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).

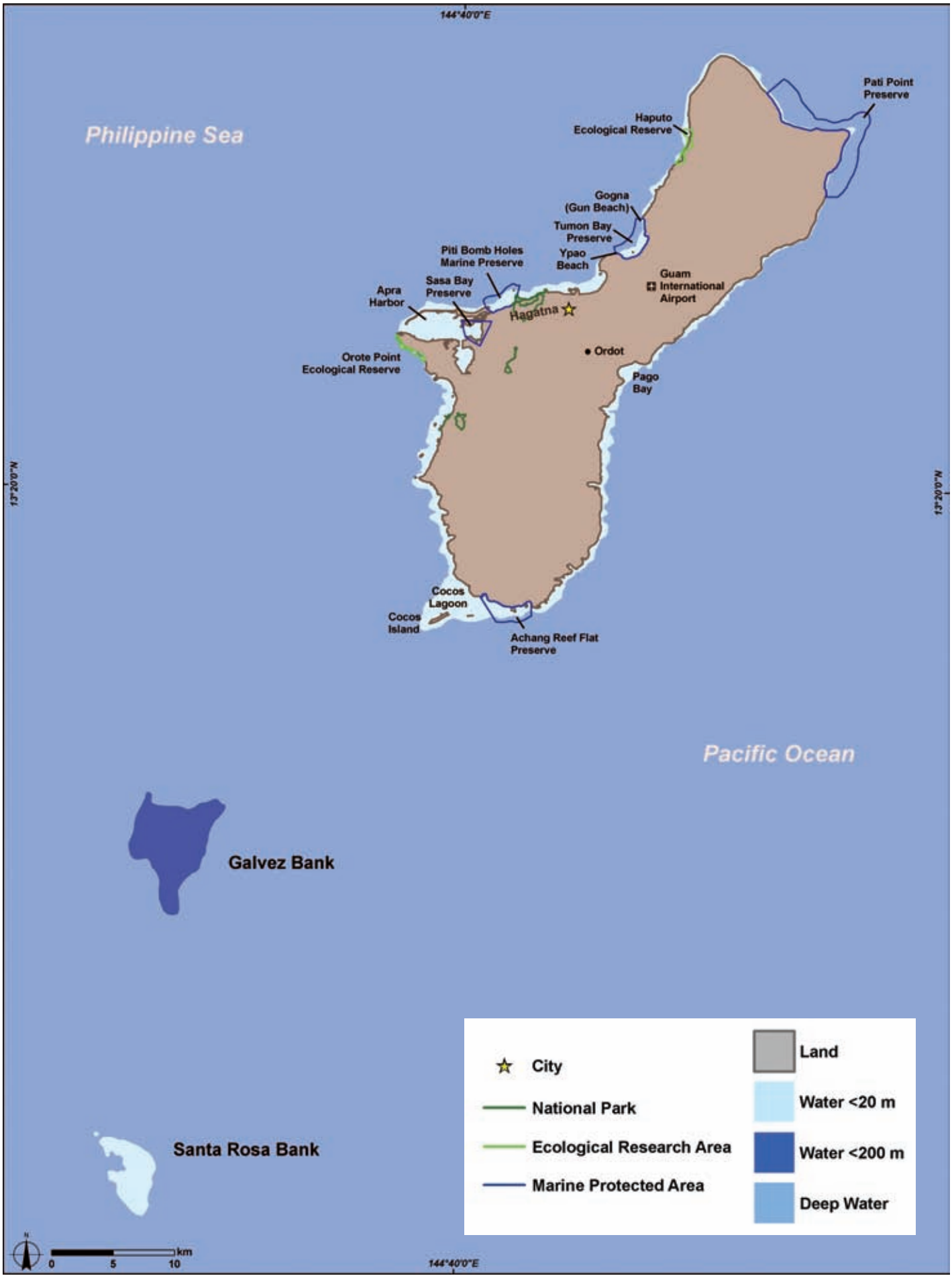

Figure GUAM-1. Locator map for Guam. (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Porter et al. (2005).

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.

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.