maragos and Holthus (1999), Price and Maragos (2000), NBTRMI (2000), and Pinca et al. (2005).

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. In 2000, the National Biodiversity Strategy and Action Plan (NBSAP) and the National Biodiversity Report 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. [19]

Federated States of Micronesia

The FSM is comprised of four states – from east to west, Kosrae, Pohnpei, Chuuk, and Yap. Along with Palau, these comprise the Caroline Islands (Figure FAS-2). Each island or group has its own language, customs, local government, and reef tenure system. FSM has high islands and low atolls, and a strong dependence on coral reefs and marine resources, both economically and culturally. Each state supports population centers on high volcanic islands surrounded by barrier reefs (Pohnpei, Chuuk) or very broad fringing reefs that are nearly barrier reefs (Kosrae, Yap). All states except Kosrae also include remote clusters of atolls and low coral islands (Maragos and Holthus 1999). Spalding et al. (2001) estimated total shallow water coral reef area off the FSM to be 5,440 km^2. Kosrae is a single volcanic island with a landmass of 109 km^2 and an elevation of 629 m. It is surrounded by a fringing reef and has a single harbor. The volcanic island of Pohnpei is the largest island in the FSM and is the FSM capitol. It has an area of 345 km^2 with a well-developed barrier reef surrounding a narrow lagoon. It and the eight nearby coral islands and atolls make up the State of Pohnpei. Chuuk State (formerly known as Truk) has 15 inhabited volcanic and coral islands and atolls. Chuuk Lagoon is the largest atoll in the FSM and serves as the population and political center of Chuuk State. It is famous for the Japanese ships that were sunk in the lagoon during World War II. Yap State has a main volcanic island approximately 100 km^2, along with 15 coral islands and atolls. The peoples inhabiting the offshore atolls and coral islands in Chuuk, Yap, and Pohnpei states are among the most traditional, with a highly sophisticated marine tenure and associated marine resource management system.

The condition of FSM coral reef ecosystems is generally good to excellent. Most of the reefs in the low islands are in excellent condition. The primary human impacts come from fishing, ship groundings, and coastal development (including dredging and filling). Sedimentation from dredging and road construction projects has resulted in localized reef destruction, including much of Okat. Construction of an airport on top of a broad reef at Okat has further damaged the reefs. On the island of Pohnpei, expansion of sakau cultivation (called kava in other cultures) has reduced rainforest cover by two-thirds, resulting in increased sedimentation on coastal reefs.

In the FSM, traditional leaders (chiefs or their equivalent) and community groups are active in traditional governance as well as western-style, democratically elected officials. This dual system provides opportunities and challenges to reef and marine resource protection. 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

19 Introductory material was taken, with slight modifications, from Pinca et al. (2005).

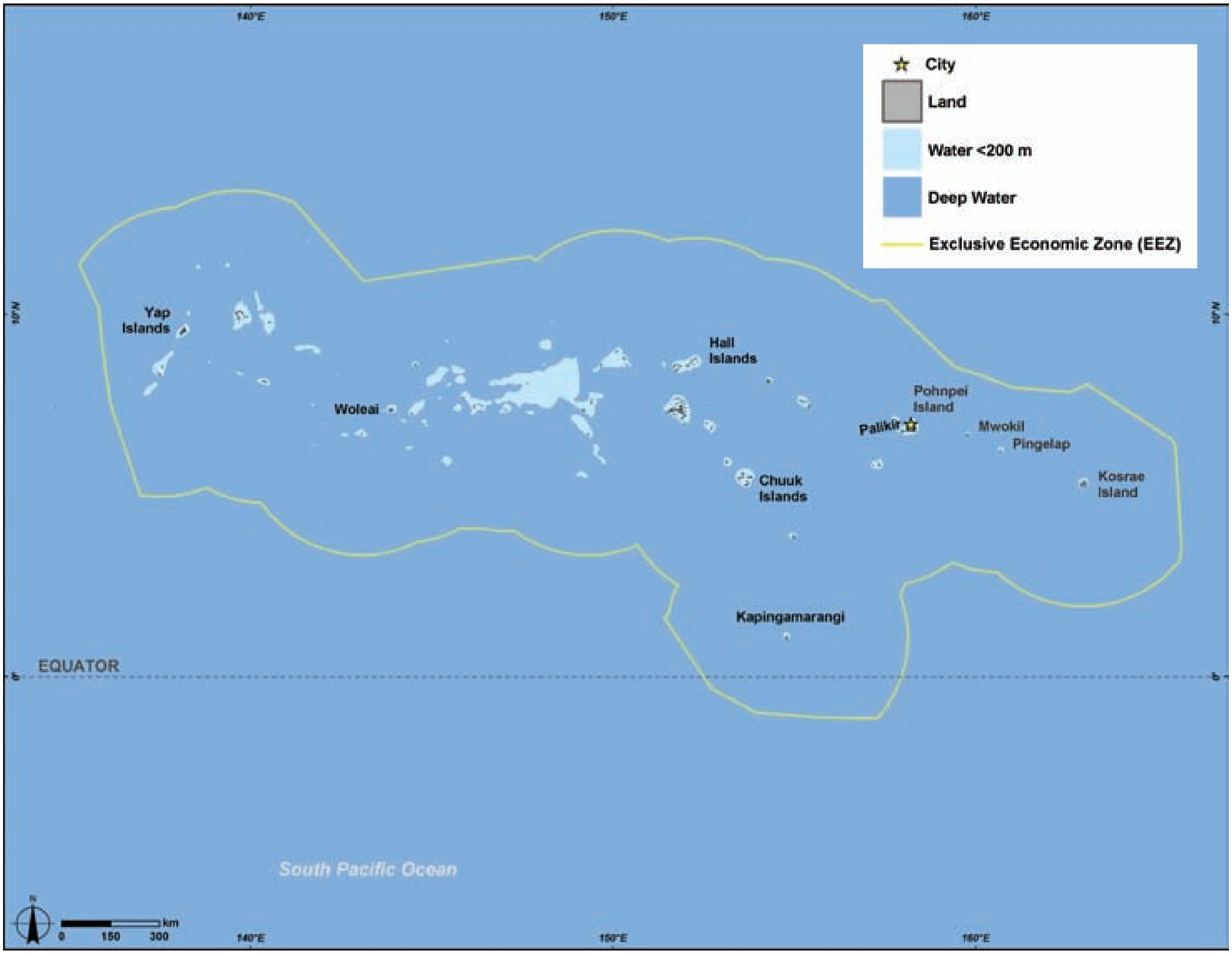


Figure FAS-2. Locator map for the Federated States of Micronesia. (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Hasurmai et al. (2005).

management agencies. 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. 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.).[20]

Republic of Palau

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 (Figure FAS-3). Palau is composed of inhabited islands and 700+ islets, stretching 700 km from Ngeruangel Atoll in the Kayangel Islands in the north to Helen Reef in the south. The archipelago consists of a clustered island group (including Babeldaob, Koror, Peleiu, Angaur, Kayangel, Ngeruangel, and the Rock Islands) and six isolated islands (Helen Reef, Tobi, Merir, Pulo Anna, Sonsorol, and Fana) that lie approximately 339 to 599 km to the southwest (Figure FAS-4). 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 to 40 m), east-west pass called Toachel El Mid.

20 Introductory material was taken, with slight modifications, from Hasurmai et al. (2005).

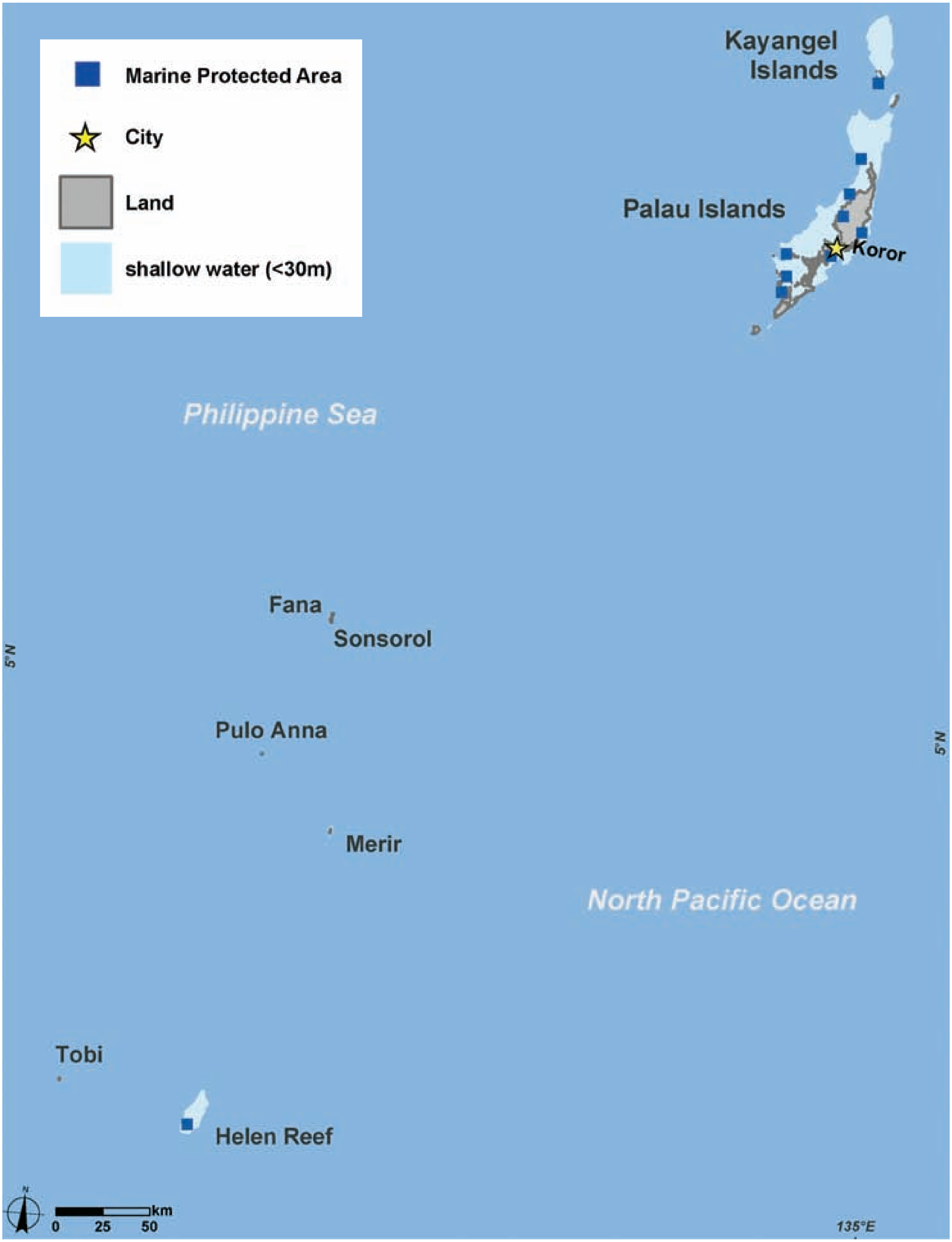


Figure FAS-3. The nation of Palau is an archipelago in the Caroline Islands. Most Palauans reside in the cluster of the northern islands (see Figure FAS-4 for detail of main island group). (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Golbuu et al. (2005).

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. Palau has the most diverse coral fauna of Micronesia and the highest density of tropical marine habitats of comparable geographic areas around the world.

Palau has already done a great deal toward limiting the impacts of tourists on reef resources. Mooring buoys, laws preventing the collection of corals, and diving tour operator education help conserve the culturally and economically important reef resources. The largest direct impact on some reef sites is now the volume of divers with varying levels of training. 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. Foreign-based fishing activities are also a problem; poachers from Indonesia and the Philippines are frequently encountered on Helen's Reef. Ship groundings have also been occurring off the main islands, as well as those in the south.

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 high tide watermark. National and state agencies, in coordination with locally based nongovernmental organizations, have put a variety of management tools in place to address issues such as fishing, recreational use, and land-based sources of pollution to protect the marine resources of Palau. Several 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. 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. Palau recently passed the Protected Areas Network Act of 2003 which provides a framework for the establishment of a MPA network in Palau. Much of the design, criteria, and regulations are still under development, and expertise and technical assistance are needed to assist in implementation.[21]

21 Introductory material was taken, with slight modifications, from Birkeland et al. (2002) and Golbuu et al. (2005).

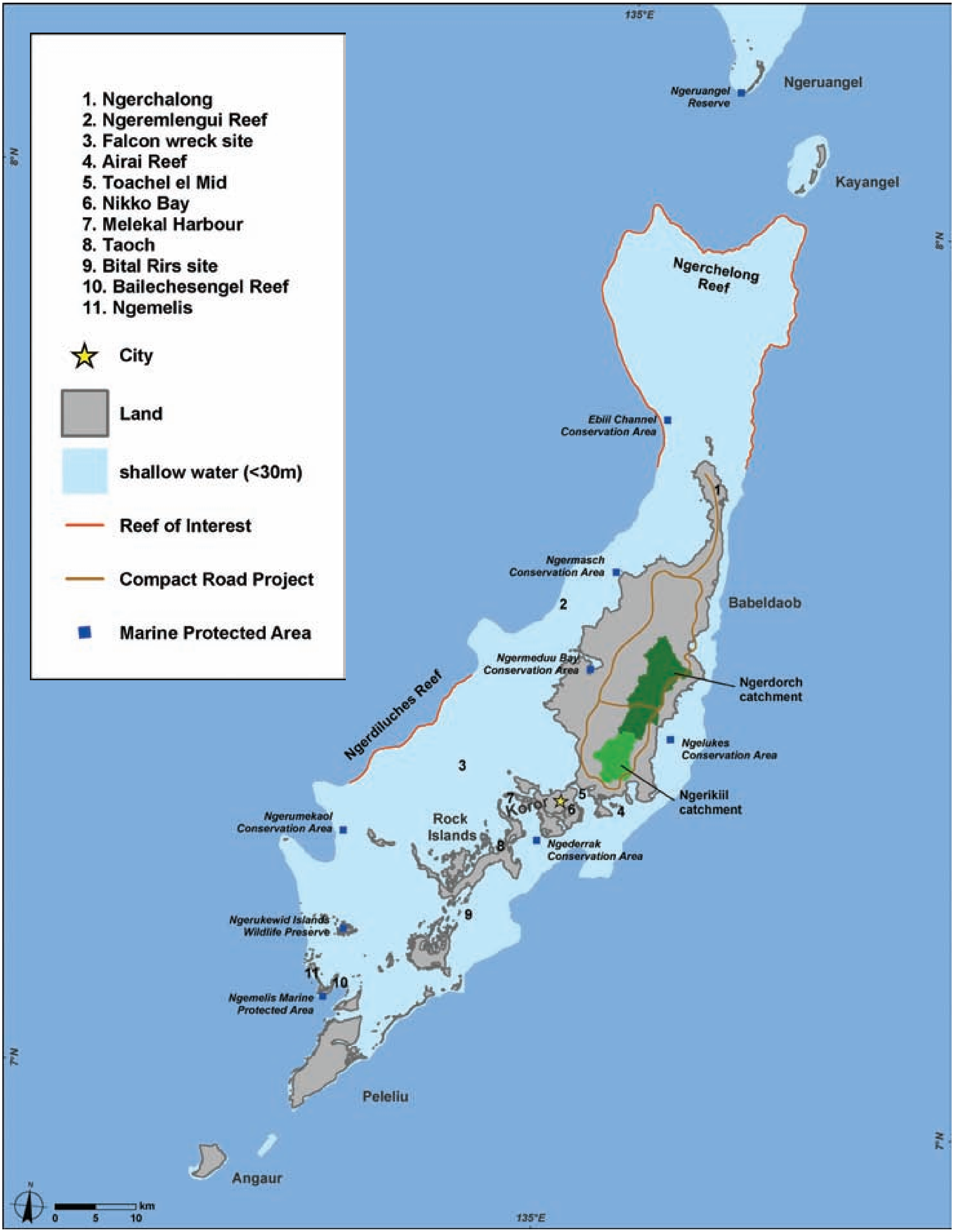


Figure FAS-4. A detailed map of Palau's main island cluster. Map: A. Shapiro. Source: Golbuu et al. (2005).

Research Needs

PACIFIC FREELY ASSOCIATED STATES	FISHING	All	Republic of the Marshall Islands	Federated States of Micronesia	Republic of Palau
Management Objective	***Research Need***				
Conserve and manage fisheries to prevent overfishing of stocks, rebuild overfished stocks, and minimize destructive fishing. *See Jurisdiction-Wide Section for additional research needs.*	Create benthic habitat maps that include fish-habitat associations to provide spatial framework for research and management activities.	√			
	Quantify the impacts of subsistence fishing on populations of fished species.	√			
	Document traditional knowledge and evaluate its application to modern fisheries management.	√			
	Determine sustainable harvest levels and fishing limits for the various fisheries.				√
	Examine how physical factors and biological components control the transport of fish and coral larvae around Palau.				√
	Evaluate implications of recent fishery regulations including bans on spearfishing, gill, and drag nets; and seasonal and spatial closures on key reef species and on fishermen.	√			
	Evaluate and characterize marine ornamental fisheries and the role of aquaculture efforts in reducing impacts associated with the aquarium trade		√		
	Characterize live reef food fish fisheries (for Asian markets), including locations and species harvested, extent of cyanide use and illegal fishing, and impacts on target populations				
	Characterize the threat to coral reef ecosystems from commercial fishing and fishing gear.		√	√	
	Determine catch per unit effort and trends in population structure of target fish species.				√
Protect, conserve, and enhance the recovery of protected, threatened, and other key species.	Assess the abundance of harvested species, including clams, fish, lobsters, and cowry shells, in outer atolls to provide early warning of population declines and unsustainable harvest levels.		√		
Evaluate and improve the effectiveness of MPAs as a fisheries management tool. *See Jurisdiction-Wide Section for additional research needs.*	Evaluate the effectiveness of the Trochus and Giant Clam Sanctuaries in protecting these species from overfishing and in preventing logging and coastal development along sanctuary shorelines.			√	

PACIFIC FREELY ASSOCIATED STATES	POLLUTION	All	Republic of the Marshall Islands	Federated States of Micronesia	Republic of Palau
Management Objective	***Research Need***				
Reduce the impacts of pollutants on coral reef ecosystems by improving the understanding of their effects. *See Jurisdiction-Wide Section for additional research needs.*	Quantify the impacts of the Majuro sewage outfall on adjacent coral reef resources, including coral recruitment rates, coral condition, and benthic cover.		√		
	Characterize the extent of nutrient and chemical leakage from septic tanks on Babeldaob Island.				√
	Evaluate impacts of coastal construction (including ports, docks, airfields, causeways, and roads) on coral reef ecosystems, especially those that are proximate to human population centers (e.g., Majuro and Likiep).		√		
	Determine the water quality around the dump area and sewage outfall.				√
	Determine the water quality in primary watersheds with current and future development plans.				√
	Quantify nutrient loads in key watersheds on Babeldaob Island.				√
Improve water quality by reducing land-based pollutant inputs and impacts on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Evaluate the effectiveness of various management strategies to protect forested land on Babeldaob Island.				√
	Manage land use in priority watersheds to significantly reduce land-based pollutants, particularly the clearing of upland rain forest areas for sakau farming.			√	
	Determine the water quality in primary watersheds with current and future development plans, and identify alternative management measures to reduce impacts; and determine their effectiveness.				√
	Develop national and state land use plans covering terrestrial and marine systems in Palau.				√
	Assess coral reef ecosystem condition adjacent to and offshore from areas of coastal development to assist in prioritization of sites to receive new sewage treatment plants and waste disposal facilities.			√	

PACIFIC FREELY ASSOCIATED STATES	COASTAL USES	All	Republic of the Marshall Islands	Federated States of Micronesia	Republic of Palau
Management Objective	***Research Need***				
Reduce the impacts from recreational use, industry, coastal development, and maritime vessels on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Quantify the impact of development on marine resources and assess the transport of pollutants from these areas into the Rock Islands.				√
	Evaluate BMPs for minimizing sedimentation associated with coastal development and changes in land use practices.			√	
	Assess impacts of motorboat fuel and antifouling paints on marine animal survivorship, including investigating gamete and larvae susceptibility.				√
	Forecast the impacts of proposed development projects on nearshore water quality and circulation patterns.		√		
	Document sedimentation associated with dredging and road construction projects and its impacts on coral reef ecosystems.			√	

PACIFIC FREELY ASSOCIATED STATES	COASTAL USES	All	Republic of the Marshall Islands	Federated States of Micronesia	Republic of Palau
Management Objective	***Research Need***				
Reduce impacts from and restore habitat damaged by vessel anchoring and groundings.	Document vessel anchoring and groundings and determine their impact on coral reef ecosystems.		√		
	Document the impacts of grounded foreign long-line vessels on surrounding reefs and prioritize mitigation efforts.			√	
Restore injured and degraded coral reef habitat.	*See Jurisdiction-Wide Section for research needs.*	√			
Evaluate and improve the effectiveness of MPAs as a management tool. *See Jurisdiction-Wide Section for additional research needs.*	Determine which areas and resources might benefit the most from additional protection.	√			
	Undertake marine eco-regional assessments to identify habitats and conservation targets, threats to these resources, and high priority areas for conservation including areas resistant and resilient to threats and spawning aggregation sites.	√			
	Develop criteria for designing networks of MPAs that include oceanographic parameters and ecological design principles.	√			
	Evaluate the effectiveness of the marine resource certification program in building local capacity for coral reef ecosystem stewardship.		√		

PACIFIC FREELY ASSOCIATED STATES	INVASIVE SPECIES	All	Republic of the Marshall Islands	Federated States of Micronesia	Republic of Palau
Management Objective	***Research Need***				
Minimize the introduction and spread of alien species. *See Jurisdiction-Wide Section for additional research needs.*	Document the presence of marine alien invertebrates in Palau, including the hydroid *Eudendrium cameum* which has the potential for becoming a 'pest' organism in Palau.				√
Control or eradicate invasive species that have the potential to cause damage to coral reef ecosystems.	*See Jurisdiction-Wide Section for research needs.*	√			

PACIFIC FREELY ASSOCIATED STATES	CLIMATE CHANGE	All	Republic of the Marshall Islands	Federated States of Micronesia	Republic of Palau
Management Objective	***Research Need***				
Minimize the effects of climate change on coral reef ecosystems. *See Jurisdiction-Wide Section for additional research needs.*	Predict the impact of increased intensity and frequency of storm events on low-lying islands and the reefs' ability to attenuate wave energy.		√		
	Examine the relationship between localized coral bleaching and heavy rain events.			√	
Mitigate the impacts from climate change on coral reef ecosystems.	Document coral recovery from the 1997-1998 bleaching event, and identify factors that contributed to its recovery.				√
	Develop hydrodynamic models of currents to predict patterns of hot and cool water during a bleaching event.	√			
Improve the capacity to forecast and respond to bleaching events.	Model circulation patterns, depth, and temperature profiles to determine which lagoons are mostly likely to bleach.		√		

PACIFIC FREELY ASSOCIATED STATES	EXTREME EVENTS	All	Republic of the Marshall Islands	Federated States of Micronesia	Republic of Palau
Management Objective	***Research Need***				
Identify causes and consequences of diseases in coral reef ecosystems and mitigate their impacts. *See Jurisdiction-Wide Section for additional research needs.*	Document the types and extent of coral disease within and among major habitat and community types.	√			
	Examine the relationship between white syndrome on ***Acropora spp.*** and untreated sewage outfalls on the leeward shore of Majuro.		√		
	Investigate the mechanism of white syndrome transmission between acroporid colonies, and evaluate potential approaches to reduce its spread and mitigate the impacts.		√		
Reduce impacts to and promote restoration of coral reef organisms affected by extreme events.	Assess the impacts of ***Acanthaster planci*** including affected species, mortality rates, and locations.		√		
	Identify measures to mitigate ***Acanthaster planci*** outbreaks.		√		
	Develop and evaluate methods to reattach massive coral heads displaced by typhoons.			√	

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Glossary

alien species: a species, subspecies, or lower taxon occurring outside of its natural range (past or present) and dispersal potential (i.e., outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans) and includes any part, gametes, or propagule of such species that might survive and subsequently reproduce (IUCN 2000). Also referred to as non-native, non-indigenous, foreign, or exotic species.

allochthonous: found in a place other than where they and their constituents were formed; derived from outside a system.

aquaculture: the propagation and rearing of aquatic organisms in controlled or selected aquatic environments for any commercial, recreational, or public purpose.

atoll: a horseshoe or circular array of reef islets, capping a coral reef system that encloses a lagoon, and perched around an oceanic volcanic seamount.

azooxanthellae: corals without symbiotic photosynthesizing algae.

biodiversity: the variability among living organisms from all sources including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species, and of ecosystems (IUCN 2000).

bycatch: fish which are harvested in a fishery, but which are not sold or kept for personal use, and includes economic discards and regulatory discards.

carrying capacity: the maximum population size that can be regularly sustained by an environment; the point where the population's size levels off in the logistic growth model.

commercial fishing: fishing in which the fish harvested, either in whole or in part, are intended to enter commerce or enter commerce through sale, barter, or trade.

coral: species of the phylum Cnidaria, including: (A) all species of the orders Antipatharia (black corals), Scleractinia (stony corals), Gorgonacea (horny corals), Stolonifera (organpipe corals and others), Alcyanacea (soft corals), and Coenothecalia (blue coral), of the class Anthozoa; and (B) all species of the order Hydrocorallina (fire corals and hydrocorals) of the class Hydrozoa (16 U.S.C. 6409).

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

coral reef: any reefs or shoals composed primarily of corals (16 U.S.C. 6409).

coral reef ecosystem: coral and other species of reef organisms (including reef plants) associated with coral reefs and the non-living environmental factors that directly affect coral reefs, that together function as an ecological unit in nature (16 U.S.C. 6409). The tropical and sub-tropical coral reef ecosystems include mangroves, seagrasses, and hard bottom communities, and warm water, light-dependent, hermatypic deep water shelf and slope corals that are typically found between 50 to 100 meters (m).

deep-sea coral: azooxanthellate reef-like structures and/or thickets that occur deeper than 50 m, and comprise species of the phylum Cnidaria in the orders Antipatharia (black corals), Scleractinia (stony corals), Gorgonacea (horny corals), and Alcyonacea (soft corals), of the class Anthozoa, and in the order Hydrocorallina (hydrocorals). Also referred to as cold-water corals.

deep-sea coral ecosystem: coral habitats that occur deeper than 50 m; are azooxanthellate (i.e., do not contain symbiotic algae); often consist of both reef-like structures and/or thickets, and other species of organisms associated with these deep-sea coral habitats, and the non-living environmental factors that directly affect deep-sea corals, that together function as an ecological unit in nature. Also referred to as cold-water coral ecosystems.

deep water coral: any reefs composed primarily of light-dependent and hermatypic (or reef-building) corals that occur in deep water shoals and slopes between approximately 50 to 100 m. Deep water corals differ from "true" deep-sea corals, which are not light-dependent and occur at greater depths. Found in a depth range known as the "twilight zone."

deep water coral ecosystem: deep water coral and other species of reef organisms associated with light-dependent deep water coral reefs and the non-living environmental factors that directly affect coral reefs, that together function as an ecological unit in nature. Occur typically between 50 to 100 m in a depth range known as the "twilight zone."

economic discards: are targeted fish that aren't retained because the harvester doesn't want them (undesirable size, sex, quality, etc.).

ecosystem: a geographically specified system of organisms, the environment, and the processes that control its dynamics. Humans are an integral part of an ecosystem.

ecosystem approach: approach aimed at protecting, rebuilding, and conserving the structure and function of marine ecosystems.

ecosystem approach to management: management approach that is adaptive, specified geographically, takes into account ecosystem knowledge and uncertainties, considers multiple external influences, and strives to balance diverse social objectives.

ecosystem restoration: return of an ecosystem to a close approximation of its condition prior to disturbance; the reestablishment of predisturbance aquatic functions and related physical, chemical, and biological characteristics.

environment: the biological, chemical, physical, and social conditions that surround organisms.

epizootic: an outbreak of disease affecting many animals of one kind at the same time.

essential fish habitat: those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.

exclusive economic zone: the zone established by Presidential Proclamation 5030, dated March 10, 1983. The inner boundary of the zone is a line coterminous with the seaward boundary of each of the coastal states.

extramural partnership: partnership carried on outside the bounds of NOAA.

fish: finfish, mollusks, crustaceans, and all other forms of marine animal and plant life other than marine mammals and birds.

fishery: one or more stocks of fish which can be treated as a unit for purposes of conservation and management and which are identified on the basis of geographical, scientific, technical, recreational, and economic characteristics. Also includes any fishing for such stocks.

fishery resource: any fishery, any stock of fish, any species of fish, and any habitat of fish.

formal education: learning that takes place in a structured educational system.

ghost fishing: lost or derelict fishing gear that continues to catch fish and other species.

herbivore: an animal that feeds on plants.

hermatypic: reef-building.

informal education: learning that takes place outside the established formal system but which meets clearly defined objectives through organized educational activities. Informal education may be voluntary and self-directed (e.g., a museum of aquarium exhibit), or systematic and guided (e.g., field trips).

intentional species introduction: an introduction made deliberately by humans, involving the purposeful movement of a species outside of its natural range and dispersal potential. Such introductions may be authorized or unauthorized.

invasive species: an alien species which becomes established in natural or semi-natural ecosystems or habitats, is an agent of change, and threatens native biological diversity.

marine biotechnology: biological techniques used in applied research and product development of marine living organisms. In particular, the use by industry of recombinant DNA, cell fusion, and new bioprocessing techniques; any technology that is applied to marine living organisms to make them more valuable to humans.

marine debris: something broken or destroyed, located in the sea, which refuses to go away (i.e., trash not readily biodegradable, including fishing nets, metals, plastics, and rubber products).

marine protected area: any area of the marine environment that has been reserved by Federal, state, territorial, commonwealth, tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein.

marine reserve: an area protected from extractive uses (i.e., no-take area).

native species: a species, subspecies, or lower taxon occurring within its natural range (past or present) and dispersal potential (i.e. within the range it occupies naturally or could occupy without direct or indirect introduction or care by humans). Also referred to as indigenous species.

overfishing: a rate or level of fishing mortality that jeopardizes the capacity of a fishery to produce the maximum sustainable yield on a continuing basis.

photosynthetically active radiation: those wavelengths of light (i.e., 400 to 700 nm) that can be absorbed by chlorophyll or other light harvesting pigments as part of the photosynthetic process. It is commonly known by its acronym, PAR.

recreational fishing: fishing for sport or pleasure.

regulatory discards: fish (targeted or not) required by regulation to be discarded, or to be retained, but not sold.

resiliency: the return of a coral reef ecosystem to a state in which living, reef-building corals play a prominent functional role, after this role has been disrupted by a stress or perturbation (UNEP 1999).

species introduction: the movement, by human actions, of a species, subspecies, or lower taxon (including any part, gametes, or propagule that might survive and subsequently reproduce) outside its natural range (past or present). This movement can be either within a country or between countries.

stakeholder: an individual or a group with a particular interest, or stake, in the management and functioning of a given resource. Coral reef stakeholders include fishers, recreational users, those whose livelihoods depend on coral reefs (related to tourism, fishing, and coastal development), researchers, and students. Also referred to as "constituent" or "user."

stressor: a physical, chemical, or biological factor that adversely affects organisms; an agent, condition, or similar stimulus that causes stress to an organism.

twilight zone: zone between 60 to 150 m for coral reef habitats. The corals that subsist in this environment are adapted to low light conditions and colder water, and are referred to as deep water corals.

unintentional introduction: an unintended introduction made as a result of a species utilizing humans or human delivery systems as vectors for dispersal outside its natural range (IUCN 2000).

U.S. Pacific Remote Insular Areas: islands and reefs appurtenant to such island, reef or atoll, as applicable: Baker Island, Howland Island, Jarvis Island, Johnston Atoll, Kingman Reef, Wake Island, Rose Atoll and Palmyra Atoll.

zooxanthellae: a group of dinoflagellates living endosymbiotically in association with one of a variety of invertebrate groups (e.g., corals, sponges). In corals, they provide carbohydrates through photosynthesis, as a source of energy for the coral polyps. They also provide coloration for corals.

Appendix A: Additional Supporting Documents

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Appendix B: Developing The Research Plan

In an effort to provide coastal and ocean managers with the most up-to-date scientific information, the NOAA Coral Reef Conservation Program developed the ***NOAA Coral Reef Ecosystem Research Plan*** to identify priority research needs and guide NOAA-funded coral reef ecosystem research for FY 2007 through FY 2011, including research conducted through extramural partners, grants, and contracts. The Plan draws mostly from information found in workshop reports, technical reports, and peer-reviewed articles, with extensive input from regional scientists both directly and indirectly (through reviews of the Plan).

The Process

As a first step, a steering committee was created to guide the development of the Plan. The Steering Committee consisted of representatives from the four line offices in NOAA with coral reef interests, i.e., the National Environmental, Satellite, and Data Information Service, the National Marine Fisheries Service, the National Ocean Service, and the Office of Oceanic and Atmospheric Research, with the latter two serving as co-chairs. Through the Steering Committee, a process was designed and agreed upon to be comprised of three major drafts (Drafts #1-3) with three levels of review (Reviews #1-3). Review 1 would be an internal NOAA review of Draft #1; Review 2 would be a review of Draft #2 conducted by NOAA and its external partners, including other Federal, state, territorial, commonwealth, and local agencies, USCRTF members, and fisheries management councils; and Review 3 would be a formal request for comments on Draft #3 announced in the Federal Register.

Drafting the Document

Draft #1 of the Plan was drafted internally using the sources mentioned above. It was distributed for review to NOAA programs with an interest in coral reef ecosystems. Based on comments received on Draft #1, we found the Plan had well-developed national research priorities, but poorly-defined regional research priorities. Because the national and regional priorities were in different stages of maturity, we split the Plan into: Part I: National Research Priorities and Part II: Regional Priorities. This allowed both parts to continue development in parallel, but on different timelines. Part I was written at a general level and consequently was less complicated. Because of this Part I proceeded at a faster pace. Part II was written at a much finer level of detail and was targeted for use by regional scientists and managers, thus its development was significantly more complex. As a result, Part II was developed by working through the USCRTF points of contact.

For Draft #2 of Part II, the USCRTF point of contact in each jurisdiction, in coordination with NOAA, determined the most expeditious and transparent way to develop their region's research priorities. Because each jurisdiction is unique; the process used to develop the regional sections was modified to suit the jurisdiction. For example: in the Hawaiian Islands, it was decided that the most inclusive way to plan their section was by organizing a group meeting of regional scientists, resource managers, and stakeholders. At this meeting, they decided to create separate working groups for the Northwestern and Main Hawaiian Islands to develop research priorities targeting the information needs of resource managers. Whereas, the management objectives and research needs in the Flower Garden Banks section were identified by the Flower Garden Banks National Marine Sanctuary staff.

Drafts #3 for Parts I and II were announced in the Federal Register for public comment on June 9, 2005 (NOAA 2005d) and April 8, 2006 (NOAA 2006b), respectively.

The final published version of the Plan will be printed as a single volume with two sections: Part I: National Research Priorities and Part II: Regional Research Priorities.

Appendix C: Requirement Drivers

Coastal Zone Management Act (16 U.S.C. 1451 et seq.)
The Coastal Zone Management Act encourages states to develop land and water use programs for the purpose of controlling coastal water pollution from land use activities. Section 303 calls for "the protection of natural resources, including wetlands, floodplains, estuaries, beaches, dunes, barrier islands, coral reefs, and fish and wildlife and their habitat within the coastal zone."

Coral Reef Conservation Act of 2000 (16 U.S.C. 6401 et seq.)
The Coral Reef Conservation Act charges the Administrator of NOAA to preserve, sustain, and restore the condition of coral reef ecosystems; promote the wise management and sustainable use of coral reefs; develop sound scientific information on the condition and threats to coral reefs; support conservation programs; and provide financial resources for coral reef conservation and management projects. The Act requires the development of a National Coral Reef Action Strategy; a coral reef conservation grants program; a partnership with a nonprofit organization to collect and allocate monetary donations from the private sector for coral reef conservation projects; an emergency assistance program; a national program conducting conservation activities that may include mapping, assessment, monitoring, and scientific research for sustainable use and long-term conservation of coral reef ecosystems that is consistent with other Federal regulations; and effectiveness reports for the grants program and national program.

Endangered Species Act (16 U.S.C. 460 et seq.)
The Endangered Species Act requires that the Secretary of Commerce list any species that is threatened with extinction in all or a significant portion of its range and designate critical habitat for that species.

Executive Order 13089: Coral Reef Protection (1998)
E.O. 13089 directs all Federal agencies whose actions may affect U.S. coral reef ecosystems to "(1) identify their actions that may affect coral reef ecosystems; (2) utilize their programs and authorities to protect and enhance the conditions of such ecosystems; and (3) to the extent permitted by law, ensure that any actions they authorize, fund, or carry out will not degrade the conditions of coral reef ecosystems." This E.O. gives specific direction to Federal agencies to implement measures to research, monitor, manage, and restore affected ecosystems, including efforts to reduce impacts of pollution, sedimentation, and fishing. It also established the USCRTF, which includes the Federal agencies with primary responsibility for coral reef resources and the affected U.S. states, territories, and commonwealths.

Executive Order 13112: Invasive Species (1999)
E.O. 13112 requires Federal agencies, to the extent practicable and permitted by law, to prevent the introduction and spread of invasive species. E.O. 13112 creates the Invasive Species Council and states that it shall be chaired jointly by the Secretaries of Commerce, Interior, and Agriculture. The Invasive Species Council is required to provide national leadership on invasive species and prepare and issue a National Invasive Species Management Plan.

Executive Order 13158: Marine Protected Areas (2000)
E.O. 13158 establishes a program in NOAA to identify and coordinate national marine protected areas for natural and cultural resources. The order calls for Federal agencies to use science-based identification and prioritization of natural and cultural resource protection.

Executive Order 13178: Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve (2000)
E.O. 13178 establishes the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve to ensure the comprehensive, strong, and lasting protection of the coral reef ecosystem and related marine resources and species of the Northwestern Hawaiian Islands. The order established Reserve Preservation Areas, where extractive uses are prohibited.

Government Performance and Results Act of 1993 (31 U.S.C. 1115 et seq.)
GPRA holds Federal agencies accountable for using resources wisely and achieving program results. GPRA requires agencies to develop plans for what they intend to accomplish, measure how well they are doing, make appropriate decisions based on the information they have gathered, and communicate information about their performance to Congress and the public.

Magnuson-Stevens Fisheries Conservation and Management Act (16 U.S.C. 1801 et seq.)
The Magnuson-Stevens Fisheries Conservation and Management Act establishes exclusive Federal management authority over fishery resources of the Exclusive Economic Zone. It is the principal law governing fishery resources of the United States. Section 2(a) states "this program is necessary to prevent overfishing, to rebuild overfished stocks, to ensure conservation, to facilitate long-term protection of essential fish habitats, and to realize the full potential of the Nation's fishery resources."

Marine Turtle Conservation Act of 2004 (16 U.S.C. 6601 et seq.)
The Marine Turtle Conservation Act assists in the conservation of marine turtles and the nesting habitats of marine turtles in foreign countries by supporting and providing financial resources for projects to conserve the nesting habitats, conserve marine turtles in those habitats, and address other threats to the survival of marine turtles.

Marine Mammal Protection Act (16 U.S.C. 1361 et seq.)
The Marine Mammal Protection Act generally prohibits taking and importation of all marine mammals, except under limited exceptions. The Marine Mammal Protection Act of 1972 was reauthorized in 1994, and found that certain species and population stocks of marine mammals are, or may be in danger of extinction or depletion as a result of human activities, and that such species and population stocks should not be permitted to diminish beyond the point at which they cease to be a significant functioning element; measures should be taken immediately to replenish any species or population stock which has diminished below its optimum sustainable level; and there is inadequate knowledge of the ecology and population dynamics of such marine mammals and of the factors which bear upon their ability to reproduce themselves successfully.

National Action Plan to Conserve Coral Reefs (2000)
The National Action Plan presents a cohesive national strategy to reverse the worldwide decline and loss of coral reefs. Conservation actions focus on understanding coral reef ecosystems and the natural and anthropogenic processes determining their health and viability and reducing the adverse impacts of human activities.

National Coral Reef Action Strategy (2002)
The National Action Strategy was developed in accordance with the requirements of the Coral Reef Conservation Act to provide information on major threats and needs in each region; identify priority actions needed to achieve the goals outlined in the National Action Plan and the Coral Reef Conservation Act; and track progress in achieving these goals and objectives. The National Action Strategy directs NOAA and its partner agencies to map, monitor, and research coral reef ecosystem resources, including increasing the understanding of the social and economic factors of conserving coral reefs.

National Marine Sanctuaries Act (16 U.S.C. 1431 et seq.)
The National Marine Sanctuaries Act established a Federal program that recognizes areas of the marine environment with special conservation, recreational, ecological, historical, cultural, archaeological, scientific, educational, or aesthetic qualities as National Marine Sanctuaries to improve conservation, understanding, management, and wise and sustainable use of marine resources.

Presidential Proclamation: Establishment of the Northwestern Hawaiian Islands Marine National Monument (2006)
The Northwestern Hawaiian Islands Marine National Monument has been set aside as a national monument by Presidential Proclamation. The area includes the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve, the Midway NWR, the Hawaiian Islands NWR, and the Battle of Midway National Memorial. The proclamation protects a dynamic reef ecosystem that is home to many species of coral, fish, birds, marine mammals, and other flora and fauna including the endangered Hawaiian monk seal, the threatened green sea turtle, and the endangered leatherback and hawksbill sea turtles. Additionally, this area has great cultural significance to Native Hawaiians and a connection to early Polynesian culture. The proclamation establishes the first national monument in which the Department of Commerce has the primary responsibility regarding management of the marine areas, in consultation with the Department of the Interior. The Department of the Interior will have sole responsibility for Midway Atoll NWR, the Battle of Midway National Memorial, and the Hawaiian Islands NWR (Bush 2006).

The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States (2002, 2005)
National assessments of the condition of U.S. coral reefs identifying the pressures that pose increasing risks to reefs, particularly in certain "hot spots" located near population centers. The report also assesses the health of reef resources, ranks threats in 13 geographic areas, and details mitigation efforts. The report is produced biennially to document the health of U.S. coral reef ecosystems.

U.S. Coral Reef Task Force Initiative: Local Action Strategies (2005-2007)
In 2002, the USCRTF adopted the "Puerto Rico Resolution" which calls for the development of three-year local action strategies by each of the seven member U.S. states, territories and commonwealths. These local action strategies are locally-driven roadmaps for collaborative and cooperative action among Federal, state, territory, and non-governmental partners which identify and implement priority actions needed to reduce key threats to valuable coral reef resources. The goals and objectives of the local action strategies are linked to those found in the National Action Plan to Conserve Coral Reefs, adopted by the USCRTF in 2000. Florida, Hawaii, Guam, the U.S. Virgin Islands, American Samoa, Puerto Rico, and the Commonwealth of the Northern Mariana Islands created specific local action strategies for select locally relevant threats, using the six priority focus areas (i.e., overfishing, land-based sources of pollution, recreational overuse and misuse, lack of public awareness, climate change and coral bleaching, and disease) as a guide.

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