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

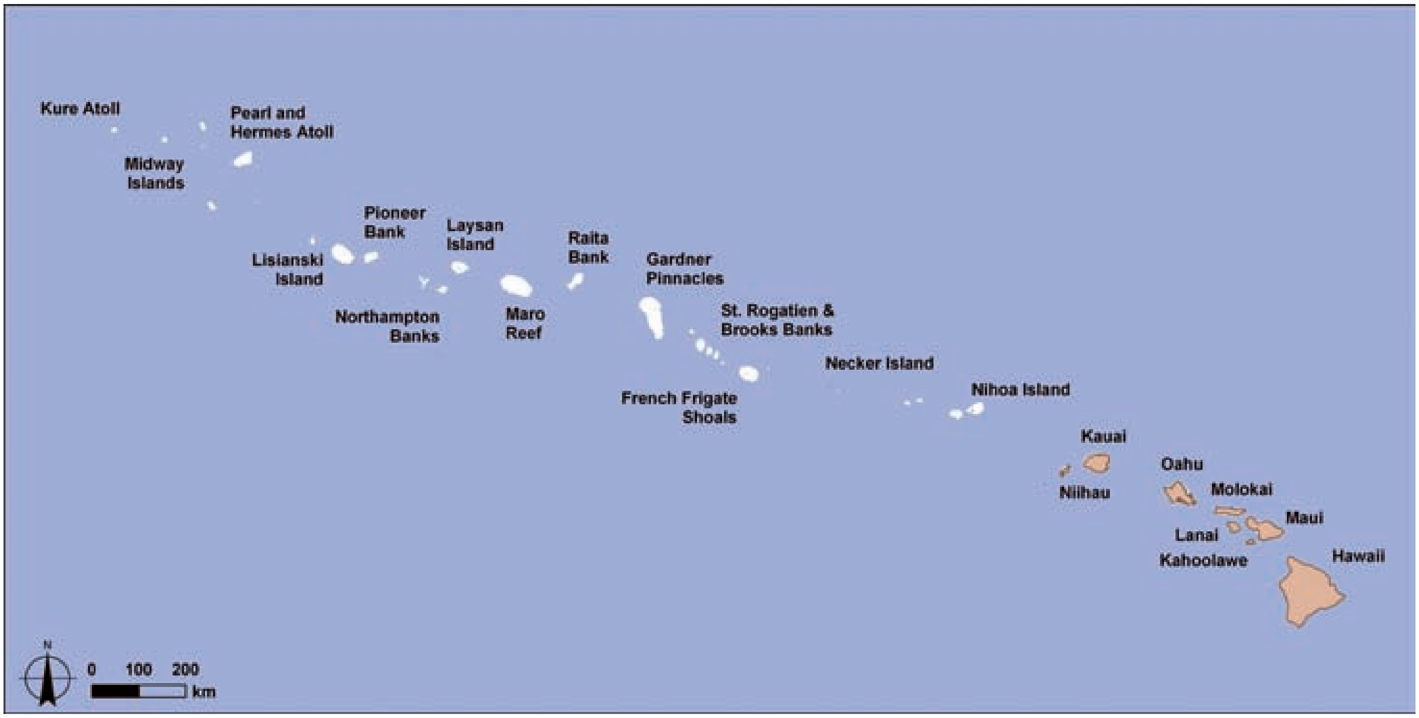

Figure HI-1. Locator map for the Hawaiian archipelago. (See Figure 5 for geographical context.) Map: A. Shapiro.

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.		√

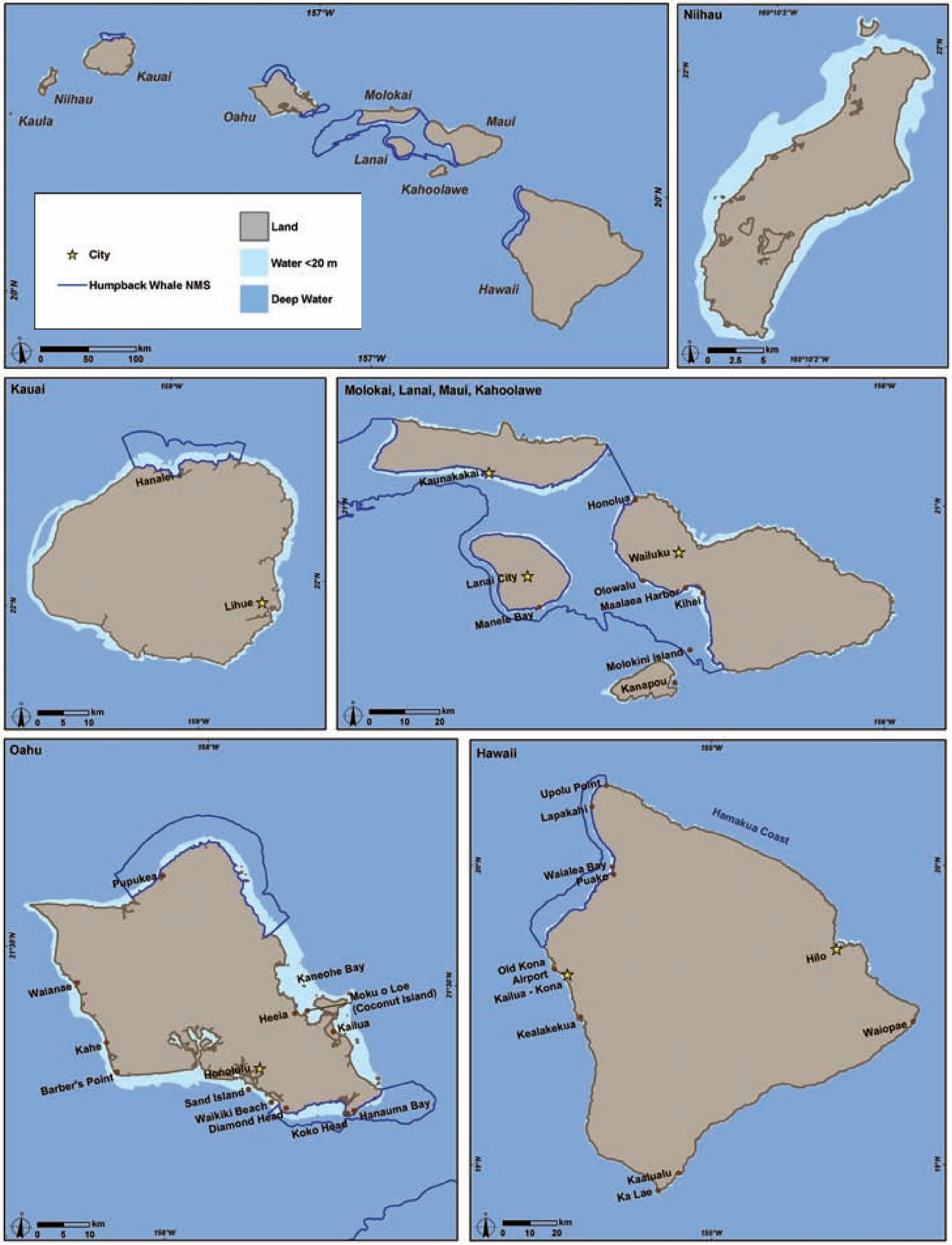

Figure HI-2. Locator map for the Main Hawaiian Islands. Map: A. Shapiro. Source: Friedlander et al. (2005a).

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.	√	

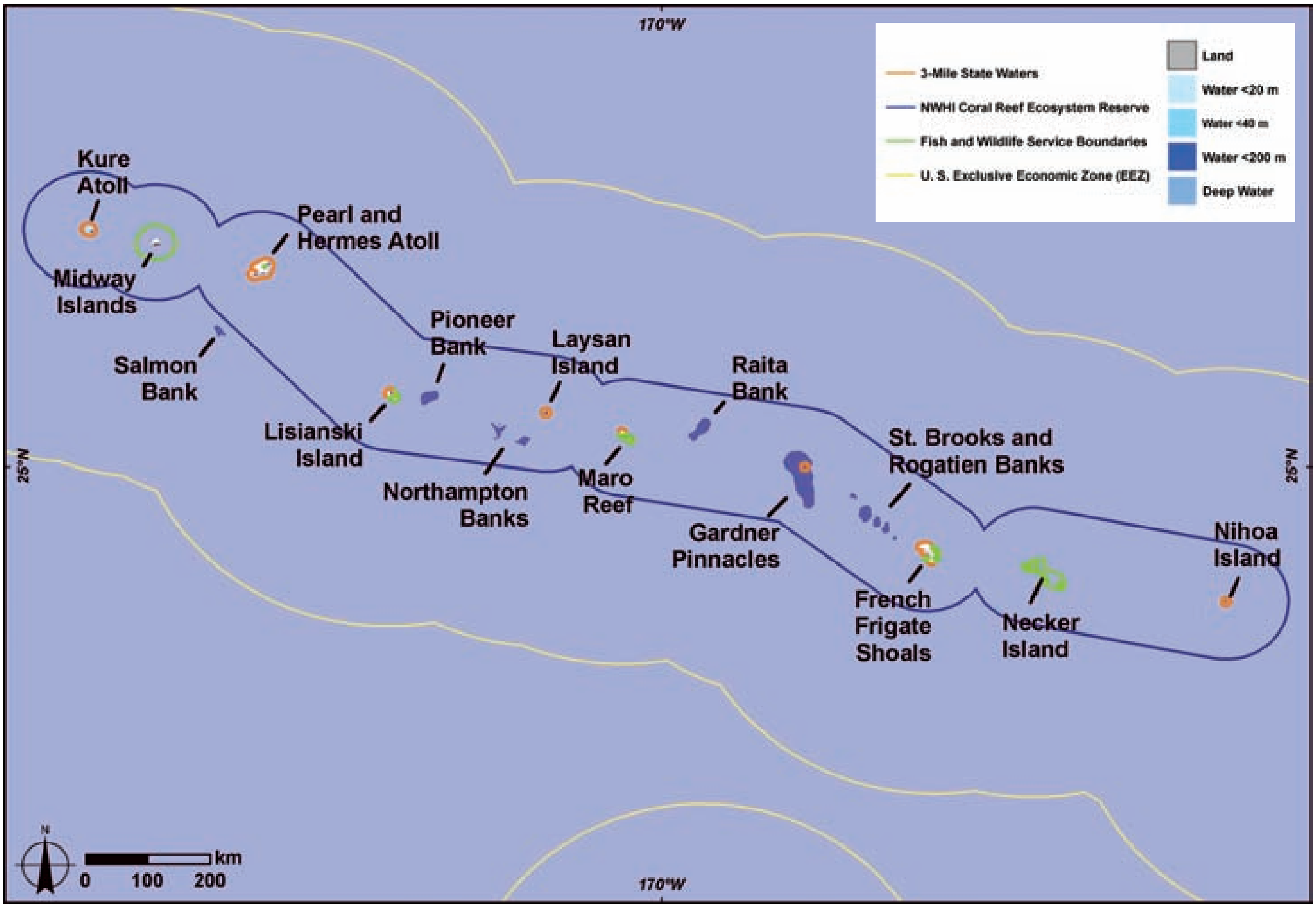

Figure HI-3. The Northwestern Hawaiian Islands, which extend across the north central Pacific, represent a vast, remote coral ecosystem that has been subjected to relatively minimal anthropogenic impacts. Map: A. Shapiro. Source: Friedlander et al. (2005b).

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,

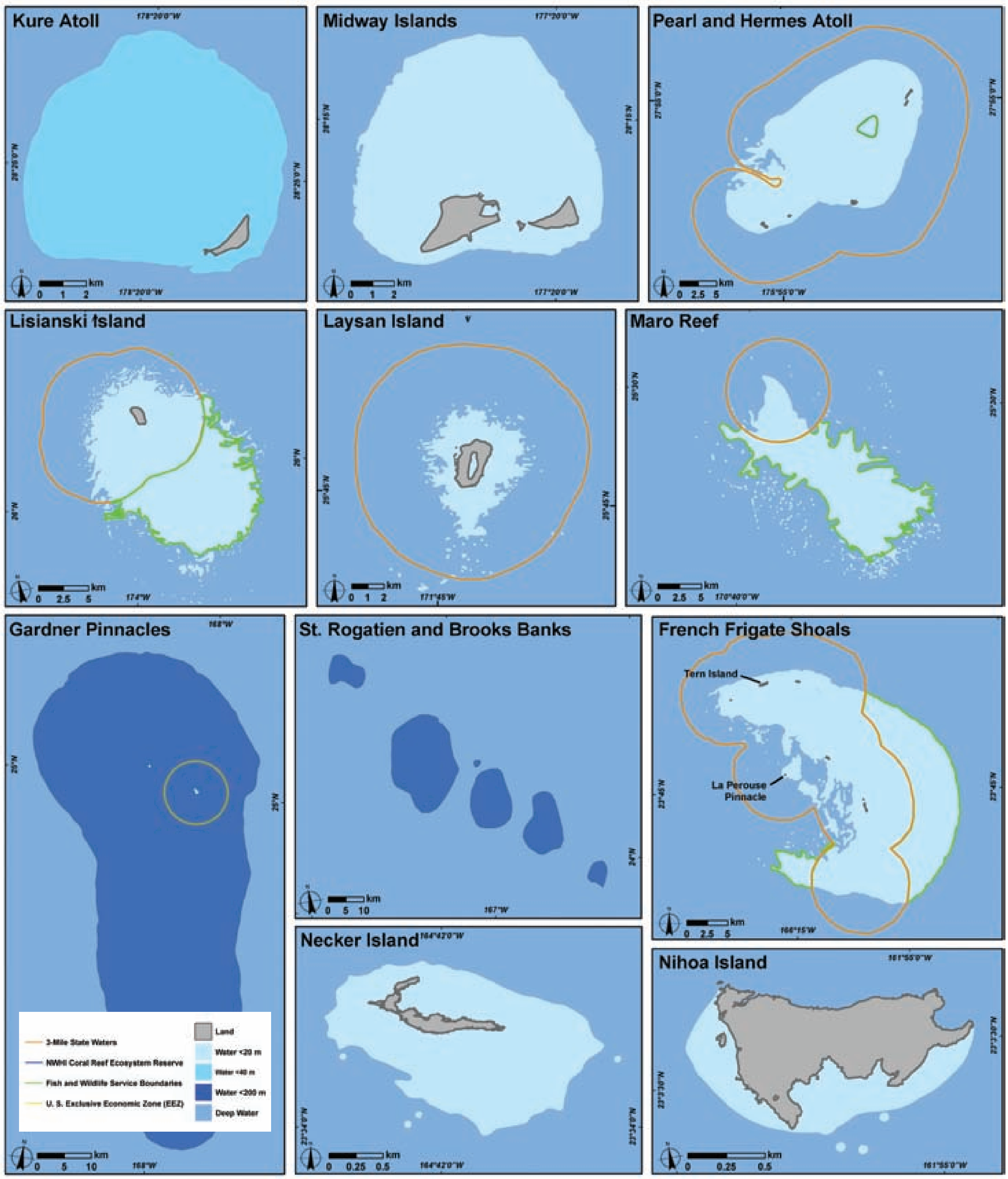

Figure HI-4. Locator map for the Northwestern Hawaiian Islands. Map: A. Shapiro. Source: Friedlander et al. (2005b).

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.

Jurisdiction-Wide Research Needs

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

RESEARCH SUPPORTING MANAGEMENT

Fishing

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

Pollution

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

Coastal Uses

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

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

Invasive Species

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

Climate Change

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

Extreme Events

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

TECHNOLOGY SUPPORTING RESEARCH & MANAGEMENT

Marine Protected Areas

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

Habitat Restoration

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