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.*	<u>Acroporids</u>
	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

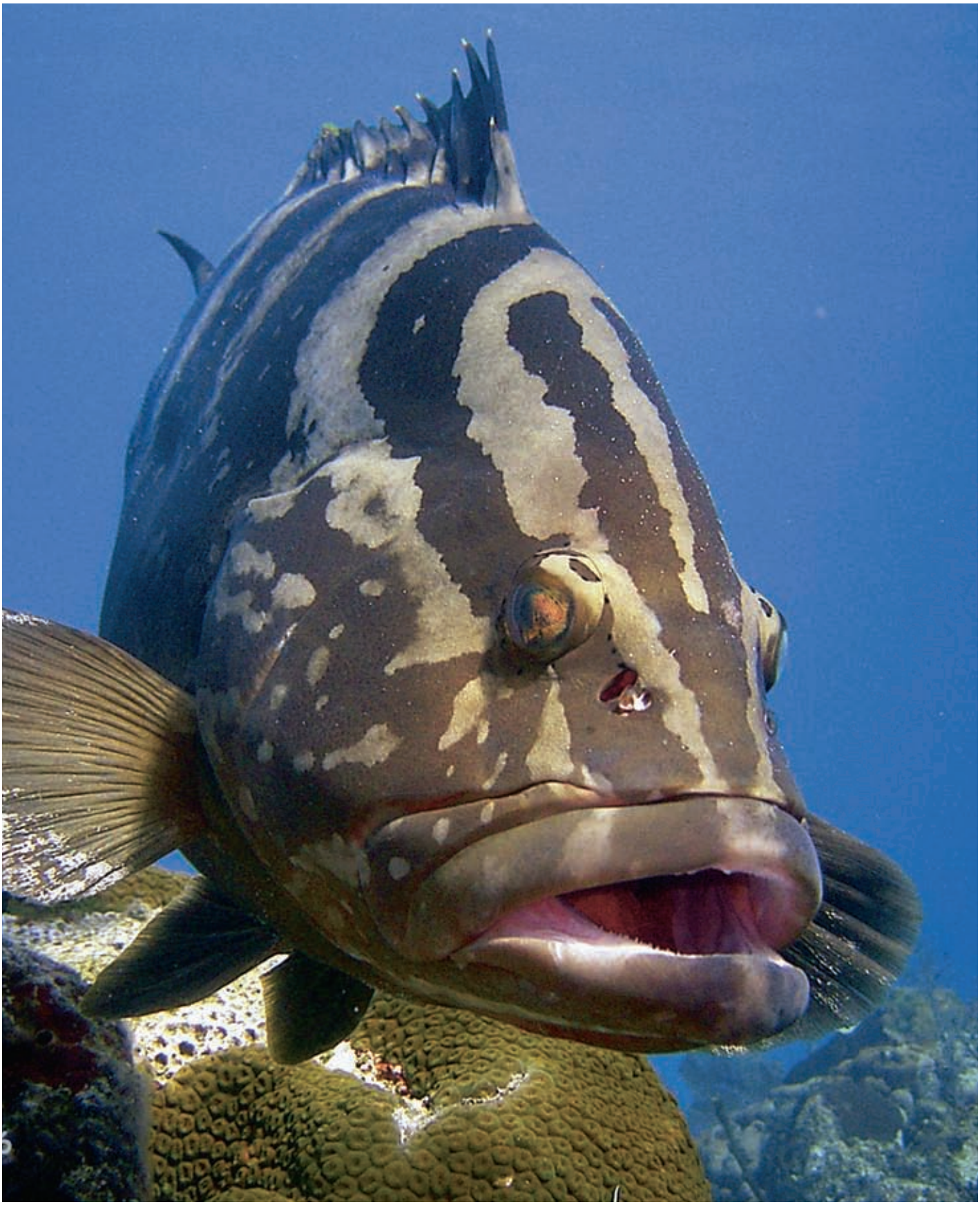
Marine Protected Areas

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).

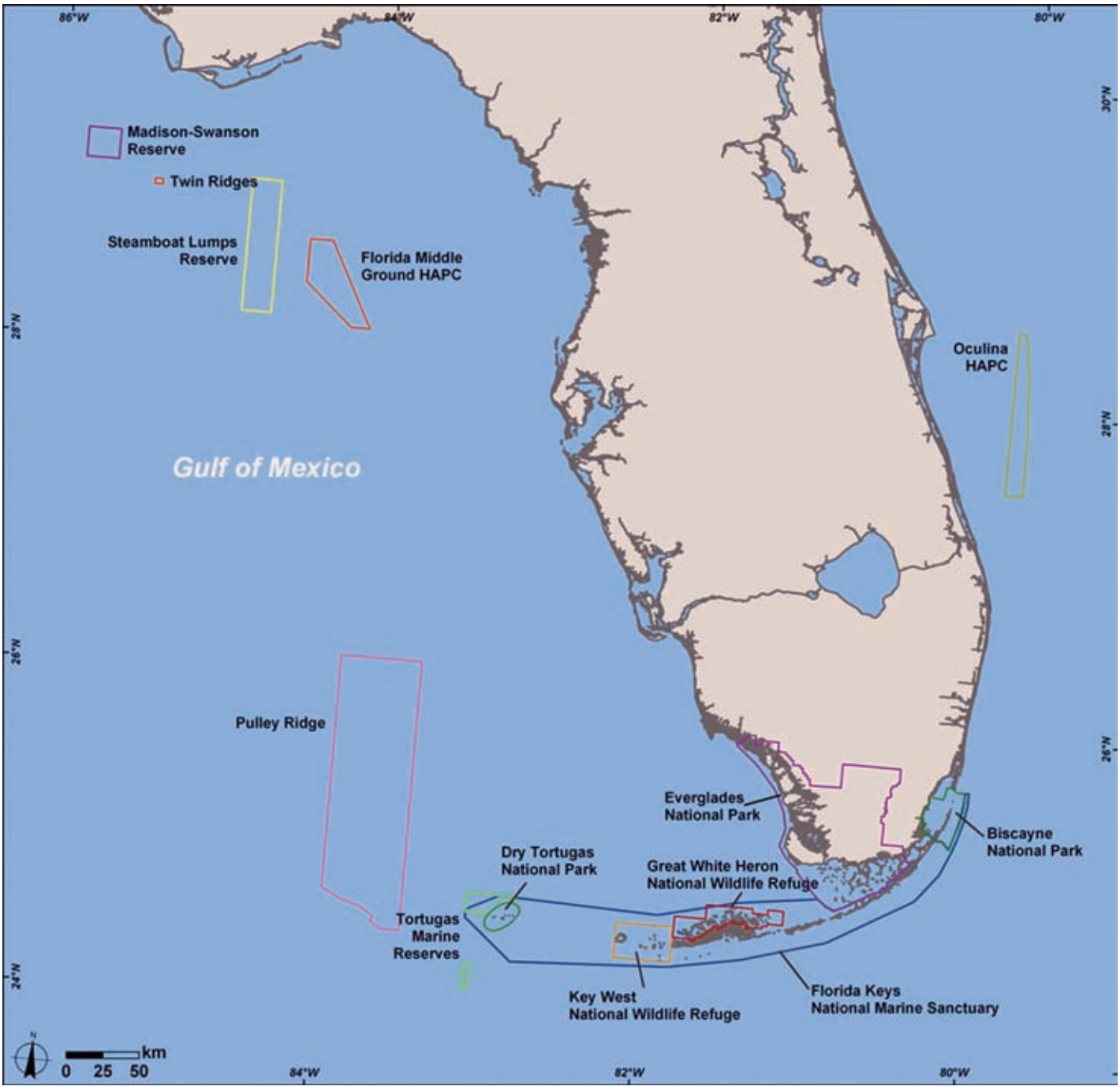


Figure FL-1. Locator map for Florida. Map: A. Shapiro.

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]

Northern Area:

- 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.

Southern Area:

- 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

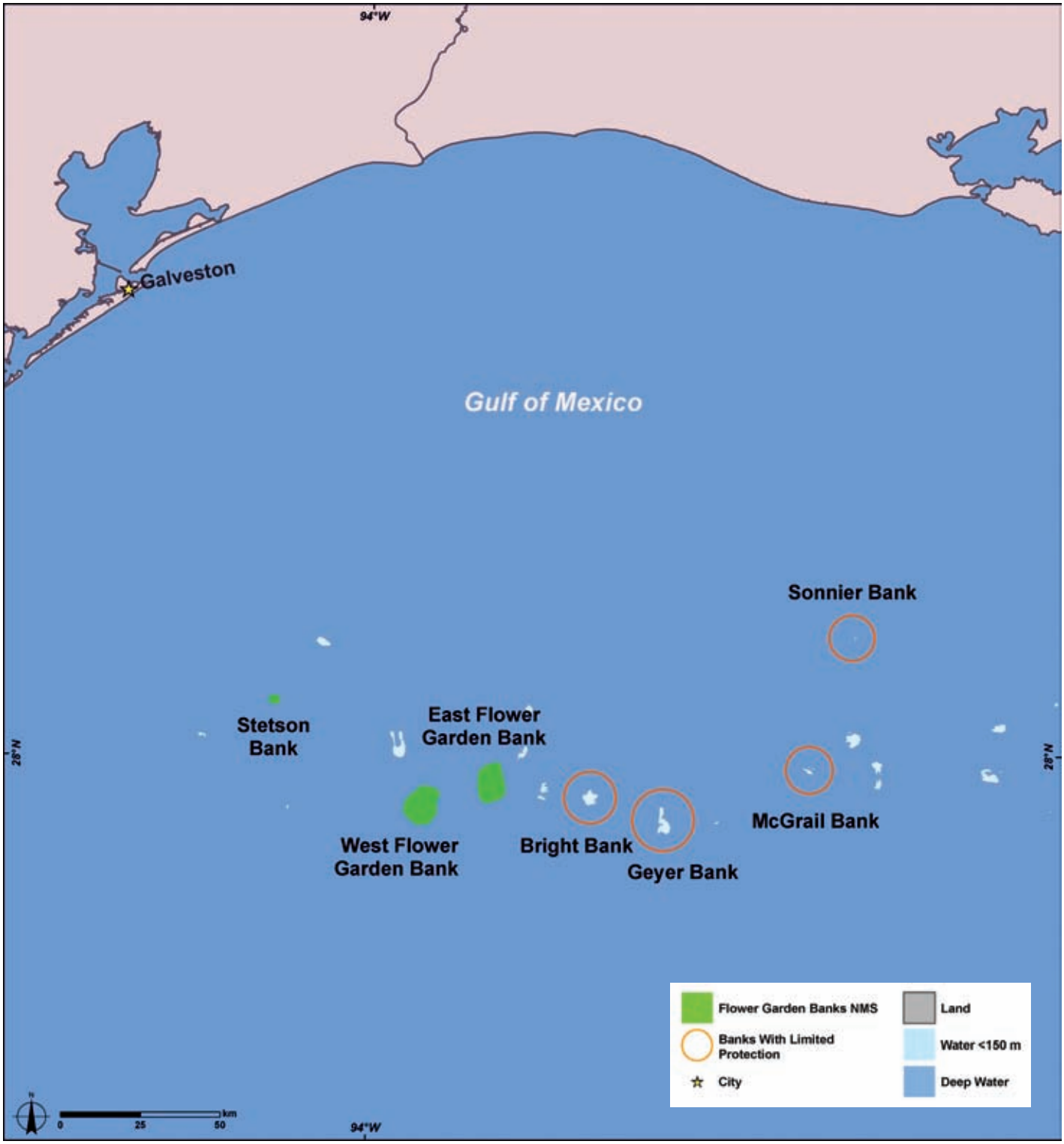


Figure FGB-1. Map showing the locations of the coral banks of the Gulf of Mexico. While some of the banks are protected by the provisions of the Flower Garden Banks National Marine Sanctuary, unprotected coral communities are present at Bright, Sonnier, Geyer, and McGrail Banks. These banks are part 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.

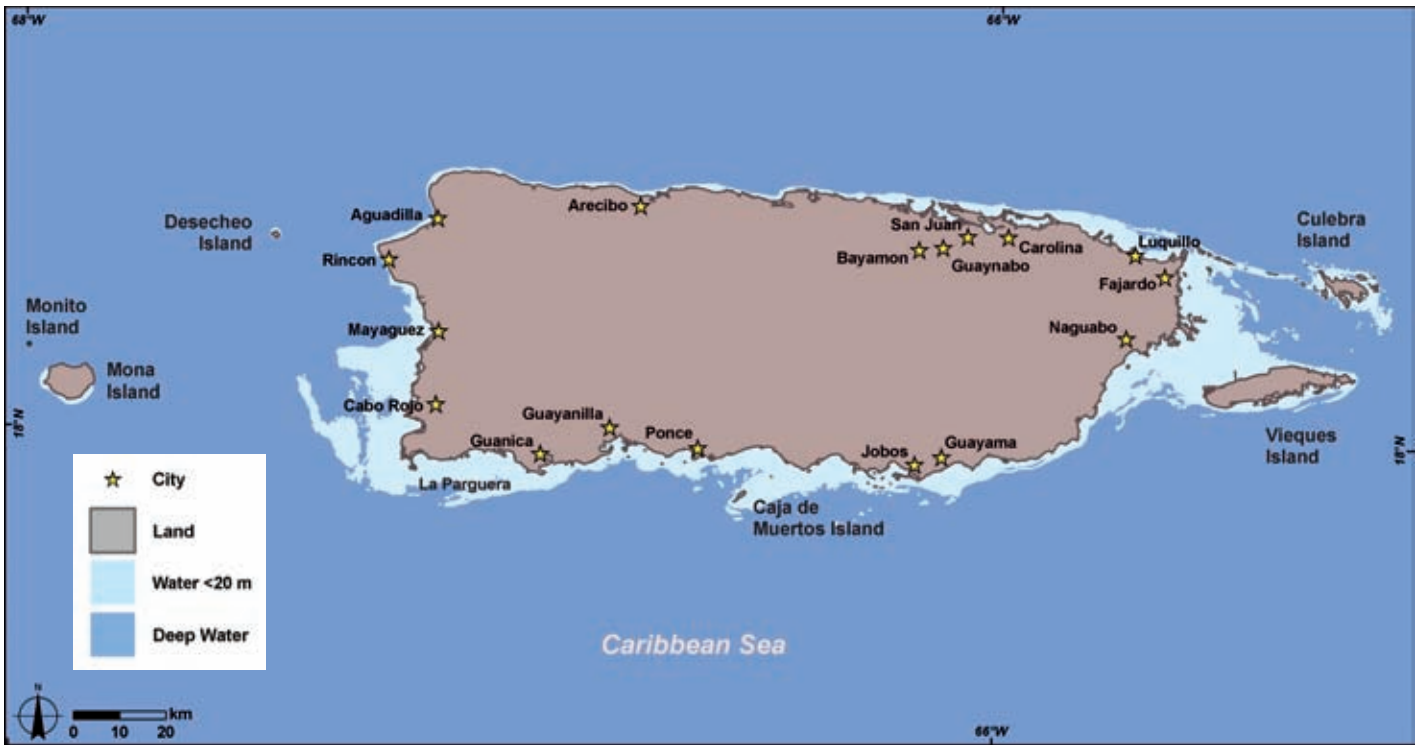


Figure PR-1. A map of Puerto Rico. (See Figure 4 for geographical context.) Map: A. Shapiro. Source: Garcia-Sais et al. (2005).

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.	Queen Conch, Spiny Lobster, and 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 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.*	<u>Acroporids</u>
	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.
	<u>Sea Turtles</u>
	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).

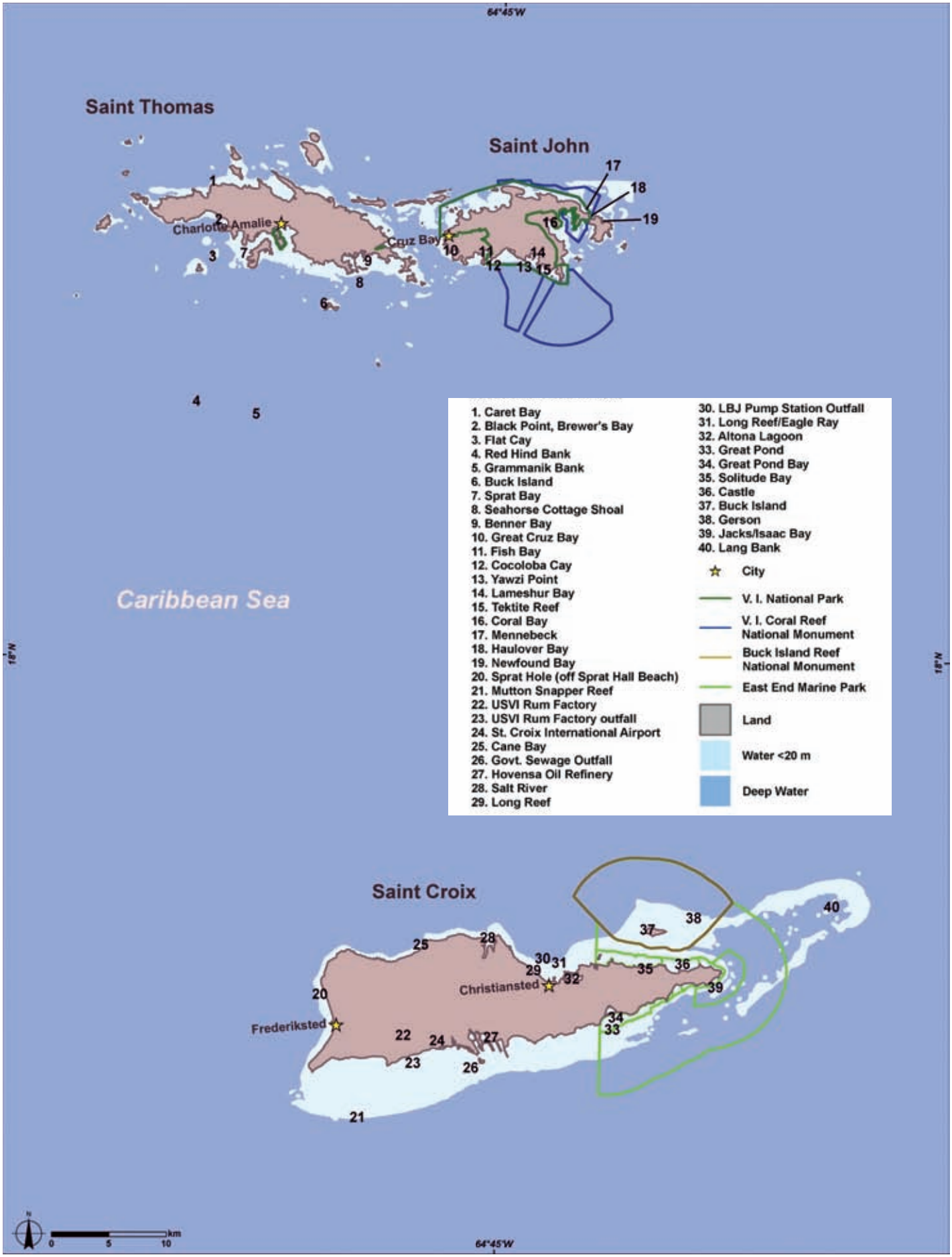


Figure USVI-1. A map of USVI showing managed areas, municipalities, and other locations of interest. (See Figure 4 for geographical context.) Map: A. Shapiro. Source: Jeffrey et al. (2005).

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.

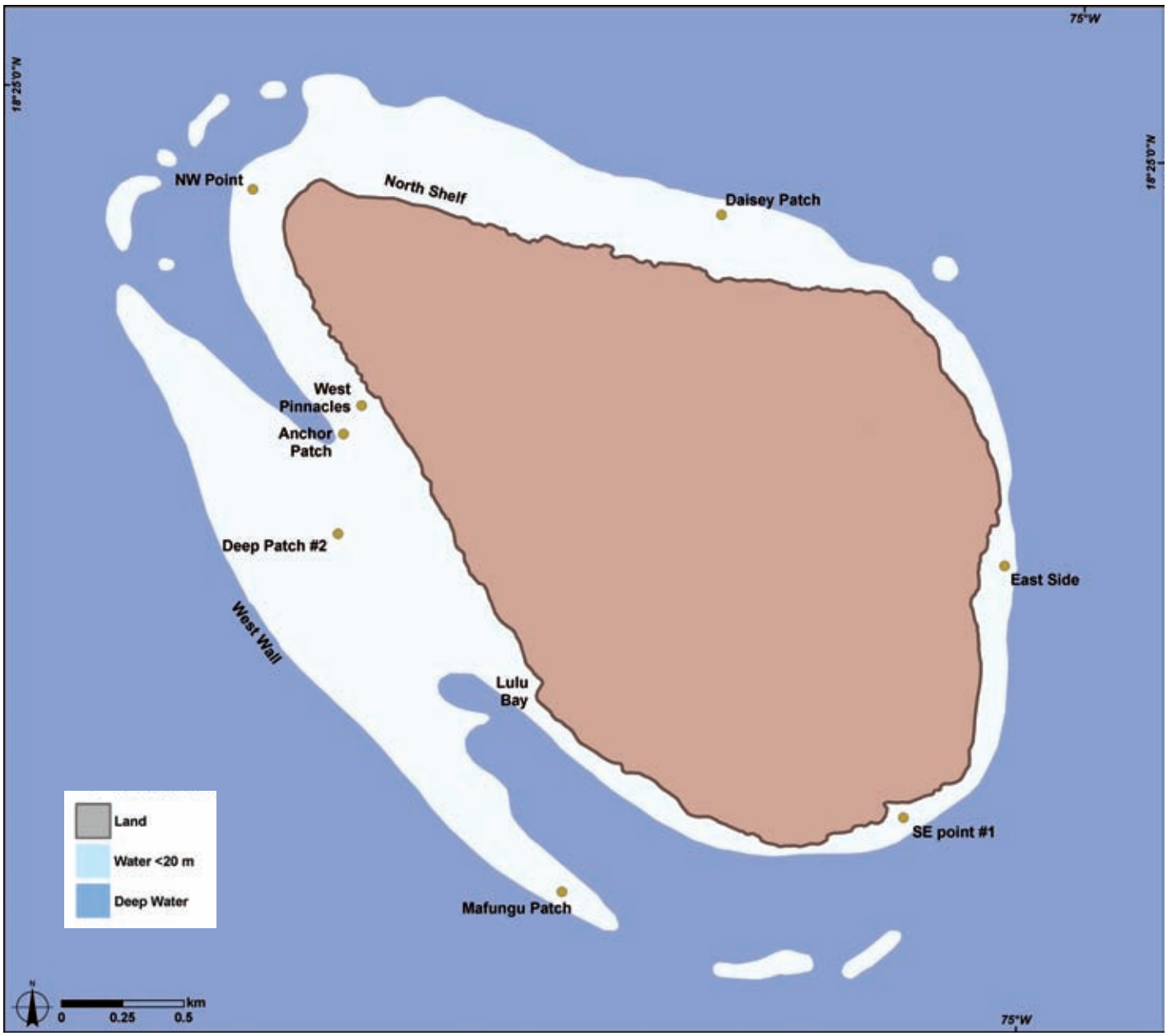


Figure NI-1. A map of Navassa Island. (See Figure 4 for geographical context.) Map: A. Shapiro. Source: Miller et al. (2005).

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

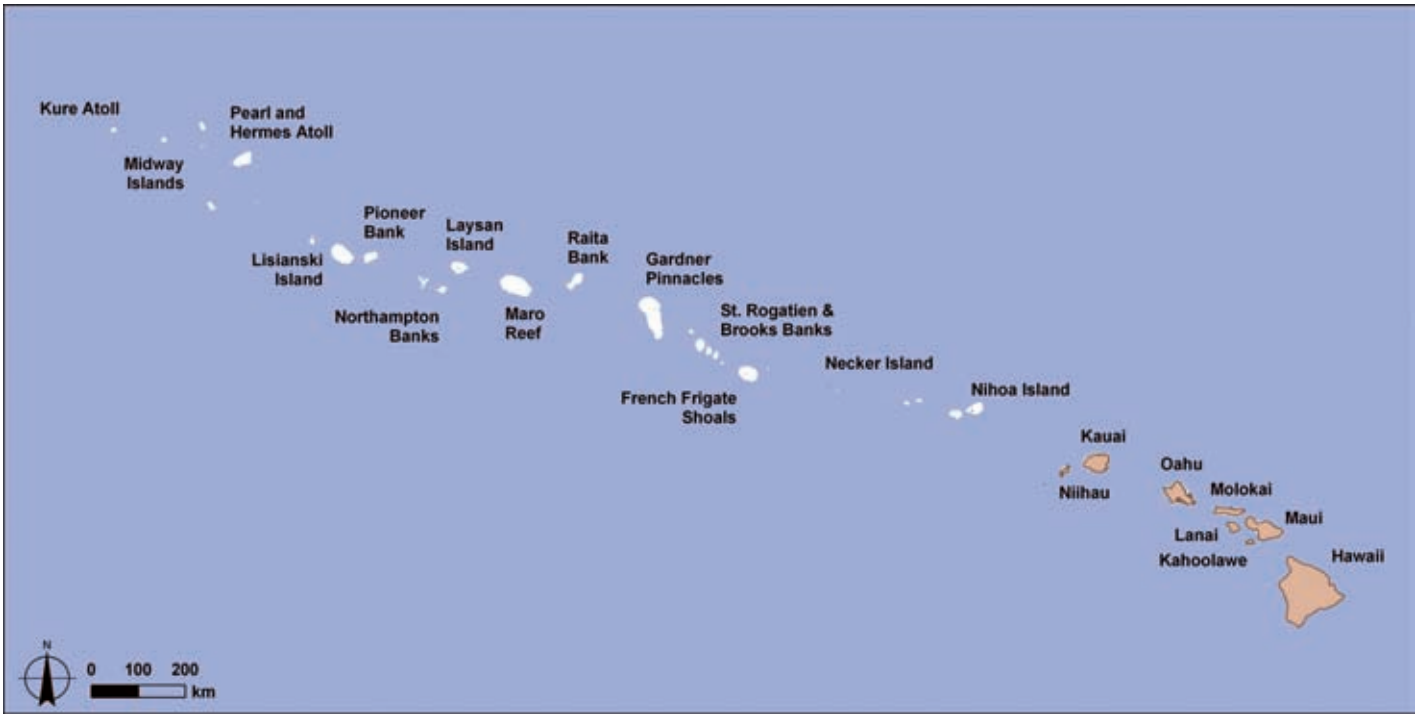


Figure HI-1. Locator map for the Hawaiian archipelago. (See Figure 5 for geographical context.) Map: A. Shapiro.

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.		√

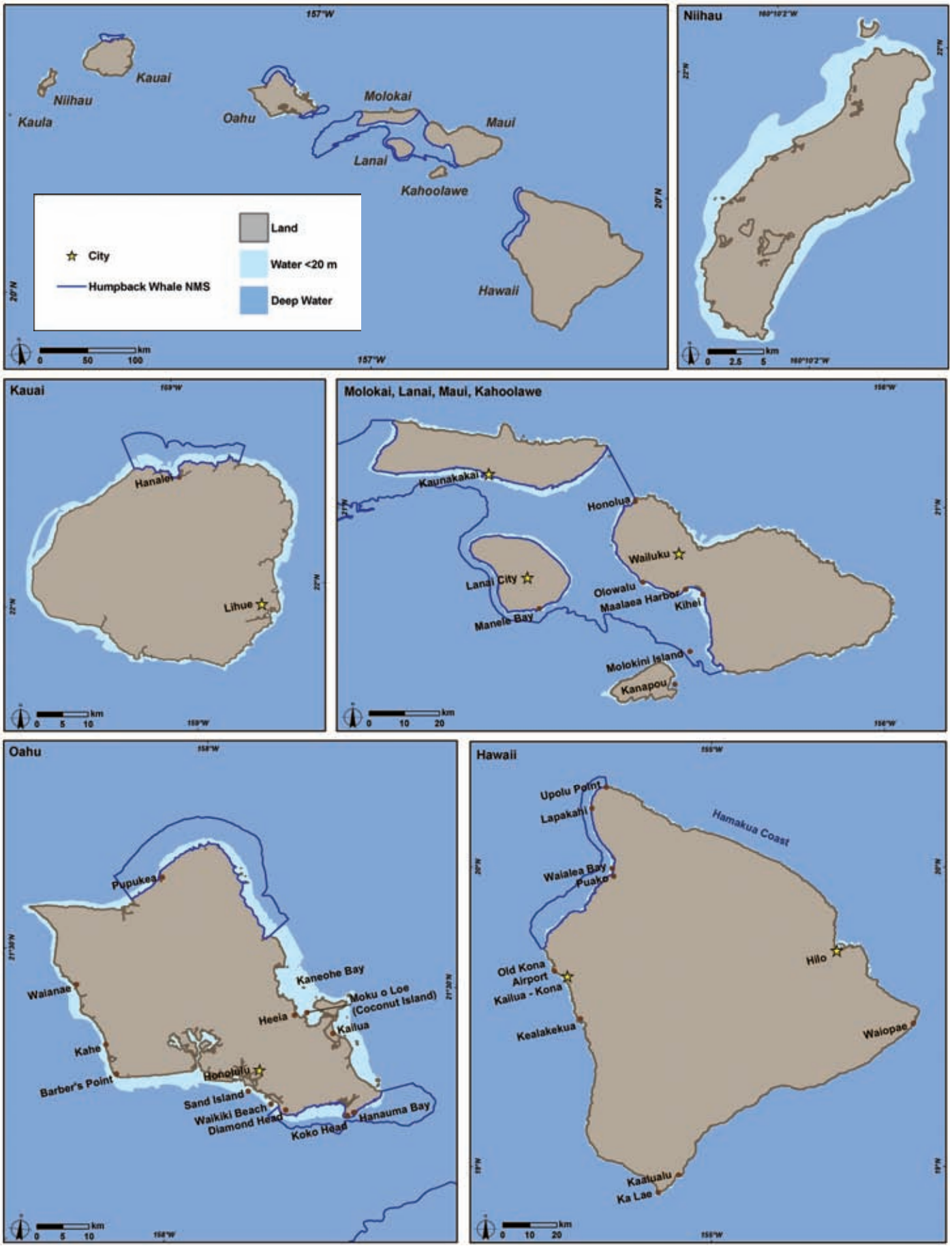


Figure HI-2. Locator map for the Main Hawaiian Islands. Map: A. Shapiro. Source: Friedlander et al. (2005a).

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.	√	

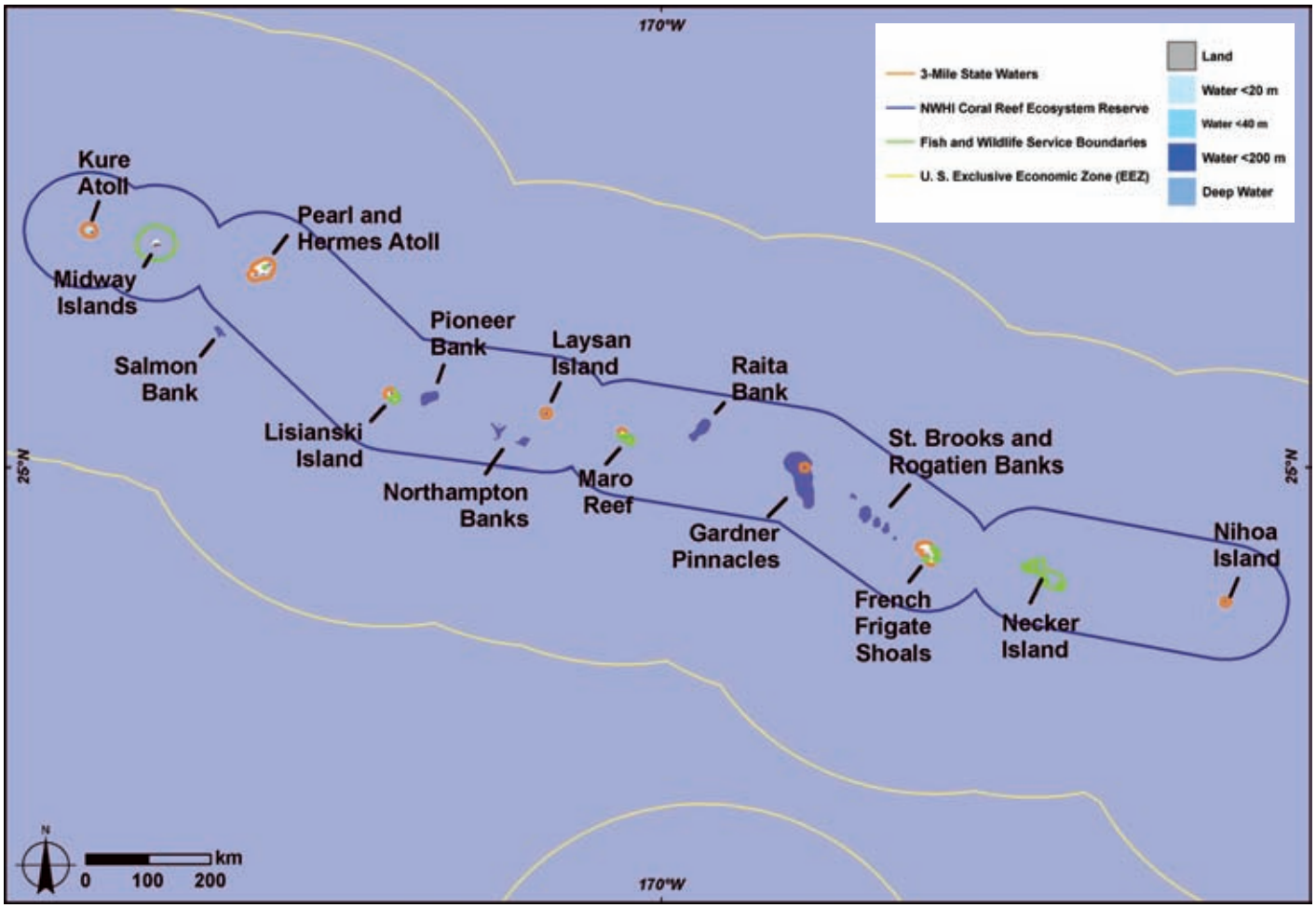


Figure HI-3. The Northwestern Hawaiian Islands, which extend across the north central Pacific, represent a vast, remote coral ecosystem that has been subjected to relatively minimal anthropogenic impacts. Map: A. Shapiro. Source: Friedlander et al. (2005b).

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,

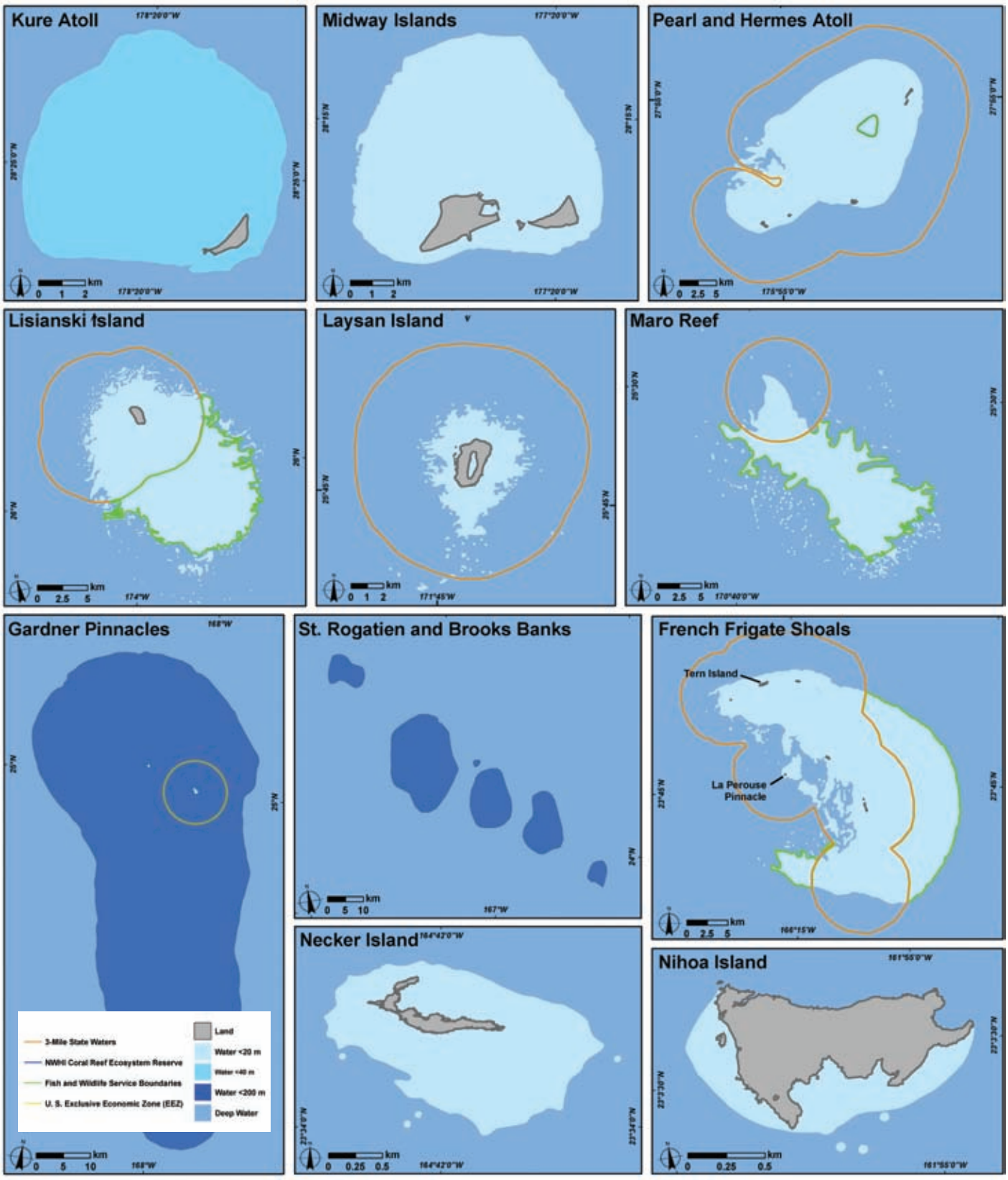


Figure HI-4. Locator map for the Northwestern Hawaiian Islands. Map: A. Shapiro. Source: Friedlander et al. (2005b).

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).

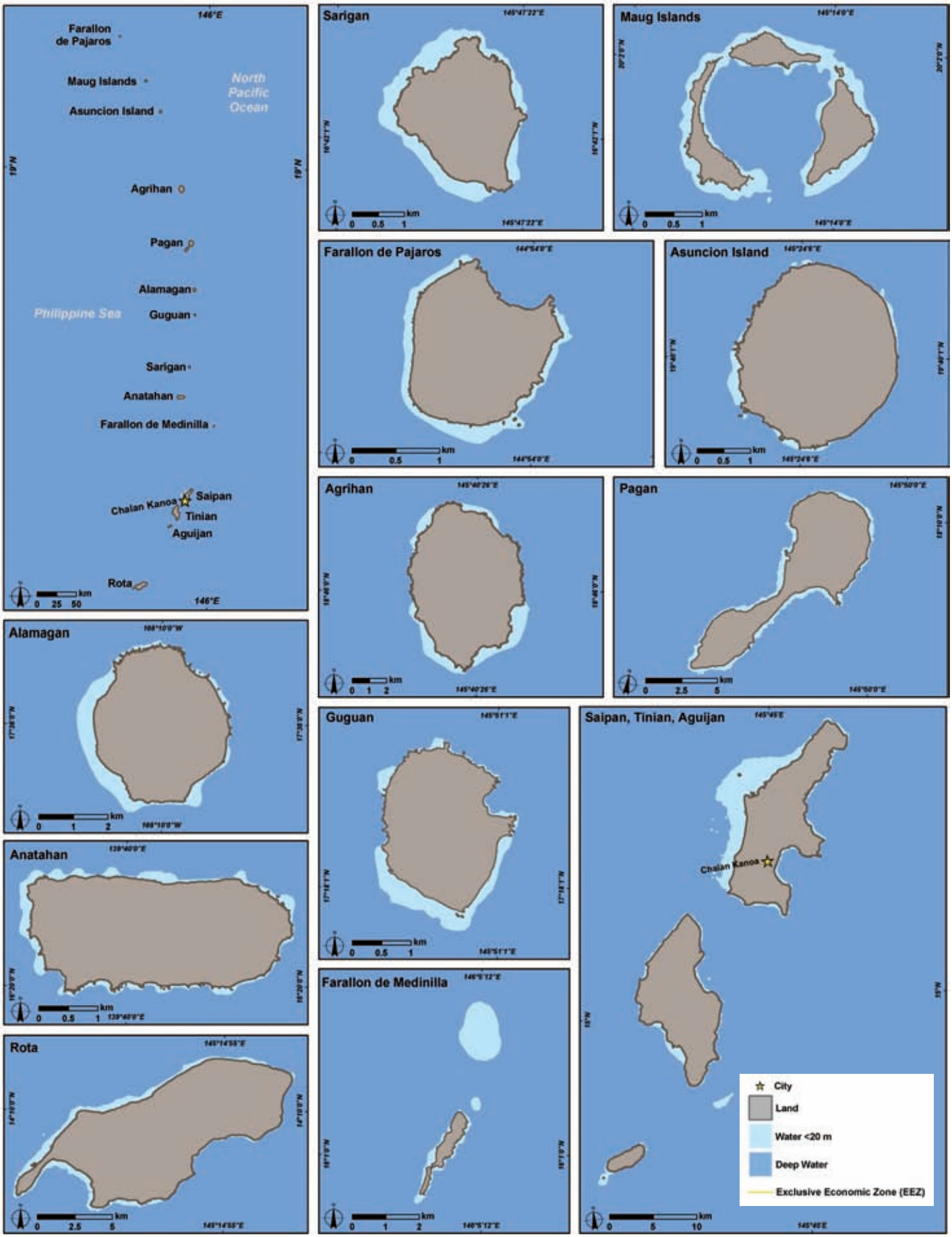


Figure CNMI-1. Locator map for the Commonwealth of the Northern Marianas Islands. (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Starmer (2005).

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 13° 28' N, 144° 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).

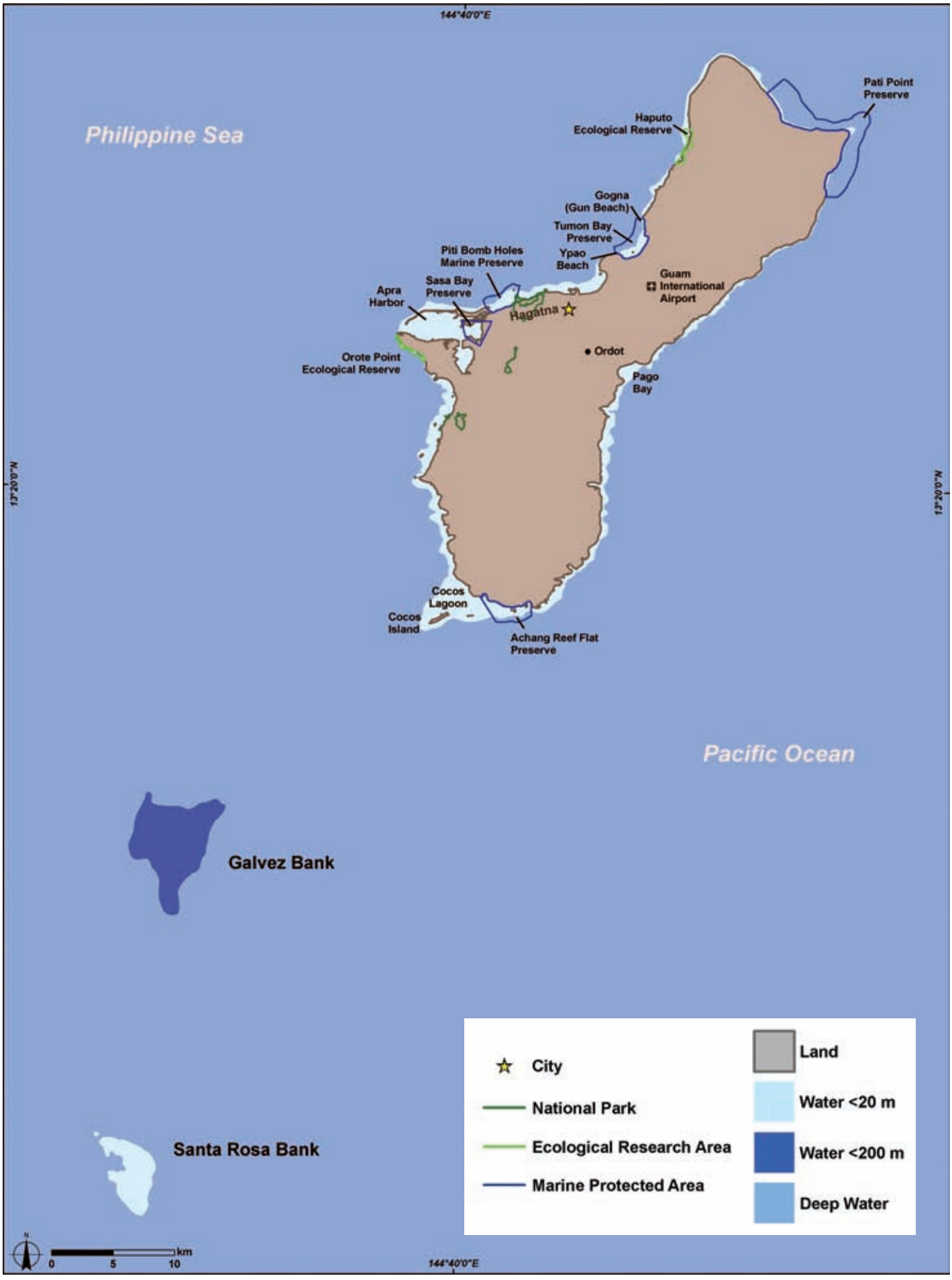


Figure GUAM-1. Locator map for Guam. (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Porter et al. (2005).

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).

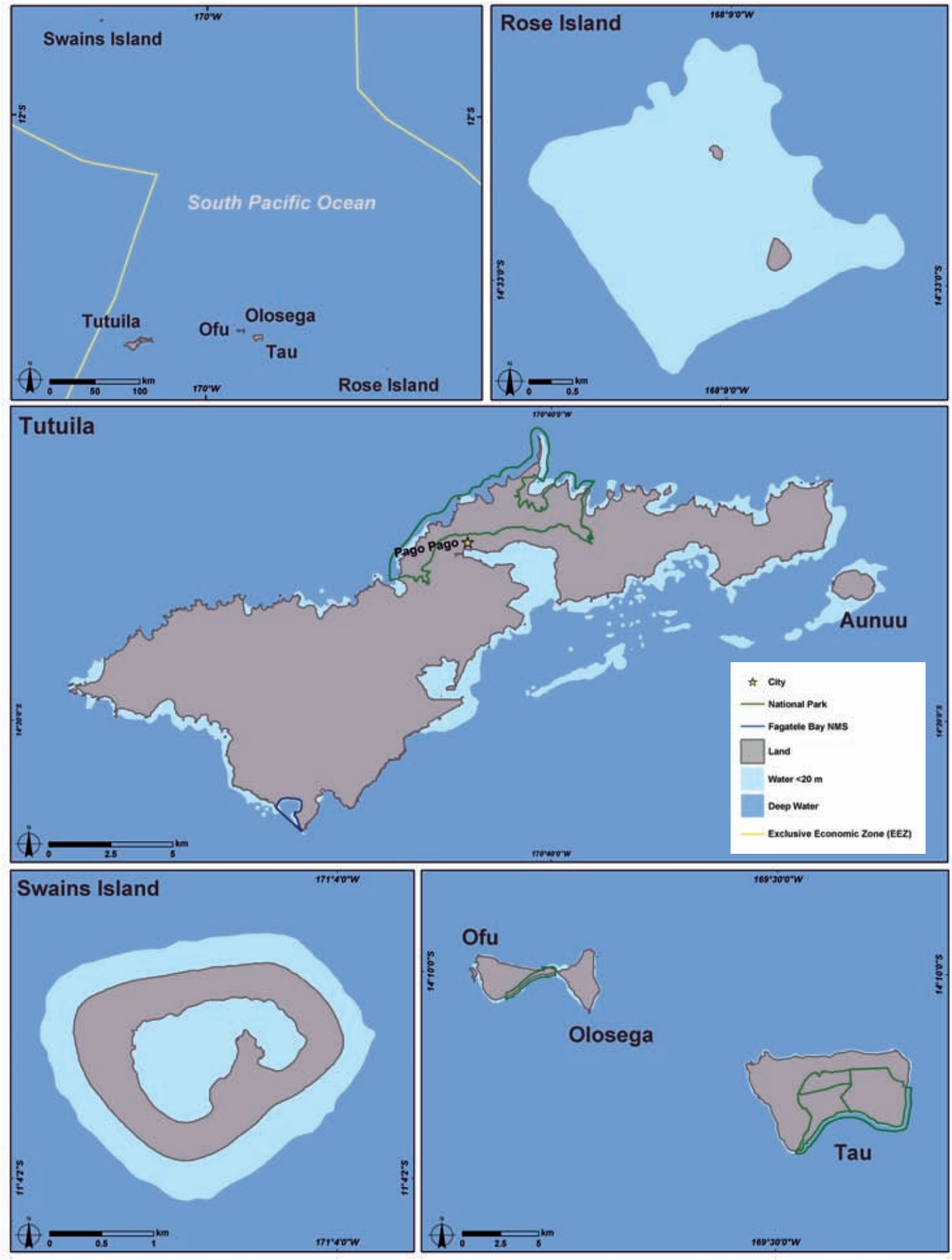


Figure AMSAM-1. Locator map for American Samoa. (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Craig et al. (2005).

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.

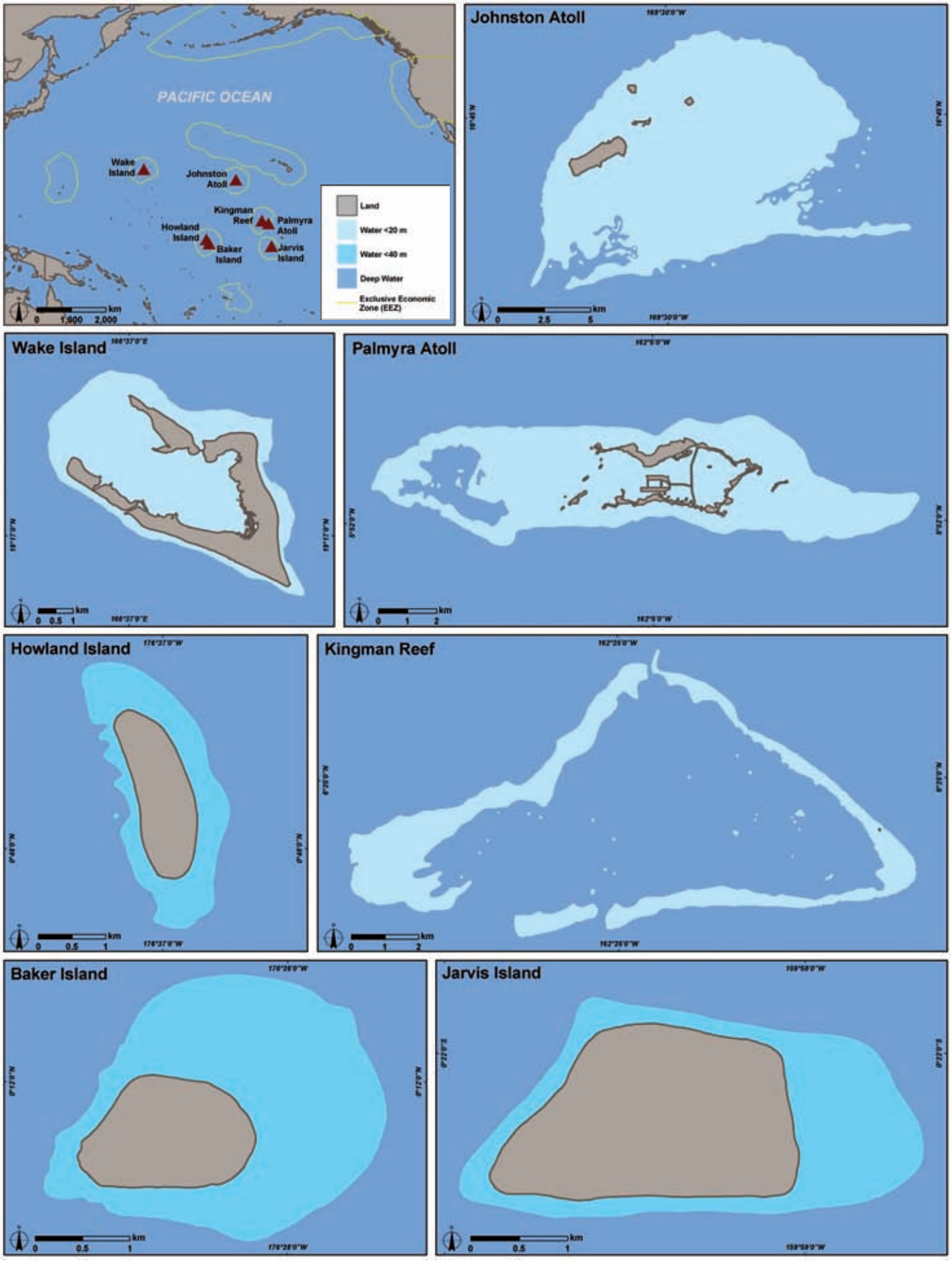


Figure PRIA-1. Locator map for the U.S. Pacific Remote Insular Areas. (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Brainard et al. (2005).

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.

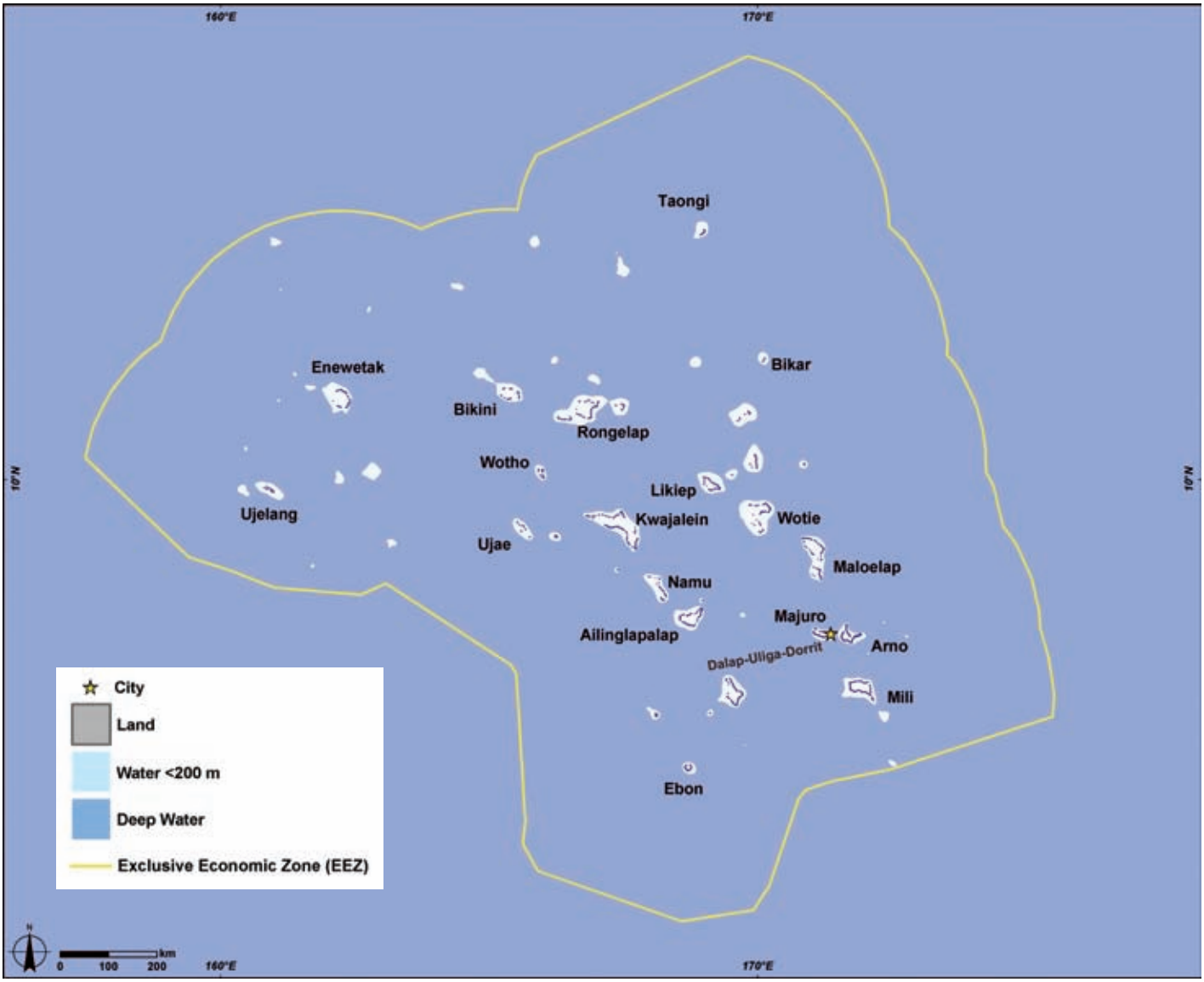


Figure FAS-1. Locator map for the Marshall Islands. (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Pinca et al. (2005).

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).

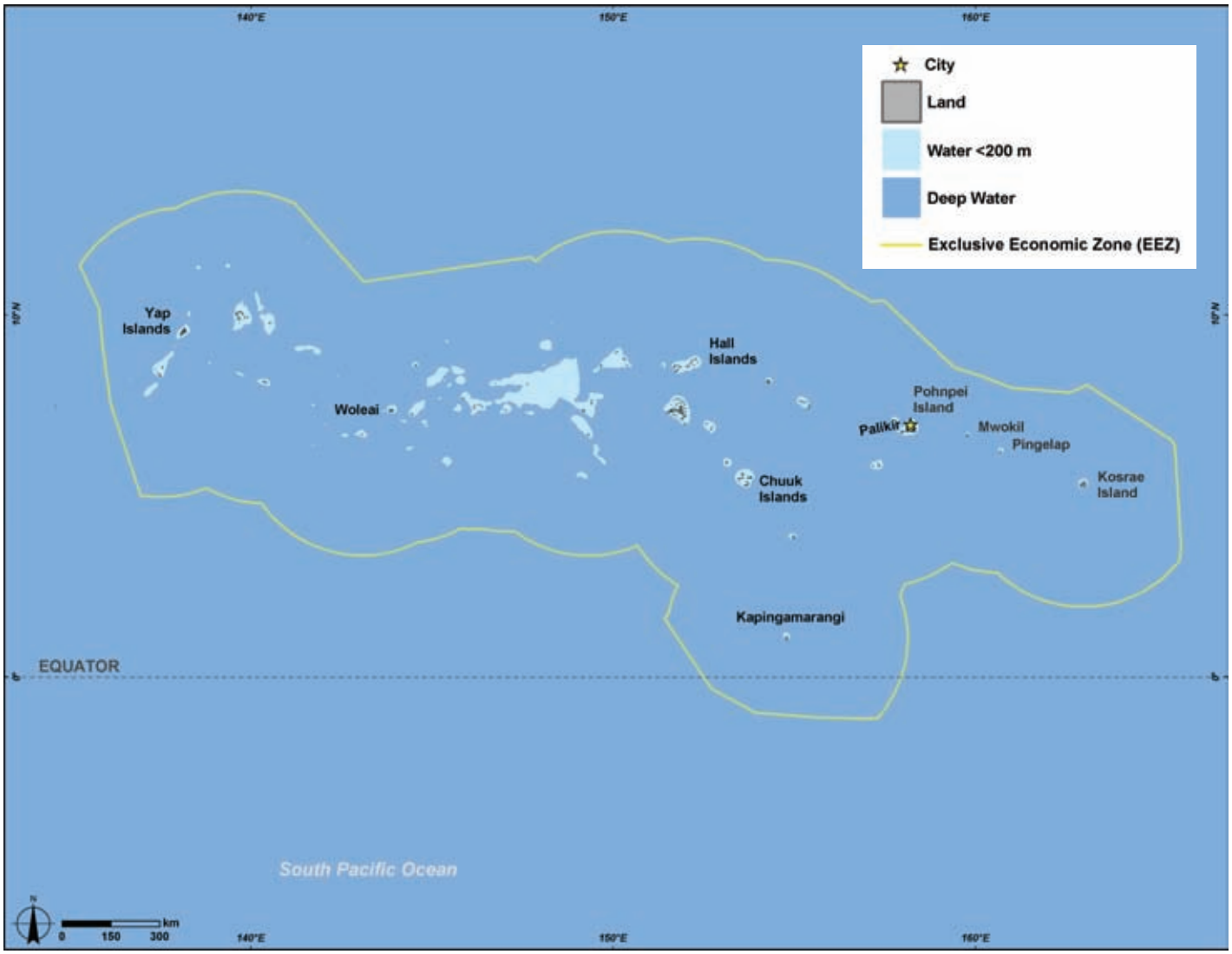


Figure FAS-2. Locator map for the Federated States of Micronesia. (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Hasurmai et al. (2005).

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).

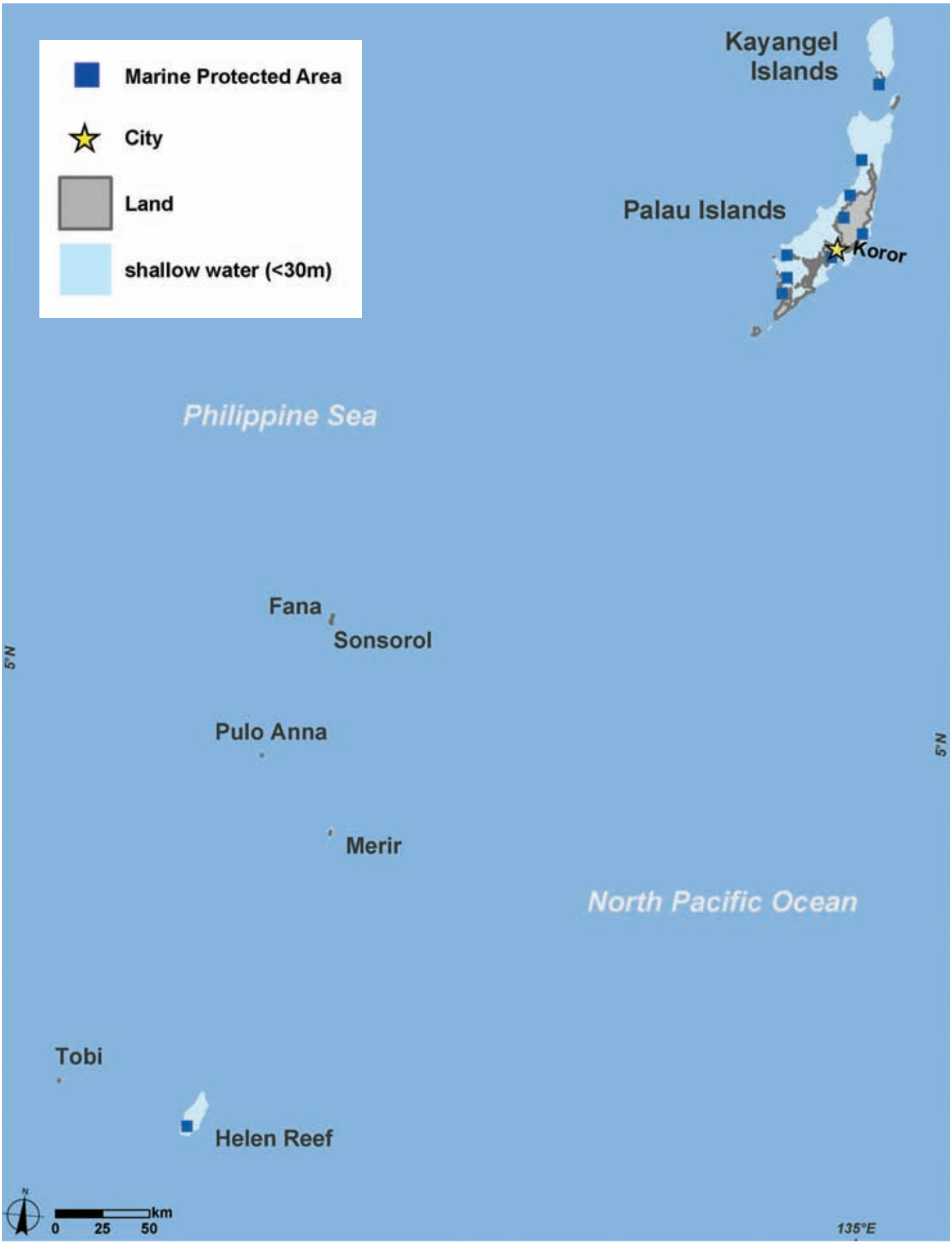


Figure FAS-3. The nation of Palau is an archipelago in the Caroline Islands. Most Palauans reside in the cluster of the northern islands (see Figure FAS-4 for detail of main island group). (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Golbuu et al. (2005).

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).

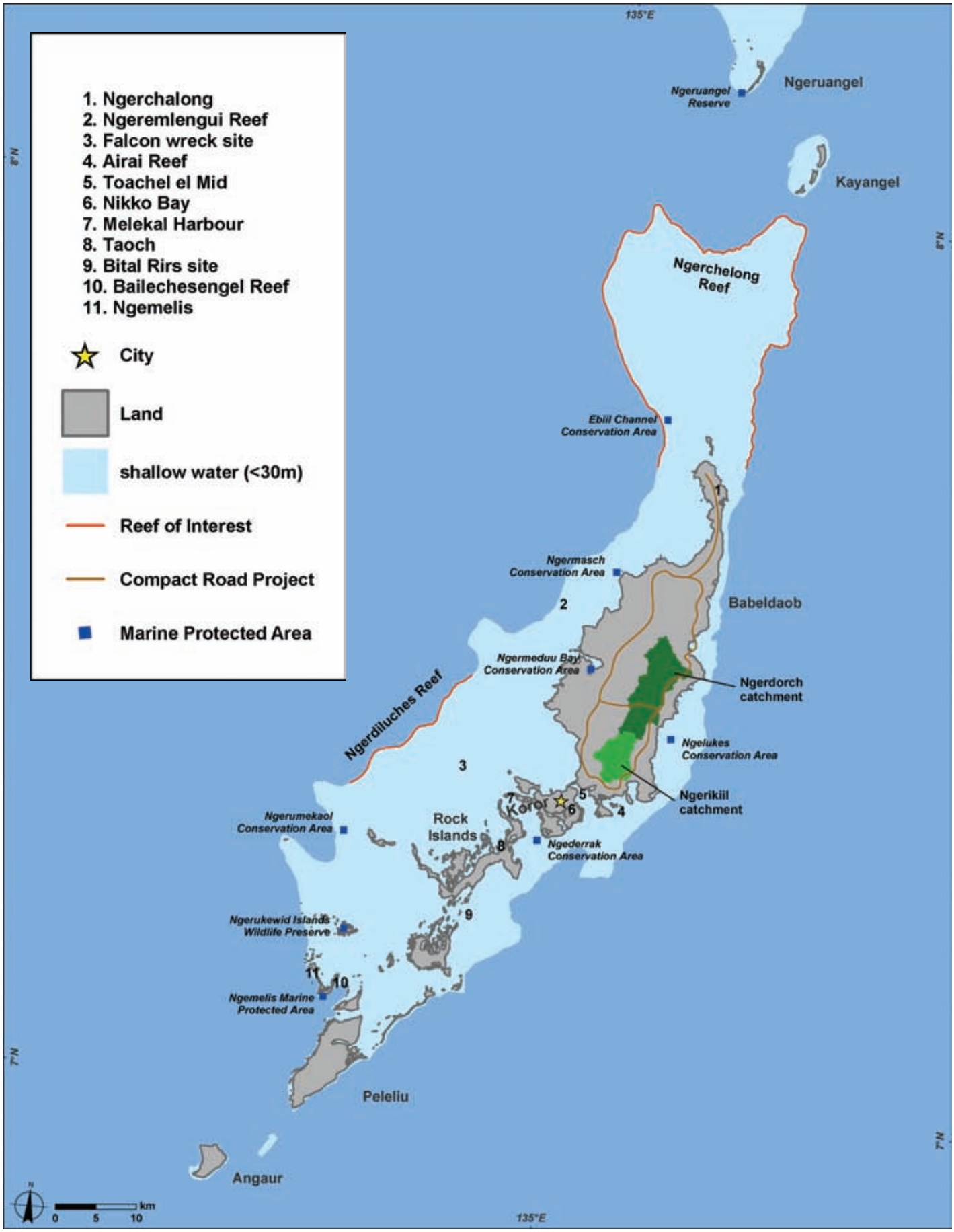


Figure FAS-4. A detailed map of Palau's main island cluster. Map: A. Shapiro. Source: Golbuu et al. (2005).

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.			√	