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.

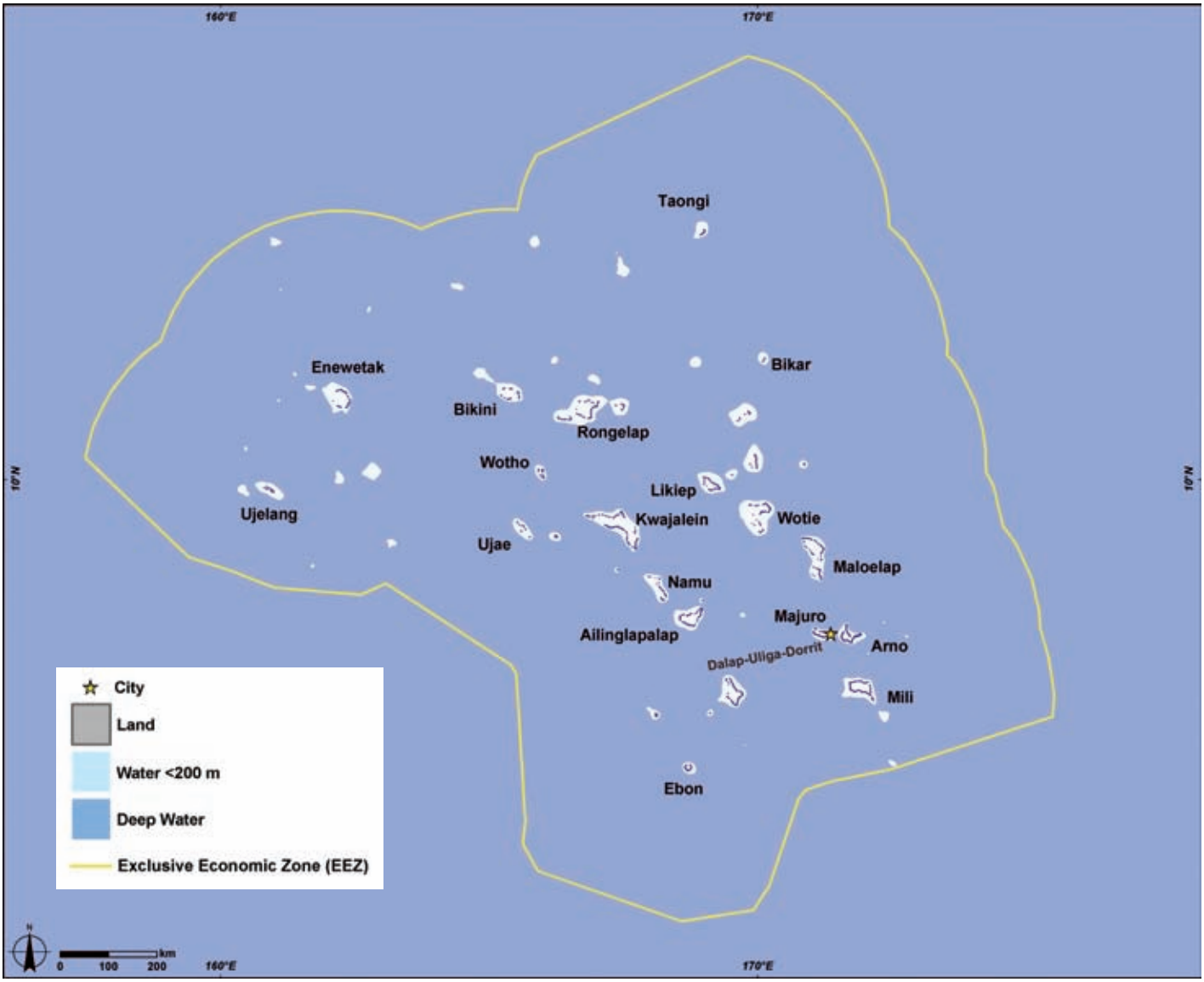

Figure FAS-1. Locator map for the Marshall Islands. (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Pinca et al. (2005).

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).

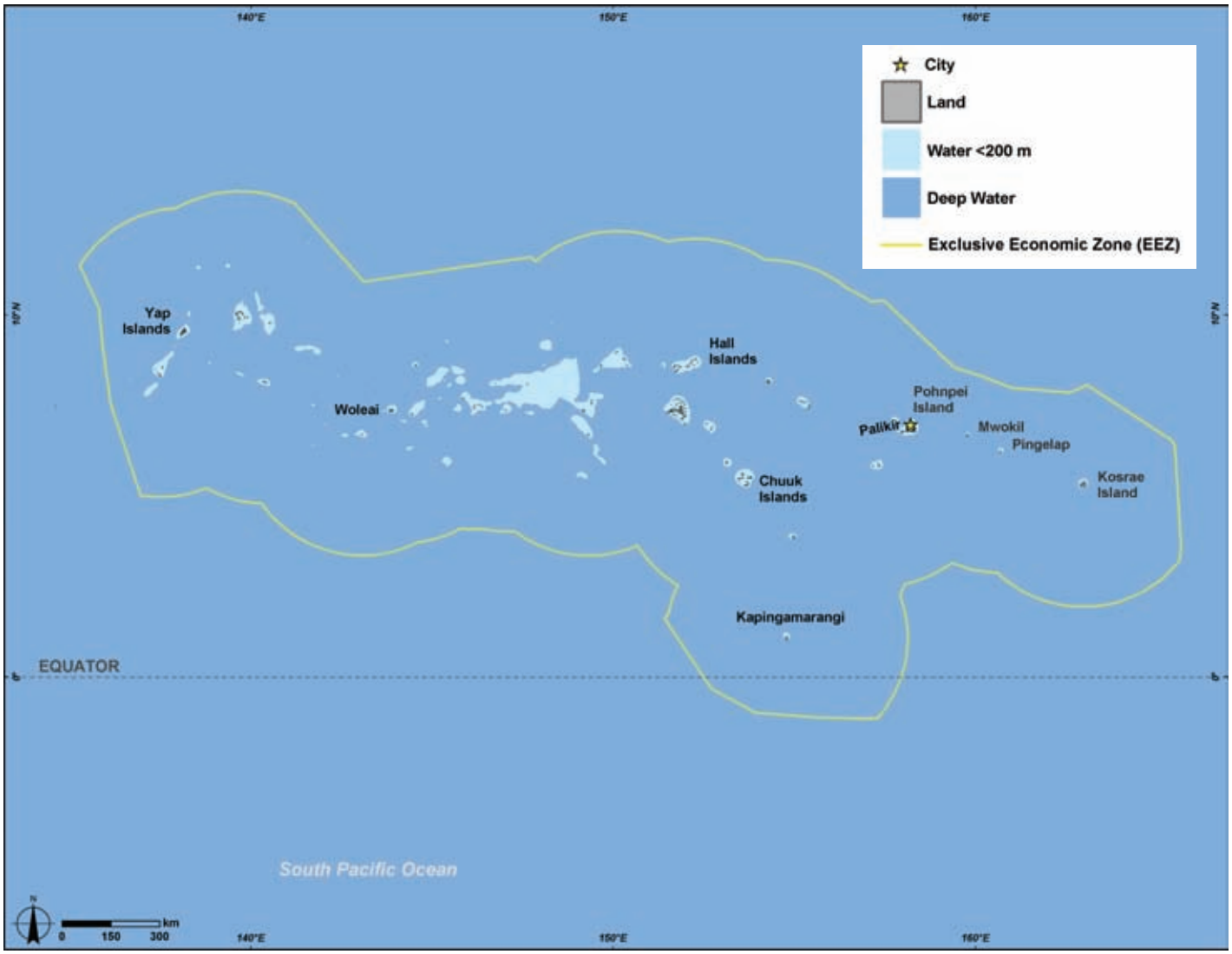

Figure FAS-2. Locator map for the Federated States of Micronesia. (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Hasurmai et al. (2005).

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).

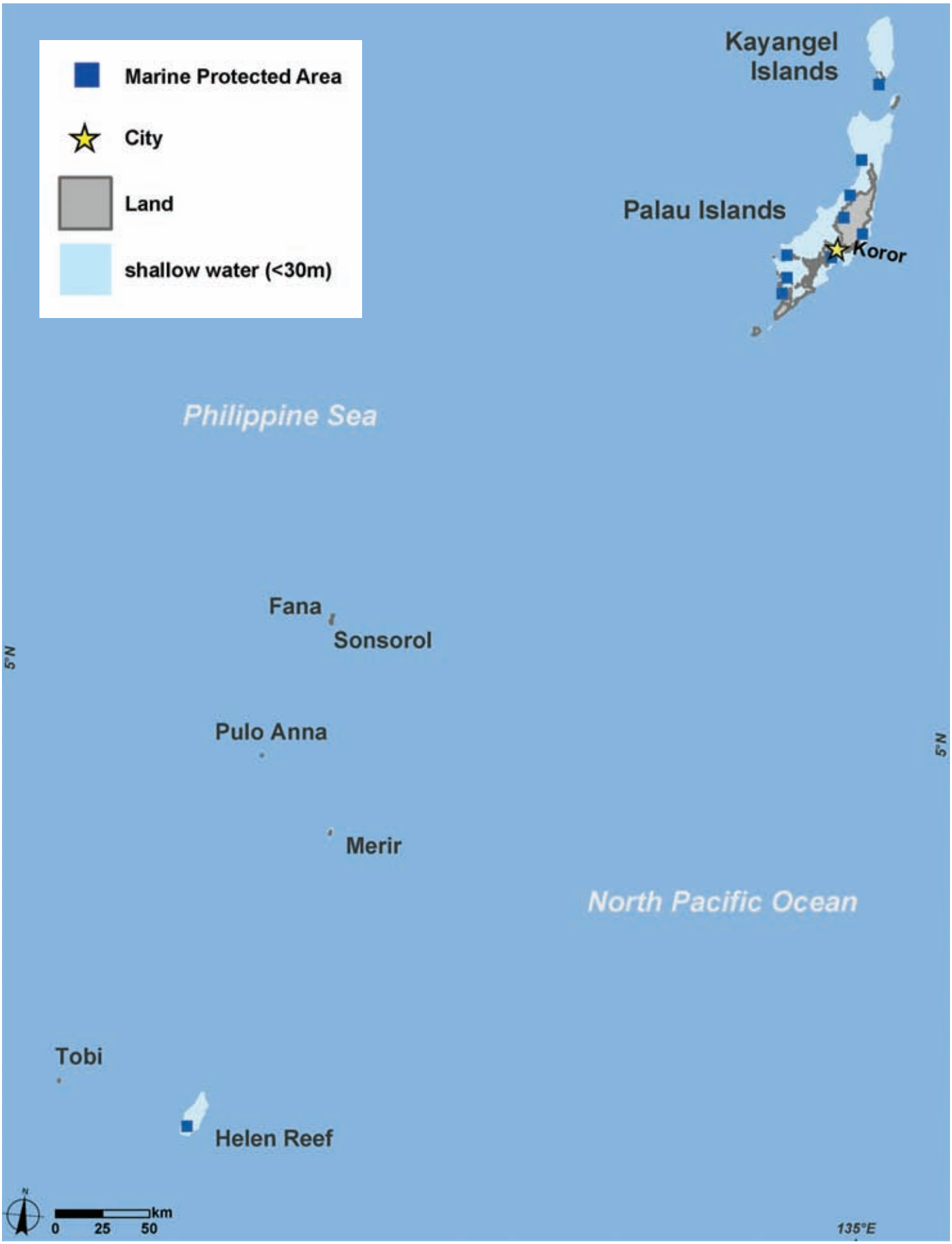

Figure FAS-3. The nation of Palau is an archipelago in the Caroline Islands. Most Palauans reside in the cluster of the northern islands (see Figure FAS-4 for detail of main island group). (See Figure 5 for geographical context.) Map: A. Shapiro. Source: Golbuu et al. (2005).

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).

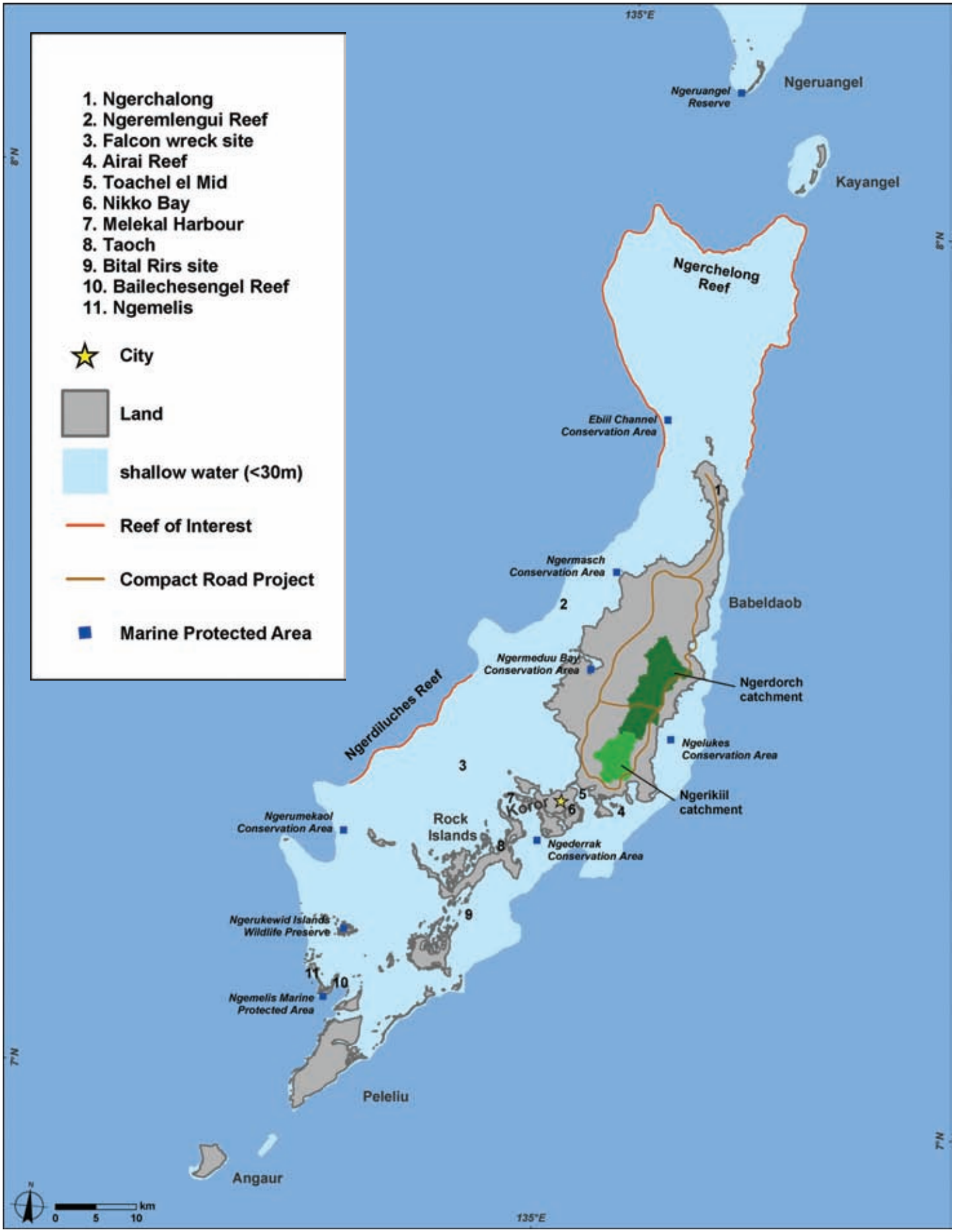

Figure FAS-4. A detailed map of Palau's main island cluster. Map: A. Shapiro. Source: Golbuu et al. (2005).

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.			√	

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.